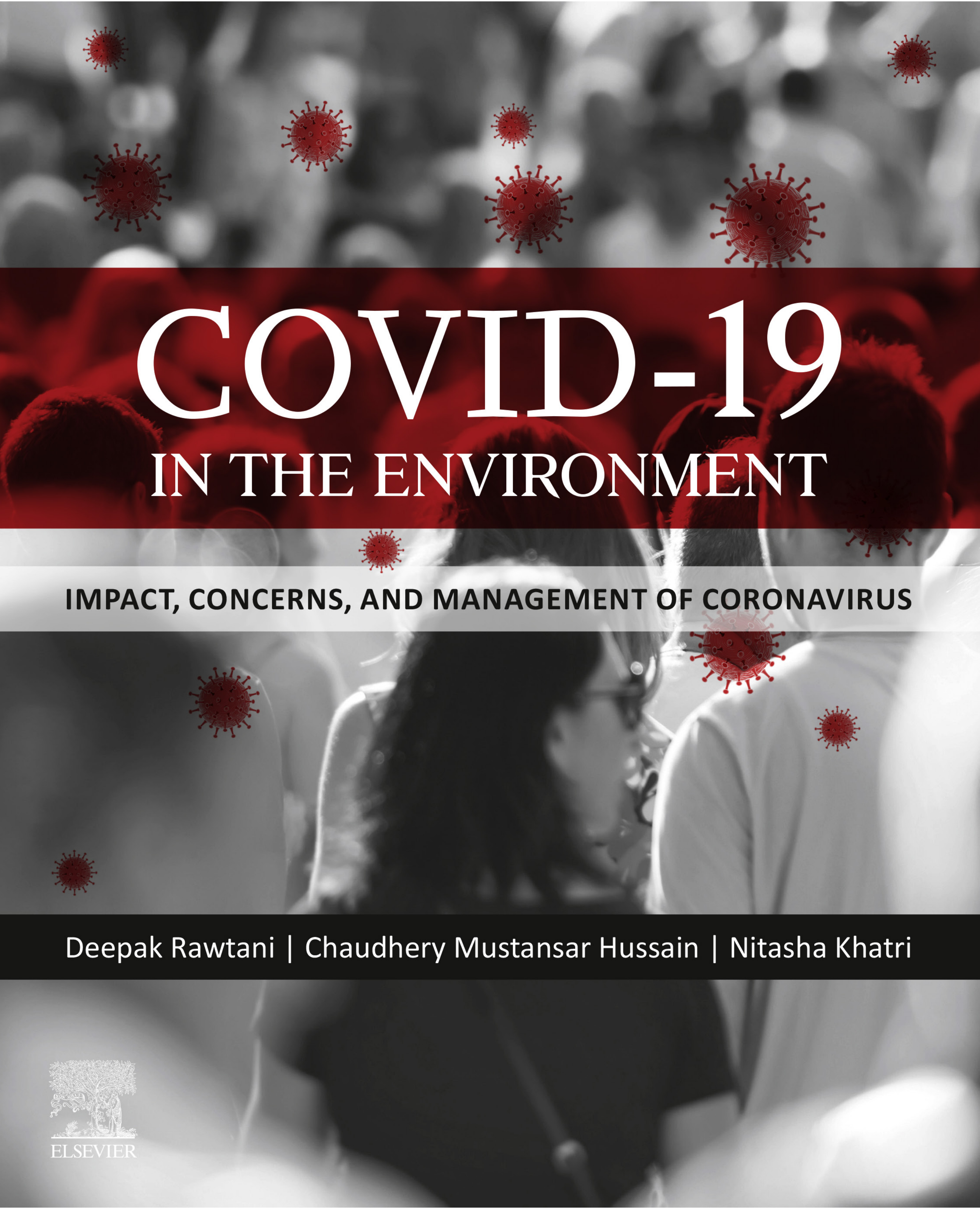

# COVID-19 IN THE ENVIRONMENT

## IMPACT, CONCERNS, AND MANAGEMENT OF CORONAVIRUS

Deepak Rawtani | Chaudhery Mustansar Hussain | Nitasha Khatri

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## Impact, Concerns, and Management of Coronavirus

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# Foreword

Close involvement with the society is the destiny of science. *COV1D-19 in the Environment: Impact, Concerns, and Management of Coronavirus* is an enthusiastic and comprehensive compilation of impact, research trends, and technologies used to tackle COVID-19 pandemic and its extensive effects on environment. The book explores the whole spectrum of environmental handling aspects of COVID-19 and cultivates a roadmap to assess real-time environmental issues related to COVID-19.

The book confers six sections ranging from transmission of COVID-19 in environment to analysis, detection, socioeconomic implications, and waste management of COVID-19. Apart from that, the readers would also get to know about trend analysis and strategies by policy makers across the globe to tackle this unprecedented situation. Every section of this book is interlinked so that the reader grasps the concept of environmental implications of pandemic and their anticipation in modern society.

I hope that this book will become a primary tool for researchers, environmentalists, academicians, and enthusiasts from across the globe to learn, teach, and practice techniques for handling the challenges posed by the widespread pandemic.

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## PART 1

# Transmission of COVID-19 in Environment

CHAPTER 1

# Introduction to COVID-19

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## 1.1 Introduction

The greatest challenge human population facing, after world war II, is the COVID-19 pandemic. The journey of virus started from a viral pneumonia with no details of the microbial agent to a severe outbreak of SARS-CoV-2 at Wuhan, China (Lu et al. 2020). The virus was identified as novel coronavirus when it was isolated from throat swab sample of an infected person by Chinese Center for Disease Control and Prevention (Chen et al. 2020). The first case of Covid-19 detected outside china was from Thailand (Bruinen de Bruin et al. 2020), however it continued spreading across the world. After a whooping number of 118,000 cases in about 114 countries, World Health organization (WHO) declared it as Pandemic on 11th March 2020. WHO declared it as global public health emergency due to the accompanying menace to global health (WHO 2020a).

With the uncontrolled and massive spread of the novel coronavirus across the world it started affecting health, economy, increment in social outbreaks and impact on environment. Wang et al. reported that the impact of pandemic is so devastating that it has brought the health care units, even the world's best medical facility, to the verge of breakdown.

The various infectious diseases have been considered as a threat to mankind as it can devastate an entire population. It is well documented as epidemiological study that the pandemic outbreaks resulted in vanishing of an entire population, in different parts of world. As per WHO, epidemiology is a study of distribution and determinants of states or events related to health, diseases, the effect of diseases, their control etc.

The pandemic situation is not new to the world, there are many reported and observed pandemic outbreaks faced by humans (Table 1.1). The pandemics have cost millions cases of morbidity and mortality (Bai et al. 2020). In the year 1346, a pandemic outbreak named black death was observed due to *Yersinia Pestis*, the same microbe again hit back in 1720 causing great plague of Marseille. A long disease outbreak by virus Vibrio chloerae caused diseases cholera that stretched for a period of more than seven years (1817–1824). A virus named Influenza A, of different strains, has caused severe flu in the various parts of world in different time periods. In 1889 Influenza A/H2N2 has caused Russian flu, in 1918 Influenza A/H1N1 has caused Spanish flu, in 1958 Asian flu spread due to Influenza A/H2N2. After ten years, 1968, another strain of the virus

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**Table 1.1** History of pandemics.

| Period / year of outbreak | Causing agent | Name of pandemic disease outbreak |
|---|---|---|
| 1346 | *Yersinia Pestis* | Plague/Black Death |
| 1720 | *Yersinia Pestis* | Great plague of Marseille |
| 1817–24 | Vibrio cholerae | Cholera |
| 1889 | Influenza A/H2N2 | Russian Flu |
| 1918 | Influenza A/H1N1 | Spanish Flu |
| 1958 | Influenza A/H2N2 | Asian Flu |
| 1968 | Influenza A/H3N2 | Hong kong Flu |
| 1976 | HIV | AIDS |
| 2002–03 | Coronovirus | SARS-CoV |

(Influenza A/H3N2) caused Hong kong Flu. The deadly HIV virus was traced in the year 1976, that cause AIDS (Acquired immune deficiency syndrome). In fact, in the last two decades it is the third time that coronavirus disease outbreak has been observed by the world, the previous two were in 2002–03 named severe acute respiratory syndrome (SARS) and in 2012 middle east respiratory syndrome (MERS).

The major infection causing agents are viruses and bacteria (City and Guilds 2014). The viral infections are more critical owing to their affect on many body parts unlike bacteria that are more local in terms of infections. Further, the rate of mutation is also very high in case of viruses for their genome size. The high rate of mutation is related to the evolution of pathogens and development of vaccination.

The outbreaks are difficult to control and it is difficult to develop and effective solution to control the viral infections owing to their frequent mutations and cross genetic translation.

The next part of the chapter will give an insight into the nature of SARS-Cov-2, the virus responsible for Covid-19.

## 1.2 Virology of SARS-CoV-2

The SARS – coV-2 virus belongs to Order: Nidovirus. The family of virus is coronaviridae and subfamily coronavineae.

There are further four genus in which the virus can be categorized viz. α, β, ϒ and δ. The two genus that mainly affect human body are α and β. The latest pandemic corona virus (SARS-CoV-2) and other viruses such as MERS-CoV, SARS-CoV, OC43, 229, and HKU1 belongs to β genus.

As shown in the Fig. 1.1, corona virus consists of a protein envelop, membrane proteins, spike glycoprotein, nucleocapsid protein, single stranded RNA etc. The peculiar crown like structure of the corona virus is due to presence of spike glycoproteins. These glycoproteins are further sub divided intwo two units namely S1 and S2. There are three domains, A,B and C, of S1 subunit (Angeletti et al. 2020). The domain A of

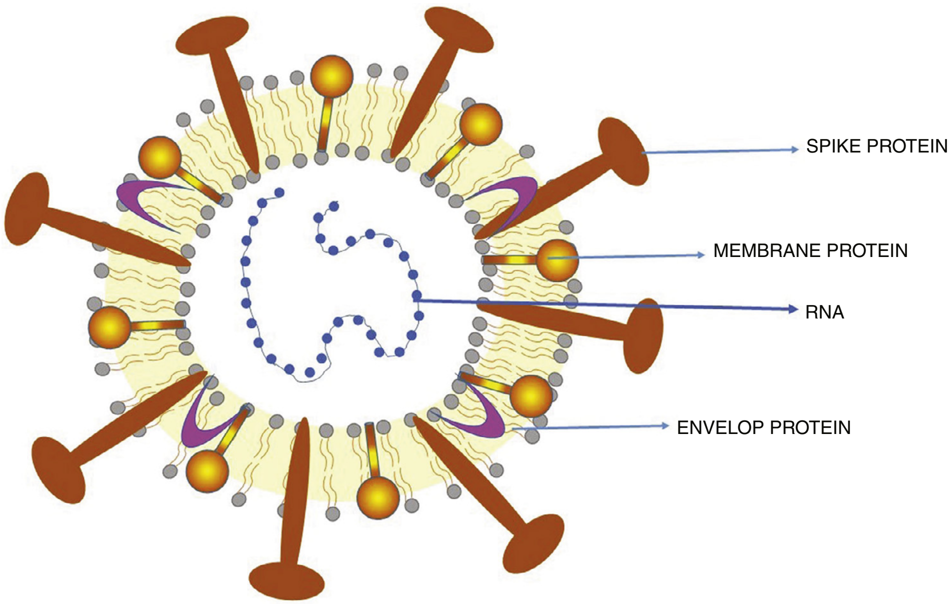


**Fig. 1.1** ***A structure of Corona Virus.***

CoV-OC43 and CoV-HKU1 is responsible for binding with the host receptors, while in MERS-CoV both A and B domains binds with the DPP4 (Dipeptidyl peptidase-4) receptor (Hulswit et al. 2019; Park et al. 2019). In case of SAR-CoV-2 and SARS-CoV domain B binds with DPP4. The S protein of SARS CoV and SARS CoV2 share many similarities and a few variances, for example the main genomic feature of SARS-CoV-2 is mutations on the receptor binding domain of S protein and presence of O-linked glycans and polybasic furin cleavage site. This helps in binding of SARS-CoV-2 virus with hACE 2 receptors more effectively as compared to SARS-CoV virus (Andersen et al. 2020).

## 1.3 Epidemiology

Previous reports stated that the about fifty percent of infected person had contact record of Seafood market of Huan, China. The market is platform to sale different sort of living wild animals including bats and poultry (Huang et al. 2020; Chen et al. 2020). It is currently speculated that the outbreak of COVID-19 in Wuhan is associated with wild animals. As per WHO reports, environmental samples form seafood market of Huan city showed presence of virus (Gralinski and Menachery 2020). There is still ambiguity about the exact source of SARS-CoV2, however based on previous studies, showing bats are host of many coroner viruses, it is believed that they may be the origin of Covid-19 also (Phan 2020). Genomic studies have revealed that one of the RNA-dependent RNA

**Table 1.2** Global situation on covid-19

| **Global Situation on COVID 19 upto 9 January 2021** | |
|---|---|
| Confirmed Cases of COVID 19 | 87,589,206 |
| Death Case due to COVID 19 | 1,906,606 |

polymerase region, in a bat coronavirus, shares a close identity of more than 96 percent with the entire genome sequence of SARS-CoV-2 (Chen et al. 2020a).

## 1.4 Geographic distribution and case counts

As per reports, globally, there were more than 87 millions cases on ninth Jan 2021 (Table 1.2). There are overall about 2 million deaths reported so far.

The geographical distribution of covid-19 cases are depicted by Fig. 1.2, showing 14-days covid-19 case notification rate per lakh, weeks 1–2 of year 2021 (ECDC, 2021).

The total number of covid-19 cases reported (upto ninth Jan 2021) are presented in the Fig. 1.3.

## 1.5 Mode of transmission

The transmission of the virus occurs mainly through the respiratory droplets of an infected person while sneezing, coughing or talking. The transmission can be direct or

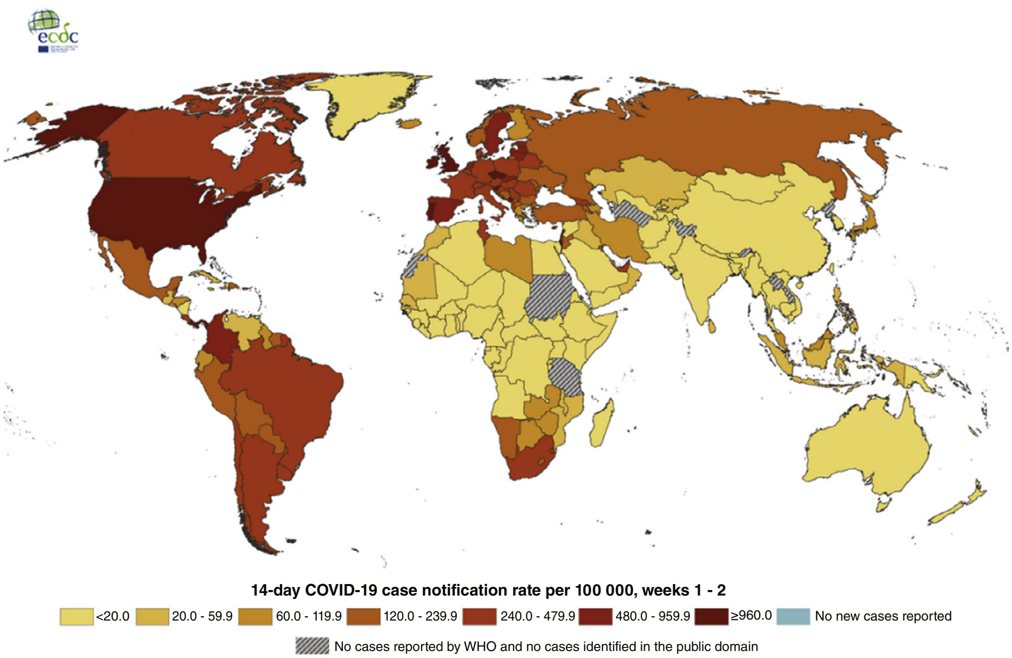


**Fig. 1.2** *14-day COVID-19 case notification rate per 100 000, weeks 1–2 (ECDC 2021).*

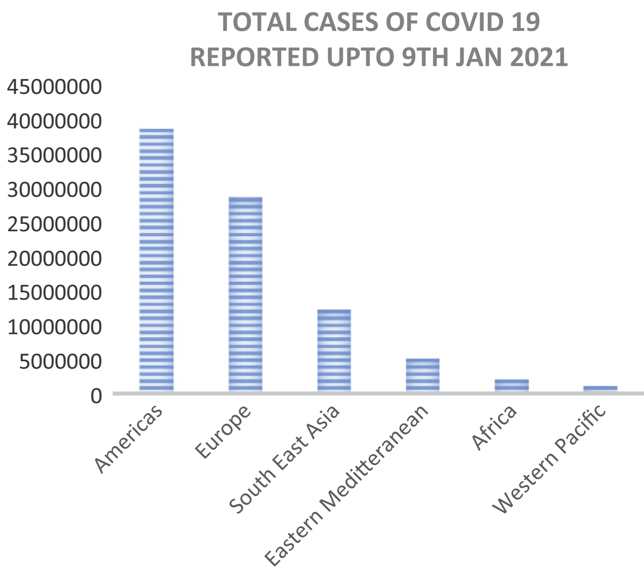


**Fig. 1.3** ***Total cases of covid-19 (9th Jan, 2021).***

indirect (Fig. 1.4 and Fig. 1.3) (Chagla et al. 2020). The direct mode of transmission can be via aerosols produced from respiratory droplets of infected patient during different processes including surgery and dental treatments. The other modes of direct transmission are secretions from an infected person like saliva, tears, semen, urine, fecal matter etc. The transfer of virus from mother to new born is also a direct mode of transmission.

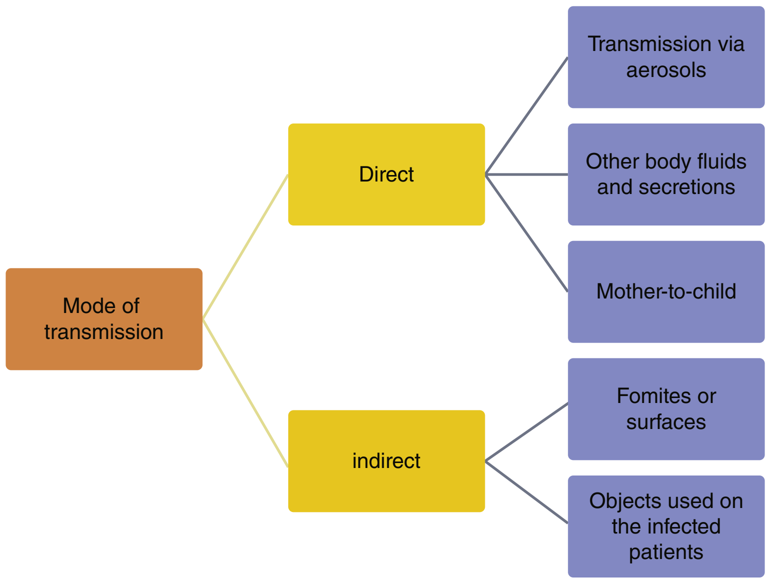


**Fig. 1.4** ***Modes of transmission.***

Indirect mode of transmission includes surfaces of furniture, fixtures etc. came in immediate contact of the patient or the objects used by the infected person.

There are reports suggesting the duration of viability of the virus on different surfaces. Stanam et al. said that the virus is viable on plastic and stainless steel surfaces for three days. They also reported that the virus is stable in the fecal matter for a couple of days, at room temperature. However, a temperature of more than 55 °C may kill the Covid-19 virus (Stanam et al. 2020). Further, the virus can also be controlled by Ultraviolet radiations and thus used for sterilization.

There are reports indicating transmission via feacal oral transmission as SARS-CoV-2 virus was detected in the stools and sewage (Heller et al. 2020). The virus may also transmit through eyes There are less reports on the transmission via eyes however, the corona virus is tested through the teas and other conjunctival emissions. The virus may spread during treatment of eyes and thus there were special guidelines for the opthalmicadiagnosis to follow while the procedures opted (Sun et al. 2020). A report generated by Repici et al., highlighted few treatments involving endoscopy may also result in transmission of the virus due to very less distance between the health personnel and the infected patient. Even asymptomatic patients can be risk for the person executing endoscopy (Repici et al. 2020).

The quarantine period optimal for controlling the corona virus dieases is 14 days as the incubation period of the virus is 14 days, approximately. The virus may spread from pregnant woman to infant. The first such case was reported in Shenzhen and there after many such cases were reported. However the fatality or mortality is negligible (Jiang et al. 2020). Chen et al. described a case study of four new born from infected mother at initial stage of the pregnancy. The infected mothers showed the typical symptoms of covid-19 i.e. cough, fever and body ache, however the level of lymphocytes were found to be less than the normal values at the time of hospitalization. The new born tested negative and the four mother recovered from the disease after few days. So it showed that the virus did not spread from the mother to the new born (Chen et al.). Liu et al. proposed their immunological view point for the reason of more susceptibility of pregnant women to corona virus (Liu et al. 2020). A study showed that the lack of vertical transmission of SARS-CoV-2 virus (Zhao et al. 2020).

## 1.6 Measure to control

Globally, various control measures are suggested by researchers, personnel working to combat the diseases. On social front, the countries affected by diseases, initially, planned and executed some well organized policies that helped to control the virus outbreak. The countries issued measures taken by government and quickly disseminated the information that helped to get full compliance and public support. In Africa, in order to control to the virus outbreak, different strategic planning like education awareness campaigns, testing for those who appeared to be infected with some other contacts were organized. The measures were to put a hold on the flourishing of the virus and hence the harmful effects on human being (Fanidi et al. 2020). One of the most severely affected countries was Switzerland, that reported a huge number of cases per capita. Salathe et al. reported the significance of testing and contact tracing and isolation in the country. Contact tracing and isolation are common intrusion to control the spread of infectious disease like Covid-19. Testing may not directly stop the spread of virus, however, the spread can be controlled by detecting the people with infections even for clinical disease compatible with covid-19. The testing is important part of measure to control the disease as rapid diagnosis and thus instant isolation of the patients may help to combat the disease. They reported that the testing is a tool to strengthened the measures to control the diseases (Salathe et al. 2020).

Phadake and Saunik, proposed the idea of repurposing the drug till the final development of effective vaccine against the virus. They mentioned about two strategies for treatment of the diseases: top down and bottom up. Top down approach is development of scientific action that can bottom up approach is repurposing the available generic medicines to fight against the virus growth. The later tactics was found to be useful and contributed well to improve global health and global viral security (Phadke and Saunik, 2020).

The drug therapy is still in the trial phase, however there are many medicines that are in use to treat the patients of covid-19 based on the studies on the virology studies on SARS-CoV-2 virus. These are certainly potential drug targets. As reported by Sanders and coworkers in a review, Remedisivir is one the most promising drug in use against the corona virus as it has shown encouraging in vitro activity towards the virus, however, it has not been approved by US food and drug administration. The other medicines like Oselamivir and corticosteroids were not recommended for treatment (Sanders et al., 2020).

Xiao and Torok reviewed the various control measures and their effectiveness. The same can be summarized as:

**i)** *Air disinfection of cities and communities*: Considering the route of covid-19 to be air borne this strategy was adapted my most of the infected countries. However, they said that the same is not an effective measure and must be end. As per WHO and National Health Commission of the People's Republic of China, the spray of the disinfectants and alcohol based fumes to clean sky, roads, vehicles etc. needs to be stopped as they higher exposure may be harmful to human health (WHO, 2020) and (Diagnosis and treatment plan of COVID-19 trial version 7. in Chinese).

**ii)** *Personal protective equipment (PPE) kit*: PPE kits includes all the accessories like gowns, gloves, face shield, etc. and it is a life savior control measure for all the front-line workers. The PPE kit gives protection from direct exposure to the aerosols produced by covid-19 patients. There is a large demand and supply of PPE kits owing to their single use. However the other factor associated with the use of PPE is their final fate in the environment. They may end up in landfills or ocean and thus adversely affects the environment.

**iii)** *Lockdown / restriction over certain activities*: Most of the affected countries have imposed lockdown to control the spread of the virus, however there are certain reports suggesting that the restriction on commutation by sealing off the boundaries is not of much value and may not control the disease. Also, the restricted activities may create anxiety and civil unrest and thus decline the compliance of public with issued guidelines like social distancing etc.

**iv)** *Public health education*: The health education in line with the scientific reports may help to control the disease as it not only brings awareness among people but also reduces the anxiety and stress level related to fake information. Studies on epidemiology must be provided timely and in an objective way that can help to access the disease more accurately. Misinformation leads to fright and anxiety among people and may hinder the implementation of control measures.

## 1.7 Pharmacologic treatments for coronavirus disease

The drugs previously used for treatment of SARS and MERs virus have prospective to treat Covid-19 virus also. The agents that showed good activity during in vitro assessment against SARS-CoV and MERS-CoV are in use during SARS and MERS outbreaks. There are some medicines that are promising as repurposed drugs for COVID-19.

*Chloroquine and Hydroxychloroquine:* The two are promising drugs in treatment and prevention of malaria and chlronic inflammatory diseases like rehaumatoid arthritis. The mechanism of action of these drugs is that they prevent the entry of virus into the cells by impeding glycosylation of host receptors, proteolytic processing and endosomal acidification. They also show immunomodulatory effects by weakening of cytokine production and inhibition of autophagy in host cells (Zhou et al. 2020 and Devaux et al. 2020). The in vitro bioactivity assays shows that the hydroxychloroquine has lower $EC_{50}$ value against SARS-CoV-2 as compared to chloroquine, after one day of growth. A study showed that in China, about 100 covid-19 patients showed improvement in radiological findings, viral inhibition and lesser progression of diseases whtne treated with chloroquine (Gao et al. 2020). Similar studies in France on 36 patients showed an improvement in virologic clearance with hydroxychlorquine. The authors also reported a more effective viral clearance with the use of combination of azithromycine with hdyroxychloroquine (Gautret et al. 2020). However, the study has limitation of small sample size. There is no clinical or safety result reported. Also, the adverse side effects of use of combination therapy is also a concern and requires additional studies.

The two drugs are considered as well tolerated treatment for malaria patients, however the two agents may be a cause of unavoidable and severe adverse effects.

*Lopinavir/Ritonavir:* Lopinavir / ritonavir is an oral drug combination for treatment of HIV and is a US food and drug administration (FDS) approved drug. It has shown in vitro activity against other novel coronaviruses by inhibition of 3-chymotrypsin like protease (Chu et al. 2004). There is no data published for the in vitro activity of the lopinavir/ritonavir for treatment of SARS-CoV-2 virus. Limited studies are conducted on the action of lopinavir/ritonavir on SARS and MERS, with major investigation on SARS only. The reports that have shown the use of lopinavir/ritonavir for treatment of Covid-19 are case reports, non randomized studies and thus we cannot ascertain the direct effect of the use of the two in treatment of covid-19. In a recent report by Cao et al. the results open label RCT were compared for lopinavir/ritonavir and standard care in 199 covid-19 cases. There was not significant difference in viral clearance was observed.

*Ribavirin:* It is a guanine analogue and known for inhibition of viral RAN-dependent RNA polymerase. It has shown promising activity against corona virus making it a potential choice for covid-19 treatment. However, the in vitro studies has shown that it has limited activity against SAR cov and high dose, as high as 1200 mg to 2400 mg orally every 8 h, is required for inhibition of viral growth. Also, a combination therapy is required along with its dosage.

The drug is given intravenously or administrated enteral and there is no evidence of treatment by inhaled administration as it is less effective (Foolad et al. 2019). A systematic review showed inconclusive results in 26 out of 30 studies reviewed. The other four studies have shown adverse effects like liver toxicity etc. (Stockman et al. 2006). Ribavirin causes severe dose-dependent hematologic toxicity. About 75 percent of patients administrated with ribavirin for SARS experiences elevations in transaminase (Stockman et al. 2006). It has limited usage for treatment in covid-19 owing to its adverse effects in pregnancy. It is generally administrated as combination therapy for bright chances of clinical efficacy.

*Other Antivirals:* Oseltamivir and Umifenovir are among the other antiviral agents. Oseltamivir is a neuraminidase inhibitor and is used against influenza virus however it has no documented in vitro activity for Covid-19 virus. Umifenovir targets the S protein/ACE2 interaction and inhibits membrane fusion of viral envelop. It is more likely to be used as repurposed antiviral agent. It is used against influenza in China and Russia and is of interest against SARS-Cov-2 virus also.

*The impact of covid-19 can be summarized as:*


The effect of the current pandemic can be divided into different aspects like health, social, economical and environment. It has effected life of many people globally. Many industries observed adverse effect be it aviation, tourism, sports, food sector, agriculture sector, small businesses, hospitality, automotive industry. On the other hand there are certain industries that are benefitted by the outbreak viz. pharmaceutical sector, companies that provide stay home offers like media, chemical, medical suppliers, Ed-Tech sector, telecom, online store.

The tourism industry shares about 10 percent of the total world GDP. During imposed lockdown the tourist were not permitted to travel any of the tourist place. The industry was put on hold for a long time and thus put the jobs of more than 50 million people working in the field at high risk (Lock 2020). The travel industry sector was bashed with large number of withdrawal and waning in demand (Upadhyay and Maroof, 2020). Asia and Africa continents suspended all air travel plans, United nations and Europe put a restriction on the entry of foreign nationals to their country (Ellis 2020).

The pandemic led to suspension of major sports events around the globe. These determents or suspensions of sports events adversely affected all the associated people working, the sports persons, media broadcaster, and the passionate fans. As per a report, the global value of sports media is around $50bn accounted for only the ten significant sports leagues (This is how COVID-19 is affecting the world of sports.). The restriction on sports led to loss of all the associated sectors, economically and socially.

The positive impact of lockdown reflected well on the services that offer stay at home products. The streaming gigantic like Netflix, amazon etc. observed a massive growth during the lockdown period.

We cannot ignore the psychological impact of the diseases increased many folds due to forced self-isolation of the infected person. The lockdown and quarantine has enhanced the panic, anxiety, depression and paranoia in the society. The other aspects are that the frontline workers who are working beyond their duty and capacity suffered a high level of stress. The fear of getting infected may also lead to obsessive thoughts and thus affects the social and progressive relations of a person.

A mixed effect was observed on chemical industries. It observed a decline in demand of the chemicals used in production of other end user items. However, a huge demand for packaging, PPE, sanitizers, hand wash, and other personal hygiene materials helped in the stability of the chemical industries. An affirmative effect on the medical supplies industries was observed due to high demand for ventilators, sterilization supplies, diagnostic supplies etc.

The shift from offline or blended learning to online learning has opened a new paradigm of teaching and thus uplifted the education technology industries. Similarly, the online buying of all the daily need items enriched the E-retail market. The online shopping is a way to keep an individual safe by decreasing the chances of social contact. The work from home culture and maintaining social distancing has transformed the whole world and increased the demand and dependence on telecom industries. Telecom sector is also finding new opportunities for growth in the novel scenario.

The effect on environment is one of the most significant and positive impact of the lockdown, the air quality showed a vivid enhancement. We were able to see the clear blue sky and significant visibility of nature. Many reports suggested a positive impact on the air quality of even most polluted cities of the world (Sharma et al. 2020). There are certain harmful effects of coronavirus also, one of them is high usage of plastic material. Personal protection equipment (PPE) is one of the biggest aid to protect the frontline workers from direct exposure to coronavirus. It is a life-saving kit for them. The PPE kit includes all the accessories like gloves, medical/surgical face masks, goggles, face shield, and gowns etc.

World health organization (WHO) and various national agencies have issued guidelines for their disposal, however, their disposal and fate in the environment is a serious concern for scientists.

The impact of social well-being of humans can't be ignored. There are reports of economic crisis, closing of well-established business that has affected all associated person and their families. The pandemic has led to prolonged exposure to stress and anxiety. The health workers and other frontline workers who are working day and night suffered a severe psychophysical stress.

The fear of getting infected leads to emerging fanatical thoughts among people. The fear of contagion increases the chances of a person to reduce the social relationships. The lockdowns and other stress conditions during pandemic can produce panic, paranoia or obsession, depressions and PTSD (post traumatic stress disorder).

## 1.8 Social implications of pandemic

The pandemic crisis has upturned every preparedness of better life be it modern technology, health care facilities, excellence of education, accessibility to any part of world and resources. As the word better is always used as reference so our accomplishments are still not ample. We all are suffering from the virus outbreak in one way or another. It has affected all of us at varied levels. The worst part was that we could not learn from our past exposure to such pandemic situations and it would be not be an exaggeration if we will say that the social impacts on this pandemic are even worse than previous ones. The social impacts on human beings are connected with financial, environmental, physical and emotional aspects. There are reports of millions of job loss, partial income loss, closing of various educational organizations, sexual and child exploitations, increase in domestic violence and deaths.

Amid covid-19 there was closure of schools and colleges and has led to loss of complete education for many children across the globe. As per report of UNESCO, in the initial month of spread (February 2020), only one country completely closed the educational institute and that affected 0.1 percent of the total enrolled learners, worldwide (UNESCO, 2020) and the value changed to 90.1 percent in the mid of April,2020 when 194 countries implemented educational institute closure. The implications of online learning exposed the disproportionate facilities like internet accessibility and e-learning tools in the various parts of world. We cannot ignore the fact that many schools and educators were not technically sound and prepared for online learning platforms. The education suffered pertaining to inadequacies of pedagogy on shifting from offline to online modality.

## 1.9 Summary and conclusion

- 87,589,206 people were infected with SARS-CoV-2 till ninth January 2021 including 1,906,606 deaths.
- The diseases started from China and then has affected about 216 countries, worldwide.
- WHO declared it as pandemic on 11th March 2020.
- It was name COVID-19 by WHO on 12th February, 2020.
- The SARS-CoV-2 virus shows similarity to Bat Co-V virus indicating the spread due to Bat.
- The infection may spread directly or indirectly.
- There are different control measures to control the spread of virus.
- Globally, scientists are working to develop and effective vaccine and few success can be marked till date.
- Social distancing is one of the most effective measure to control the spread.
- It has affected all aspects of life.

## 1.10 Conclusions

SARS-CoV-2 is a highly infectious virus with the ability of human-to-human transmission. The origin of corona virus is considered as zoonotic as its initial transmission was from animal to humans. There is an exponential rise in the cases of Covid-19 across about 196 countries, globally. The WHO continuously monitors the data of new cases, mortality and reclamation with vigorous worldwide surveillance. It is reported that the rate of mortality is quite low (1.2–1.4 percent) and subject to various factors like age, previous health and immunity, diabetes, lung diseases etc. We should avoid all kind of national and international travel to minimize the chances of spread of diseases. The control measure like social distancing and regular hygiene check are highly desirable. The outbreak has held the World to a standstill till today and appears to continue for a longer time even with the various control measures adapted amid the pandemic. The outbreak has affected major sectors of the world disrupting the global economy and international trade. The initial lockdown has certainly improved the environment with respect to water and air quality and noise level. The pandemic is a lesson that we may modify or improvise our actions to make the mother earth to smile again.

The epidemiology of COVID-19 throws a light on the growth and spread of diseases. We all should follow social distancing and regular sanitization to avoid the further spread of high risk Covid-19 infection. Governments may impose lockdown and curfew for strict implementation of social distancing to reduce the spread of the infection. The use of artificial intelligence and advance information technology may enhance the potency of surveillance system that may help further to strategize the steps to control the diseases.

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# CHAPTER 2

# SARS-CoV-2 and the wastewater environment

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## 2.1 Introduction

The emergence of the novel coronavirus disease in 2019, which is now known as Covid-19, and its rapid spread throughout the world forced the World Health Organization (WHO) to declare the outbreak a global pandemic (WHO, 2020). Its transmission from human-to-human happens when individuals touch infected surfaces and transfer the virus to one's mouth, nose, or eyes. However, other people remain contagious while they are asymptomatic. This highly contagious group of people is described as super spreaders as they rapidly transmit the disease without themselves being aware that they are carriers of the disease. Generally, infectious viruses have been reported to survive for long periods outside their host organism (Weber et al., 2016), with survival spans of several hours being reported on several common surfaces, thereby increasing the transmission opportunity through contact (Ye et al., 2016). The transmission also occurs through the transport of small airborne droplets present in the air resulting in possible human-to-human transmission driven by air circulation (Ashour et al., 2020; Wagginton and Boehm, 2020).

Faecal transmission routes are also possible as the virus RNA signature has been widely found in infected patients' excreta. This has been attributed to possible viral replication in the gut (Holshue et al., 2020). Literature suggests that the novel coronavirus may survive in stool samples for at least four days (Weber et al., 2016) while other coronaviruses remain transmittable in untreated sewage for days to weeks (Casanova et al., 2009). This is yet another potential transmission passage that is completely dependent on personal hygiene. Sewage in places with infected people could be another transmission route through the generation of small airborne droplets.

A typical example is the Hong Kong SARS outbreak in 2003, where a faulty sewerage system was considered behind the disease outbreak amongst residents (Peiris, et al., 2003). In this regard, the possibility of a substantial viral load in wastewater systems, coupled with a potential generation of small airborne droplets during wastewater

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treatment, requires that wastewater systems be regarded as potential transmission pathways for the novel coronavirus. The sewerage network's current nature that connects buildings further increases the risk of exposure within and between buildings and can be considered highly risky for hospital and healthcare environments. Generally, the role of sewage-contaminated airborne droplets in transmitting the novel coronavirus requires further research considering that RNA fragments of the virus have been reported in sewage influent before any clinical cases were reported (Medema et al., 2020).

The removal and inactivation of infectious viruses in wastewater are critical in controlling waterborne diseases. Studies on the presence of viruses in wastewater and their fate through wastewater treatment plants have focused primarily on enteric viruses, which transmit gastrointestinal diseases via water. Most enteric viruses are non-enveloped, consisting only of proteins and nucleic acids, while enveloped viruses contain an outer lipid membrane in addition to proteins and nucleic acids. Generally, enveloped viruses have been assumed to be absent in wastewater and further considered rapidly inactivated when released to wastewater. However, recent studies (Pinon and Vialette, 2018; Holshue et al., 2020) suggest that certain enveloped viruses may survive long periods in wastewater. Our current state of knowledge on enveloped viruses in wastewater has been limited due to, inter alia, a lack of appropriate methods for capturing and detecting infectious enveloped viruses in water. A few studies have previously attempted to better understand the presence, survival, fate, behavior, impact, and risk of enveloped viruses in wastewater (Ye, 2018). Despite the paucity of data on enveloped viruses' behavior in wastewater, few studies have suggested the survival of enveloped viruses in wastewater at cooler temperatures, with most viruses adsorbing to the wastewater biosolids during wastewater treatment (Ye et al., 2016).

The knowledge gained from viral survival studies to date has shed some light on the methods for recovering and characterizing infectious enveloped viruses from wastewater. The development of better characterization techniques for detecting infectious viruses in wastewater has further provided a promising tool for monitoring infectious enveloped or non-enveloped viruses in wastewater samples. Currently, protein reactions are believed to drive the destruction of the enveloped virus when free chlorine is used. In contrast, genome reactions are considered to drive the destruction of the enveloped virus when $UV_{254}$ is used. Therefore, improved characterization will provide a better understanding of the behavior of enveloped viruses during disinfection.

## 2.2 Virus transmission in wastewater environments

Waterborne pathogens are generally responsible for spreading several human diseases. For instance, enteric viruses cause infections in the human gut and are mainly transmitted via faecal matter exposure (Fannin et al., 1985; Fong and Lipp, 2005; Boone and Gerba, 2007). Enteric viruses such as norovirus, coxsackievirus, echovirus, and reovirus have been frequently detected in sewage (or untreated wastewater) with very high infectious concentrations detected (Fong and Lipp, 2005). In this regard, if wastewater is insufficiently treated, the infectious enteric viruses in the final effluent can contaminate surface water resources that are used for recreation, agriculture irrigation, or serve as drinking water sources (Okoh et al., 2010; Borchardt et al., 2004; Gallimore et al., 2005). Enteric viruses are mostly non-enveloped and consist of nucleic acids and protein capsids (Fig. 2.1), with diameters ranging in size from 20 - 100 nanometers. Previous research on wastewater treatment and monitoring efforts has generally focused mainly on the removal and inactivation of non-enveloped enteric viruses (Ye, 2018). In this regard, non-enveloped viruses have been widely studied compared to enveloped viruses.

Enveloped viruses contain a lipid membrane outside of their nucleic acids and protein capsids (Fig. 2.1). Enveloped viruses are responsible for several high-profile diseases in humans, such as SARS, MERS, avian influenza, and Covid-19. They are also responsible for less dangerous illnesses such as the common cold. Enveloped viruses have widely been assumed to be absent in wastewater environments, mainly because of the limited number of studies available (Ye, 2018). However, enveloped viruses enter wastewater, but methods for their detection and an understanding of their mechanistic fate are currently lacking.

Generally, available clinical and epidemiological evidence suggests that wastewater environments are potential reservoirs for enveloped viruses. This, therefore, calls for our concerted effort to expand our current knowledge regarding enveloped viruses and wastewater environments. However, to successfully do this, advanced analytical techniques for capturing and monitoring infectious enveloped viruses or their signatures in wastewater are required. There is also a need to evaluate the survivability of enveloped viruses that potentially enter municipal wastewaters in support of a better understanding of possible risks that wastewater may present from an occupational health point of view.

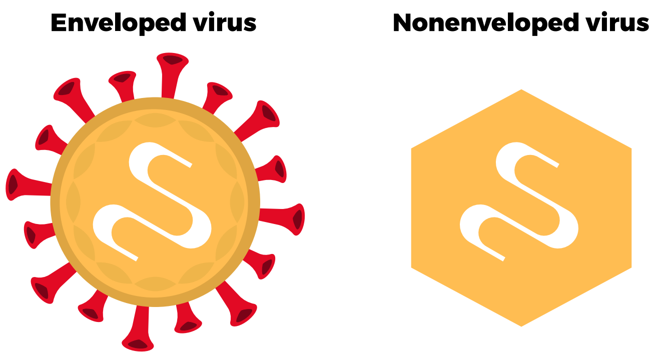


**Fig. 2.1** ***Structural illustrations of enveloped and non-enveloped viruses. Adapted from Ye, 2018.***

## 2.3 Enveloped viruses transmittable through wastewater

The continued mutation of the novel coronavirus, as well as the re-emergence and persistent waves being reported, has always been associated with the risks of environmental transmission compounded by exposure pathways to several viral infections (McKinney et al., 2006; Brown et al., 2007; WHO, 2014; New York Times, 2020). The novel coronavirus is closely related to previously reported viruses such as SARS reported in 2004, the Middle East Respiratory Syndrome (MERS) reported in 2012 (WHO, 2014). These significant similarities influence the rapid global spread and mortality of novel coronavirus, despite significant measures having been put in place to mitigate public health impacts and ensure continuity of critical infrastructure (Ashour et al., 2020; Wagginton and Boehm, 2020). Also, various vaccines have been developed to reduce transmission and mortality.

Generally, the risk of environmental transmission is compounded by the novel coronavirus's survival potential and presence in the wastewater environment. One area of key interest is the presence and survival of the novel coronavirus in sewage systems, particularly latrine sludge (Zhou et al., 2017), based on their common use in developing countries. Although the novel coronavirus is mainly spread through respiratory channels, research done before has detected the viral RNA material in the faecal matter from infected people. This has been attributed to the possible co-infection of cells within the gut (Zhou et al., 2017). This secondary infection is the main reason the genetic material has been detected in the faecal matter after it is no longer detectable through normal clinical testing (Xiao et al., 2020). Interestingly, the role of sewage in the outbreaks of both the SARS and the Covid-19 has been implicated but never confirmed (Wang et al., 2005; New York Times, 2020).

Although enveloped viruses are often more fragile, research has also indicated that coronaviruses can survive on various surfaces (Casanova et al., 2010) and wastewater (Gundy et al., 2009) for long periods. Other studies have further indicated that coronaviruses tend to adsorb to wastewater biosolids during wastewater treatment and be completely inactivated by the treatment process (Wagginton and Boehm, 2020). Therefore, the multi-barrier treatment processes for wastewater are currently thought to provide enough protection against possible non-compliance regarding coronaviruses (Wagginton and Boehm, 2020), resulting in negligible public health risks. Therefore, the associated public health risks for treated wastewater and water reuse are likely negligible. However, the ageing infrastructure coupled with poor operation and maintenance practices in many countries is a major risk regarding the sustainable management of the novel coronavirus in wastewater and a proper global mitigation strategy of Covid-19.

### 2.3.1 Coronaviruses

Different coronaviruses can cause respiratory and gastrointestinal illnesses (Vabret et al., 2006), with some strains being responsible agents for epidemics of deadly acute pneumonia diseases. The overall case-fatality rate for the SARS outbreak in 2003 was 10 percent (WHO Website; 2004), while the accumulated case fatality rate of MERS was 35 percent (Alsolamy and Arabi, 2015). Infected individuals shed SARS and MERS coronavirus genetic material in their stool and urine samples with high frequency, and infectious SARS coronaviruses isolated from human stool samples (Chan et al., 2004). As reported by The Associated Press in a publication of the 11th of February 2020, a recent outbreak of the novel coronavirus identified infected residents despite living on different floors, prompting concerns regarding the possible spread of the novel coronavirus through building sewerage pipes. Furthermore, viral shedding has been reported for other low pathogenic strains of human coronaviruses (Risku et al., 2010; Jevšnik et al., 2013), and infectious coronavirus has been isolated from human stool samples (Vabret et al., 2006), suggesting their possible presence in wastewater.

### 2.3.2 Influenza viruses

Infectious avian influenza viruses (AIV) are shed in an extremely high concentration in bird faeces (Webster et al., 1978). They are transmitted primarily via the faecal-oral route in birds (Watanabe et al., 2014). Occasionally, humans can acquire AIV (H5N1), resulting in fatality rates of up to 53 percent between 2003 and 2017, as estimated by WHO (WHO, 2017). The transmission route of AIV from poultry to humans is still elusive, but several transmission routes are hypothesized, including direct contact with the infected poultry and contact with virus-laden faecal matter (Markwell and Shortridge, 1982; Peiris et al., 2007). While human-to-human transmission has rarely been reported in human AIV cases, infected individuals can shed AIV in their stool samples (de Jong et al., 2009; Hu et al., 2013). The concentration of AIV H5N1 detected in rectal swab samples has been reported to range from $8.6 \times 10^2$ to $1.5 \times 10^6$ gene copies/mL (de Jong et al., 2006; Buchy et al., 2007). Like AIV, seasonal human influenza virus strains have been detected in faeces at concentrations of $10^4$–$10^6$ gene copies/g of stool samples (Chan et al., 2011).

### 2.3.3 Other enveloped viruses

Zika virus is an emerging mosquito-borne human pathogenic virus, and Zika virus genetic material can be detected in urine specimens (Gourinat et al., 2015). Some mosquito-borne enveloped viruses that include the dengue virus and West Nile virus have also had their genetic materials widely detected in urine (Poloni et al., 2010; Hirayama et al., 2012; Barzon et al., 2013), with infectious West Nile virus isolated from the urine of acutely infected individuals (Barzon et al., 2013). Alternatively, wastewater is a habitat for mosquito larvae, with resultant adults carrying and transmitting these enveloped viruses (Duffy et al., 2009; Ponnusamy et al., 2011; Hossini et al., 2017).

Cytomegalovirus can be hosted by all age groups, in most cases, asymptomatically, but can be a threat to those who are immunodeficient or immunocompromised.

Infectious cytomegaloviruses can be shed in the urine from infants and children infected at birth (Noyola et al., 2000). Contact with urine is a suspected transmission route of cytomegalovirus. On the other hand, the Ebola virus, causing deadly haemorrhagic fever, can enter wastewater when patients shed bodily fluids that contain high levels of infectious viruses (Bausch et al., 2007; Mora-Rillo et al., 2015; Bibby et al., 2017).

## 2.4 Virus survival in wastewater

The virus should retain its infectivity for the virus present in water to cause illness until they enter their host. A measure of the extent to which viruses survive is given in terms of the length of time they lose 90 percent of their original infectivity, generally referred to, in short, as the $T_{90}$ value. Enveloped viruses have often been assumed to be less stable in water, but this assumption is too simplistic. The $T_{90}$ values available in the literature suggest that the susceptibility of enveloped and non-enveloped viruses to environmental conditions is quite comparable (Brainard et al., 2017). In this regard, some coronavirus and avian influenza viruses retain their infectivity as long as non-enveloped viruses. Coronaviruses, SARS, and 229E, for example, have a $T_{90}$ in excess of one day in several human waste samples (Brainard et al., 2017). For context, one day is the maximum retention time of wastewater in a common sewage system. Casanova (2015) have reported the destruction and inactivation of enveloped surrogate viruses in human sewage. Results indicate that enveloped viruses can undergo significant inactivation in sewage over a few days, depending on environmental conditions, prompting the need for longer holding times during wastewater treatment to accommodate the right environmental conditions.

However, the current survival studies on enveloped viruses are limited, with less reported for raw wastewater and available reports focusing on laboratory-based studies. If the viruses can survive in raw wastewater and then enter the wastewater treatment plants (WWTPs), viruses need to be removed or inactivated effectively through the treatment processes. The mechanisms and removal efficiency of non-enveloped enteric viruses in WWTPs have been reviewed in previous publications (Gerba, 1981; Hurst and Gerba., 2009). For non-enveloped viruses, the removal efficiency from wastewater depends on virus adsorbing to biosolids during primary and secondary treatment (Gerba, 1981; Ye, 2018). Ye et al. (2016) have reported the partitioning behavior of enveloped viruses to follow a similar pattern to non-enveloped viruses. This suggests that the fate and behavior of enveloped viruses in wastewater should focus on their interaction with biosolids and the resultant risks associated with handling wastewater sludge. Therefore, significant and comprehensive studies are required for enveloped viruses to strengthen our limited ability to predict the fate of infectious enveloped viruses in WWTPs. Currently, wastewater effluent disinfection is generally applied to inactivate viruses during wastewater treatment.

## 2.5 Virus inactivation by disinfection treatment

Disinfection is used in WWTPs to inactivate pathogenic viruses and other microorganisms. The disinfection efficacy of several disinfection methods has been widely reported for non-enveloped viruses (Aieta and Berg, 1986; Kim et al., 1999; Kitis, 2004), whereas limited data is available for enveloped viruses. However, a recent study identified aspects of enveloped viruses that can be exploited to achieve adequate disinfection using chemical oxidants or UV radiation (Ye et al., 2018). This study by Ye et al. (2018) developed a framework for analyzing molecular reactivities. This procedure can also be used to study how enveloped viruses can survive under various environmental conditions. In this regard, the focus on reviewing virus inactivation mechanisms by ultraviolet 254 ($UV_{254}$) and free chlorine becomes key, as these are the commonly used disinfection methods.

### 2.5.1 UV disinfection

UV is one of the most applied disinfection methods as viruses are mostly sensitive to UV due to the high photo-reactivity of nucleic acids present in viruses. Low-pressure mercury lamps emit the highest UV intensity around 254 nm; therefore, most studies on virus inactivation focus on this specific region (i.e., $UV_{254}$).

Our current knowledge of virus inactivation mechanisms has been established primarily with non-enveloped model viruses. A study of bacteriophage MS2, for example, suggests that the inactivation of a non-enveloped virus by $UV_{254}$ is mainly attributed to damage in the viral genome (Wigginton et al., 2012). Follow-up studies have underscored the findings that the $UV_{254}$ reactivity of viral genomes correlates to virus susceptibility to $UV_{254}$ (Beck et al., 2013; Sigstam et al., 2013; Ho et al., 2016; Qiao et al., 2018). Two main factors that determine the $UV_{254}$ reactivity of viral genomes include genome size and types. Other mechanisms of virus particle damage by $UV_{254}$ can also lead to non-enveloped virus inactivation. In the MS2 model, protein damage sensitized by adjacent viral RNA sequences contributes to 20 percent of the observed virus inactivation (Wigginton et al., 2012). In contrast, in non-enveloped dsDNA viruses, the damaged genome can be repaired in the host cell, resulting in higher resistance to $UV_{254}$ (Sinha and Häder, 2002). Although genome reactions are believed to drive the inactivation of the model enveloped virus by $UV_{254}$, the comprehensive mechanisms of enveloped virus inactivation by $UV_{254}$ have not been thoroughly established and require further investigation.

### 2.5.2 Free chlorine disinfection

Free chlorine is a strong oxidant that readily inactivates microorganisms. Free chlorine is an aqueous solution of chlorine species: HOCl, $OCl^-$, $Cl_2$ (aq), and $Cl_2O$ (aq) (Sivey et al., 2010), with the primary oxidant species being the neutral molecule hypochlorous acid (HOCl). Based on the non-enveloped MS2 model, the reactions of free chlorine with virus proteins and genomes impact viruses' ability to bind, enter and replicate in the host cell (Wigginton et al., 2012). The inactivation of enveloped viruses with free chlorine has only been compared to non-enveloped viruses in one study. The enveloped bacteriophage Phi6 and Ebola virus were significantly inactivated more than non-enveloped bacteriophages MS2 and M13 in 0.5 percent sodium hypochlorite solution (Gallandat et al., 2017). However, that report provided limited information on the chlorine demand of samples and other important experimental conditions. Consequently, it is impossible to draw general conclusions regarding the comparable chlorine activation capacity for enveloped and non-enveloped viruses, with further studies required.

A bottom-up characterization of enveloped virus inactivation could help identify molecular features that drive inactivation. With this information, we would be better equipped to select and improve disinfection methods for treating enveloped viruses. This is particularly important during outbreak events when culturing viruses to see how well disinfection is working is often not possible.

## 2.6 Established research on SARS-CoV-2 and wastewater

Current research indicates that enveloped viruses are inactivated much faster than non-enveloped viruses in wastewater (Gundy et al., 2009; Casanova et al., 2015; Bibby et al., 2015; Ye et al., 2016; Brainard et al., 2017). Furthermore, they partition to wastewater solids just like non-enveloped viruses (Ye et al., 2016), and wastewater temperature is positively linked to their inactivation rates (Ye et al., 2016). In wastewater treatment processes, these viruses generally become susceptible to oxidant disinfectants (Rice et al., 2007; Ye et al., 2018) while the presence of an envelope appears to protect them from UVC light (Ye et al., 2016).

### 2.6.1 SARS-CoV-2 virus and wastewater treatment plants compliance

Wastewater treatment plants are generally designed to reduce microbial risk and other chemical pollutants in support of compliance. Based on the current ability of the wastewater treatment process in the compliant removal of E.coli and other related pathogens, the multi-barrier wastewater treatment systems are considered effective enough in removing the novel coronavirus and its RNA fragments during treatment. Nevertheless, there may still be a certain level of risk of wastewater exposures that need to be studied, considering that the novel coronavirus has been found in human waste such as urine or faeces. The risk of transmission through wastewater is even higher in communities where sewage overflows are prevalent, sewage infrastructure is absent, or ageing happens to be the case in most developing countries. In this regard, ageing infrastructure coupled with the poor operation and maintenance practices associated with the wastewater sector in developing countries becomes a major risk regarding sustainable management of the novel coronavirus in wastewater, thereby hampering the proper risk mitigation strategy of Covid-19.

### 2.6.2 Implications of novel coronavirus detection in wastewater

The detection of the novel coronavirus genetic material in the faecal matter has prompted wide collaborative research regarding the novel coronavirus's possible occurrence in wastewater. Some studies confirm the viral RNA presence in numerous wastewater samples (Medema et al., 2020). Although not much surprising to detect the viral RNA in wastewater, its presence presents challenges regarding wastewater reuse and circular models. However, the novel coronavirus and its RNA fragments are not expected to persist through the wastewater treatment and disinfection process (Wigginton and Boehm, 2020), although some consider the risks associated with small droplets generated during primary and secondary treatment still need to be considered. However, it is of paramount importance to note that no viral RNA has been detected in potable water to date (CDC, 2020). The current urgency to know more about the novel coronavirus has driven the establishment of research collaboration networks in the interest of coordinating monitoring efforts and sharing protocols, and this is something that had never been seen before for previous pandemics.

One other challenge linked with the Covid-19 is the development of reliable analytical techniques that provide accurate and precise measures of the disease and pathogen prevalence in environmental samples. The development of reliable analytical tools, particularly those that offer online and remote monitoring, is critical to ensure the current clinical testing is complemented by the 'environmental surveillance' or 'wastewater epidemiology'. Despite these setbacks and currently limited research data, the following remain scientifically factual;

- The novel coronavirus is sensitive to disinfectants and high temperatures, and therefore less stable in currently applied wastewater and drinking water treatment processes;
- Drinking water systems are safe, based on years of research and knowledge on other more robust viruses than SARS-CoV-2.
- SARS-CoV-2 is not an important waterborne pathogen, the primary route of transmission being droplets through coughing and sneezing and contact with contaminated surfaces. As a result of this and with no epidemiological signals that sewage workers are at risk, the risk of SARS-CoV-2 transmission via sewage is considered low, and current protective measures for these workers are considered adequate.
- Monitoring the viral RNA fragments in sewage is very sensitive and critical as an early warning system complementing the clinical testing.

However, the above conclusions should be considered with a clear understanding of the global wastewater sector challenges, particularly with regards to poorly operated and maintained treatment plants, estimated to discharge more than 80 percent of untreated sewage into rivers in most developing countries (WWAP – United Nations World Water Assessment Programme, 2017).

## 2.7 Outbreak response and research needs

### 2.7.1 Outbreak response

A logistical challenge for the medical profession is to provide clinical testing for COVID-19 at a pace that ensures effective contact tracing and isolation of confirmed positive cases to curb the spreading of COVID-19. This is because the testing process is time-consuming, labor intensive, and is generally hindered by a lack of testing kits. In this regard, wastewater-based epidemiology (WBE) becomes an alternative that complements clinical testing. This potentially provides information on the disease's prevalence in communities by testing for the viral RNA fragments in wastewater (Yang et al., 2015).

In support of WBE, Pinon and Vialette (2018) have emphasized the need to conduct large-scale studies in artificial environments such as WWTPs serving specific communities to track disease prevalence. The potential benefits of data from such studies for the communities are quite significant. They would include (i) a measure of the scope of the outbreak, (ii) decision support, (iii) impact prediction, (iii) assessment of required interventions, and (iv) serves as an early warning tool.

The successful use of a WBE approach to detect trends of covid-19 in wastewater as an early warning system will require analytical techniques that provide data much quicker so that online monitoring of the RNA fragments at the point of collection is achievable. At present, the most used method to detect the SARS-CoV-2 and its RNA fragments is the polymerase chain reaction (PCR) assay, and this is also currently used globally for clinical testing. The high sensitivity and specificity requirements of the PCR assay method make its handling in the laboratory very complicated, as it also requires highly skilled personnel and long, complex data processing and analyses. This is not favorable to on-site, online monitoring of samples in support of WBE. There is, therefore, a need to develop alternative analytical techniques and tools that are robust enough to trace the SARS-CoV-2 sources accurately and quickly through the WBE. Quick detection of the virus facilitates rapid response and prevents transmission promptly, thereby allowing the screening of asymptomatic carriers.

Recent studies have shown that simple devices can provide an alternative as powerful tools for quick detection of pathogens such as SARS-CoV-2, further indicating infection transmission (Magro et al., 2017). Such simple devices' strength is their ability to integrate all the key processes required for testing into an inexpensive material (Magro et al., 2017). In this regard, the entire testing procedure can be done and completed without using a pump or need for power supply, thereby overcoming the PCR limitation and the need for its multistep processes. These simple analytical devices are quite sensitive and provide high-quality and precise assays for pathogens comparable to PCR laboratory assays. This is evidenced by previous work done in Uganda (Reboud et al., 2019) that demonstrated that tests, including pathogen sequencing, could be completed within 50 min, thereby providing high quality, faster, and precise diagnosis for malaria than PCR

Another advantage of using these simple paper analytical devices is that the papers are easily handled, stored, transported, and easy to dispose of through incineration without the risk of environmental contamination. Furthermore, the devices only require visual interpretation, making them easy and simple to use, with significant potential to effectively detect pathogens in wastewater, thereby providing a fast method for quantitative monitoring of RNA fragments as indicators of SARS-CoV-2 in wastewater (Yang et al., 2017).

### 2.7.2 Research needs

Several key areas of research that require attention in terms of handling potentially highly infectious liquid wastes such as wastewater have been highlighted in the literature (Bibby et al., 2017), and these include the following:

#### *2.7.2.1 Need for mechanistic model of viral deactivation*

Generally, there is a need for a shift from historical, descriptive models of environmental virus deactivation to mechanistic models (Decrey et al., 2015). Unlike descriptive models, mechanistic models can enable quick use and application of deactivation behavior to emerging pathogens and their exposure scenarios. Therefore, specific physical, biological, and chemical mechanisms in wastewater matrices would require further research. Additionally, the impact of outer lipid envelopes on deactivation mechanisms needs further research as the emerging viruses are enveloped. However, it should be noted that the task requires significant caution, based on Biosafety Levels involved, and this would require access to limited specialized laboratory facilities.

#### *2.7.2.2 Improved characterization of exposure and transmission pathways for wastewater environments*

Current evidence points to the high exposure risk from untreated wastewater faced by wastewater workers and the public. In this regard, specific areas that would require further research attention include (i) identification and outlining specific exposure scenarios, (ii) potential exposure from accidental releases such as combined sewer overflows, (iii) the potential for virus-laden wastewater droplets and (iv) the dynamics of structurally diverse viruses present during wastewater treatment.

#### *2.7.2.3 Reconsideration of surrogate evaluation of emerging pathogens*

Surrogate microorganisms such as MS2 bacteriophage have been widely used to study pathogens' fate and persistence in the environment. However, the significant changes in the viral occurrence of enveloped viruses suggest that it may be best practice to use the pathogen of interest (Wigginton et al., 2015). Moreover, evidence has shown that these surrogates are quite limited and insufficient to prove a better understanding of viral occurrence and deactivation in the wastewater environment. In cases where the use of the actual pathogen is not possible, several surrogates are used so that various aspects of target pathogen physiology are captured. Even if the BSL3 and BSL4 viruses can be studied, it is important to include a surrogate virus in the same samples that contain the pathogenic viruses to allow direct comparison with other studies. In such cases, it is recommended to include the bacteriophage MS2 as it has been widely used, and this would facilitate inter-laboratory comparison and validation.

#### *2.7.2.4 Appropriate disinfection approaches of high strength waste*

High strength or high organic content waste includes infectious viruses excreted from infected people in the form of blood, vomit, faeces, and wastewater. Although control of pathogen release at the source through disinfection using chlorination reduces the contamination downstream, the use of hyper-chlorination on high organic content wastes is not enough to inactivate pathogens (Sozzi et al., 2015). This is because part of the chlorine gets consumed by the high organic matrix present in the waste. In this regard, the use of alternative disinfection methods like pH adjustment or heat is required. Therefore, further understanding of how disinfection such as chlorine and UV function in high-strength waste is critical.

#### *2.7.2.5 Communication requirements*

A critical limitation in viral pandemic responses is the lack of a better understanding of the linkages between the wastewater surveillance data and clinical testing. Positive and proactive communication is critical for building stakeholder and public trust in the value that the two approaches bring and how they complement each other to mitigate challenges posed by COVID-19.

#### *2.7.2.6 General research needs*

The increasing outbreak of viral diseases has highlighted the need to document all known viral pathogens to reduce the associated risk. Of note, there is a need to reduce human-wildlife interactions as almost all viral pandemics are known to have come from the wild. This information is critical to guide future outbreak response and reduce the risk of zoonotic diseases.

The presence of the novel coronavirus in different environmental media, particularly wastewater, warrants urgent systematic investigation. Inaction poses the risk of the novel coronavirus becoming a seasonal infectious virus. Delays in the admission of vaccines have resulted in numerous viral waves and associated mutations. Therefore, what is needed is proactive preparedness through the documentation of all known viruses with origins from the wild.

Predictive models will play a key role in providing information on the occurrence and other characteristics of enveloped viruses, thereby reducing the need to study every virus under every condition (Brainard et al., 2017). The use of wastewater to monitor virus circulation in communities and detect outbreaks before clinical cases are identified is another promising area as this approach has been used before for pathogenic bacteria

(Diemert and Yan, 2019), non-enveloped viruses (Berchenko et al., 2017), and more recently for the novel coronavirus (Medema et al., 2020).

## 2.8 Conclusions

In conclusion, the novel coronavirus is probably not the only novel virus that will originate from wildlife. There is an increasingly close interaction between humans and animals due to the destruction of the ecological infrastructure, which provides wildlife's natural habitat. The close socio-ecological interaction has been seriously threatening global public health due to the warming climate. There is a need for research and policy to shift from reactive interventions to proactive approaches that allow anticipation of future virus outbreaks and ensure preparedness. There is a need to approach the challenge holistically and avoid future outbreaks from becoming pandemics. This requires scientists from all sectors and policy to work together and take a more comprehensive approach that allows significant understanding of viruses that potentially pose a risk to public health. The current pandemic experience has further shown the need to refrain from focusing on one sector as this will only aggravate the challenges in other sectors resulting in job losses and economic downturn. This then calls for a transformational change through circular modeling that facilitates integrated and holistic assessment of the present and future scenarios, including a clear understanding of environmental factors shaping possible transmission routes.

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CHAPTER 3

# Role of environmental factors in transmission of COVID-19

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## 3.1 Introduction

An outbreak of the disease caused by Severe Acute Respiratory Syndrome Coronavirus ID 19 (SARS-CoV-2) has been occurring over a wide geographic area and an exceptionally high proportion of the world population has been infected as compared similar previous infectious diseases. The deadly virus SARS-CoV-2 is the causative agent of the deadly pandemic Coronavirus Disease (COVID-19). The present Coronavirus (CoV) that caused the disease COVID-19 is found to be a mutated strain of its pre-occupied strains namely Severe Acute Respiratory Syndrome (SARS) and Middle East Respiratory Syndrome (MERS) causing CoVs (FDA 2020). Both the pre-existing CoVs were termed as SARS-CoV and MERS-CoV, respectively. The diseases SARS and MERS were epidemic in China in 2003 and in the Middle East especially in Saudi Arabia (was the epicentre) in 2012, respectively (BBC 2020; CDC 2020; FDA 2020a; She et al. 2020; Shereen et al. 2020; WHO 2020a–e). SARS-CoV-2 has found 50–80 percent similar nucleotide sequence in its genome as compared to the genome sequences of the SARS-CoV and MERS-CoV (Andersen et al. 2020). As per the opinion of the Chief scientist of World Health Organization (WHO) Dr Soumya Swaminathan, a creation procedure will have a crucial genetic marker that SARS-CoV-2 is missing is (Ramesh, 2020). It proves the fact that SARS-CoV-2 is a natural strain of CoVs family (Ramesh 2020).

The epidemic SARS was highly infectious and China was its epicentre. Around 774 people had lost their live in SARS which was 14 percent of the total infected cases (BBC 2020; Caly et al. 2020; Guo et al. 2020; Habibzadeh and Stoneman 2020; She et al. 2020). In MERS, 35.7 percent mortality rate was observed out of all the infected 2,182 cases (Chafekar and Fielding 2018). However, all previous records were broken by COVID-19 because, as per rolling data as on 22.12.2020, it has infected around 77.86 million individuals, out of which, 54.75 million people have recovered from the disease and 1.71 million people have died. Although, the rate of infection SARS-CoV-2 is very high in comparison to the above two CoVs, the death to infection rate is still low i.e. 2.19 percent as on 22nd December 2020

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(WHO 2020e). Similarly, the rate of recovery is also very high i.e. 70.32 percent as compared to SARS and MERS. SARS had its epicentre in China and MERS had its epicentre mostly in Saudi Arabia (as it had experienced 1,807 infections and 705 deaths alone in MERS) although it spread to 27 countries, but COVID-19 has affected 216 countries. Up to the April 2020, the death rate was almost 4.55 percent which was the panicking message from COVID-19 to make the world united to fight against it (She et al. 2020; Shereen et al. 2020; Fig. 3.1).

Due to the novel strain, no specific vaccine or medicine is available for the treatment of COVID-19. As a result, with the most advanced health care system, USA top the list among the mostly affected countries, behind which Italy, Germany, France, Spain, Russia hold the rank of higher frequency of contracting COVID-19 disease till the end of May 2020 (Fig. 3.2). As per experts from WHO, it would take 9 to 12 months to develop a vaccine if everything will be in order and the current expectation is January 2020 in which vaccine should be available in most of the countries (Ramesh 2020; FDA.gov, 2020). So, all myths during the end of May-June 2020 to come up with a vaccine within few weeks were practically seemed to be unprecedented (Ahn et al. 2020). Therefore, drug repurposing was the only clinical options for the treatment of the disease. Many existing drugs with antimalarial potencies such as Chloroquine (Yao et al. 2020a, b) and Hydroxychloroquine (Science News 2020), anti-HIV capacity such as Lopinavir or Ritonavir (Cao et al. 2020; Smith et al. 2020), medicines with nucleoside analogue Remdesivir (Brown et al. 2019; Ko et al. 2020; Wang et al. 2020a; Wit et al. 2020), macrolides such as Azithromycin (Smith et al. 2020), monoclonal antibodies against COVID-19 (Tocilizumab Xu et al. 2020) and corticosteroids or infected (with COVID-19) blood plasma are only re-purposed without much clinical experiences (Choudhary 2020; Smith et al. 2020). As per WHO chief scientist, "the antimalarial drug hydroxychloroquine (Yao et al., 2020a) is considered as a "game-changer" as it works fine in contextual treatment of COVID-19 patients. Similarly, the anti-cancer drugs remdesivir is under the solidarity trial SARS-CoV-2 whereas the two antiviral drugs lopinavir-rotnavir combination has been considered as "efficient" for the treatment of COVID-19. However, still the world needs a target specific medicine or vaccine to combat the deadly pandemic COVID-19" (Ramesh 2020). Currently, recommendation of the use of steroids to save the life of critical COVID-19 patients is also found to be useful (WHO 2020a–f).

As an alternative clinical approaches, several conventional or alternative medicines (such as homoeopathy, Ayurveda and traditional Chinese medicines) or approaches (such as high throughput *in silico* tools and specific enzyme inhibition approaches) using both wet and dry laboratory tools are suggested for the possible treatment of COVID-19 (Paital et al., 2014). It is because alternative medicines have found to tremendous curing activity in clinical trials against several diseases (Hati et al. 2012; Paital et al. 2011; 2014, 2015; 2017; Cao et al. 2020; Chu et al. 2004; Chafekar and Fielding 2018; Mishra et al. 2019; Caly et al. 2020; Dong et al. 2020; Jin et al. 2020; Huang et al. 2020; Raja et al. 2020; Vellingiri et al. 2020; Zhou et al. 2020). Specifically, under the

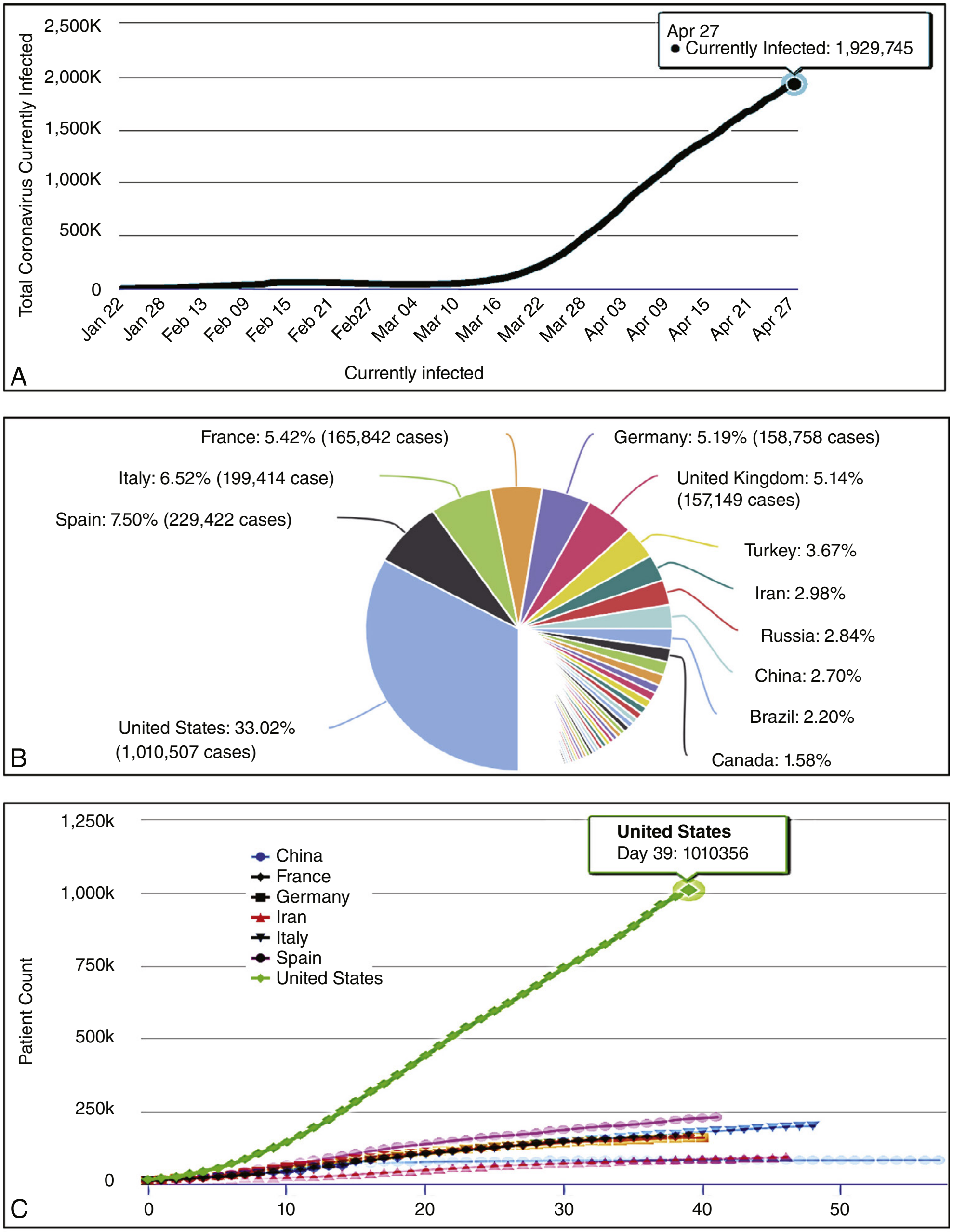



**Fig. 3.1** ***Colour figure indicating countries, territories or areas with confirmed cases of COVID-19 up to 20 April 2020.*** a) Number of confirmed cases in world and the graph is still risings on 27th 2020 indicating no saturation point of the disease, so more time is required to develop resistance in human against COVID-19, b) few major countries that shares the respective percentages of total infection in the world, c) USA is the most affected country that still experiencing a sharp rise in cumulative number of cases, by number of days since 10,000 cases in "Y" axis (data source: WHO, 2020; Worldometers, 2020 under creative common license).

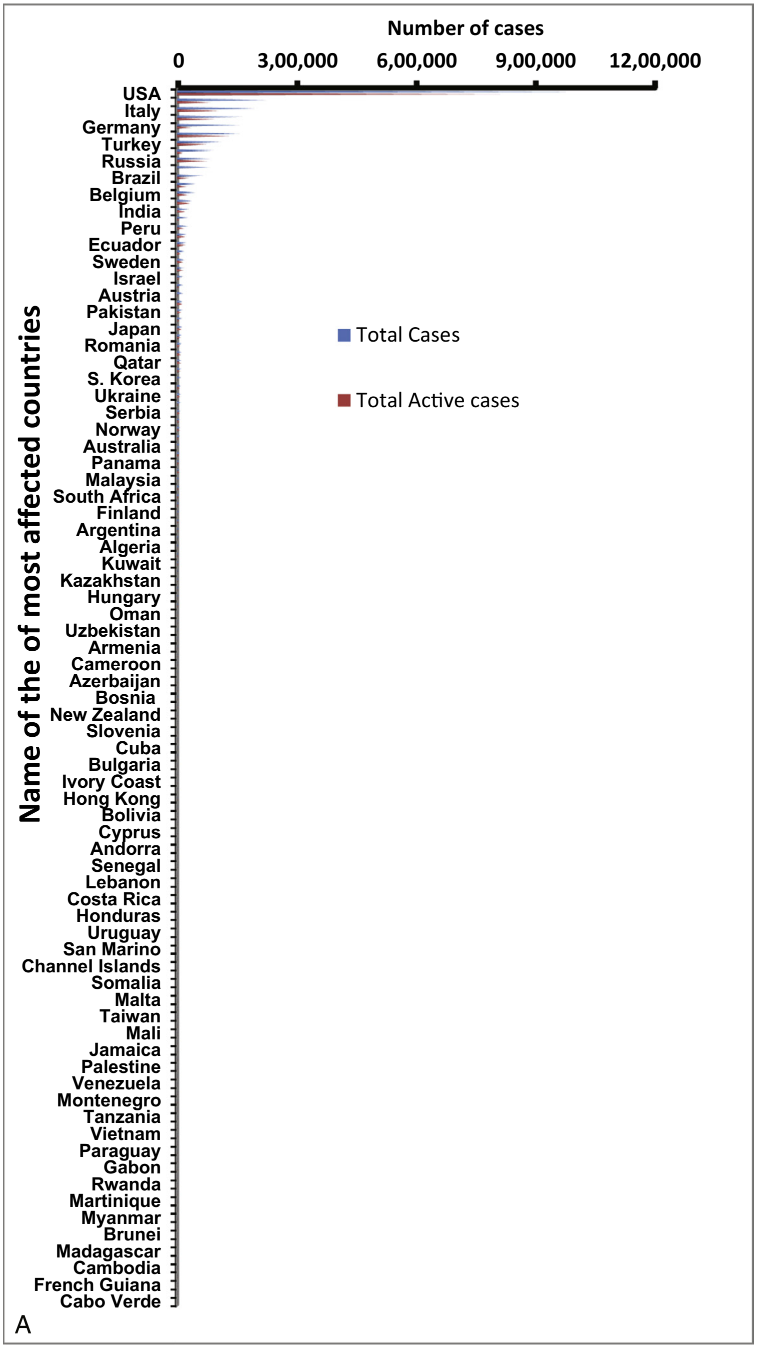



**Fig. 3.2** ***Top countries of world that have tested ≥100 COVID-19 cases till 28th May 2020 (Source, WHO, 2020).*** a) Ranking of countries in descending order (top to bottom) as per the COVID-19 infection and active infection cases status as on 28.05.2020, b) ranking of countries in descending order (top to bottom) as per the total number of death and recovered cases as on 28.05.2020.

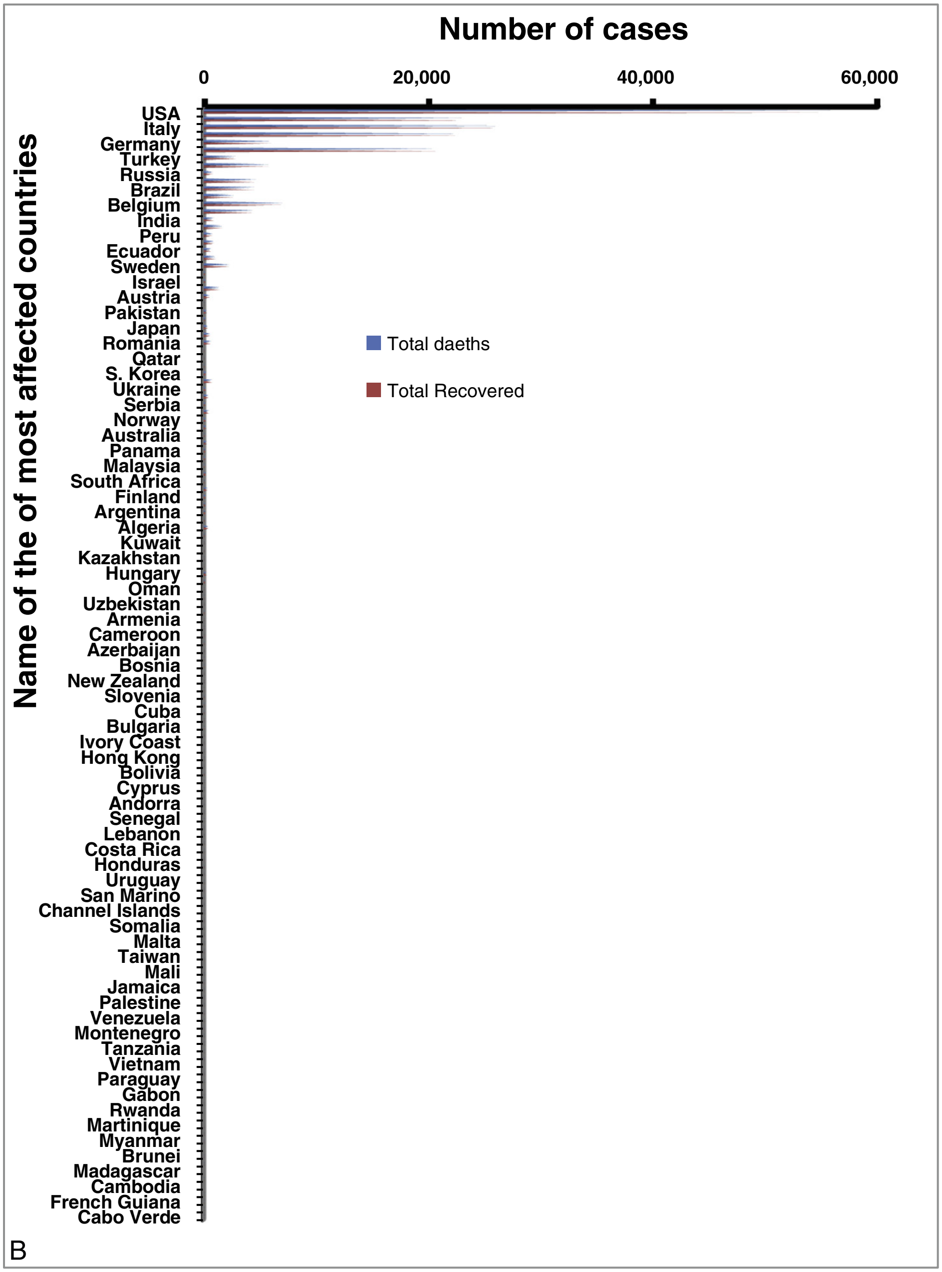

Number of cases
0
20,000
40,000
60,000
Name of the of most affected countries
USA
Italy
Germany
Turkey
Russia
Brazil
Belgium
India
Peru
Ecuador
Sweden
Israel
Austria
Pakistan
Japan
Romania
Qatar
S. Korea
Ukraine
Serbia
Norway
Australia
Panama
Malaysia
South Africa
Finland
Argentina
Algeria
Kuwait
Kazakhstan
Hungary
Oman
Uzbekistan
Armenia
Cameroon
Azerbaijan
Bosnia
New Zealand
Slovenia
Cuba
Bulgaria
Ivory Coast
Hong Kong
Bolivia
Cyprus
Andorra
Senegal
Lebanon
Costa Rica
Honduras
Uruguay
San Marino
Channel Islands
Somalia
Malta
Taiwan
Mali
Jamaica
Palestine
Venezuela
Montenegro
Tanzania
Vietnam
Paraguay
Gabon
Rwanda
Martinique
Myanmar
Brunei
Madagascar
Cambodia
French Guiana
Cabo Verde
Total daeths
Total Recovered
B

**Fig. 3.2** (Cont'd)

crisis of non-availability of specific medicines or vaccines, it is also proposed that high throughput *in silico* screening (Paital et al., 2013) may be adopted to screen and develop suitable inhibitor(s) against the polymerase enzymes, viral proteins or even against the host cell receptor ACE2 i.e. Angiotensin-Converting Enzyme 2. As such methods were found to be useful in previous studies for the interaction between proteins and their respective inhibitors (Paital and Chainy 2013; Paital et al. 2011, 2013, 2015; Swain et al. 2020; Paital and Agrawal 2020). This would save time and money that are two important factors at this time point. Under such an uncertain condition, prevention of COVID-19 by social distancing (Das and Paital 2020b; Das et al. 2020a, b; Paital 2020; Paital et al. 2020) and by other associated modes such as sterilizing hands and using masks are given equal importance (FDA 2020b; Feng et al. 2020; WHO 2020h). Under such uncertainty with specific medicine and global chaos against COVID-19, very few research or review articles are contributed towards the environmental implications especially in relation to air pollution in relation to COVID-19.

Rolling data indicates that articles on COVID-19, environment especially air pollution and use of mask are very scanty in PubMed as on 13th August 2020 (Fig. 3.3A). However, the number of hits observed in other repository such as Google scholar was different because it was observed the search engine covers every article irrespective of their scientific articulation. The number was little bit higher because on the aspect of "COVID-19, air pollution and use of mask" in Google scholar indicating the need of scientific importance to be given on this aspect (Fig. 3.3B). Therefore in the present article, emphasis was given to correlate among COVID-19 pandemic, air pollution and use of proper mask even indoors where, and the former two have made a common hotspots. Although, COVID-19 is imparting terrible effects as seen in 222 countries, territories etc., it has indirectly very positive effects on the self-regeneration process of nature especially on air qualities of specific towns such as Bhubaneswar, New Delhi in India (Panda et al. 2020; Paital et al. 2020), in Bangladesh (Islam et al. 2020), in Saudi Arabia (Anil and Alagha 2020) and in UK (Higham et al. 2020). Air, water and noise pollutions are reduced in many parts of the planet (Anser et al. 2020; Fuwape et al. 2020) because of the lesser outdoor activity of human beings under the lockdowns. Humans were found off street and self-locked inside home to avoid SARS-CoV-2 infection. On the other hand, some areas that witnessed heavy pollution during pre-COVID-19 time period have yet not fully free from the grip of (air) pollution. Also the air pollution is coming back to its previous position under unlocked states globally irrespective of the control of the disease.

Air pollution acts as the causative agent for diseases such as bronchitis, asthma and many other lung diseases. COVID-19 is known for its fatal activity in causing respiratory choke and therefore, causes mainly respiratory disorders and common cold associated symptoms (Paital et al. 2020). The virus has chosen respiratory tracts as its primary attacking organ because of the specific receptors (Paital and Agrawal 2020). Therefore, it is believed that COVID-19 and air pollution could have an intricate relation with each

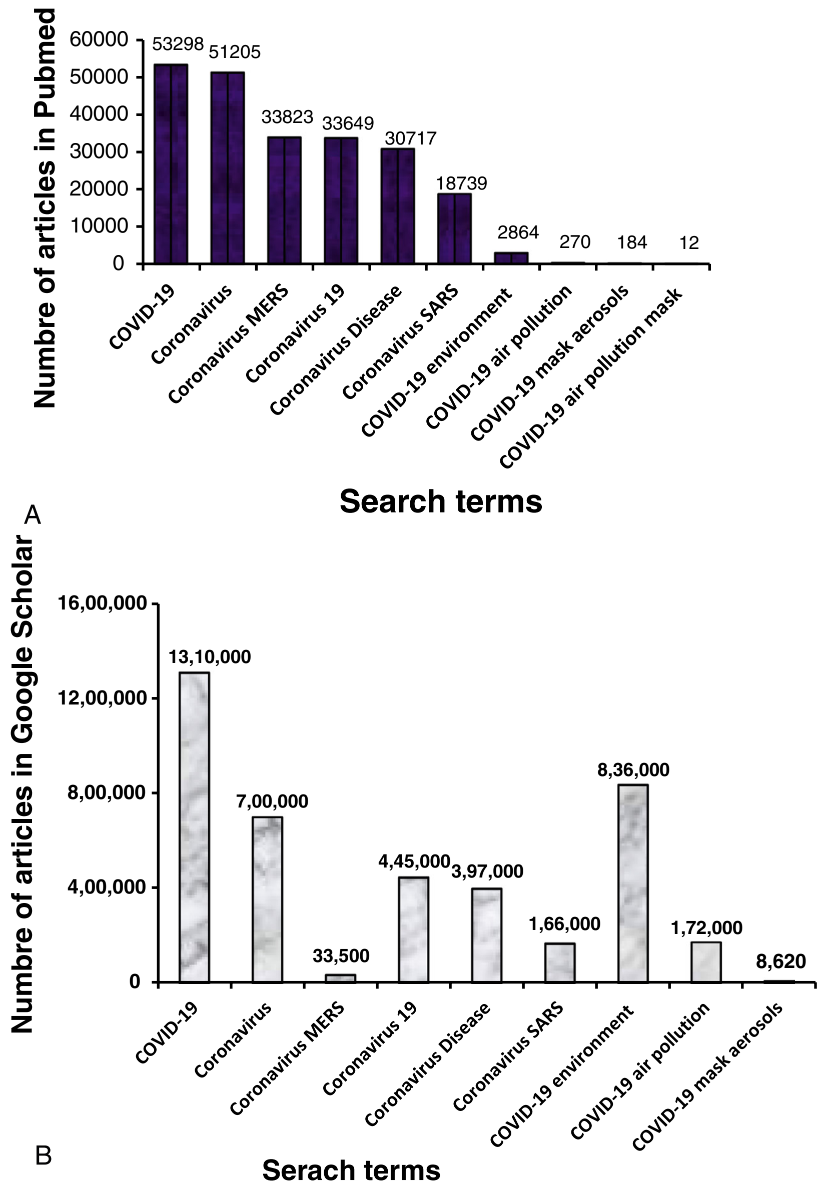



**Fig. 3.3** ***Number of articles found in PubMed and Google Scholar on COVID-19 in relation to environment specifically air pollution and use of mask.*** The search was made on 28th April 2020 in PubMed (a) and on 07.07.2020 in Google Scholar (b) and the data may vary with real time. The number in each bar represents the number of hits received against the respective terms.

other (Sarfraz et al. 2020; Sharma and Balyan 2020; Fig. 3.3). Mainly, polluted air can create many breathing issues in human leading to easy entry of the virus to infect healthy people. Particulate matters (PMs) act as the main contributor for air pollution (Comunian et al. 2020). So, both liquid and solid PMs may act as cargo to carry SARS-CoV-2 as the virus can non-specifically binds to any surface. Observing the high COVID-19 cases in specific areas of some countries such as USA (Liang et al. 2020), China (Zhu et al. 2020a, b) and India with very high air pollution indices indicate in favor of the above logic (Comunian et al. 2020; Paital et al. 2020a–c). In some areas, the indoor air quality is also polluted and is not up to level for breathing. Therefore, use of appropriate mask even indoors in such areas is recommended. Especially, use of medical mask where air pollution and COVID-19 together made their hotspots is strongly recommended. Home-made masks prepared using normal fabrics with higher pore size do not work to filter air PMs with high efficacy. Therefore, such home-made masks those do not filter particulate substances must not be used or if made, must be at least multilayer and enough capable to filter particle size of 0.3 μm. The objective of the current review was to find out the need (in relation to air pollution), type and status of the use of mask under COVID-19 outbreak.

To find correlation and current status among COVID-19 outbreak, air pollution and use of mask, all authentic news sources such as Reuters News sources, BBC news, Times, Hindustan India, India Today, World health organizations, different government portals etc. along with scientific literature were analyzed. Relevant literatures were carefully selected and included for the current review article. All figures or tables that are reproduced under creative common attribution license with citation of their respective sources. Also, discussion on COVID-19 infection in relation to temperature, humidity and water are discussed.

## 3.2 Clinical aspects of COVID-19 outbreak

SARS and MERS had caused the death of 774 and 779 human lives, respectively, whereas COVID-19 is responsible for the death of 327,821 people across 216 countries which make an emergency situation. Rolling data specify that a total 28,584,158 individuals have contracted the disease as on 13.09.2020 and still the number is increasing every day in 216 countries since its spreading started (CDC 2020; FDA 2020a; WHO 2020a). Total 916,955 people has been has killed in the pandemic. Specific medicines or vaccines are not available to control the infectious disease because the SARS-CoV-2 is a novel mutated form of its previous strains (FDA 2020a; Jin et al. 2020).

From clinical point of view, patients suffering from this disease usually exhibit symptoms of flu such as common cold, dry cough, fever, tiredness are the preliminary sign of the disease and complications in breathing followed by respiratory choke can be the deadly end point events noticed in the disease that lead to death of patients (Das et al. 2020a–c). Many infected patients can also be asymptomatic i.e. they contract the disease but do not exhibit any of above symptoms. Some infected persons can also exhibit only few of the common cold associated symptoms and they are referred as mild cases (Paital et al. 2020). Those suffers respiratory difficulties are considered as severe cases and need emergency medical care. Although, depending immunity, the severity of the disease is different in different people all categories of above infected patients can infect healthy persons. Above symptoms are correlated with the infection rate and location of the patient in the respiratory tract (Velavan and Meyer 2020). SARS-CoV-2 enters the respiratory passages in the direction of nasal passage, upper respiratory tract, lower respiratory tracts and finally alveoli of lungs. At the end point, due to huge fibrosis, alveoli become unable to exchange respiratory gases i.e. $O_2$ and $CO_2$ leading to respiratory choke and death of patients. The virus can infect a healthy subject from the infected person's body fluid especially cough or from any object(s) that bear the virus in its surface (Kannan et al. 2020). Immunologically, SARS-CoV-2 found to use ACE2 receptor of the human host cells, and uses its "S" protein to defuse its genome to the host cell (Robson 2020). The viral protein "S" splits into "S1" and "S2" to facilitate this process. Although, it was predicted that the disease will have an end within May 2020

**Table 3.1** A prediction model showing the expected end of the pandemic created by COVID-19.

| Countries | End 97 percent | End 99 percent | End 100 percent |
|---|---|---|---|
| World | 30-May-20 | 16-Jun-20 | 27-Nov-20 |
| China | 27-Feb-20 | 4-Mar-20 | 9-Apr-20 |
| South Korea | 18-Mar-20 | 26-Mar-20 | 27-Apr-20 |
| New Zealand | 17-Apr-20 | 25-Apr-20 | 11-May-20 |
| Australia | 18-Apr-20 | 27-Apr-20 | 3-Jun-20 |
| Vietnam | 18-Apr-20 | 25-Apr-20 | 3-May-20 |
| Iceland | 19-Apr-20 | 25-Apr-20 | 13-May-20 |
| Austria | 20-Apr-20 | 29-Apr-20 | 14-Jun-20 |
| Luxembourg | 23-Apr-20 | 3-May-20 | 6-Jun-20 |
| Niger | 24-Apr-20 | 30-Apr-20 | 12-May-20 |
| Jordan | 25-Apr-20 | 7-May-20 | 23-May-20 |
| Djibouti | 26-Apr-20 | 29-Apr-20 | 8-May-20 |
| Thailand | 26-Apr-20 | 7-May-20 | 11-Jun-20 |
| Lebanon | 26-Apr-20 | 8-May-20 | 30-May-20 |
| Switzerland | 28-Apr-20 | 9-May-20 | 6-Jul-20 |
| Cyprus | 29-Apr-20 | 8-May-20 | 25-May-20 |
| Uzbekistan | 1-May-20 | 6-May-20 | 20-May-20 |
| Spain | 2-May-20 | 14-May-20 | 2-Aug-20 |
| Andorra | 2-May-20 | 13-May-20 | 4-Jun-20 |
| Germany | 4-May-20 | 16-May-20 | 5-Aug-20 |
| Croatia | 4-May-20 | 15-May-20 | 15-Jun-20 |
| Norway | 4-May-20 | 19-May-20 | 21-Jul-20 |
| Costa Rica | 4-May-20 | 15-May-20 | 4-Jun-20 |
| Israel | 5-May-20 | 17-May-20 | 8-Jul-20 |
| Czech Republic | 6-May-20 | 19-May-20 | 10-Jul-20 |
| Latvia | 6-May-20 | 20-May-20 | 17-Jun-20 |
| Malaysia | 7-May-20 | 20-May-20 | 8-Jul-20 |
| France | 7-May-20 | 19-May-20 | 8-Aug-20 |
| Azerbaijan | 7-May-20 | 17-May-20 | 15-Jun-20 |
| Turkey | 9-May-20 | 17-May-20 | 8-Jul-20 |
| Italy | 9-May-20 | 23-May-20 | 30-Aug-20 |
| Portugal | 9-May-20 | 20-May-20 | 17-Jul-20 |
| Greece | 9-May-20 | 24-May-20 | 12-Jul-20 |

*(continued)*

**Table 3.1** (Cont'd)

| Countries | End 97 percent | End 99 percent | End 100 percent |
|---|---|---|---|
| Sudan | 11-May-20 | 16-May-20 | 23-May-20 |
| Slovenia | 11-May-20 | 28-May-20 | 13-Jul-20 |
| Philippines | 11-May-20 | 23-May-20 | 7-Jul-20 |
| Bangladesh | 13-May-20 | 20-May-20 | 17-Jun-20 |
| Iraq | 13-May-20 | 28-May-20 | 9-Jul-20 |
| Belgium | 14-May-20 | 26-May-20 | 1-Aug-20 |
| Macedonia | 14-May-20 | 24-May-20 | 19-Jun-20 |
| United States | 15-May-20 | 27-May-20 | 5-Sep-20 |
| United Kingdom | 17-May-20 | 29-May-20 | 20-Aug-20 |
| Japan | 17-May-20 | 2-Jun-20 | 18-Aug-20 |
| Moldova | 17-May-20 | 27-May-20 | 2-Jul-20 |
| Algeria | 17-May-20 | 29-May-20 | 9-Jul-20 |
| Ukraine | 19-May-20 | 28-May-20 | 7-Jul-20 |
| Belarus | 20-May-20 | 29-May-20 | 7-Jul-20 |
| Iran | 21-May-20 | 10-Jun-20 | 24-Oct-20 |
| UAE | 22-May-20 | 2-Jun-20 | 23-Jul-20 |
| Canada | 23-May-20 | 5-Jun-20 | 21-Aug-20 |
| Dominican Republic | 23-May-20 | 2-Jun-20 | 16-Jul-20 |
| Peru | 23-May-20 | 2-Jun-20 | 28-Jul-20 |
| Cuba | 24-May-20 | 7-Jun-20 | 11-Jul-20 |
| Ireland | 24-May-20 | 9-Jun-20 | 31-Aug-20 |
| Denmark | 24-May-20 | 17-Jun-20 | 19-Oct-20 |
| Russia | 25-May-20 | 5-Jun-20 | 19-Aug-20 |
| India | 25-May-20 | 4-Jun-20 | 1-Aug-20 |
| Netherlands | 25-May-20 | 10-Jun-20 | 9-Sep-20 |
| Singapore | 25-May-20 | 2-Jun-20 | 16-Jul-20 |
| Oman | 26-May-20 | 6-Jun-20 | 10-Jul-20 |
| Romania | 29-May-20 | 14-Jun-20 | 25-Aug-20 |
| Brazil | 30-May-20 | 9-Jun-20 | 16-Aug-20 |
| Hungary | 30-May-20 | 15-Jun-20 | 5-Aug-20 |
| Poland | 31-May-20 | 16-Jun-20 | 30-Aug-20 |
| Finland | 1-Jun-20 | 19-Jun-20 | 25-Aug-20 |
| Indonesia | 5-Jun-20 | 21-Jun-20 | 29-Aug-20 |
| Panama | 5-Jun-20 | 23-Jun-20 | 3-Sep-20 |
| Kazakhstan | 5-Jun-20 | 17-Jun-20 | 2-Aug-20 |
| Georgia | 7-Jun-20 | 26-Jun-20 | 29-Jul-20 |
| Guinea | 9-Jun-20 | 20-Jun-20 | 28-Jul-20 |
| Egypt | 9-Jun-20 | 4-Jul-20 | 29-Oct-20 |
| Mexico | 10-Jun-20 | 22-Jun-20 | 7-Sep-20 |
| Chile | 11-Jun-20 | 30-Jun-20 | 28-Sep-20 |
| Argentina | 14-Jun-20 | 3-Jul-20 | 15-Sep-20 |
| Pakistan | 15-Jun-20 | 29-Jun-20 | 12-Sep-20 |
| Sweden | 16-Jun-20 | 6-Jul-20 | 17-Oct-20 |
| Afghanistan | 22-Jun-20 | 9-Jul-20 | 4-Sep-20 |
| Saudi Arabia | 23-Jun-20 | 6-Jul-20 | 28-Sep-20 |
| Kuwait | 24-Jun-20 | 17-Jul-20 | 20-Oct-20 |

*(continued)*

**Table 3.1** (Cont'd)

| Countries | End 97 percent | End 99 percent | End 100 percent |
|---|---|---|---|
| Bolivia | 3-Jul-20 | 20-Jul-20 | 15-Sep-20 |
| Colombia | 4-Jul-20 | 26-Jul-20 | 1-Nov-20 |
| Guatemala | 19-Jul-20 | 18-Aug-20 | 18-Dec-20 |
| Albania | 20-Jul-20 | 18-Aug-20 | 29-Oct-20 |
| Bahrain | 26-Jul-20 | 4-Sep-20 | 6-Apr-21 |
| Qatar | 5-Aug-20 | 26-Aug-20 | 2-Feb-2 |

Data are modelled by considering the newly identified case(s) per day in different countries from the day their citizens had contracted the disease to 26th April 2020. There is every chance that the modelled data can be inaccurate depending on the complex, evolving, and heterogeneous realities on CoV-19 and the infections to the people of different countries. So this prediction is believed to be uncertain by nature. Such predictions are only in silico, and in vivo the results may vary partially, or completely depending on the real time daily data and the evolving nature of the virus and the type and magnitude of immunity developed in people (Jianxi, 2020).

in many countries (Table 3.1, supplementary Fig. 3.1) and it is still uncontrollable in many countries as of the end of August 2020. The evolving nature of the virus was argued to be the limitation to the above prediction to be true (Jianxi 2020). For example, countries like Qatar may still have the disease up to fifth August 2020, and heavy (air) pollution is believed to be the reason for it (Paital 2020).

## 3.3 Air pollution and COVID-19

Air pollution is a serious environmental issue worldwide. It contributes to ~4.2 and 3.8 million deaths each year for breathing polluted ambient (outdoor) and indoor air, respectively (Zoran et al. 2020a). Indoor polluted air includes smoke from stoves and unclear fuels consumption for cooking (Zoran et al. 2020b). The fact is alarming because about 91 percent people worldwide are unable to breathe quality air as the air quality in those places surpasses WHO guideline limits (WHO, 2020f). Exposure to pollutants, especially to air pollutants has immense importance on the life of human and non-human organisms metabolism, life span, physiology and, studies on it are done predominantly (Chainy et al. 2016; Paital 2013, 2014; 2016a, 2016b, 2016c; Paital et al. 2015; 2016, 2018, 2019).

### 3.3.1 Current status of air pollution

When the levels of harmful substances are introduced into Earth's atmosphere and the harmful gases increases beyond the limit, air pollution occurs (Khilnani and Tiwari 2018). Main constituents of air pollution include many gases including $NH_3$, $CO_2$, $SO_2$, nitrous oxides, $CH_4$, and chlorofluorocarbons, particulate matters (solid/liquid organic and inorganic particles), and unwanted biological molecules (Pohl et al. 2017; Paital and Agrawal 2020). Air pollution can be fatal to both human and non-human bodies and massively attacks crops and the other plants, therefore, causes damage to the ecosystems and tampers the natural beauty (Mattiuzzi and Lippi 2020). Mainly human activities are dominated for creating air pollution as compared to natural processes that also can generate air pollution (Lelieveld et al. 2019).

Air becomes polluted as a result of excessive combustion of fossil fuels in industries and vehicles have become the major risk factor for maintaining the health of ecosystem. Massive steps are been taken to have a grip on the rapidly increasing air pollution, albeit results obtained are not satisfactory (Perera 2017). For examples, UK experience 40,000 excess deaths each year under air pollution (Gori et al., 2020). Therefore, identifying the toxic element level in the air and their control has created an emergency not only in UK but also in many other counties such as China, New Delhi of India and Qatar (Robertson and Miller 2018). Such emergency situation has mandates an urgent action by government and non-government organization, institutions, locals and also by individuals to minimize the industrial fossil fuel burning to smoking and vehicular trafficking (Holgate 2017).

As per data collected by WHO, air pollution is found to be responsible to kill an estimated seven million people annually in the world. The most dangerous fact about air pollution revealed that 90 percent people are unable to breathe pollution free quality air. So, stringent actions are invited to fix the large smog found over industrial area, cities to indoor smokes (Wang et al., 2020b), as all of them create major threats to human health as well to climate (Hodgson and Hitchings 2018). It is documented that both indoor and outdoor air pollution contributes to millions of premature deaths every year. Many of such morbidities are found to contract largely with co-morbidities such as cardiac and brain strokes, other cardiac diseases, various lung diseases including

**Table 3.2** Risk of co-morbidity (diseases) under air pollution.

| Health outcome | Evidence | Population | Relative risk | Relative risk* | Proof |
|---|---|---|---|---|---|
| Acute infections in LST | Strong | Children aged 0–4 years | 2.3 | 1.9–2.7 | SE |
| Chronic OPD | Strong | Women aged ≥ 30 years | 3.2 | 2.3–4.8 | SE |
| | Moderate I | Men aged ≥ 30 years | 1.8 | 1.0–3.2 | SE |
| Lung cancer (coal) | Strong | Women aged ≥ 30 years | 1.9 | 1.1–3.5 | SE |
| | Moderate I | Men aged ≥ 30 years | 1.5 | 1.0–2.5 | SE |
| Lung cancer (biomass) | Moderate II | Women aged ≥ 30 years | 1.5 | 1.0–2.1 | ISE |
| Asthma | Moderate II | Children aged 5–14 years | 1.6 | 1.0–2.5 | ISE |
| | Moderate II | Adults aged ≥ 15 years | 1.2 | 1.0–1.5 | ISE |
| Cataracts | Moderate II | Adults aged ≥ 15 years | 1.3 | 1.0–1.7 | ISE |
| Tuberculosis | Moderate II | Adults aged ≥ 15 years | 1.5 | 1.0–2.4 | ISE |

LST- lower respiratory tract, OPD- obstructive pulmonary disease, S-Sufficient evidence, IS-insufficient evidence, *data at 95 percent confidence interval (source Ritchie and Roser, 2020; IHME, 2020).

chronic obstructive pulmonary disease, lung cancer and acute respiratory infections (Veras et al. 2017; Table 3.2). Mostly low- and middle-income countries suffer the highest from the air pollution induced complications. In such area air pollution is so high it makes a condition like foggy atmosphere (Fig. 3.4) and New Delhi in India had experienced it last year (WHO 2020f).

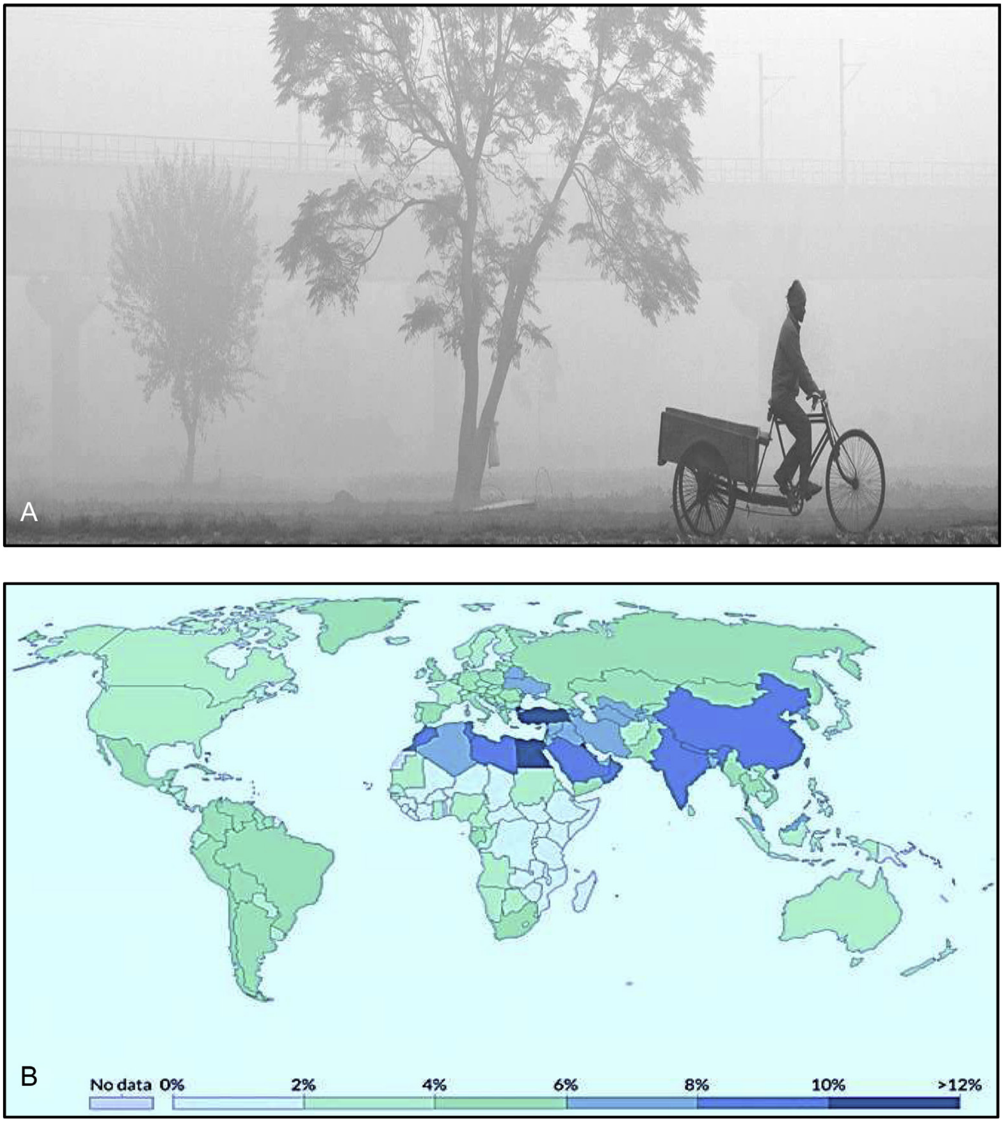



**Fig. 3.4** ***Air pollution and its consequences in some area.*** a) Air pollution that makes a notion of foggy atmosphere (Source WHO, 2020f), b) Colour intensity map showing global death rate by air pollution. Percentage shows the death rate by air pollution as compared to other diseases (source, IHME, 2020).

### 3.3.2 Air pollution and $PM_{2.5}$ and $PM_{10}$

Particulate matters are the main contributor for air pollution. It decreases the clarity in air and therefore affects the visibility and makes difficulty to breathe such air (Kim et al. 2015). Particulate matters include all solid and liquid particles that are found in the suspended condition in air. Many of them are usually hazardous and act as major risk factors for imposing much co-morbidity in human (Thompson 2018). PMs constitute both organic and inorganic particles including dust, pollen, soot, smoke, and liquid droplets. Therefore, diversity in particle origin, size composition is observed in PMs. PMs are either directly emitted from the processes such as fuel burning or flying dust or can be indirectly from the gaseous pollutants previously emitted to air (Orru et al. 2017). Considering the diversity in average diameter of different PMs, they are classified into two categories. One small category of PMs having average aerodynamic diameter of 2.5 μm and the other one is the larger one with the average diameter of 10 μm are classified. Less than 2.5 μm (usually around 0.1 μm) sized PMs are referred as ultra-fine PMS.The former one is called as the fine PMs and later one is referred as the course PMS. Fossil fuel burning generates fine PMs and the road side dust are the examples for course PMS (WHO, 2020c; WHO 2020d).The aerodynamic features of PMs can be used to determine how they are behaving in air such as movement, transportation, aggregation and their removal from the mixture (Zhai et al. 2018). Particles having the same aerodynamic diameter may have different dimensions and shapes. Some airborne particles are over 10,000 times bigger than others in terms of aerodynamic diameter. From aerodynamic properties, their severity of affecting respiratory tracts may also be determined (Tositti et al. 2018).

WHO has defined PMs as one of the most influential health risk factors. In ambient (outdoor) air pollution condition, the mean aerodynamic diameter of PMs with 2.5 μm or less ($PM_{2.5}$) is usually found in urban and industrial areas (Kim et al. 2015;Tositti et al. 2018). Quantity of such PMs in above areas usually ranges from > 10 to over 100 or 200 μg $m^{-3}$ and that of $PM_{10}$ are found to be < 10 to over 200 μg $m^{-3}$ (WHO, 2020f). And, all sorts of PMs can impose major health risks especially respiratory diseases and associated complications that lead to other diseases (Thompson 2018; WHO 2020f)

### 3.3.3 Air pollution and co-morbidity

Air pollution has positive relation with many associated diseases. Some of them are asthma, flu symptoms, respiratory complications, bronchitis, emphysema, other lung and heart diseases, and various respiratory allergies (Brauer 2010). So, mainly air pollution aggravates above diseases that act as cause for contracting other associated diseases such as heart attack, blood pressure and diabetes. Respiratory issues are mainly linked with $NO_2$ emission. And, the level of $NO_2$ is considered as a common tracer gas in areas to estimate the severity of air pollution. It is also correlated with various industrial activities, as its level elevates with fossil fuel consumption by machineries. On the other hand this gas also has distinct positive correlation with air pollution associated morbidities and c-morbidities (He et al. 2020a;

2020b). Air pollution is considered to cause many deaths and an increase in occurrences of respiratory diseases (Brauer 2010). As per a study done by WHO, death of 4.6 million people are observed every year in diseases that are found directly related to poor air quality (Cohen et al. 2017). Even it was estimated that poor air quality imposed deaths are more than the death accounted for road accidents each year (European Environment Agency 2005). Breathing impure air is a global issue and in 2102, PMs have caused 193,000 deaths in European countries (Ortiz et al. 2017). Air pollution in China was severe in 2016, and it was responsible for 4000 preventable deaths daily i.e. 1.6 million mortalities (Rohde and Muller 2015; Wang et al. 2012). Several models predict that mortality due to air pollution (Hoek et al. 2013), with an increase of all-cause mortality ranging from 0.13 percent per 10 μg $m^{-3}$ of $NO_2$ per day (He et al. 2020a,b) to 2 percent per 10 μg $m^{-3}$ of $NO_2$ on a 5 day period (Chiusolo et al. 2011), or a global hazard ratio of 1.052 (95 confidence intervals 1.045 to 1.059) per increase of 8.1 ppb in $NO_2$ (Crouse et al. 2015; Dutheil et al. 2020b). Therefore, the reduction in $NO_2$ emissions in China is predicted a 6 percent reduction in mortality. It counts that ~100,000 lives are saved in China only due to reduction of $NO_2$ emission under COVID-19 induced lockdown. Similar scenario needs to be calculated for other countries. However, it is summarised that air pollution especially PMs have a strong correlation with generating respiratory disorders in human. Therefore, logically, COVID-19 must have a specific relation with air pollution, and it is analyzed to be true in several case studied, in China, being the recent one (Dutheil et al. 2020a). This could be true because both produce respiratory associated diseases (Brauer 2010) such as dry cough, asthma and other respiratory diseases including respiratory arrest. Therefore, more examples are not needed to make an affirmation of the above fact (Das and Paital, 2020a).

### 3.3.4 Cross relation between air pollution and COVID-19

It is advocated that exposure to quality air or breathing a good quality air is correspondingly vital as food and supplements to fight various stresses (Paital 2013, 2014; Mishra et al. 2029). Under COVID-19 pandemic, for the first time in history, human beings are lifting heavy weight to reduce pollution by doing nothing. The modern social life of human beings has got a pause under lockdowns while, lockdown had also enormous progressive effects on several ecosystems and especially in urban and industrial environments (Das and Paital 2020b; Child 2020). Cleaner air is considered as a first-hand outcome of the environmental regeneration process under COVID-19 induced lockdown. In India, it leads to give a cleaner air to breathe in New Delhi that experienced heavy air pollution during pre-COVID-19 time. Under the clean air, Himalayan mountain range is now visible from the Northern Delhi which was not possible earlier under heavy air pollution. Similarly, the Everest mountain range is also now visible from the head quarter due to drop in air pollution in Nepal. Similar observations are documented in the UK. The UK has experienced a large scare decrease $NO_2$ emissions and PMs level in March to May 2020 as compared to the same time in 2019 (Child 2020). In the USA where the air pollution sources are usually from vehicular operations, its environments are experiencing from a reduced level in values of air PMs (EPA 2017, 2020; WHO 2020a, b). Space organizations such as NASA and the European Space Agency have clicked the same feature of the radical reduction in emissions of both $NO_2$ and $CO_2$ in specific area such as in China, USA, and Italy (Zehner 2020), where the pollution level was comparatively high in pre-COVID-19 time. Such reduction in air pollution events have usually contributed to the reduction in both vehicular and industrial operations where combustion of fossil fuels including coal are high (Paital 2020; Paital et al. 2020). As per the locals from many places that experiencing a sharp rise in reduction of air pollution, "*nature has returned and is taking back possession of the city*" (Child 2020). China that alone contribute to 6 percent $CO_2$ emissions globally last year is now found to experience at least a dramatic reduction of nearly 25 percent $CO_2$ and $NO_2$ emissions. Therefore, SARS-CoV-2 and self-revival practice of nature is proposed to be considered as a normal evolutionary strategy set by nature her-self to self- regenerate (Bhattacharyya 2020; Child 2020; Paital 2020; Paital et al. 2020) because, it was not possible during the pre-COVID-19 time periods.

### 3.3.5 Air pollution and COVID-19

Specific effects of air pollution and COVID-19 outbreak and vice versa are observed. Due to social lockdowns including shutdown of industries, pollution level in the air in many cities is reduced to provide a cleaner air to breathe (Paital et al. 2020). As studied by NASA scientists, the reduction in $NO_2$ pollution, a strong indicator of air pollution, was first evident in Wuhan city, China, the epicentre of COVID-19 and was then gradually observed worldwide (NASA 2020). Central China alone has experienced a 30 percent reduction in $NO_2$ emissions (NASA 2020). $CO_2$ emissions are considered as another index for air pollution (Hanaoka and Masui 2019). Due to COVID-19 outbreak, $CO_2$ emissions was found to be reduces by 25 and 6 percent in China and worldwide, respectively (Myllyvirta 2020). China, where the COVID-19 epidemic started (CarbonBrief 2020), is also a country severely affected by air pollution (He et al. 2020a, b). During the initial stage of COVID-19 infection, 3,158 deaths were reported in China alone, out of the total worldwide death toll of 4,607. Seeing such a vast reduction in air pollution under lockdowns in many countries (China's $CO_2$ emissions decreased by a quarter), the COVID-19 pandemic is proposed to be decreased with decrease in air pollution. Furthermore, besides the reduction in the rate of reduction of mortality under the increased air quality, it also contributes in prevention in spreading of many non-communicable diseases (Chen and Bloom 2019; Neira et al. 2018).

#### *3.3.5.1 Clinical aspects of air pollution on COVID-19 outbreak*

Air pollution can increase the chance of COVID-19 outbreak via comorbidities or by increasing the chance of other respiratory illness (Dutheil et al. 2020a). In China, air pollution is considered as a risk factor for several respiratory infections as they carry microorganisms and affect body's immunity. Significant positive association was observed between air pollutants such as $PM_{2.5}$, $PM_{10}$, $NO_2$ and $O_3$ and COVID-19 outbreak in

China (Zhu et al. 2020a,b). The above authors have found that COVID-19 confirmed cases are positive correlated with the level of air pollution. They have noticed a 10-μg/$m^3$ increase (lag 0–14) in $PM_{2.5}$, $PM_{10}$, $NO_2$, and $O_3$ was associated with a value of 2.24 percent (95 percent CI: 1.02 to 3.46), 1.76 percent (95 percent CI: 0.89 to 2.63), 6.94 percent (95 percent CI: 2.38 to 11.51), and 4.76 percent (95 percent CI: 1.99 to 7.52) with increase in the daily counts of COVID-19 confirmed cases, respectively. On the contrary, a 10-μg/$m_3$ increase (lag 0–14) in $SO_2$ was associated with a 7.79 percent decrease (95 percent CI: −14.57 to −1.01) in COVID-19 confirmed cases (Zhu et al. 2020a,b). Therefore, specific precautions are advised to be taken under high $NO_2$ polluted areas. It is proposed that a long-term exposure especially to this pollutant may act as one of the most important contributors to fatality caused by the COVID-19 virus. Supporting to above fact, it was calculated that in Italy, Spain, France and Germany, out of 4443 fatality observed at the beginning of the pandemic, 3487 deaths contributing 78 percent of the total death were confined to cases where $NO_2$ pollution was predominant (Ogen 2020). From a case study, it was confirmed that atmospheric pollution can be considered as a co-factor for the extremely high level risk of COVID-19 outbreak and lethality in Northern Italy (Conticini et al. 2020). More particularly, similar suspected environmental persistence of SARS-CoV-2 via air pollution is proposed in the Po Valley of Northern Italy (Di-Cerbo, 2020) . Since, regional air pollution persistence is highly linked to COVID-19 infection and outbreak, it can be considered as a putative disease risk factor (Martelletti and Martelletti 2020). Therefore, zonation may be done in such areas to employ specific management or preventative measures for COVID-19 (Frontera et al. 2020).

Various molecular mechanisms are put forth to explain the air pollution induced risk of fatality under COVID-19 outbreak. Factors related to ethnicity, environment, behaviors, associated sickness, and clinical treatment involving Angiotensin Converting Enzyme 2 (ACE2 that act as receptor for COVID-19), a component of the renin-angiotensin system, are speculated to be affected by severe air pollution via the interference of $NO_2$ on ACE2 expression (Alifano et al. 2020; Paital and Agrawal 2020; Fig. 3.5). On the other hand, environmental factors including air pollution, smoking and particulate matters are intricately increasing the risk of comorbidities such as high blood pressure, and sugar related diseases, and cardiac diseases and pulmonary sickness. Rheumatic diseases such as arthralgias and arthritis may be prevalent in about a seventh of individuals and also have a relation with air pollution (Misra et al. 2020). Above comorbidities can increase the chance of severity of COVID-19 (CarbonBrief 2020).

The vice versa effects of COVID-19 on air pollution are prominent in many cities across the world (Paital et al. 2020). In a case study in Barcelona, Spain it was observed that the reduction of $NO_2$ (−45 to −51 percent) and $PM_{10}$ (−28 to −31.0 percent) mainly due to the reduction in traffic emissions (Tobias et al. 2020). Such factors are prevalent in countries such as India, Italy, USA, China, Germany and many other countries, Therefore, indirectly, COVID-19 induced lockdown and reduction in air pollution have also reduced the risk of many respiratory health issues (Dutheil et al. 2020b).

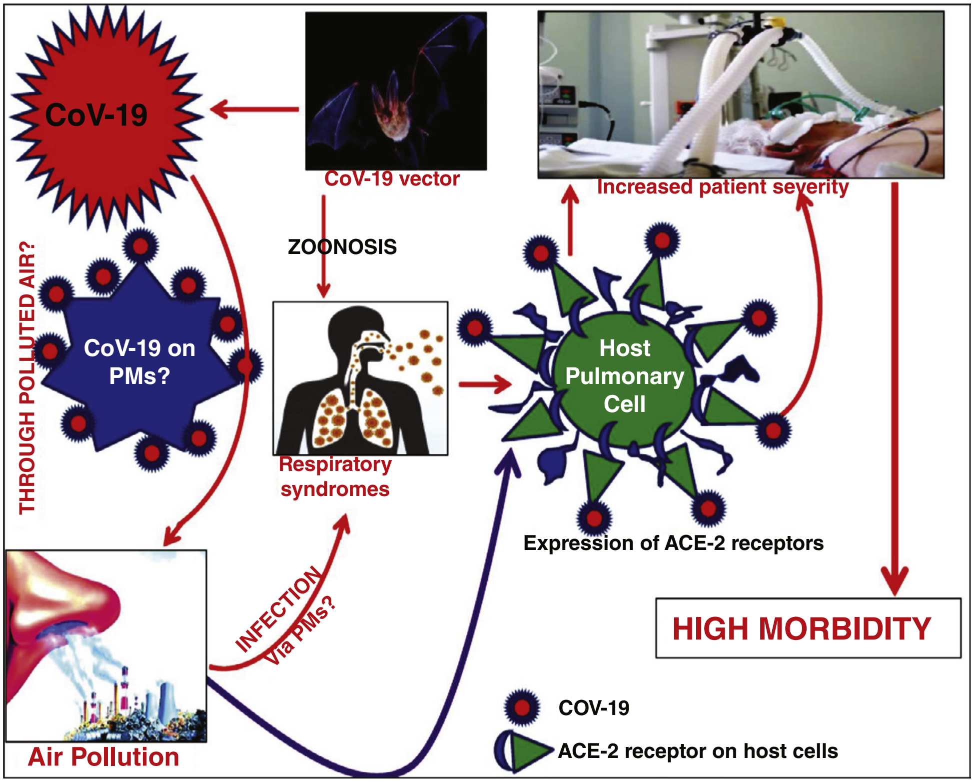



**Fig. 3.5** ***Possible effects of air pollution on COVID-19 severity via ACE-2 expression.*** Air pollution has a positive correlation with Angiotensin I Converting Enzyme 2 (ACE-2), (that acts as SARS-CoV-2 attachment receptor) expression in human and that may accelerate the viral infection and severity in COVID-19 patients leading to fatality. A possible mechanism of the virus propagation via particulate matters (PMs), as one of the reliable index for air pollution, is explained.

## 3.3.6 PM and COVID-19, a possible link

### *3.3.6.1 Air particulate matters*

The PMs are considered as one of the foremost air pollutants. They have very dynamic role for acting as cargo for various substances (Mukherjee and Agrawal 2018; Bradney et al. 2029). Particulate matters constitute dust, pollen, soot, smoke, and liquid droplets of any other material origin particles. However, the size, shape and origin must give an aerodynamic diameter within the range of 10 μm that allow them to be in suspended condition in air (Alfaro-Moreno et al., 2007; Greenfacts 2020). Out of many, plastic PMs are found in the terrestrial and aquatic environments and are generated as a bead of plastic fragments of micro to nanometer range. Although, they are termed as micro or nano-plastics (Leung and Sun, 2020), their aerodynamic diameter can also fall within the PMs range. Plastic, other solid and liquid PMs, can adsorb or absorb micro-organisms that sustain on them, toxic trace elements etc (Liang et al., 2020). This nature is facilitated in solid PMs due to their high surface area and functionalized surfaces. Other than these properties, climatic state (e.g., pH and water salinity), surface charge of PMs, and trace element oxidation status in PMs, adsorption rate into the adsorbents, persistence of the PMs and to be adsorbed molecules etc. can also influence the cargo activity of the PMS. Roughness of the surface of the PMs also could be a main contributor to allow the attachment of other smaller and lighter materials on them. When inhaled, the PMs themselves or the materials attached on them can enter into the respiratory tract of the animals including human and can trouble the respiratory system (Bradney et al. 2019). Therefore, it is predicted that the particulate matters or aerosols can be the additional factors for the increase in the COVID-19 and this chance could be more where vehicular operations are higher (Fig. 3.6).

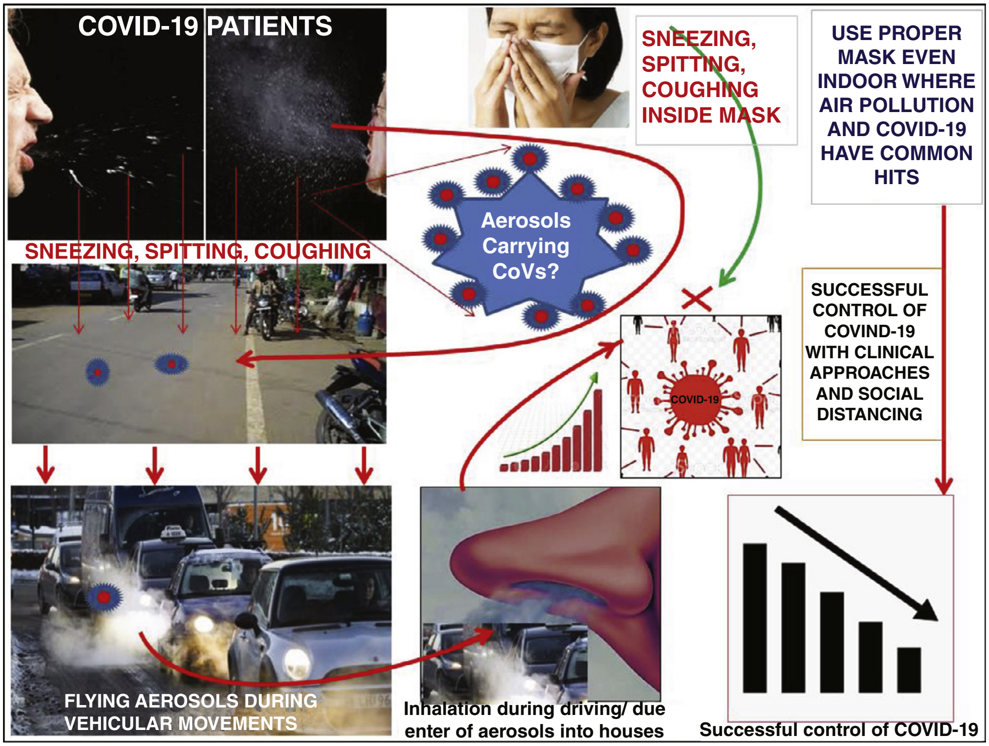



**Fig. 3.6** ***Possibility of transmission of COVID-19 via air from the dropped down air droplets from COVID-19 patients.*** As per the calculation one aerosol or particulate matter particle can carry at least >100 SARS-CoV-2. When infected patients (in case of asymptomatic) sneeze, cough, spit or even talk on road without masks, the aerosol can fall into the ground or road. Gradually the droplets can dry and during vehicular movements, they can again come back to air up to certain height and can inhale by healthy persons during travelling. The chance of above cycle can be seen where the road surface is occupied with dust and vehicular operations are more frequent. However, when mask is used by the infected patients and healthy person, the above process may not have any effects.

#### *3.3.6.2 Surface attachment properties of SARS-CoV-2*

As per a very recent study by Chin et al. (2020), SARS-CoV-2 is not very specific to get adsorbed or absorbed by surfaces. They can attach to any surface ranging from paper cardboard, plastic, coin, metals, clothes, any other aerosols etc. and the virulence of the virus can be maintained from few hours to few days on the above materials. The authors have also stated that SARS-CoV-2 can withstand a wide pH (3–10) while attached to the surfaces, although temperature can deactivate them substantially. It is opined *"SARS-CoV-2 in virus transport medium (final concentration ~6.8* log *unit of 50 percent tissue culture infectious dose [TCID50] per mL) was incubated for up to 14 days and then tested for its infectivity (appendix p 1). The virus is highly stable at 4 °C, but sensitive to heat. At 4 °C, there was only around a 0.7* log*-unit reduction of infectious titre on day 14. With the incubation temperature increased to 70 °C, the time for virus inactivation was reduced to 5 mins*" (Chin et al. 2020). Although no study has been done whether PMs can act as cargo for the tiny viruses but logically it is expected that PMs can bear them on their surfaces. It is because they are non-specifically can be attached to a wide range of surfaces.

#### *3.3.6.3 PMs as cargo*

If logically PMs can carry viral particles, calculation considering the surface area of both can give a clue about it. If the diameter of $PM_{2.5}$ is 2.5 µm, their average radius would be 1.25 µm. Therefore, using the formula (surface area = $4\pi r^2$, where $\pi = 3.14$ and "r" stands for the radium of a sphere, let's consider PMs are roughly spherical), the surface of $PM_{2.5}$ with radius (r) 1.25 µm and the surface area of $PM_{10}$ (with $r = 5$ µm) would be 19.63 and 314.16 µm$^2$, respectively. It must be remembered that the results are a rough calculation. The diameter of SARS-CoV-2 is 0.065 to 0.125 µm that would give an average radius of 0.095 µm (Shereena et al. 2020). Using above formula, the average surface area of SARS-CoV-2 would be of about 0.11 µm$^2$. After dividing the surface areas of $PM_{2.5}$ and $PM_{10}$, with the surface area of the virus, it is found that theoretically, a solid $PM_{2.5}$ and $PM_{10}$ can carry > 95 and 2856 SARS-CoV-2 particles, respectively. Theoretically, the liquid PMs may carry less virus particles as they occupy the virus within themselves. However, such analysis predicts that in general, PMs can theoretically increase the risk of SARS-CoV-2 infection. Probably for this reason, COVID-19 cases are very high in places of few countries such as USA and Italy where, air pollution is more as compared to a place that experiencing low or no air pollution (Paital et al. 2020). Therefore, specific use of mask is recommended to get rid of SARS-CoV-2 infection.

### 3.3.7 Need of mask

Under the outbreak of any air born or air transmissible or any aerosol transmissible diseases, use of mask is highly recommended. Therefore, during flu, SARM or MERS, use of mask is mandatory for all. However, a proper mask can only restrict the pathogen to enter and protect the mask wearing person.

#### *3.3.7.1 Mask and its use under endemic and pandemics*

Out of fear or by self-understanding or after imposed by the Government, using mask has become the paramount act everywhere under the pandemic of COVID-19. The WHO and few studies demand that aerosols can carry the SARS-COV-2 viral particle(s). WHO has accepted that droplet particles of size >5–10 μm in diameter originated from the patients sneeze and cough carry the virus (WHO 2020g). Therefore face masks is used regularly as one of the preventive measures against the SARS-CoV-2 infection via infected patients body fluids especially via cough and sneeze. Definitely, it slows the spread of the deadly outbreak (Parker 2020). Different types of masks are available as per the need (Supplementary Fig. 3.2). Therefore, N95 masks are highly recommended to be used by medical and paramedical staffs those are at high risk of infection from the daily hospital activities to give medical care to infected patients. It is because the mask can filter 95 percent of tiny particles within size 0.3 μm. Similarly, medical masks can filter as much as 60 percent to 80 percent particles of 0.3 μm size and come with different varieties. It is less protective than N95 mask. A good homemade mask prepared using regular fabrics with multilayer materials to make it dense enough to capture viral particles can work but it must allow breathing comfort. However, its capacity will not be > 50 percent to filter the aerosols. Finally, the home made masks using filters in between the two layers of fabrics can have the efficiency of filtering 23 percent and 33 percent of 0.3 μm size particles. One experimental result suggests that two layers of paper towels used as mask can also filter or block above range of viral filtration (Parker et al. 2020). While using no mask is also fully effective under proper social distancing cases. Following stringent lockdowns can help to keep all safe when combined with social distancing and regular hand-washing type of daily hygienic practices. And the used mask must be used once after washing and must be used by a single person (Das and Paital, 2020a).

#### *3.3.7.2 Mask for covid-19*

In Eastern countries, few have advocated for the use of masks and also few have begun to advocate that it contains the virus after use so, must be risky for others. However, research shows masks are effective as stopping the spread of respiratory illnesses (Walcott 2020). Since the outbreak of COVID-19, routine practice has been observed in China and other Asian counties South Korea, India and Japan to use face masks. Some states in China have enforced compulsory to wear mask to their citizens violation to which is found to be punishable. India has enforced to use mask as a policy in public, however, China's national guideline has adopted a risk-based approach in offering recommendations for using face masks among health-care workers and the general public. In some countries such as USA, use of mask to healthy people is not strongly recommended (Feng et al. 2020). Owing to the importance, necessity and protective measures provided by masks, different nations have adopted different criteria for their use (Table 3.3, Feng et al. 2020). However, logically, wearing masks pays nothing but it can protect healthy subjects from the disease. Although this information is not new, many people do not

**Table 3.3** Recommendation or use of mask in different countries (Source, Feng et al., 2020).

| County/Place | Type of recommended mask |
|---|---|
| China | People at moderate risk of infection: surgical or disposable mask for medical use. People at low risk of infection: disposable mask for medical use. People at very low risk of infection: do not have to wear a mask or can wear non-medical mask (such as cloth mask). |
| Hong Kong | Surgical masks can prevent transmission of respiratory viruses from people who are ill. |
| Singapore | Wear a mask if you have respiratory symptoms, such as a cough or runny nose. |
| Japan | The effectiveness of wearing a face mask to protect yourself from contracting viruses is thought to be limited. |
| USA | Centers for Disease Control and Prevention does not recommend that people who are well wear a face mask (including respirators) to protect themselves from respiratory diseases, including COVID-19. |
| UK | Face masks play a very important role in places such as hospitals, but there is very little evidence of widespread benefit for members of the public. |
| Germany | There is not enough evidence to prove that wearing a surgical mask significantly reduces a healthy person's risk of becoming infected while wearing it. |
| India | Mask is mandatory for all irrespective people follow the quality and type of mask. |

use mask. Therefore, still awareness need to be created for the proper use (covering both nose and mouth) of proper mask (that can filter PMs).

#### *3.3.7.3 Mask even for indoor inhabitants in COVID-19 hot spots*

Air pollution is considered as world's leading risk factors for death, attributed to 5 million deaths each year i.e. counts about 9 percent of deaths globally. It also acts as the route for much other secondary disease (Walker 2020). Death rates under air pollution related diseases and associated issues are 100-fold more in low and medium income countries as compared to the high income countries. Globally, death rates from air pollution have been falling. This has mainly been the result of progress on tackling indoor pollution. This is mainly attributed to indoor air pollution (Ritchie and Roser 2020). Indoor air pollution is considered to be responsible for 1.6 million premature deaths each year. Therefore, it is one of the largest ecological issues where human does not feel safe even inside home particularly in poor countries who cannot afford clean fuels for daily cooking. The wide range of deaths under indoor air pollution is really alarming as the graph is rising with time. A comparison from 1990 to 2017 for deaths and associated issues under indoor air pollution indicates that it act as a leading cause of increasing death risk and associated co-morbidities such as heart disease, pneumonia, stroke, diabetes and lung cancer (Fig. 3.7A, B). In the chart in Fig. 3.7, it is noticed that indoor air pollution is one of the leading risk factors for death globally. As per study, about 1.6 million people died prematurely in 2017 under indoor air pollution related health risks and age groups of 60–69 and ≥70 are more prone for the risk in the order they are stated (Fig. 3.7C). This death toll number in 2017 under indoor air pollution was four


**Fig. 3.7** ***Use of inappropriate mask made up of by mosquito net used in Cuttack, Odisha, India.*** a) Bunch of homemade inappropriate mask, b) one of the pulled from the bunch and its middle main portion found to made up of by mosquito net like mesh, c) the pore size of the mask is found to be near about 2 mm. Such masks need to be banned and authorised person must sell mask.

times more than the number of homicides – close to 400,000 in 2017. As discussed earlier, countries that suffering from low sociodemographic index top the list (Fig. 3.7D). Therefore, in such places, COVID-19 may make an outburst, where steps such as social lockdown may not work as a successful preventive measure (Paital et al. 2020).

From the above discussion, one thing is very clear that COVID-19 infection rate has a positive correlation with air pollution. Although, the disease in not air born, but air pollution has a definite effects on the propagation of the virus in human host (Liu et al., 2020). Mainly the severity of the disease is found to be high in patients registered in areas where air pollution is predominant as compared to areas that experience cleaner air (APGH 2019). The WHO has made a press release recently accepting the transmission of the virus by air (WHO 2020g), therefore, one of the major routes of transmission of SARS-CoV-2 via air is confirmed. A study in Iran on March 17, 2020, covering the above debate has confirmed that COVID-19 is not communicated by air. The study has confirmed that the samples collected within 2 to 5 m distance from the patients' beds were tested negative for SARS-CoV-2 (Faridi et al. 2020). However, such studies need to be conducted in multiple countries and under different conditions to ascertain the fact (APGH 2020). However, indoor air pollution associated diseases have a positive correlation with the rate of severity and death in COVID-19 patients, indicating the recommendation of using appropriate mask even indoor where air pollution and COVID-19 made a common hit. In many places homemade inappropriate mask are sold and therefore, local or national governments must take care to develop proper standards for the homemade masks so that the purpose is not diluted (Fig. 3.8).

As depicted in the Fig. 3.9, current state of high COVID-19 status as of the end of August 2020 Therefore, a recent literature have cited that *"It is time for governments and public health agencies to make rational recommendations on appropriate face mask use to complement their recommendations on other preventive measures, such as hand hygiene. WHO currently recommends that people should wear facemasks if they have respiratory symptoms or if they are caring for somebody with symptoms. Perhaps it would also be rational to recommend that people in quarantine wear facemasks if they need to leave home for any reason, to prevent potential asymptomatic or presymptomatic* *transmission. In addition, vulnerable populations, such as older adults and those with underlying medical conditions, should wear facemasks if available. Universal use of facemasks could be considered if supplies permit. In parallel, urgent research on the duration of protection of facemasks, the measures to prolong life of disposable masks, and the invention on reusable masks should be encouraged. Taiwan had the foresight to create a large stockpile of face masks; other countries or regions might now consider this as part of future pandemic plans"* (Chin et al. 2020).

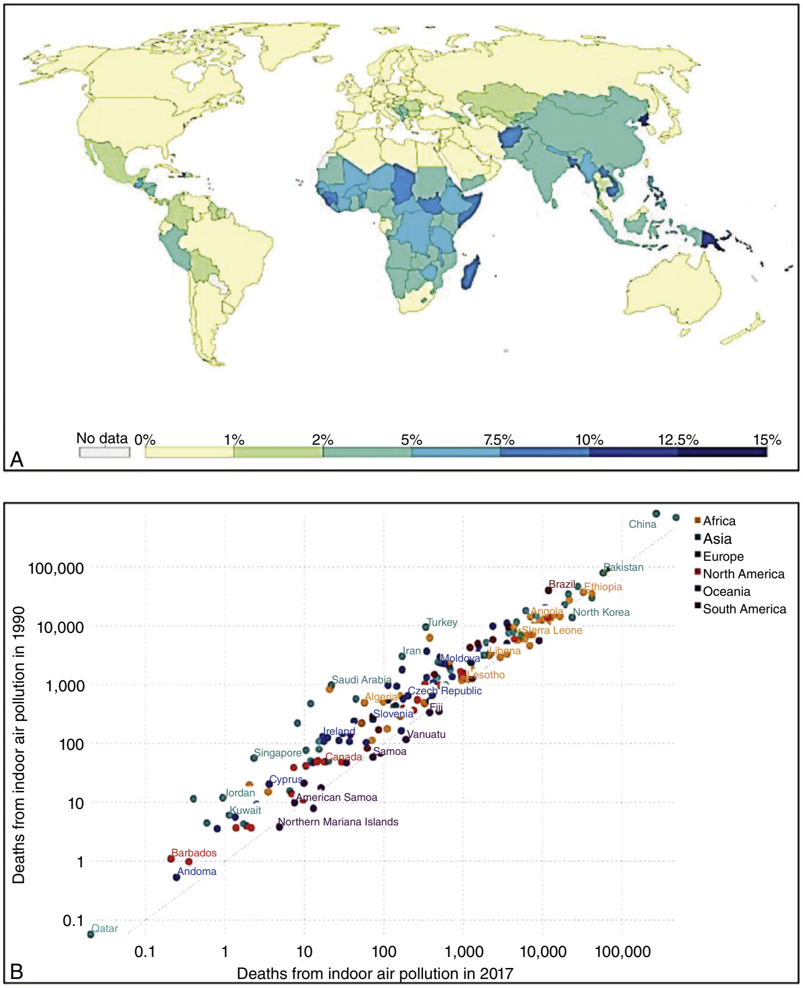
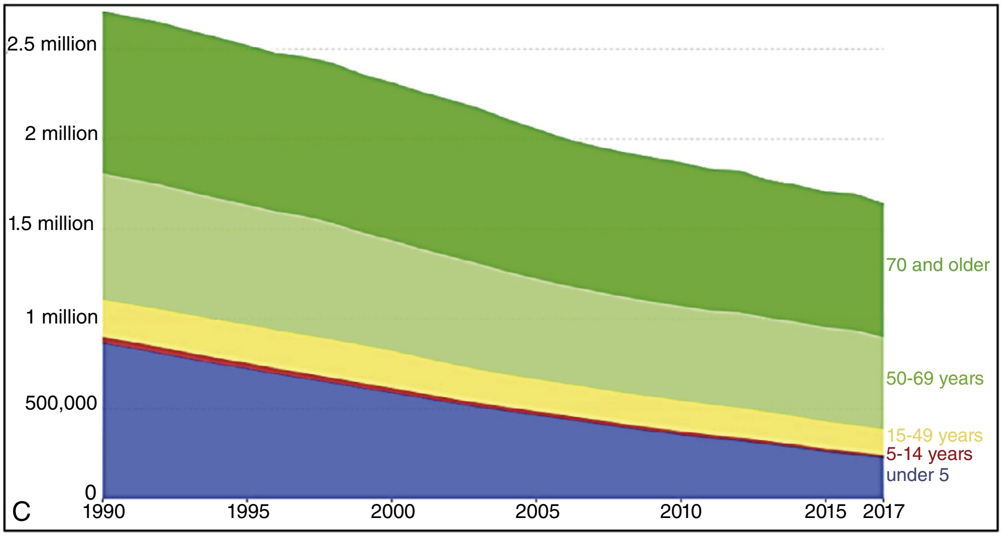



**Fig. 3.8** ***Indoor air pollution mediated death in world.*** a) A colour intensity map showing global death rate by indoor air pollution. Percentage shows the death rate by indoor air pollution as compared to other diseases, b) Number of deaths by indoor air pollution in 1990 versus 2017, c) Indoor air pollution death as a function of age. Old age people above 69 year are more prone for indoor air pollution risk, d) Indoor air pollution rate per 100,000 people in 1990 versus 2017 in country wise distribution. All graphs are rising makes a concern of indoor air pollution (Source, IHME, 2020 under creative common license attribution).



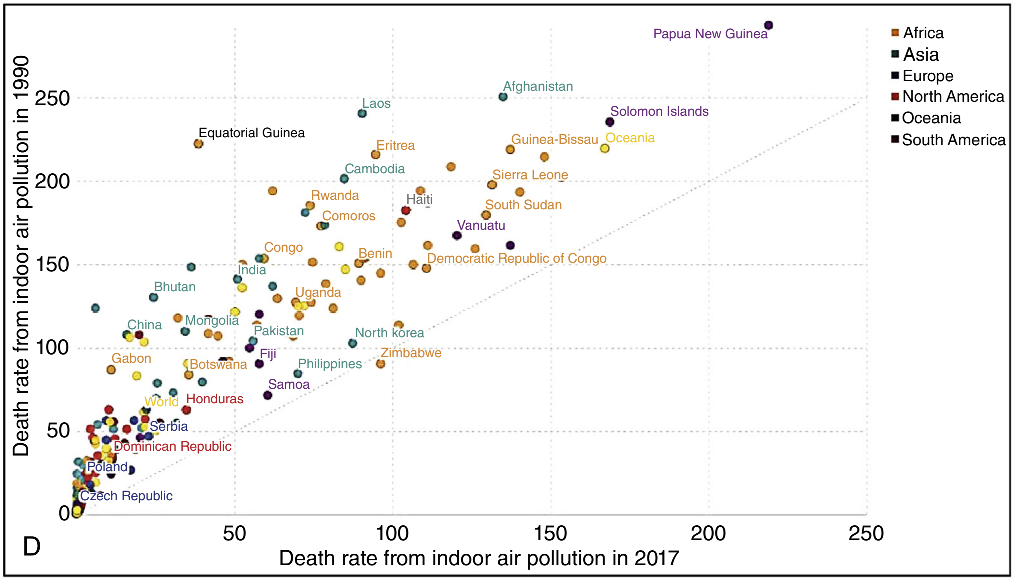




Fig. 3.8 (Cont'd)

## 3.4 COVID-19 infection under varied environmental temperature, water and humidity

The rate of infection and spreading of SARS-CoV-2 via other environmental factors are also profusely studied by the end of December 2020. However, data on the effects of temperature on the rate of infection are plausible as results from different studies are found to be opposite to each other (Zhu et al., 2020b).

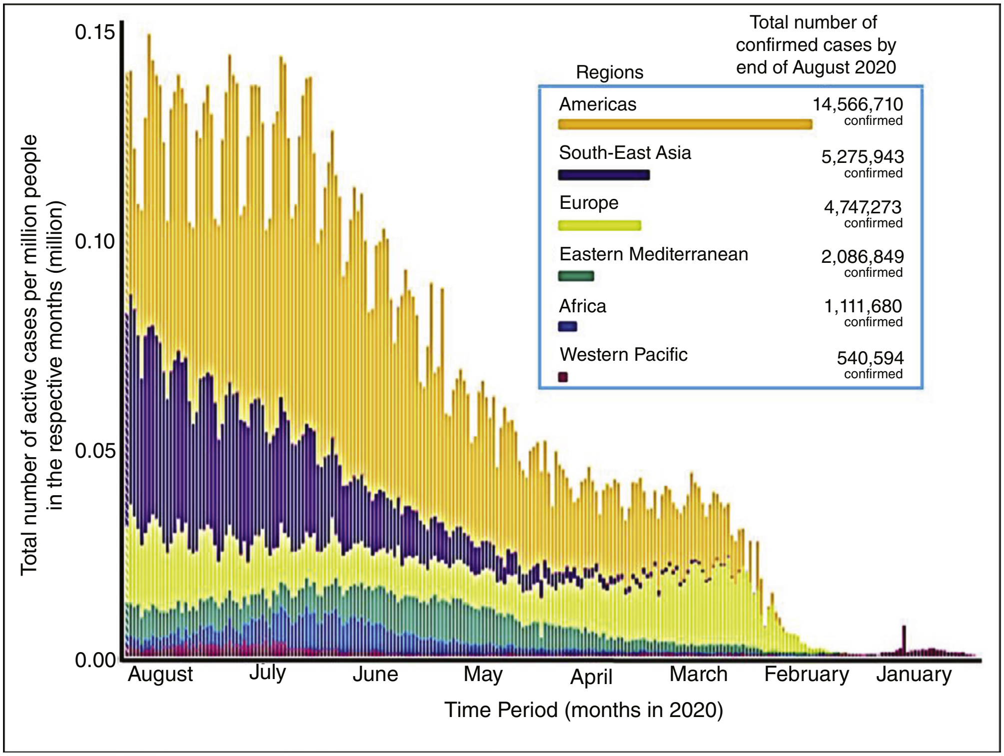



**Fig. 3.9** ***Current global status of COVID-19 outbreak by end of August 2020.*** As per the latest data obtained from the WHO zonation up to the end of August 2020, the total numbers of confirmed COVID-19 cases per million people are higher in American countries followed by the European and Asian countries (total number indicated in insert). However, the outbreak has affected 2016 countries as of August 2020 (source WHO 2020b under creative common attribution).

One preliminary study on the climate data by April 2020 indicates that COVID-19 induced death indicates in countries that encounter comparatively large cases are with cold weather (Yao et al., 2020b). And countries having hot weather had less number of COVID-19 cases, indicating temperature could be a strong factor for COVID-19 cases (Raina et al. 2020). The same authors also reported that the countries with low humidity could be responsible for favoring the transmission and survival of the SARS-COV-2. However, the authors could not conclude concretely about the particular contribution of temperature on SARS-CoV-2 events. In contrast, Ma et al. (2020) made a study at Wuhan city, China and vividly find a positive association between COVID-19 daily death counts and diurnal temperature range (r value = 0.44), but the association between COVID-induced death and relative humidity was negative ($r = -0.32$). They observed that one unit rise in diurnal temperature range was associated with a 2.92 percent (95 percent CI: 0.61 percent, 5.28 percent) increase in COVID-19 deaths in lag 3 but when the temperature data was merged relative humidity, a decline of COVID-19 death in lag 3 and lag 5, with the greatest decrease both in lag 3 [−7.50 percent (95 percent CI: −10.99 percent, −3.88 percent) and −11.41 percent (95 percent CI: −19.68 percent, −2.29 percent)] was noticed (Ma et a., 2020). It suggests that change is environmental temperature and humidity must have a definite relation with COVID-19 cases and mortality (Wang et al., 2020b). A recent study by Xie and Zhu (2020) indicates that mean environmental temperature from 122 cities of China from January 2020 to February 2020 show a positive linear relationship with the number of COVID-19 cases with a threshold of 3 °C (Leung and Sun, 2020). The authors did not get any evidence supporting that new cases of infection could decline with a rise in temperature (FDA 2020). However, the limited time period study and that to a confined geographic location could be the limitation of the study (Xie and Zhu, 2020).

In India, Goswami et al. (2020) have used Sen's Slope and Man-Kendall test, Generalized Additive Model of regression and Verhulst (Logistic) Population Model and reported from the demographic data in May 2020 that interaction of average temperature and average relative humidity had some influence of the on the incidence of COVID-19 cases but the results were not consistent (Gori et al., 2020). Adding to a large scale demographic data analyzed from climatic data from 166 countries by March 2020 had given a clue. Considering wind speed, median age of the national population, Global Health Security Index, Human Development Index and population density, Wu et al. (2020) have concluded that both temperature and relative humidity were negatively correlated to daily new cases and deaths under COVID-19. Interestingly, at every 1 °C rise in temperature was associated with a 3.08 percent (95 percent CI: 1.53 percent, 4.63 percent) decline in daily new cases of COVID-19 (Paital et al., 2013). Similarly, a 1.19 percent (95 percent CI: 0.44 percent, 1.95 percent) decrease in daily new deaths under COVID-19, whereas a 1 percent increase in relative humidity was associated with a 0.85 percent (95 percent CI: 0.51 percent, 1.19 percent) decrease in daily new cases and a 0.51 percent (95 percent CI: 0.34 percent, 0.67 percent) reduction in daily new deaths under COVID-19. Therefore, if this large scale data analyzed from 166 countries by Wu et al. (2020) are to be believed, then COVID-19 must have a negative relation with temperature and relative humidity are to be concluded (Paital et al., 2013).

Discussing the environmental prospective of COVID-19 such as change in air quality, temperature and humidity are covered, but at the same time, accumulation of waste especially medical, industrial and household waste and their gradual release to water bodies was of great concern (Saadat et al. 2020). Therefore, detecting COVID-19 in the environment was of the most important concern to prevent the infection (SanJuan-Reyes et al., 2021). Water bodies were therefore considered as the prime spots to analyses for the presence of COVID-19. In view of the impacts of COVID-19 and changes in the other global-scale phenomena influencing water resources (e.g., global climate change), it was felt that an urgent need for interdisciplinary collaborations to study water and setting new strategies to address water issues are needed (Sivakumar 2020). SARS-COV-2 viruses were detected in waste water (Aguiar-Oliveira et al. 2020) and also in soil (Núñez-Delgado 2020). Therefore, spreading of the virus by water and soil or even by sewage sludge, as well as on plants growing on them cannot be ruled out (Núñez-Delgado 2020). Therefore, fighting with COVID-19 via implementations of several environmental implications wit multidisciplinary approaches are suggested (Lauc et al., 2020).

## 3.5 Conclusion

Air pollution has negative effects on the rate of propagation and severity of COVID-19 cases, even the rate of death is higher in patients found in air polluted areas as compared to clearer air area (Zhu et al., 2020a, 2020b). The mechanism may be attributed to $NO_2$ induced higher expression of ACE-2 receptor that acts as binding cite of SARS-CoV-2 in respiratory cells in human (Fig. 3.10). Although, there was a debate continuing on the topic that whether COVID-19 transmission is air mediated, articles supporting both the concept are available. However, WHO has already declared that COVID-19 can air transmitted. Low or medium income countries are found to experience both indoor and outdoor air pollution (APGH 2020). Both air pollution and COVID-19 lead to respiratory associated health risks and mortality. Therefore, use of appropriate mask in every such areas (even indoor) are strongly recommended where COVID-19 and air pollution have made their common hits (Wang et al., 2020b). Although the information about use of mask is not novel, still many people do not use mask regularly and it becomes the reason of contracting COVID-19. Therefore, more awareness need to be generated for the proper use (covering both nose and mouth) of proper mask (that can filter PMs). International and national organizations must give due importance on use of appropriate mask in those countries as well as both in developing or developed countries, where similar situation is prevalent. On the other hand, involvement of other environmental factors such as temperature, relative humidity, waste water and soil must also be included or targeted for the control of COVID-19. Interdisciplinary approaches to resolve environmental associated issues with COVID-19 are suggested.

## Declarations

**Conflicts of interest/Competing interests:** The author declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

**Availability of data and material:** The sources of few cartoons or figures collected from Deccan Heralds, EurekaAlert.com, LifeSciences.org, Giant microbes, Pharmaceutical Technology.com under creative common attribution license are acknowledged.

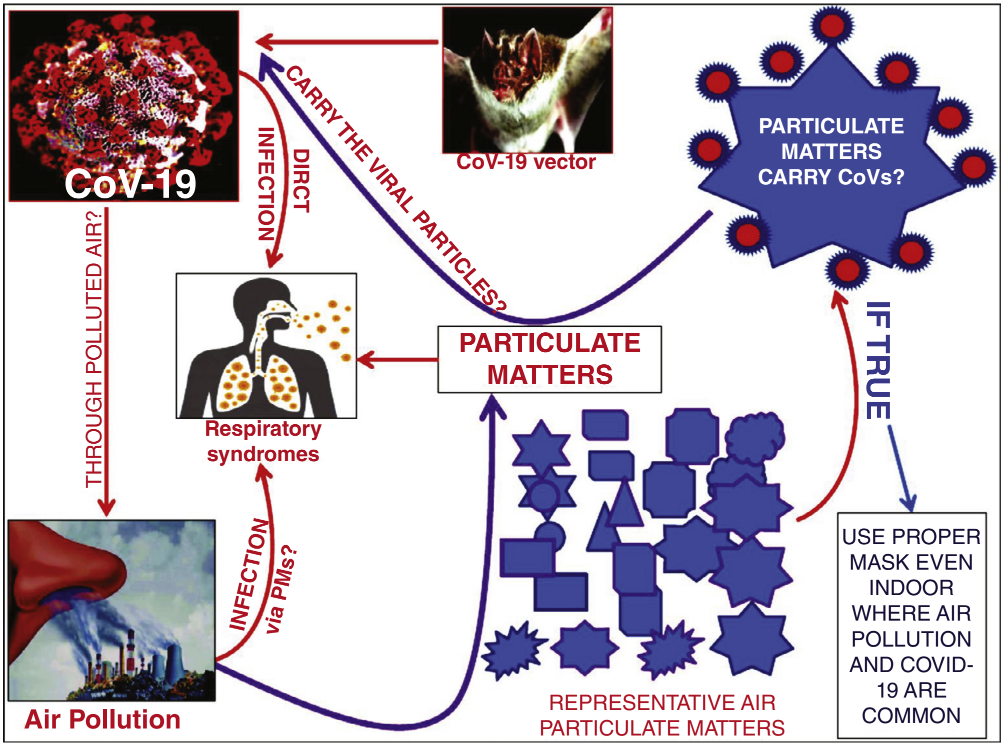



**Fig. 3.10** ***Need of strict use of mask in places where COVID-19 and air pollution made common hotspots.*** It is reviewed that air pollution has a positive correlation with both infection and severity in COVID-19 cases. WHO has declared that the virus SARS-CoV-2 can be viable up to certain hours and therefore can infect healthy people. Since, the virus can non-specifically attached to all surfaces, therefore, they can be found in particulate matters or aerosols too. Therefore, if it is true, then strict use of proper mask are suggested. Use of homemade masks without filtering capacity (for particulate matters and aerosols) is highly discouraged. Proper mask need to be used by all outdoor and even indoor is suggested where the chance of heavy air pollution including invading aerosols and particulate matters into the inhabiting premises is prevalent.

**Code availability:** Not applicable.

**Authors Contribution: BRP:** Conceptualization; Data curation; Formal analysis; Funding acquisition; Investigation; Methodology; Project administration; Resources; Software; Supervision; Validation; Visualization; Writing – original draft and editing. **PKA:** Conceptualization; Methodology; Writing – original draft and editing.

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## Abbreviations

| | |
|---|---|
| ACE2 | Angiotensin-Converting Enzyme 2 (ACE2), |
| AQI | Air Quality Index |
| BBC | British Broadcasting Corporation |
| CDC | Centers for Disease Control and Prevention |
| $CO_2$ | Carbon dioxide |
| CoV | Coronavirus |
| COVID-19 | Coronavirus diseas-19 |
| CREA | Centre for Research on Energy and Clean Air |
| ESA | European Space Agency |
| FDA | Food and Drug Administration |
| HIV | Human Immune Deficiency Virus |
| MERS | Middle East respiratory syndrome |
| NASA | The National Aeronautics and Space Administration |
| NIH | National Institutes of Health |
| $NO_2$ | Nitrogen oxide |
| PM | Particulate Matter |
| PM2.5 and PM10 | particulate matter with fine and coarse particles with a diameter between 2.5 and 10 μm, respectively |
| SARS | Severe Acute Respiratory Syndrome |
| SARS-CoV-2 | Severe Acute Respiratory Syndrome Coronavirus 2 |
| WHO | World Health Organisation |

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## PART 2

# Monitoring and Analysis of COVID-19 in Environment

# CHAPTER 4

# Sampling and analytical techniques for COVID-19

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## 4.1 Introduction

Corona Virus disease, also termed as COVID-19, was declared as pandemic in March 2020 and was first discovered in China (Wuhan City) in December'19. It is an contagious disease and the transmission was rapidly increased covering many cities by March'20 and was declared as pandemic. The severe acute respiratory syndrome coronavirus2 is said as beta corona virus (β Cov) through which COVID-19 or acute corona virus disease is caused (Chan et al., 2020 and Gorbalenya et al., 2020). Corona virus disease is transferred from individual to individual, through droplets of saliva or discharge from the nose, when an infected person sneezes or coughs. The virus feasts from individual to individual through small respiratory droplets and can land on near surfaces. It is said that the Covid-19 virus can lasts up to 3 days therefore avoiding the spread of corona virus was mainly focused on wearing mask, washing hands frequently with soap, frequently using hand sanitizer, and keeping a distance from people who are contaminated from corona virus. Older people and people underlying medical problems such as diabetes, chronic respiratory diseases, cancer, and cardiovascular diseases are likely to develop serious illness (Prasad, 2020 and Nadeem, 2020). Usually 3 people can get infected through an individual who is affected from SARS-COV2 (Liu et al., 2020). The symptoms can vary from human to human. Some people suffer from fever, cough fatigue, while other people remains asymptomatic, some people have symptoms which are similar to influenza or the common cold (Udugama et al., 2020 and Li et al., 2020).

Individuals are tested as many as possible by the Public health experts. A strategy has been made, where the infected people are tracked and their contacts are traced to reduce the spread of virus. Around the globe all the governments are constantly working out on this testing method arrays at a variant extent. A positive single strand RNA is present in severe acute respiratory syndrome coronavirus and the SARS coronavirus present in bat, which are genealogically similar to the beta corona virus (Gudbjartsson et al., 2020). Spike, Envelope, Membrane, and Nucleocapsid (which are denoted by S, E, M, and N respectively) are the four structural protein of which the each virion is encompasses, and the diameter of each virion is about 50–200 nm. With the help

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of spike, envelope, and membrane, envelop of the virus was created, while the RNA genome of the virus was hold by nucleocapsid protein (Bai et al., 2020). It is conducted by the researcher in the early study the natural potential host of the severe acute respiratory syndrome coronavirus are bats (Wu et al., 2020 and Lu et al., 2020). Lam and his co-worker also reported and concluded that in Malayan pangolin the intermediate host are bats (Lam et al., 2020).

To detect corona virus several diagnostics methods have been used. By detecting the viral RNA, the infection is directly detected in direct test, while the antibodies are measured against the exposed host in virus in indirect test. Appropriate clinical decisions should be made during this pandemic, by selecting appropriate analytical techniques with rapid detection and accurate results and also techniques with sufficient sensitivity and selectivity (Cheng et al., 2020). Real-time reverse transcription polymerase chain reaction RT-PCR is the most frequently and expansively used analytical method as it is the direct recognition technique used for the detection of SARS corona virus, in this method the amplification of nucleic acid is conceded. To determine the antibodies in defiance of the SARS-CoV-2, immunological techniques are used (Thomson and Nachlis, 2020).

CRISPR -clustered regularly interspaced short palindromic repeats, is a novel analytical technique conveyed by Thomson and nachlis in the emerging methods. In the last past months, not only clustered regularly interspaced short palindromic repeats but quite a few point of care and speedy test techniques have been similarly accessible apart from nucleic acid based technique and immunological assay, implemented in laboratory. The use of number of analytical techniques has been permitted by the World Health Organization (WHO) and US Food and Drug Administration (FDA) (Thomson and Nachlis, 2020). The result relies not only on equipment and method used but also on sample collection methods/protocol, reagents used, sample and reagent storage requirements, and risk of cross contamination. While selecting a consistent and swift analytical technique, these factors must be considered for suitable conclusion and early actions for public health (Cheng et al., 2020).

This chapter deliberates in detail about the sampling techniques intended for the detection of novel corona virus, and also the analytical techniques which are used for the recognition of corona virus (COVID-19).

## 4.2 Sample collection specimen for the detection of COVID-19

The sampling specimens can be divided into two parts, Environmental sampling and Human sampling. The speedy spread of diseases may ascribe the active shedding of virus with presence of patients who have not produced any symptoms, as a result, direct spread or indirect spread can occur via droplet route or via contact with contaminated environment respectively.

### 4.2.1 Environmental sampling

Transmission which occurs through airborne is not a major route of infection; however, there are possibilities of airborne transmission of SARS-CoV-2 as the suggestion were made through clinical and experimental investigation (Tabatabeizadeh, 2021 and Van Doremalen et al., 2020). When a person sneezes or coughs, the respiratory droplets or aerosols settle down on the environmental surfaces and results in contaminating the surfaces or the contamination can occur, when an infected person comes in direct contact with the surfaces. As a result, many studies have been conducted by the researchers to study the airborne transmission of SARS-CoV-2 and sampling was done from isolation rooms, health care settings, and quarantine rooms. To determine the persistence of SARS-CoV-2 contamination in air and on surfaces, environmental sampling is carried out (World Health Organization, 2020), it can also help to determine the extent of contamination and how surface and air may get contaminated with SARS-CoV-2. Knowledge about transmission pathways and persistence in the environment of SARS-CoV-2 is still emerging (Aytogan et al., 2020).

## 4.3 Human sampling

To detect the corona virus in multidisciplinary, research laboratory, and in laboratories of people health, numerous sample examples are been used (Cheng et al., 2020). For SARS-CoV-2, the entire test should be accompanied in consultation with a healthcare provider. The specimen should be collected as soon as possible, once pursuing the testing decision has been made. The collection of specimens should be done in an appropriate manner as it is the most significant step for diagnosing an infectious disease in laboratory and if it is not collected in appropriate manner than the result may lead to false negative. Often, the respiratory specimens are assembled from the upper respiratory tract such as nasopharynx and oropharynx and are less frequently assembled from the lower respiratory tract specimens (bronchoalveolar lavage fluid (BLF)). For the acute phase of infection, ideally which is within 7 days, the upper respiratory specimen are collected and patients who remains symptomatic for more than a week, the lower respiratory specimen are collected (Lee et al., 2020 and CDC COVID-19 team response. 2020). Different types of sampling specimens are used to detect COVID-19 (Fig. 4.1).

In this section, different types of specimen mainly Nasopharyngeal, Oropharyngeal, sputum, Tracheal aspirate, Bronchoalveolar lavage, blood, and urine sample specimen are discussed (Table 4.1).

### 4.3.1 Upper respiratory tract sampling

#### *4.3.1.1 Nasopharyngeal specimens*

In nasopharyngeal swabs, a sterile swab/cloth stick is used for sampling process, the stick was inserted impenetrable into the nasopharynx, afar from the hard soft

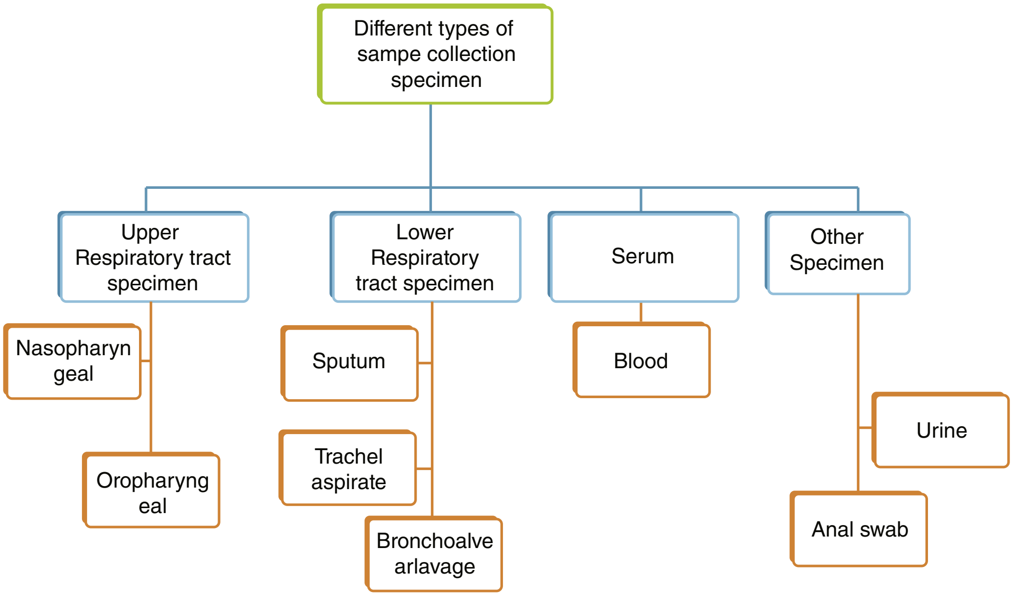


**Fig. 4.1** ***Different sample specimens for detection of COVID-19.***

palate transition, and as a result a direct contact is achieved with the mucosal wall of posterior nasopharyngeal. The introduction of swab stick mandates the interaction through the nasal cavity on its way in hence a pure specimen of nasopharyngeal is not obtained. In a fit adult, the normal dimension of nasal cavity is about 5–7 cm (Lieberman et al., 2009). However in nasal swabs, flocked swab sticks are used for sampling of front side of nasal cavity and by eluding deep introduction of the flocked swab stick, probable a pure nasal swab can be obtained. In 2003 when the outbreak of SARS took place, a group of scientist defined an alternative method for nasopharyngeal sampling that is nasopharyngeal aspirate (NPA). To obtain an untainted nasopharyngeal sample without collecting the contamination from frontal nasal cavity, instead of a swab stick, catheter suction is used and in the nasopharynx, it is threaded followed by suction activation enunciating mucus of nasopharyngeal into a ploy. Chan and his co-workers equated the nasopharyngeal specimens by nasal swab samples and throat swabs samples and initiate that NPA detects beta coronavirus viral RNA in definite patients (Chan et al., 2004). An another study was also conducted during 2003 outbreak in Hong Kong, where it is reported that equated to nasopharyngeal specimens, Nasal and pooled throat swabs provide greater analytical yield (Chan et al., 2004). Currently in the COVID-19 pandemic, SARS-CoV-2 viral flaking is deficient in NPA samples, as a main method in most studies, swabbing is utilized for respiratory sampling. The process of upper respiratory tract specimen collection was described in Fig. 4.2.

**Table 4.1** Different types of specimens used for the detection of Covid-19.

| Sr. No. | Specimen | Specimen type | Apparatus and Swabs used | Analytical techniques preferred for further analysis | References |
|---|---|---|---|---|---|
| 1. | Upper Respiratory tract specimen | Nasopharyngeal specimens | Artificial fiber swabs with plastic or wire shafts | Real time polymerase chain reaction (RT-PCR) | Pondaven-Letourmy et al. 2020 |
| | | Oropharyngeal specimens | Artificial fiber swabs with plastic or wire shafts | Real time polymerase chain reaction (RT-PCR) | Liu et al. 2020 |
| | | Nasal mid-turbinate (NMT) specimen collection | Flock tapered swab | Real time polymerase chain reaction (RT-PCR) | Palmas et al. 2020 |
| | | Anterior nasal (nares) specimen collection | Flock or spun polyester swab | Real time polymerase chain reaction (RT-PCR) | Palmas et al. 2020 |
| | | Nasopharyngeal wash or nasal wash | Attach a catheter suction apparatus | Real time polymerase chain reaction (RT-PCR) | Calame et al., 2020 |
| | | Saliva | A Sterile container leak proof screw cap | Real time polymerase chain reaction (RT-PCR) | Wong et al. 2020 |
| 2. | Lower respiratory tract specimen | Bronchoalveolar lavage fluid (BSF), tracheal aspirate, pleural fluid, lung biopsy | Sterile leak proof screw cap collection cup | Real time polymerase chain reaction (RT-PCR) | Zhou et al. 2020 |
| | | Sputum | Sterile leak proof screw cap sputum collection cup | Real time polymerase chain reaction (RT-PCR) | To et al. (2020) |
| 3. | Serum | Blood | Sterile leak proof screw cap container | Immunoassay test | Peng et al. 2020 |
| 4. | Other specimens | Urine | - | Real time polymerase chain reaction (RT-PCR) | Liu et al. 2020 |
| | | Anal swab | – | RT-PCR | Peng et al. 2020 |

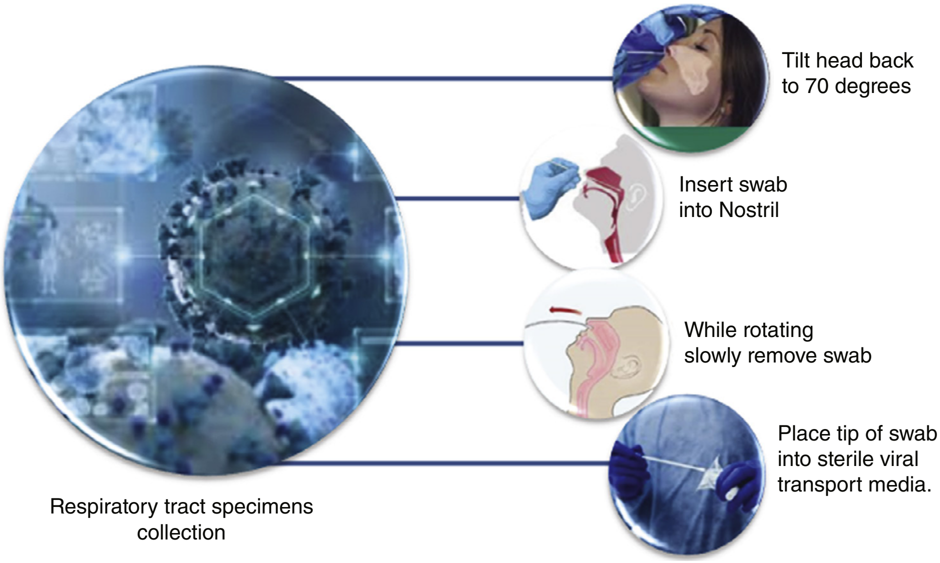


**Fig. 4.2** ***Process for collection of Upper Respiratory tract specimen.***

#### *4.3.1.2 Oropharyngeal swab*

The Oropharyngeal swab is also known as "throat swab". Four Oropharyngeal sub-sites such as tonsils, base of tongue, posterior pharyngeal wall, and soft palate sampling are conceded. Behindhand the hard palate, the oropharynx is positioned, which further at the hard-soft palate transition inaugurates. Most commonly the sampling is carried from posterior wall of pharyngeal as it is considered as the functional range of the nasopharynx. Currently in the COVID-19 pandemic, OPS are used commonly for respiratory sampling (Zou et al., 2020). During the pandemic, the OPS are used as sole sampling in many countries (Qian et al., 2020). However, Xie and his co-workers reported that OPS have low negative predictive value that is only 9 out of 19 COVID-19 positive patients were seropositive. To increase diagnostic yield, attention was paid on repeating sampling from multiple sites including lower respiratory tract (Xie et al., 2020). Ye et al. compared the Nasal Swab, Nasopharyngeal Swab, Nasopharyngeal Aspirate, and Oropharyngeal Swab methods for respiratory sampling for SARS-CoV-2 viral RNA. They concluded that nasopharyngeal aspirate had a greater conclusive rate than other respiratory specimens, while it is also conducted that combination of nasal swab oropharyngeal swab were least harmful during sampling (Ye et al., 2020).

### 4.3.2 Lower respiratory tract sampling

#### *4.3.2.1 Sputum specimens*

During involuntary induction or voluntary coughing, sputum collection is performed. Sputum collection was performed into a sterile container with the patients having cough by To et al. IN the collected specimens, they demonstrated the viral RNA levels (To et al., 2020). It is reported by Lo et al. that 90 percentage of nasopharyngeal swab samples detected SARS-CoV-2 RNA, while deceptively inattentive in 10 percentages (Lo et al., 2020). Pan and his co-workers also rebound the superiority of sputum for SARS-CoV-2 viral detection. They reported that compared to throat swabs, sputum samples shows higher viral loads (Pan et al., 2020).

#### 4.3.2.2 Tracheal aspirate

Tracheal aspirate can be obtained from instinctively ventilated covid patients through catheter from an endotracheal tube or from tracheotomised patients by directly tracheal suction. It is published in Chinese Society of Anaesthesiology that tracheal intubation is recommended for COVID-19 patients with critical illness. Generally this tracheal intubation is avoided unless it's necessary as it is an aerosol-producing procedure (Zuo et al., 2020). To the health care workers, the collection of tracheal aspirates specimens sample poses higher risk of contamination. A viral load comparison was made on upper respiratory sample vs endotracheal aspirates form 16 COVID-19 patients by Huang et al. and they base a claim that viral RNA value are noticeably have higher values equated to nasal and oropharyngeal swab specimen (Huang et al., 2020).

#### 4.3.2.3 Bronchoalveolar lavage

Initial in Wuhan Institution of Virology, the SARS-CoV-2 genome identification was performed through Bronchoalveolar lavage (BAL) samples (Zhou et al., 2020). In sampling process of Bronchoalveolar lavage, a premeditated quantity of fluid is acquaint with and collected from trachea and bronchi through the introduction of bronchoscope into bronchi and trachea. For the viral detection of SARS-CoV-2, China and Europe published the bronchoalveolar lavage fluid usage, since December 2019 (Yu et al., 2020; Wang et al., 2020 and Reusken et al., 2020). Accumulating evidence suggests that in case of false negative NPS and OPS viral detection, BAL is comparatively useful.

### 4.3.3 Serum specimen

#### 4.3.3.1 Blood specimen sample

For immunoassay methods, serum samples are collected in which 50–200 μL blood is drawn in a capillary for immunoassay test, which ranges from 5 to 10 mL. The immunoassay method used for blood sample is lateral flow immunoassays (LFIA) (Bendavid et al., 2020). A study was carried by Huang et al. where, from SARS-CoV-2 about 41 people were infected. Sampling of blood specimens was carried in which only six were positive, while in sampling with respiratory specimens all of them were positive with SARS-CoV-2 (Huang et al., 2020).

When the first case of SARS-CoV-2 appeared in United States, all the respiratory specimen sampling as well as other specimens sampling such as, Nasopharyngeal swab, Oropharyngeal swab. Examination of Serum, urine, and Stool samples was done from which except serum, the nasopharyngeal swabs, Oropharyngeal swab, urine, and stool samples were positive (Holshue et al., 2020). The existence of viral RNA in specimens (blood and urine) and the relation between organ system involvement and clinical manifestation are still not known. Therefore values of SARS-CoV-2 infection are low in blood compared to other specimens (Peng et al., 2020).

### 4.3.4 Other specimen

#### *4.3.4.1 Urine*

Urine is said to be the most effortlessly taken biological sample. In some current studies, the biochemical parameters of urine (blood and protein) between severe COVID-19 patients and healthy controls are different (Liu et al., 2020a and Bonetti et al., 2020). When COVID-19 is transmitted to a person, the consignment of virus increases and as it surges, the peptides present in the coronavirus as well as the chemical metabolites reactions caused from the coronavirus are defecated in the urine. The beginning time and quantity of defecation in urine are connected to the virulence of relevant microorganism, and the quantity of viral consignment at the period of main exposure, person's immunity, metabolic rate and current diseases (Peng et al., 2020).

## 4.4 Analytical techniques for the detection of COVID-19

Analytical techniques are very imperative for the controlling of infection and avert spreading of COVID-19. In amalgamation with the data of therapeutic and epidemiologic, the current standard for identification is positive real time reverse transcriptase polymerase chain reaction (RT-PCR). To know the epidemiology improvement and measure vaccine reactions, serological assays are used, but in the severe stage of disease, they are impulsive for diagnosis (Rivett et al., 2020).

Analytical techniques for detection of COVID-19 can be categorized into two parts. The first part for the recognition of SARS-CoV-2 RNA the molecular assays techniques using real time reverse transcriptase polymerase chain reaction (RT-PCR) and it is also said as nucleic acid based amplification using RT-PCR. The second part includes immunological and serological assays that are carried out by identifying the antibodies formed by an individual or by detecting antigenic protein in infected individuals (Fig. 4.3). During the acute phase of infection, SARS-CoV-2 infected individuals are identified through testing of SARS-CoV-2 viral RNA. Patients develop antibodies against the virus and the detection of these antibodies can be performed through immunological and serological assays. Nucleic acid detection based techniques along with the advancement in medical diagnosis have become a trustworthy and rapid technology for the recognition of corona virus. Polymerase chain reaction (PCR) known as the gold standard test as compared to other tests it has high rapid detection, specificity and sensitivity for detection of viruses. To diagnose the early infection, the sensitivity of

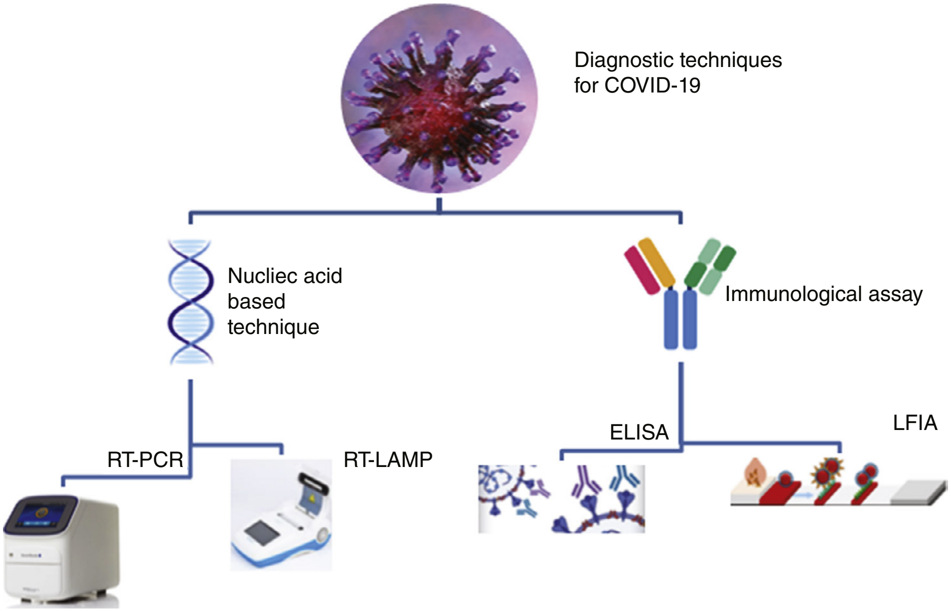


**Fig. 4.3** ***Different Analytical techniques to detect COVID-19.***

real time reverse transcriptase polymerase chain reaction (RT-PCR) is adequate hence to identify the causative agent of COVID-19 (SARS-CoV-2 viral RNA) it can be reflected as main method (Shen et al., 2020; Wan et al., 2016 and Noh et al., 2017). In RT-PCR, risk of eliciting false negative and false positive result is the vital issue. In many suspected cases, typical COVID symptoms are reported but computed topography images were not diagnosed (Wang et al., 2020). This method is widely used over the world wide to detect the SARS-CoV-2 viral RNA but it sets some limitation such as it cannot be used for the purpose of monitoring the phases of virus infection and progress, so serological testing is carried out to identify the earlier infection and protection.

In this section, different types of analytical technique such as nucleic acid based techniques as well as some immunological assays or serological tests for the detection of SARS-CoV-2 are discussed.

### 4.4.1 Nucleic-acid based techniques (Real-time reverse transcriptase polymerase chain reaction (RT-PCR))

To identify the virus, presence of nucleic acid in the sample is analyzed in the Nucleic-acid based technique. As it is said, the most communal method to detect the viral RNA is RT-PCR (real-time reverse transcriptase polymerase chain reaction. This technique is also used in the diagnosing and reconnaissance of viruses (Corman et al., 2020; Mackay et al., 2002 and Drosten et al., 2013). Generally samples of upper respiratory tract are used in the RT-PCR to detect COVID-19, but few studies have been carried out where sample such as serum, stool, or ocular secretions are used in RT-PCR. In RT-PCR, with the help of RNA-dependent DNA polymerase (reverse transcriptase), the genomic RNA of virus is converted into DNA. Small DNA sequence primers are designed, who recognizes the specific complementary sequence of viral RNA genome and through reverse transcriptase a complementary short DNA copy (cDNA) of viral RNA is generated (Fig. 4.4). Using a sequence specific DNA probe labeled with fluorescent molecule and a quencher molecule or fluorescent dye, as the PCR reaction progresses the amplification of DNA is monitored in real time. The amplification of cycle is repeated about 40 cycles in an automated system until and unless the viral cDNA is detected. Usually this detection occurs by a fluorescent or electrical signal (VanGuilder et al., 2008). Depending upon the PCR version, the result of RT-PCR may take time from an hour to few days. RT-PCR test can be conceded in two different methods, the one step method and the two step method. In the one step method, there is a one reaction tube in which RT and DNA both are added in the same tube. As the name suggests, it is a lone step technique. While in two-step approach, to run the amplification reactions and separate reverse transcription, more than one tube is used, it offers higher sensitivity and great flexibility (Wong et al., 2005). As quick set up and limited handling of samples are required generally in one step approach, it is the extensively used technique for the recognition of novel corona virus.

The cross-contamination occurs amongst the real-time reverse transcription polymerase chain reaction (RT-PCR) steps and also errors occur while pipetting out solutions is also condensed. Till now, several diverse genomic regions of SARS-CoV-2 which includes ORFIb or ORF8 regions, and the nucleocapsid, spike protein, or the RNA polymerase (RNA-dependent) or envelope (E) genes are targeted through RT-PCR and this technique is widely used in the molecular diagnostic tests (Aguiar et al., 2020; Rabaan et al., 2020; US food and drug administration, 2020 and Carter et al., 2020). Many evolutions are made in RT-PCR constantly to improve detection method and for more automated procedure (Zhen et al., 2020). Even though RT-PCR is most broadly used method but it has some disadvantages such as expensive laboratory instrumentation, highly personal skills are required to operate, and the result could take days to generate. Therefore across the globe many laboratories and companies are working to improve the efficiency of RT-PCR technology and also to develop alternative techniques (Carter et al., 2020).

### 4.4.2 Limitations of RT-PCR

RT-PCR test have advantage of accepting large batches of sample so test facility and PCR are machines are too costly and when the transportation of sample to the laboratory are included, it take more days than usual. Additionally, well trained man-power

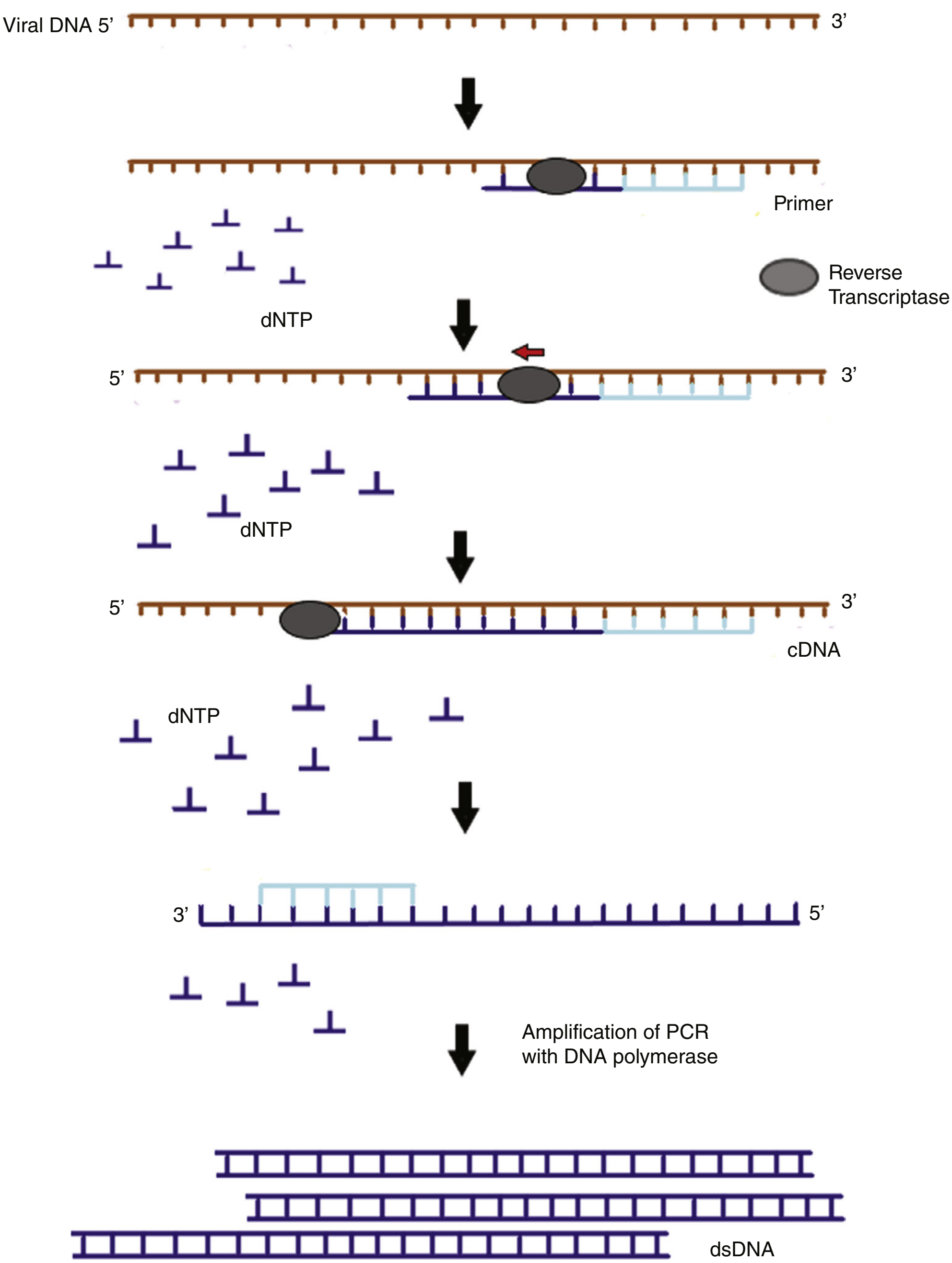


**Fig. 4.4** ***Reverse Transcriptase polymerase chain reaction process.***

is required for assay procedures and sample preparations. In RT-PCR assays, a specific locus is targeted and in the sample if specific locus is not reported by RT-PCR than negative result would be reported by the assay. It is indicated by genomic data collection that interchange, insertion, recombination, and deletion, are common in CoVs, so the genome of the virus changes due to them (Benvenuto et al., 2020; Cui et al., 2019). In this case, when the mutation occurs at primer or at probe binding site with a single-nucleotide polymorphism, the true RT-PCR results can be vitiate. Due to low concentration of virus in sample, the early infection is not detected in RT-PCR specifically in cases that do not show any symptoms and it may cause outcome in incorrect negative results (Diao et al., 2020).

## 4.5 Reverse transcriptase loop-mediated isothermal amplification (RT-LAMP)

For each cycle in real time reverse transcription polymerase chain reaction, multiple temperature change is essential with sophisticated thermal cycling apparatus (Notomi et al., 2000), therefore alternative strategies are develop, where at a constant temperature the amplification is carried out and also thermal cycle need is eliminated. RT-LAMP is one of the alternative strategy developed and also a cost-effective and rapid testing for SARS-CoV-2 detection. Set of four primers are required with a specific gene target or target region, so the sensitivity is enhanced and for the detection of RNA, LAMP is combined with reverse transcriptase step. As a by-product, magnesium pyrophosphate precipitate in solution, which caused turbidity, by measuring this turbidity or with the help of photometry the amplification result, can be detected. As measuring the turbidity or measuring the fluorescence with the help of intercalating dyes, in real time the reaction is followed. Since the real time Reverse-transcriptase loop-mediated isothermal amplification diagnostic testing necessitates only heating and graphical inspection, hence its effortlessness and compassion make it a likely for virus detection (Thai et al., 2004).

Zhang and his co-workers prepared RT-LAMP test, in this test conversion of cDNA from viral RNA using reverse transcriptase is done. For rapid colorimetric recognition with a DNA-binding dye, the amplification is consequently carried out for the conversion of viral RNA to cDNA by DNA polymerase DNA-dependent [26]. A distinctive in designed DNA polymerase enzyme directed with RNA is used, an aptamer is reversibly bounded and is coupled with DNA polymerase enzyme directed with RNA and the RTx activity is inhibited by this aptamer at below 40 °C. To detect viral RNA, a colorimetric LAMP has been used and was effective at the levels of approx. 480 RNA copies. The viral RNA is detected by colorimetric LAMP in cell lysates. As without interference and also it provides rapid and simple detection of SARS-CoV-2 viral RNA it provides an alternative to RT-PCR test (Zhang et al., 2020).

## 4.6 Immunological and serological assays

Usually examination of blood serum or blood plasma has been carried out in serological testing but it has been expanded the testing including saliva, sputum, and other immunological fluids in which the immunoglobulin G and immunoglobulin M antibodies are present are tested. With valuation of trajectories of mutually short term and long-term trajectories, assortment of antibodies and also in its profusion the serological test plays vital part in epidemiology and as well as in vaccine development. The first detectable antibody in the serum was IgM which switched to IgG. In infected patient IgM was detected after few days or weeks so it indicate the early stage of infection while IgG indicate the recent or earlier infection and the manifestation of post infection immunity is also used to put forward by IgG. In current years, for the recognition of antibodies and antigens derived from pathogens, and also the intricacy and understanding of serological assays have improved. These experiments have enormous prospective to know the epidemiology of corona virus (Loeffelholz et al., 2020; Udugama et al., 2020; Zou et al., 2020 and Chatterjee et al., 2020). The test results of this test may get impacted by delay in antibody construction in infected patients who are seronegative but positive in molecular genetical assays or nucleic-acid-based technique, the patients may be seropositive but the results are negative for nucleic acid based technique as the seropositive test indicate earlier infection or minor infection, and the last impact is that the assay has limitation in susceptibility and attentiveness. Due to the low specificity or sensitivity this last impact is significant, as even a minor false positive result in leading to the misleading of predictive antibody prevalence among the population, which would create a detrimental impact on the population (Payne et al., 2020). Compared to immunoassays, the test in which the RNA sequence is recognized in the virus is said to be more operative. In the past, problems are caused in immunoassays due to molecules like rheumatoid factor, interferon, and non-specific IgM (Giri et al., 2020). Such potential interferents' levels could be highly variable in SARS-CoV-2 patients. When the infection is produced at early stage, the response to virus from antibody would be false negative result by immunoassays. When people are tested who do not show any symptoms or show slightly symptoms in local populations, the sensitivity might be stumpy and only less amount of antibodies would be generated. Hence such several cases are present than the sensitivity might be lesser. Due to past SARS-CoV-2 like illness, it confuses the specificity of antibody response through which the results might be biased. Authenticating an assay of antiviral antibodies, several difficulties may occur and one of them appropriate negative and positive controls avaibility. Before 2019, the serum pools were taken and the negative controls are at ease to come, while samples from SARS-CoV-2 patients or CR3022 monoclonal antibodies recuperate the positive controls (Bendavid et al., 2020).

The SARS-CoV-2 detection is mainly depend on detection of IgM antibody or else IgG antibody which are precise to specific viral antigen such as spike glycoprotein and nucleocapsid protein. For the recognition of SARS-CoV-2 RNA, in immunological testing, approaches such as enzyme-linked immunosorbent assay, lateral flow immunochromatographic assay, neutralization bioassay, and precise sensors are used. Each of these methods have some advantage such as speed, automation and multiplexing, while also it has some disadvantages such as dedicated laboratories and trained personnel required. Many alternative methods for the recognition of COVID-19 are also developed, such as methods to detect antibody, rapid tests of antigen where to identify the viral antigen, the antibodies are used (Chatterjee et al., 2020).

### 4.6.1 Enzyme-Linked immunosorbent assay (ELISA)

ELISA is designed to detect and quantify substances such as peptides, proteins, hormones, and antibodies and it is a microwell plate-based assay technique. The time for test result is usually of 1–5 h and this test can be qualitative or quantitative (Chatterjee et al., 2020). Typically the plates are coated with viral protein in case of COVID-19. If the viral RNA is present in the sample, the antiviral antibody will bind precisely. This can be detected by adding an extra tracer antibody which would produce fluorescent or colorimetric based results. This test takes less time and also multiple samples can be tested at time (Li et al., 2020a).

### 4.6.2 Lateral flow immunoassay

Lateral Flow Immunoassay, a qualitative chromatographic assay, which is movable, small, and used at point-of-care. The result is obtained in 10–30 min as the test is a rapid diagnostic test (RDT). To a substrate, the sample is applied where it flows to immobilize viral antigen band, if the sample is SARS-CoV-2 positive than at the band the antibodies of anti-CoV2 are collected along with the tracer antibodies as a result, a color develops which indicate positive result. In LFIA, on nitrocellulose membrane, via capillary flow the sample moves before developing color. This test has advantages such as no trained personnel required, and is inexpensive while it has disadvantage that only qualitative results are provided. The analysis of infection is possible when, with having symptoms it is used in conjugation (Carter et al., 2020).

### 4.6.3 Neutralization assay

The ability of an antibody to inhibit virus infection of cultural cells and cytopathic effect of viral replication is resulted, is determined in Neutralization assays. Samples such as whole blood, plasma, or serum are diluted and are used in this assay. At decreasing concentrations this diluted samples are added to cell cultures. By determining the threshold at which the neutralizing antibodies are able to prevent viral replication in the infected cells, the neutralizing antibodies level can be restrained. Neutralizing assays result usually takes time of about 3–5 days but these days are reduced in hours in recent advances or studies (Postnikova et al., 2019 and Muruato et al., 2020). The limitation of this assay is that it requires cell culture facilities, while in the case of SARS-CoV-2 it is risky to precede due to the spread of virus suggested in biosafety level 3 (BSL3) laboratories. It is important in short term effects as well as in long term effect to determine the neutralizing antibodies.

### 4.6.4 Luminescent immunoassay

The limits of detection for antibody based reagents are lowered in the Luminescent assays. In this assay, usually fluorescence and chemiluminescence are convoluted. Magnetic chemiluminescence enzyme immunoassay which is peptide-based is developed by Cai and his co-workers for the detection of COVID-19. An avaibility of two new fully automated serological test were announced by Diazyme Laboratories, Inc, where the test runs on fully automated Diazyme DZ-lite 300 Plus analyzer of chemiluminescence (Cai et al., 2020 and Srivastava et al., 2020).

## 4.7 Other tests

### 4.7.1 Biosensor test

In biosensor test, via electric, enzymatic, optic, and through other methods, measureable readout is done through the conversion of definite biomolecule interaction. One of the techniques is surface plasma resonance (SPR) in which interference with incident light is restrained at a solid boundary due to local disturbance (absorption of antibody or antigen). On a gold substrate, corona viral surface antigen was anchored for detection of SARS virus; an SPR-based biosensor was developed (Park et al., 2009).

A CANARY biosensor was announced by PathSensors Inc. recently to detect the SARS-CoV 2 virus. An immunosensor based with cell was utilized. In which with signal amplification, the virus is couples captured. For result, this sensor takes about 3 to 5 min (Antiochia, 2021).

### 4.7.2 Rapid antigen test

Rapid antigen test allows detecting the viral antigens and are complementary to molecular genetic assays or nucleic acid based techniques (Khan et al., 2020 and Diao et al., 2020). Capture of viral antigens from an analytical sample, a specific monoclonal antibody is provided and this mechanism is used in rapid antigen test. A particular format is not required for this assay (Che et al., 2004), for example, in 2005 an enhanced chemiluminescent immunoassay for SARS-CoV (Diao et al., 2020), in 2004 a colorimetric enzyme immunoassay for SARS-CoV (Che et al., 2004), and recently for detection of SARS-CoV-2 nucleocapsid protein, a fluorescence lateral flow assay (Yang and Sun, 2005).

## 4.8 Conclusion

Corona Virus is an infectious disease and was first discovered and diagnosed in Wuhan city of China in December 2019. The beta corona virus (β Cov) was identified as Severe

Acute Respiratory Syndrome Coronavirus 2 (SARS-COV2) which causes covid-19. Many sampling techniques are used to detect corona virus. The environmental sampling is also carried out to detect the spread of Corona virus in environment. Human sampling which are upper respiratory tract specimens which includes nasopharyngeal specimens, and Oropharyngeal specimens, lower respiratory tract specimens which include specimens of sputum, BLF, and tracheal aspirate, serum (blood), and other samples such as urine are conceded to detect Corona virus. Analytical techniques such as nucleic acid based techniques (RT-PCR technique and RT-LAMP technique), and immunological assays are used (ELISA, LFIA, luminescent immunoassays, and neutralization assay), while these techniques have some advantages as well as drawbacks. Some biosensors are also developed recently to detect the novel corona virus.

## 4.9 Future perspective

Among numerous techniques are accessible for the identification of corona virus, the RT-PCR is the most trustworthy and extensively used technique but this technique is costly and many countries are not able to afford the number of test as the population is more. Therefore in several countries, several test kits for COVID-19 are recalled. New technologies are developed such as CRISPR-based diagnostics and microfluidic point of care test system in serological assays, are implemented for practical approach. Bearing in mind the fact that the prospect of corona virus infection, like the flu viruses will persist in the inhabitants, hence various testing techniques for detection of different diseases must be well thought-out in future as a repetitive testing.

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# CHAPTER 5

# Sensor-based techniques for detection of COVID-19

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## 5.1 Introduction

SARS-CoV-2 is a single-stranded and enveloped RNA virus having four important structural proteins i.e. nucleocapsid (N), membrane (M), envelope (E) and spike (S). S protein is a glycoprotein that plays an influential role in viral envelope binding, synthesizing, entering and passing (Jiang, Hillyer and Du, 2020; Nasrollahzadeh et al., 2020; Soufi et al., 2020) and consists of N- terminal $S_1$ subunit and C- terminal $S_2$ subunit liable for receptor-binding and cell membrane fusion respectively. During the infection, an interaction among plasma membrane and $S_1$ receptor takes place due to which corona virus binds to the host cell causing post-translational alterations in $S_2$ subunit resulting in virus fusion and entry into target cell (Florindo et al., 2020; Shin et al., 2020; Talebian and Conde, 2020). Globally, more than 85 million people are infected and more than 1 million people have died. Generally, testing assay i.e. real-time reverse transcriptase polymerase chain reaction (RT-PCR), thermal screening guns, enzyme-linked immune-sorbent assay (ELISA) are most extensively used for analysis of COVID-19 but considering the seriousness of global healthcare, there is requirement for novel techniques that are rapid, specific, sensitive, in-expensive and extra reliable. This will avoid the unnecessary quarantining of individuals who are not at all infected with corona virus (Carter et al., 2020). The main cause of death rate and morbidity in humans and sometimes animals are due to infected viruses. So, it is very necessary to have proper detection methods at an early stage. COVID-19 has various symptoms like dry cough, fever, tiredness, difficulty in breathing, loss of smell, and chest pain. Due to these symptoms, serious medical attention is required. Asymptomatic individuals are the most dangerous ones because of them the extent of transmission gets increase and as a result of this fact, detection techniques are of utmost priority (Catanzaro et al., 2020; Khan, Liu and Xue, 2020).

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## 5.2 Current diagnosis strategies for COVID-19

The onset of the pandemic caused by the novel coronavirus has elevated the death rate to a greater extent, due to which the need of novel sensor-based techniques for COVID-19 detection is imminent. COVID-19 has various symptoms like dry cough, fever, tiredness, difficulty in breathing, chest pain, loss of smell, etc. and due to these symptoms, serious medical attention is required. Asymptomatic individuals are the most dangerous ones because due to them the extent of transmission gets multiply. Owing to this fact, it is necessary to innovate novel sensor- based detection methods for COVID-19 detection. Commercially, there are two substantial strategies of detection methods accessible. Molecular assay represents the first strategy in which PCR- based or nucleic acid hybridization technique is in operation. Serological or immunological assay is another strategy, in which antigenic proteins are detected in infected individuals. RT-PCR is currently the most widely used molecular-based testing method. These molecular- based techniques typically desire sample having pathogens from infected individual, along with nasal- cavity swab and phlegm samples. Serological assays, mainly play a significant function in the study of disease transmission of coronavirus and in deciding the no symptom individual resistant position. Serological methods are not utilized for screening tests or for the determination of initial stages of infection but surely might be helpful for affirming the presence of corona virus disease (Saadat, Rawtani and Hussain, 2020; Wölfel et al., 2020). These two classifications succor an objective of overlying in curbing down of corona virus widespread, so it is necessary to make its usage more prominent.

The primary objective of molecular and serological based testing strategies is to identify SARS-CoV-2 infected individuals during the initial phase of infection. Before the onset of actual running of the test i.e. pre-diagnostic phase, unadulterated collection of samples from the respiratory region must be done for brief and precise detection of the novel coronavirus. While the test is going on i.e. diagnostic phase, the ongoing RT-PCR assessment continues as first preference for the etiologic conclusion of COVID disease whereas neutralizer- based procedures are put forward as additional tool. After the trials get completed, the outcomes ought to be cautiously interpreted utilizing both sub-atomic and serological discoveries. At last, arbitrary access, co-ordinated gadgets approachable at the point of care with versatile limits will encourage the quick and precise conclusion with checking and extraordinarily aid the control of the pandemic. From the Fig. 5.1, it could be interpreted that there are enough detection methods, but practically some methods have limitations like; time-consuming, expensive, low accuracy and sensitivity rate, unsuitability for on-site analysis and require professional technical personnel, etc. Therefore, those detection techniques are required which can be practiced anywhere, under any circumstances having low-cost, eco-friendly, no technical personnel require and most importantly, have accuracy in the results. Generally, the molecular-based assays are analogously more susceptible and faster than immunoassay strategies and can be employed effortlessly towards manual detection of the virus.

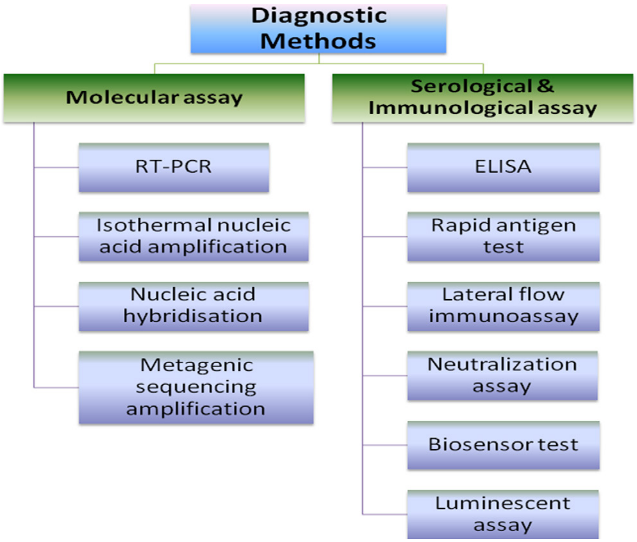


**Fig. 5.1** ***Diagnostic Methods.***

Although having these advantages, many molecular-based assays have varied probable constraints in efficiency, subtlety and selectivity, usually generated by high genetic alterations of several viruses. Contrarily, RT-PCR is commonly using as a routine testing method for COVID-19 detection (Qiu et al., 2020) that take three to four days for test results with sometimes false- negative report. These individuals having incorrect negative test reports subsidize for further spread of the virus in large number. It is important to move towards contactless optical approaches to restrict the spread of virus and control the increasing number of cases. So for this intent, strategies based on sensor technology are adequately practiced for the fast detection of the virus. Certainly, there are numerous nano-based structure, comprising graphene oxide (GO), polymeric nanomaterial and metallic nanoparticles (NPs) for the virus detection. Metallic NPs- based diagnostic methods are recorded for diversified varieties of scientifically significant virus with prime target on virus detection and assessment technique (Iravani, 2020). Nanostructure materials can revel in exceptionally convenient surface interactions between analytes and sensors or any other chemical composition because of remarkable surface-to-volume ratios and allowing highly-qualified viral detection (Nasrollahzadeh et al., 2020; Talebian et al., 2020). An illustrative layout for current diagnostic techniques and probable biosensor for COVID-19 shown in Fig. 5.2 (Cui and Zhou, 2020).

## 5.3 Sensor- based technologies for SARS-CoV-2 detection

Sensors are fabricated of transducers and biological/chemical receptors (antibodies, DNA, enzymes, etc.). Initially, the receptors combine explicitly with target analyte and

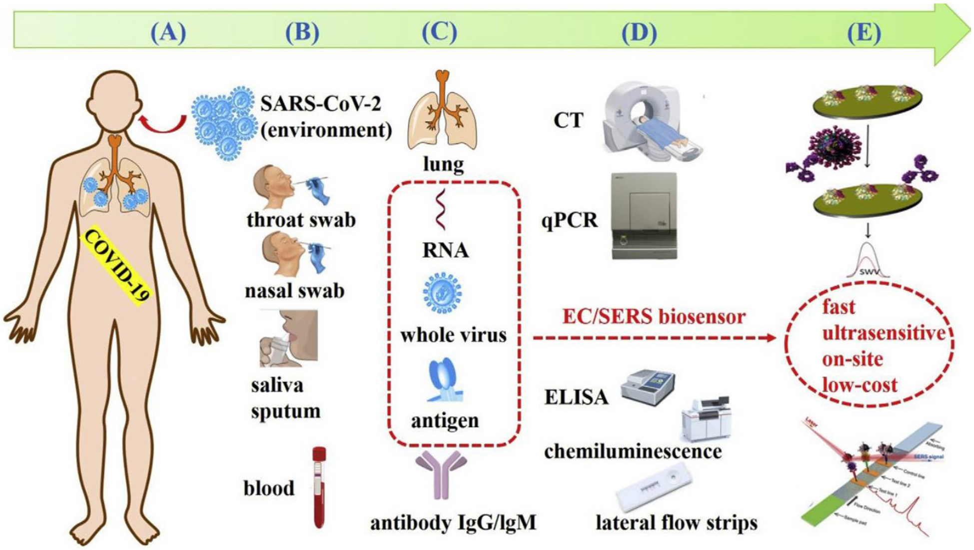


**Fig. 5.2** Pictorial layout showing (A) An individual having SARS-CoV-2. (B) Samples taken from suspected case. (C) Biomarkers or indicators for diagnosis. (D) Detection methods to analogous biomarkers. (E) Probable biosensors for virus detection. *(Reproduced with permission of Cui and Zhou, 2020a).*

transducer transmutes the recognition process into a signal (Ozer, Geiss and Henry, 2020). Biosensors are biological sensors. Biological sensor are those instruments that are formulated of transducer and biological element. These biological elements are associated alongside the material present for examination and transforms the outcome into charged signals with the help of transducer. Biosensors have three parts i.e. analyte recognizer and signal producer, transducer and e-reader. There is no need of any substance to get proliferating for producing signals or specimen undergo various laboratory treatments. Biological sensors are practiced to identify the quantity of biological constituent like biomolecules or biological structure. Through conformational mutations of sensor proteins, the interactions among the receptor and related ligand could be determined and furthermore, enzymatic based- detection technique is the most crucial recognition method, Overall, an optimal biosensor have crucial characteristics involving; longer shelf life, convenient to use, cost-effective, quick feedback time, remarkable sensitivity, numerous detecting methods, etc. Generally, biosensing platforms for identification are hinged on three key features, including:

- Identifying target
- Recognition methods (depending on aptamer, nucleic acids probes)
- Signals-transduction method intensification (Cheng and Toh, 2013)

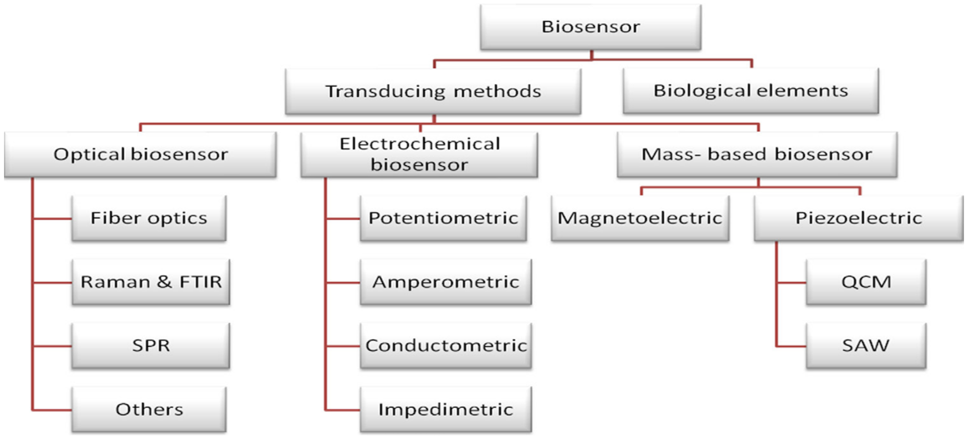


**Fig. 5.3** ***Classification of Biosensors (SPR- Surface Plasmon Resonance, FTIR- Fourier- transform infra-red spectroscopy SAW- Surface Acoustic Wave, QCM- Quartz Crystal Microbalance).***

An exhilarating option to customary detection assessment is viral- based methods as viral biological sensors can give economical, quick, precise, attenuated and mobile tenet. Fig. 5.3

Tests formulated on biosensors majorly confide on transforming the biomolecules interaction with respect to the quantifiable information by virtue of electrical, optical and mass-based biosensor techniques. The vast majority of the new sensors in both exploration and advertising center are focused around electrical and optical receptors. These incorporate handy compact gadget, screen-printed terminals, single-particle detector (Goode, Rushworth and Millner, 2015). For collection of samples, health workers must use personal protective equipments which comprise eye wears, gloves, good quality mask in which virus transmission is inhibited while taking sample. Those health workers who are handling the samples should also take precautions while handling because at the time of handling the chances of transmission is maximum. Steps of accumulating and obtaining specimen for identify COVID-19 contingent on scientific device having biological material technology are shown in Fig. 5.4.

## 5.3.1 Transducing method biosensors

### *5.3.1.1 Optical biosensors*

This is a typical transducing form of biosensor having a bio-recognition sensitive element combined with an optical transducer arrangement. The aim is to produce signal when there is any alteration in the quantity of a measured substance (analyte). Optical biosensors include two modes: label- free and label- based. In label- free mode, the signal detected gets developed by analyte and transducer interaction whereas in label-based mode, labels are used and the signals are then generated by colorimetric,

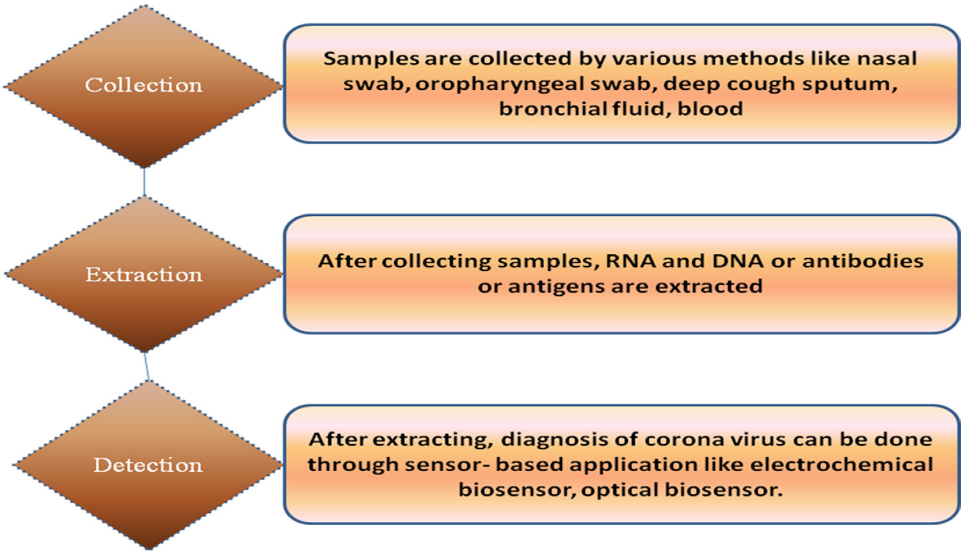


**Fig. 5.4** ***Steps of accumulating and obtaining samples.***

fluorescent/ luminescent method. Optical biosensors are valuable substitute for detecting virus because of the reason that it is inexpensive and eradicate the requirement for nucleic acid amplification. Only few optical biosensors are present having Lab-on-a-chip (LOC) technique that intensifies nucleic acid for fluorescent assay (Arranz and Ripoll, 2015; Zhuang et al., 2020). Fig. 5.5 demonstrates the processing of optical biosensor.

A research was conducted to build up an optical fiber sensor dependent on transient wave absorbance for explicit diagnosis of corona virus in perspective of point of care devices. This examination was dependent on two recommendations i.e. determination of proteins of virus surface and host resistant proportion but host vulnerable reaction was not exact pointer of COVID-19. With least initial-preparation, coronavirus can be detected using filament optic- absorbance biosensor in the saliva specimen directly. This methodology was depended on modification in sensitivity of radiance that was returning to interior of the filament optic analysis on a U-shape pattern by utilizing green illuminating discharging diode since Au NPs consume in the range of 520 to 545 nm. For better understanding of virus in biological sample, optical biosensor is an satisfactory option as it can illustrate information by combining data retrieved from diagnosis and imaging both (Yao, Yang and Duan, 2014). Molybdenum disulfide biosensor has been formulated which is susceptible in nature, have less cost and depends on fluorescent immunosensor for the utilization of virus identifier. This field has been advanced by variety of researches involving surface plasmon resonance (Kim et al.,

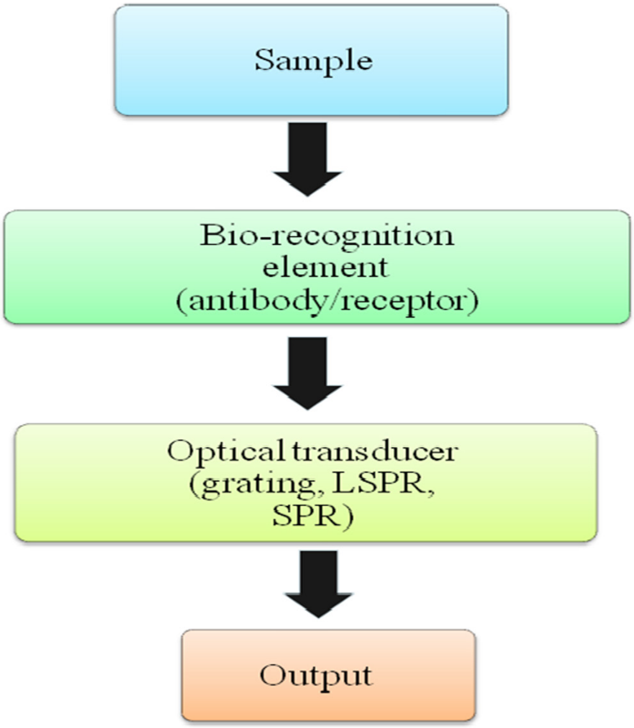


**Fig. 5.5** ***Optical biosensor working (LSPR- localized surface plasmon resonance SPR- surface plasmon resonance).***

2020), fluorescence, Surface Enhanced Raman Scattering (SERS)- based techniques (Carducci et al., 2020) and can be employed as viral detection.

#### *5.3.1.2 Electrochemical biosensors*

Electrochemical biosensor is a device that revamps chemical information of particular sample concentration to scientifically useful signal. Transducer surrounded by a recognition element is present in electrochemical biosensor and further recognition element reacts with the target analyte to produce signals. Electrochemical biosensor classified as amperometric (Eivazzadeh-Keihan et al., 2019; Nohwal, Chaudhary and Pundir, 2020) potentiometric (Ravina et al., 2020), impedimetric or conductometric. For antigen capturing, oxide of graphene or Au NPs or antibody gets adhere to active conductor surface and results in altered antibody-antigen electrode which finally produced with already formed oxide of graphene or Au NPs or antibody to establish sandwich-type arrangement. LOD is correlated with immense electrochemical current of silver and specific surface area of graphene oxide. Electrochemical biosensors imitate the typical stage encompassing microelectronics conductors engraved on display. Nonetheless, the confinement and distillation of specimen requires few hours (Khan et al., 2020). Electrochemical biosensors are formulated using gold NPs modified carbon- electrode for MERS- CoV detection and demonstrate a definite response of 0.001–100 ngml$^{-1}$ for MERS CoV-2 and 0.01–10,000 ngml$^{-1}$ for human CoV-2 with limit of detection of 1.0–0.4 pgml$^{-1}$ for MERS-CoV-2 and human CoVs respectively (Layqah and Eissa, 2019).

#### *5.3.1.3 Mass- based Biosensors*

Mass- based biosensors are better acknowledged as gravimetric biological sensors. The fundamental theory of these biosensors is based on mass variations. Majority of mass based biosensors practice piezoelectric crystals by means of surface acoustic wave instruments or quartz crystal microbalance. Mass- based biosensors can be classified in two types i.e. piezoelectric biosensors and magneto-electric biosensors.

##### 5.3.1.3.1 Piezoelectric biosensors

Piezoelectric (PZ) biosensors are one of the competent devices that utilize piezoelectric reaction to compute transformation in frequency of resonance by converting them to an electrical charge. This equipment incorporates less testing time, utility, particularity, stability and peccability. The typical type is Quartz-crystal microbalance (QCM) and hence QCM has proved as a versatile tool, but the only disadvantage of these types of sensors is that they cannot be used for truly static measurements (Zuo et al., 2004). Another study for identification of specific corona virus immunoglobulin in blood, a latest point of care technique has been accounted and co-ordinated with ELISA. Columns covered with corona virus S-protein peptide were utilized as a methodology having consequences of lesser duration assessment from ELISA test (Zuo et al., 2004).

##### 5.3.1.3.2 Magneto-electric biosensors

Magnetic immuno-assay in contrast with ELISA is an advanced type of bedside testing for diagnosis of particular immunoglobulin in plasma. In this assay, immunological purification columns were covered with S-protein of corona virus. These protein sensitive immunoglobulin, penetrated at non-identical cluster in plasma and washed off via immunological purification columns. Some particular immunoglobulin were continued to present in the purification column and marked along with isotype specified immunoglobulin. The subsequent immunoglobulins were administered to mark streptavidin- operationalized magnetic nanoparticles. These improved nanoparticles were then identified through recurrence magnetic combining diagnostic technique, with the help of compact magnetic electronic gadget that shows statistics in visible manner (Pietschmann et al., 2020). This table illustrates different diagnostics methods with their detection limit (Table 5.1).

It ought to be noted that besides these four devices, other devices like FET-based, plasmonic-based, molecular imprinted polymer- based, colorimetric- based biosensor

**Table 5.1** Biosensors and their detection limit.

| Analytes | Diagnostic method | Type of biosensors | Detection limit | Threshold range | References |
|---|---|---|---|---|---|
| Anti- N protein | Optical- LSPR | Transducing biosensor | 1.00 pg $mL^{-1}$ | 0.100 pg $mL^{-1}$ – 1.00 $ngmL^{-1}$ | (Huang et al., 2009) |
| cDNA/ nucleic acid | Optical- LSPR | Transducing biosensor | 0.220 pm | 0.100 pM − 1.00 µM | (Qiu et al., 2020b) |
| Oligonucleotide probe | Optical-LSPR | Transducing biosensor | 2.00 Nm | 1.00 Nm − 1 µM | (Shi et al., 2015) |
| NG-8 aptamer/ Helicase protein | Piezoelectric biosensor | Mass- based biosensor | 3.50 ng $mL^{-1}$ | 0.50 – 1.00 $\mu gmL^{-1}$ | (Lee et al., 2018) |
| Human proteins/ antibody for each virus | Electrochemical biosensor | Transducing biosensor | 0.400 pg $mL^{-1}$ | 0.010 – 1.00 × $10^4$ $ngmL^{-1}$ | (Layqah and Eissa, 2019) |

are in use that has totally different detection strategies like detecting surface antigen or whole virus, detecting antibodies, cytokines, and nucleic acid.

## 5.4 Other novel developed sensor- based technologies for COVID-19 detection

### 5.4.1 Field effect Transistor- based biosensor

Field- effect biosensor (FEB) or metal oxide- semiconductor field effect transistor biosensor MOSFET, is formulated by varying in the surface potential followed by the binding of molecules on graphene sheets. The sheets of graphene were varnished by specific antibodies against spike protein of SARS-CoV-2 within the formulation of the biosensor and as a result, it successfully detected virus traces in culture medium with a detection threshold of about $1.6 \times 10^1$pfu $ml^{-1}$ (Seo et al., 2020) and detection threshold of $2.42 \times 10^2$ copies/mL in analytical samples (Seo et al., 2020). FET provided the requisite of marginally positive- charged $S_1$ protein in the presence of SARS-CoV-2 spike $S_1$ subunit protein (CSab) receptors on the surface of graphene and subsequently, better subtlety in was observed (Sengupta and Hussain, 2021). To identify cytokines in human body fluids, wearable and reshape-able graphene-based FET biosensors were manufactured with aptamer-modified graphene functioning as the conducting channel. This kind of biosensor has advantages like uniform sensing response, prominent mechanical durability while reconciling with irregular surface like human epidermis (Wang et al., 2020). Hence, through this, it can be interpreted that wearable sensors are favorable devices for uninterrupted observation.

### 5.4.2 Molecular imprinted Polymer- based sensors

Molecular Imprinted Polymer (MIP)- based sensors are formulated by chemically combining functional monomer and cross-linker in the region of group of atoms that are bonded together. This is one of the unique, selective, and sensitive ways for COVID-19 detection. The preferred polymers chosen for establishing the sensing material belongs to acrylic class and for enhanced conductivity, these polymers can buttressed above graphene/metal oxides. Certainly, molecular imprinted nanoparticles with an exclusive competence for particular identification and attaching of the spike protein receptor- binding domain of SARS-CoV-2 perhaps contemplated as a satisfactory approach (Parisi et al., 2020).

### 5.4.3 Lateral flow immuno-chromatographic assay

Lateral Flow Immuno-chromatographic assay (LFIA) is an elementary device used to identify approximate and partially quantifiable occurrence of a target substance (like antibodies, antigens) in a liquid sample without any need of specially designed and expensive equipment. It is also termed as lateral flow test or rapid test. By translating the concentration line of hue test strip LFIA can identify the small concentration of virus if present with the help of an electronic reader. The most accepted electronic reader is phone camera which is acclimated to capture picture of the strip and analysis of analyte in the sample but by virtue of contrasting camera stipulations and regulations. There are few constraints that occur while applying phone-based camera and also, transferring of pictures through connecting devices like USB cable affects the picture quality (Zheng et al., 2016). The method in particular detects antibodies (like IgG) in human serum and according to a study, it was introduced by implementing lanthanide-doped polystyrene nanoparticles (Chen et al., 2020). On a nitrocellulose membrane, a recombinant nucleocapsid phosphoprotein of SARS-CoV-2 was distributed to capture the specific immunoglobulin. This method is proved to be a fast and sensitive technique for detection with positive response after clinical evaluation with sensitivity of 85.29 percent and specificity of 100 percent (Zeng et al., 2020). Subsequently, these biosensors can figure out interaction among antigen-antibody attachments for different target position in specific sampling. While calculating, IgG levels contrary to SARS-CoV-2 antigens, these biosensors demonstrate huge discernment and subtlety.

### 5.4.4 Colorimetric assay

Some devices are utilized for the identification of nucleic acids and for this purpose colorimetric assay is performed. The basic principle of this device is to scrutinize the concentration of the fluid sample by measuring its absorbance of a selected wavelength of light. Majorly, two varieties of the colorimetric assay are in use i.e. gold NPs-based and paper-based. The gold NPs solutions have maximal absorption length in disperse medium. When the agglomeration of gold NPs occur, proportion changes and color turns red to blue or purple with inflated retention peak. When the surface ligand attach to target analytes and these target analytes further binds to maximum amount of Au-NPs with the help of ligand, the agglomeration of Au NPs takes place with change in hue (Hung et al., 2010; Deng et al., 2013). In gold NPs-based colorimetric assay, it was clinched by manufactured Thiol-modified antisense oligo-nucleotides having adequate particularity for N-gene (nucleocapsid phosphoprotein) of SARS-CoV-2 and as a consequence, it showed potential selectivity and observed through normal- vision but the processing may vary with quantity of loaded virus (Moitra et al., 2020). For paper- based, paper is the most important raw material. It is one of the unique tools that exist in nature and have been used in diagnosis of several diseases for a long time. Modification in quick detection techniques like lateral flow assay was imported in paper-based technique and achieve acceptance in identification of viruses, bacteria etc. by reason of unification and agility. Presently, microfluidic tools are the prevailing paper-based devices that practice paper as a substrate for different techniques and analyse infection transference because paper is cheap, economical, bright, recycled and effortlessly available (Sher et al., 2017; Mao, Zhang and Yang, 2020). As an alternative to stereotypical technology for COVID-19 detection, pyrrolidinyl peptide nucleic acid having nanoparticles accumulation is used in paper-based assessment for diagnosing DNA. To incorporate complementary DNA filaments fortuitously, peptide probes are captivating alternative to nucleic acid probes due to its chemical stability (Teengam et al., 2017).

### 5.4.5 Double-operational plasmonic biosensor

Typical biosensor techniques like electrochemical or mass-sensitive have been concealed by persistent researches and improvement in this field. Plasmonic-based biosensors are undergoing formulation for several years and till now various instruments have been manufactured using this technique. Plasmonic biosensors have diverse advantages over orthodox methods like high reliability, reusability, detection without using labels, quick response time, monitor in actual- time, smooth treatment with minimal needs of electrical compounds. Simultaneously, it has some disadvantages too like it is unable to discriminate between different binding surfaces, mass-movement is less, binding also cause stearic hindrance and sometimes results get misinterpreted (Helmerhorst et al., 2012; Jensen and Thomsen, 2012; Ozer, Geiss and Henry, 2020). Double- operational plasmonic biosensor integrates the LSPR technique and plasmonic photo-thermal (PPT) biosensor that results in a formation of minor gold nanoisland chip, which acts as a better alternative for COVID-19 detection. This bi-functional LSPR and PPT-based sensor displays tremendous receptiveness in the vicinity of SARS-CoV-2 array having detection threshold of 0.22 pM by permitting accurate recognition of particular target in multigene association (Qiu et al., 2020).

### 5.4.6 Membrane- arranged mammalian cell- antibody type biosensor

One more biosensor is popularized that is set up on layer- arranged mammalian cells having $S_1$ antibody of human beings. As this technique depended on bioelectric perception access, it had been acknowledged that membrane- bound immunoglobulin and protein interactivity showed discriminatory and noticeable changes in bioelectric cells component. This variety of sensor was formulated as ready to be used forum, having convenient read- out technique that operated via smart phone. This technique can be demonstrated as an up-coming approach for COVID-19 detection because this technique has ability to identify and diagnose SARS-CoV-2 surface antigen without any additional specimen handling (Mavrikou et al., 2020). According to other researches, quick and unambiguous measurements of optical technique was reported in single stride with no need of preparing specimen that utilize S-protein definite nanoplasmonic resonance biosensor and it had been interpreted that this form of biosensor recognized some 30 particles of virus in 15 min with detecting limit of 370 $vpmL^{-1}$. Therefore, it was acknowledged that investigating both smart phone and generic microplate reader can be taken further by this technique and may be endorsed quickly in both everyday clinical surroundings and resource bounded setups (Huang et al., 2020).

Hence, through all these sensor- based technologies we can conclude that biosensors are playing essential role in the identification of SARS-CoV-2 along with frequently practiced RT-pcr, ELISA etc. Nanomaterial properties like huge surface area-to-volume percentage, the extent of reaction, adsorption, and quantum size effects, all are crucial in the designing of biosensing techniques (Maduraiveeran, Sasidharan and Ganesan, 2018; Nasrollahzadeh et al., 2020; Srivastava et al., 2021). Properties like size and shape are also taken into consideration for the enhancement of LOD and significant sensitivity or selectivity with speedy response regarding the sample analyte. Table 5.2 emphasizes on nanoparticles utilized for detection of covid-19.

## 5.5 Recent trend - Wearable Sensors

Wearable sensor-based technology are emerging detection methods for diagnosing novel coronavirus and is rapidly gaining popularity in the market. This technique is simple and easy to use. Simultaneously, wearable sensors are used for monitoring biochemical and charged signals in the body. Wearable devices such as smart watches help in monitoring physiological changes like pulse rate (PR), Heart period variability (HPV), resting pulse rate (RPR) and breathing frequency (BF), these are considered to be the probable labels of COVID-19 infection (Fig. 5.6). As consequences of alliance of numerous assessments, these assessments show collaboration of larger signal/noise intensity proportion than particular signal lone and thus have greater anticipating amount. However, measurements like body's internal organs temperature and blood oxygen level (BOL) have analytical value because of high pervasiveness of fever and respiratory manifestations in COVID-19 are not generally calculated by these wearables (Musher, Abers and Corrales-Medina, 2019).

Several aspects of the cardiovascular system like HPV, PR, heartbeat, etc. are considered for COVID-19 monitoring and changes in their readings could be a possible marker for COVID-19 infection. Hence their monitoring is dominant and for this objective, ECG and PPG (photoplethysmography) are commonly in use wearable technology. ECG monitor electrical activity of heart rate and PPG utilizes specific nanometer wavelength (light) for monitoring alterations in blood volume (Seshadri, Drummond, et al., 2017, 2017, 2019; Seshadri, Magliato, et al., 2019). ECG sensors are implemented in core of the skin whereas PPG can be positioned on surface of body locations like earlobes, wrist, etc. Therefore, PPG is more adaptable and can be enforced in many forms like ear buds, watch, etc. (Luo et al., 2020; Massaroni et al., 2020). Devices like WHOOP also measure cardiovascular strain depending upon duration spent in HR zone. Another important factor for monitoring is respiration rate, because shortfall of breath, lung tissue inflammation, coughing causes serious damage to the infected person. So, the person who has higher chances of COVID-19 exposure should use wearable gadgets to record subtle alterations in functioning of respiratory system before the

**Table 5.2** Nanoparticles for detection of COVID-19.

| Analytes | Diagnostic method | Type of biosensors | Detection limit | Threshold range | References |
|---|---|---|---|---|---|
| Anti- N protein | Optical- LSPR | Transducing biosensor | 1.00 pg $mL^{-1}$ | 0.100 pg $mL^{-1}$ – 1.00 $ngmL^{-1}$ | (Huang et al., 2009) |
| cDNA/ nucleic acid | Optical- LSPR | Transducing biosensor | 0.220 pm | 0.100 pM − 1.00 μM | (Qiu et al., 2020b) |
| Oligonucleotide probe | Optical-LSPR | Transducing biosensor | 2.00 Nm | 1.00 Nm − 1 μM | (Shi et al., 2015) |
| NG-8 aptamer/ Helicase protein | Piezoelectric biosensor | Mass- based biosensor | 3.50 ng $mL^{-1}$ | 0.50 – 1.00 $\mu gmL^{-1}$ | (Lee et al., 2018) |
| Human proteins/ antibody for each virus | Electrochemical biosensor | Transducing biosensor | 0.400 pg $mL^{-1}$ | 0.010 – $1.00\times 10^{4}$ $ngmL^{-1}$ | (Layqah and Eissa, 20199) |

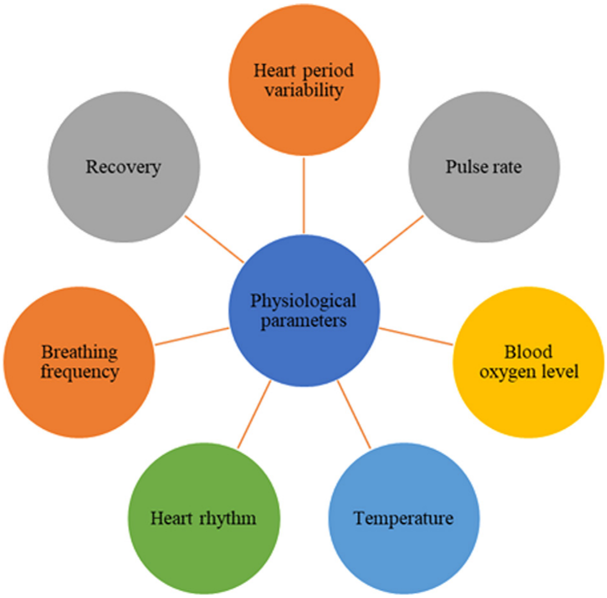


**Fig. 5.6** Physiological Parameters.

outbreak of viral manifestations. Wearable devices are boon for frontline staff because they have high submission to infected persons on daily basis. Additionally, guidelines for corona virus includes the assessment of repose respiration rate as a basic criterion for the internal care unit (Tomlinson et al., 2018; Tamura, 2019; Tayfur and Afacan, 2019). Therefore, the practice of wearable biosensors to have an idea on the changing values could provide an objective of remaining substantially active and fit in the course of the pandemic.

## 5.6 Future perspectives and challenges of biosensors for the detection of COVID-19

The most foremost challenge for formulating these biosensors is to recognize the low magnitude of signal that occurs between bio-receptor and analyte. Recognizing the low-magnitude is a major problem so metallic nanomaterials like (gold/silver) are used as labels to increase the recognition sensitivity (Ganio et al., 2009). For this objective, forthcoming researches must done on the basis of more biochemical characteristics of nanoscale substances in manufacturing of nanomaterial- based biosensing approaches for particular virus detection, chiefly SARS-CoV-2 (Fig. 5.7). Under current circumstances, it is important to develop portable, sensitive, and space friendly biosensors devices. For the formulation of modern biosensing devices, label- less techniques like SPR, SERS

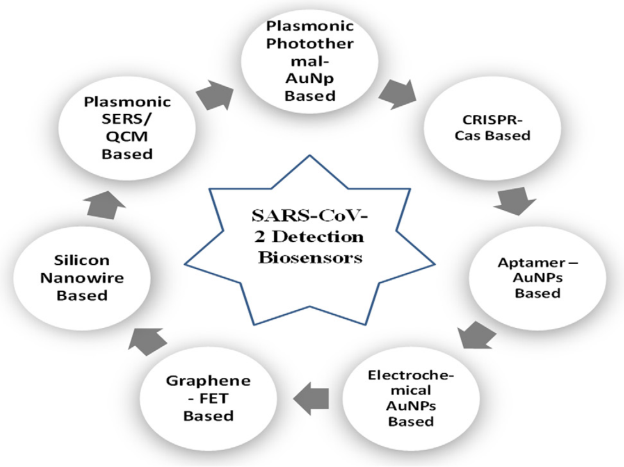


**Fig. 5.7** SARS-CoV-2 detection biosensors.

(Surface Enhanced Raman Scattering), QCM (Quartz-Crystal Microbalance) are proved to be more favorable. Gold nanoparticles, silicon nano wires and paper-based biosensors are primarily practiced as labels in electro-chemical biosensors by virtue of their accuracy and sensitivity. While using these labels, detection of limit can also be taken as an important factor because of low viral concentration in samples. Above all this, taking up wearable sensor technology should be a wise step.

## 5.7 Conclusion

It is clearly evident that brisk, advantageous, and extensive analysis are needed for the prevention of the spread of the novel coronavirus. Both traditional and modern procedures are beneficial but traditional procedures are costly, labor-demanding, time- consuming, and require high precision while testing. So, in order to counter such limitations, it is required to move towards sensor- based approach because they are extremely sensitive, discerning and affordable and distinctly worthy for the diagnosis. It is imperative to build up a sensitive and explicit insightful framework to diagnose the novel coronavirus transmission in the environment. For more improved outcomes and performances, diverse varieties of biological markers might be utilized in combination with different techniques and results obtained by using different techniques must be compared with each other for more accuracy and precision. However, optical biosensors with the entirety of its advantages have powerful aspect in the ecological examination. The only challenge of using optical strands for distinguishing the illness is change in temperature. Consequently, sensors assembled are generally working at particular temperature and put forward inaccurate readings if the specimen turn torrid or cool as this thermal alienation is further convenient for outside operations. COVID-19 breakout quenches some obstacles on the prolongation of certain activities universally as it influences numerous individuals and consistently deteriorates medical conditions. On that account, for finer reproducibility and reliability, furthermore research should be carried out within the areas of signal-based techniques. Moreover, for certain positive validation of the results, sample analysis from developed techniques must be combined along with analysis from oral swabs to come up with a conclusion i.e. whether to quarantine at health center or at home. In future, further studies and researches ought to be done by taking into considerations that designing must be innovative and extra work have to be done on methodologies and technologies to make them faster for handling pandemics and life-threatening infectious diseases. There is also an urgent need to produce novel point of care techniques that can give an on-site detection, without the need of trained personnel. Prominently, these biosensing gadgets are boon for asymptomatic SARS-CoV-2 patients, as these biosensors will immediately diagnose the virus but some logical impediments and possibilities for natural or synthetic sensors certainly stay until the needs of dependable, precise and early identification of contagious infection attain. In order to deal with the current situation, a well-coordinated, rapid, time-effective and precise response is the ultimate requirement of the time.

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# CHAPTER 6

# Modern digital techniques for monitoring and analysis

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## 6.1 Introduction

Covid-19 is caused by a novel coronavirus (SARS-CoV-2), it is transmitted via fomite or aerosol transmission. World Health Organization (WHO) declared the COVID-19 as a global pandemic due to its high transmissibility (WHO, 2020a). The COVID-19 virus is fatal to the people with underlying health conditions or co-morbidities; the fatality rate of the virus is higher than 1 percent with no effective therapeutic option(Saadat et al., 2020). Therefore, government bodies, along with different international organizations, are working towards containment and mitigation of the virus for controlling the transmission of the virus (Whitelaw et al., 2020). The detection of the virus is done by various physical testing methods such as Polymerase chain reaction (PCR), Real-time polymerase chain reaction (Rt-PCR), protein testing, nucleic acid testing, point of care testing and also via computed tomography in severe cases (Saadat et al., 2020; Verma et al., 2020). These testing methods are reactive, i.e., these methods are utilized when symptoms of the infection occur, the need of the hour is the utilization of proactive methods that can predict the behavior of the virus and alert the individual for probable transmission along with precautionary measures. This is when digital technology comes into play, it can be used for monitoring, surveillance, detection, and prevention from COVID-19. Digital technology can facilitate and coordinate strategies that are difficult to achieve manually (Council of Europe, 2020; Ting et al., 2020). It has also been observed that digital technology has been combined with different databases such as travel and tourism, database transport database for the isolation, tracing, monitoring, and reporting of the suspected cased of the COVID-19. This chapter will discuss the digital technology utilized for monitoring, surveillance, detection, prevention, and mitigation of the impact COVID-19 by classifying the digital response tools into two categories the tools which utilize artificial intelligence (Chowdhury et al., 2020) and based on digital tools.

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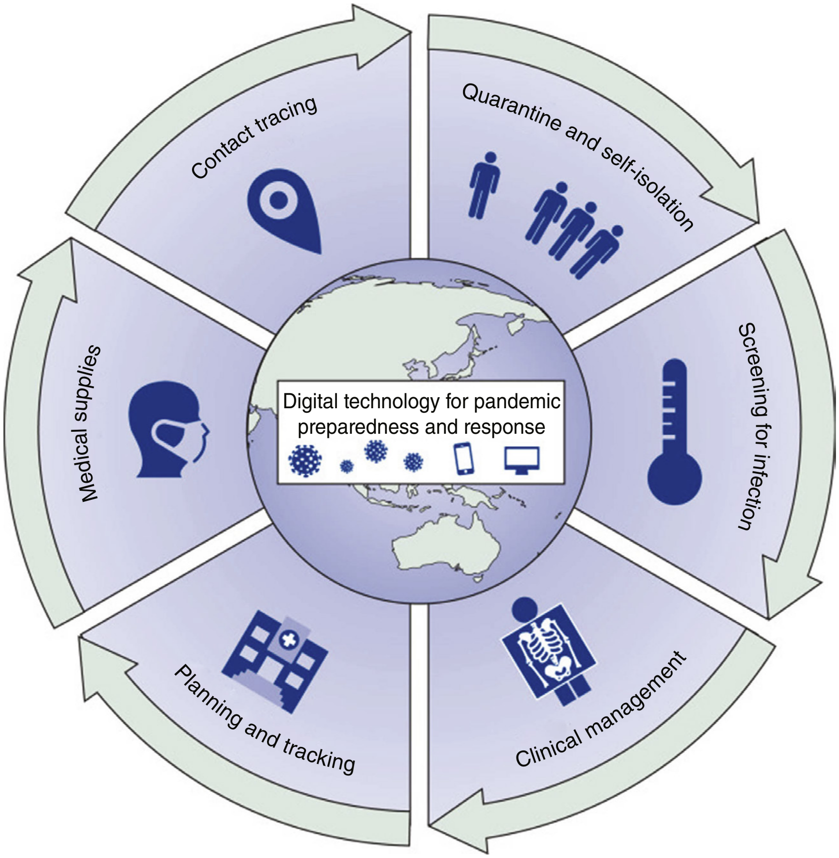


**Fig. 6.1** ***Different applications of digital techniques for monitoring and analysis of covid-19 (Source: Whitelaw et al., 2020).***

## 6.2 Classification of the digital techniques for COVID-19

Modern digital tools and techniques can be classified based on their utilization and the basis of artificial intelligence. The penultimate purpose of these tools is prediction, prevention, monitoring, and mitigation of the risks associated with the pandemic COVID-19. The digital tools based on utilization can be classified as outbreak responsive tools, proximity tracing tools, and symptom tracking tools (Fig. 6.1). The tolls utilizing artificial intelligence can be classified as planning and tracking tools, surveillance tools, diagnostic tools, health prediction tools, disease tracking tools, and tools used for clinical management along with computational biology tools (Whitelaw et al., 2020).

### 6.2.1 Digital tools based on its utilization

For case identification and contact tracing, various digital tools have been developed, these devices are stand-alone devices, or they can be combined with other instruments for proximity tracing, outbreak response, and symptom tracking (WHO, 2020a).

#### 6.2.1.1 Outbreak response tools

These tools are designed by government bodies for health care personnel involved in outbreak response and contact tracing activity, which are responsible for the supervision of complex rational data of cases and their contacts (CDC, 2020). The data is obtained by electronic data entry of the case and contact by the health care personnel or first responders. The utilization of outbreak response tools is done for contact tracing, monitoring of contacts, case investigation and automatic analysis, and performance monitoring (CDC, 2020; WHO, 2020a). The practical outbreak response tools must manage the dynamic relationship between the contacts and cases. This phenomenon is observed because the contacts may be related to multiple cases, which in turn would generate further contacts leading to the creation of a transmission chain (CDC, 2020; WHO, 2020a). The outbreak response tool must be flexible and tuneable so that the workflow of field workers conducting contact tracing can be maintained along with effective monitoring and implementation of the contact tracing by the supervisor. World health organization has partnered with the Global outbreak alert and response network for the creation of Go Data Software application (CDC, 2020); it is specially designed for field workers for contact tracing and has been utilized in multiple countries (WHO, 2020a).

#### 6.2.1.2 Proximity tracing tools

As the name indicates, this type of tool predicts the risk of exposure of COVID-19 by tracing the proximity of the individual by location-based GPS and Bluetooth technology (CDC, 2020). These tools identify the person who may have been exposed to the infected individual by assessing the probability of coming into the close (less than 1 meter) or frequent contact with the infected individual (CDC, 2020; WHO, 2020a). However, proximity may not be the only factor responsible for transmission, or risk of exposure, since exposure may differ based on the type of areas such as open-air space or enclosed space. Due to these reasons, the proximity tracing tools are less useful as their effectivity requires the implementation of these tools at a large scale. Further studies are to be conducted, and sufficient evidence needs to be collected for increasing the effectiveness of the proximity tracing tools for contact tracing. These tools can be divided into centralized and decentralized tolls (WHO, 2020a). In centralized tools, the contact history of the devices is processed by the health authority or by the government, whereas in decentralized tools, data is collected and processed by individual devices. There are privacy concerns such as disclosure of personal data because of the use of these types of tools. The success of these tools depends upon wide-scale applicability and adoption of the same tool, which in turn is dependent upon the availability of stable mobile network and smartphone, which is charged, fully functional, and is always accessible (CDC, 2020). The reliability of these tracing tools is affected as many individuals, along with children, do not have access to digital devices. Proximity tracing is often confused with contact tracing; the proximity tracing is reliable only when applied on a large scale, whereas contact tracing is an established public health practice, the proximity tracing tools can aid in contact tracing (WHO, 2020a).

#### 6.2.1.3 Symptom tracking tools

These tools are designed for the systematic collection of self-reported signs and symptoms to access the probability and severity of the infection due to COVID-19 (CDC, 2020). These tools can be integrated with the contact tracing process so that proper precautions can be taken by contact tracing teams when they are visiting the area with a security barrier or in-person visits. These tools can enhance the reports by sending symptoms to the health department and in-person visiting contact tracing team (WHO, 2020a). These tools have particular challenges such as limited specificity and positive predictive value for respiratory infection; they also have the potential for misdiagnosis or non-diagnosis of other ailments that need medical assistance. For enhancing the effectiveness of these tools, these must be integrated into contact tracing; robust and effective follow-up action must be taken if there is no self-report for a predetermined number of days. Due to these reasons, self-reporting tools cannot replace traditional contact tracing (WHO, 2020a).

#### 6.2.1.4 Digital tools for screening of infection

Different countries have utilized multiple tools for the screening of the infection of COVID-19. For directing and screening individuals towards different resources, china utilizes free web and cloud-based tools (Liu, 2020). For the detection of individuals with fever, a high-performance infrared camera was set up in Taiwanese airports; these cameras were responsible for capturing a real-time thermal image of the passengers and segregate the passengers with fever (C. J. Wang et al., 2020). For the identification of the hotspots and clusters of infection, the Singapore government measured the temperature of the individuals at multiple entry points such as the workplace, schools, and public transport. This data from the thermometer was monitored for the identification of hotspots so that testing can be initiated (National, n.d.). Apart from different countries, Iceland has initiated large-scale testing of asymptomatic individuals. The data is collected using mobile technology and is combined with a dataset of clinical and genomic sequencing data for the identification of the transmission and pathology of the virus (Cisco, 2013) and helps in understanding the transmission and prevalence of the virus in asymptomatic patients. For identification of the emerging outbreak of COVID-19, a private company in the USA has collected real time data on a cluster of febrile illness (Miller et al., 2018) and it is combined with national study in capturing the increasing heart rate of individuals with smartwatch applications (Topol, 2020). These technologies are enterprise driven or investigational and have not been implemented into policies and practice. For the uptake of systematic screening technologies, specialized training of the health personnel is required along with huge funds (Rauhala, 2020). The effectiveness of the digital system is limited because of the high prevalence of asymptomatic patients as compared to other infectious diseases (Rauhala, 2020; WHO, 2020b). Some researchers from the European Centre for Disease Prevention and Control believe that majority of the Chinese passengers from major cities could not have been detected because of these factors (Assessment, 2020).

#### *6.2.1.5 Quarantine and self-isolation*

Quarantine and self-isolation with the help of digital technology can be implemented for the individuals that have been exposed to infection with viruses. In a system introduced as China's quick response (QR) code system, the health and movement of the individual can be controlled and monitored. In this system, the individuals are instructed to fill symptom surveys along with body temperature after this QR code is generated, which acts as a health status certificate and travel pass. The QR code is color-coded, and individuals are categorized as a low, medium, and high-risk individuals, the individual with green code, was permitted to travel unrestricted, while individuals with red color code were kept in quarantine or self-isolation for 14 days (Liu, 2020). Various devices, such as drone-borne cameras, surveillance cameras, and portable digital recorders, were employed to restrict public gatherings (Liu, 2020). In Australia, mainland international travelers were quarantined in hotels on arrival, and if the legislation found individual breaching quarantine, then they were forced to wear tracking devices with a substantial penalty (Journal, 2020). In Taiwan, government-issued mobile phones with GPS for electronic monitoring of home quarantined individuals, if there was a breach of quarantine, then authorities were alerted, and a hefty fine was levied on the individual (J. Wang et al., 2020). In South Korea, people were advised to download an application at the time of quarantine, and authorities were alerted if there was a breach of quarantine (Fisher and Choe, 2020). Cloud technology was linked to wrist bands in Hong Kong, and individuals were required to wear these bands at the time of self-isolation, hefty fines were implemented if there was a breach of self-isolation (Liu, 2020). The individuals can easily bypass mobile phone solutions if the individual leaves the place of isolation or quarantine without their cellular device. Technological innovations are useful when they are combined with other strategies and technologies (WHO, 2020b).

#### *6.2.1.6 Tools used for contact tracing*

Aggressive contact tracing has been applied in South Korea using bank details, GPS, security camera footages, facial recognition technology, and data records from vehicles and mobile phones for establishing real-time data and detailed timeline along with travel history. People of South Korea received COVID-19 alerts on their mobile devices, and the individuals that were in contact with the infected individuals were instructed for testing and self-isolation (James et al., 2013; Fisher and Choe, 2020). Due to these regressive measures, South Korea maintained the lowest per capita mortality rate as compared to other countries (Fisher and Choe, 2020; Johns Hopkins and Johns Hopkins University, 2020). A mobile application using Bluetooth technology has been launched in Singapore, which uses short-distance signals and saves the data up to 21 days, and if the individual is tested positive for COVID-19, then the contacts of the infected individuals are alerted by the health care officials of the government. Singapore also has a low mortality rate (National, n.d.). Smartwatch application has been developed in Germany for monitoring heart rate, temperature, and sleep pattern of the individual, which is used to predict the signs of viral infection. The data collected from this application is presented in the form of an online interactive map for the entire nation (Douglas Busvine, 2020). The contact tracing application has certain drawbacks such as not all exposure requires quarantine; if the individual is wearing Personal Protective equipment or uses a thin screen, then quarantine is not necessary. In a study, it is suggested that for these applications to work, 60 percent of the total population of the country must utilize these applications (Ashkan Soltani et al., 2020; University of Oxford, 2020).

## 6.2.2 Based on artificial intelligence

### *6.2.2.1 Planning and tracing*

Artificial intelligence (AI) combined with big data analytics is used for tracking, tracing, and prevent the spread of infection in different countries. China's Wuhan was the epicenter of the pandemic, and the authorities used mobile phone, payment application, and social media to track the movement of people at the time of infection, this information was combined in the form of migration map which was used to trace people (Wu et al., 2020; Zixin et al., 2020). The data machine learning models were used for the prediction of the outbreak, transmission dynamics of infection, and border checks along with surveillance (Liu, 2020; Wu et al., 2020). In Sweden, a platform was developed for health care workers to monitor realtime cases, Personal protective equipment, ventilator, staffing and volume of cases across the country for effective planning and management of patients (Drees, 2020). Due to this data, dashboards are created for the visual display of disease burden on the global and national map (Drees, 2020). The Ministry of the health of Singapore has developed UpCode, which displays the demographics of the disease across age, sex, and location to the plot recovery time of the infected individual (National, n.d.). Web-based platform for up to date visuals for tracing the number of cases and death around the world due to COVID-19 was developed by John Hopkins University (MD, USA) (Johns Hopkins and Johns Hopkins University, 2020). AI algorithm was used to integrate the effect of climate on transmission along the projections (McCall, 2020). The AI models have been implemented, but they have specific limitations such as the data collected cannot be generalized as the AI uses Chinese samples and different data sets such as social media, online traffic has created noise in big data sets, therefore, producing potentially overfitted models (James et al., 2013; W Naudé, 2020; Wim Naudé, 2020). The noise produced must be filtered with accurate prediction and trends along with that the accuracy, reliability, and validity of each AI forecast must be assessed while projections are interpreted (Steyerberg and Harrell, 2016; W Naudé, 2020).

#### 6.2.2.2 Surveillance

Public health surveillance can be defined as the continuous and systematic collection, analysis, and interpretation of the health-related need for the planning, implementation, and evaluation of the public health practice (Wenger et al., 2009). The combination of information technology with public health and its policies has created a new field known as infodemilogy (Eysenbach, 2011). Free access to the machine-readable literature has been given by the Allen Institute of Artificial Intelligence, which includes information about the group of coronaviruses. More than 44,000 articles and 29,000 publications have been incorporated in their database, along with the unstructured data from websites or social media regarding containment of future outbreaks of COVID-19 and other infectious diseases (L. L. Wang et al., 2020). Health map and Surveillance and Outbreak Response Management and Analysis System (SORMAS) are online surveillance tools which can be used as early detection system as compared to the traditional tools (Helmholtz Centre for Infection Research (HZI), n.d.). A modern outbreak response tool, BlueDot outbreak software, was the first organization to report the outbreak of COVID-19 (Bogoch et al., 2020).

#### 6.2.2.3 Diagnosis using radiology image

AI is used for the compilation of the data generated from the quick and precise diagnosis of the COVID-19, it was found that the application of AI gives time to radiologists, and due to this diagnosis of the COVID-19 can be done rapidly and less expensively as compared to traditional tests. Computed Tomography, as well as X-rays, have been used for this purpose (Narin et al., 2020). COVID-Net is an AI application that was used for the diagnosis of the COVID-19 symptoms; via deep learning technology, the results are combined and cross-reference with different lung conditions of COVID-19 from patients (Wang and Wong, 2020). In a study, it was observed that the diagnosis of COVID-19 symptoms was made using CT image and inception migration neural network with 89.5 percent accuracy (S. Wang et al., 2020). A three-dimensional learning mode was created to recognize COVID-19 pneumonia from Influenza A viral pneumonia using a deep learning system; it was observed that the model was 86.7 percent accurate (Butt et al., 2020; S. Wang et al., 2020). A three-dimensional framework for the identification of the chest CT was constructed using a neural network, that can precisely differentiate between the symptoms of community-acquired pneumonia and other lung diseases (Jin et al., 2020). In a different study, it was observed that the disadvantages of the deep neural network such as black box could be subdued by quantitative clarification and diagnosis of the AI network (Huang et al., 2020). In a different approach, an automated tool has been developed that can collect and quantify symptoms of the virus and the patient; this was done using deep learning methods through which growth of the infection and its reaction to cure can be studied. The method is its developmental stage and is not practiced yet, for the confirmation of the COVID-19 Reverse Transcription Polymerase Chain Reaction (RT-PCR) method is used, their disadvantages include time duration and execution (Emery et al., 2004).

#### *6.2.2.4 Disease tracking*

The use of artificial intelligence can track COVID-19 spread according to time and place. It was discovered that the respiratory patterns of the patients suffering from COVID-19 were different from that of seasonal flu, influenza, and regular cold. Fast breathing or tachypnoea was eminently observed in COVID-19 patients (Cascella et al., 2020). For the preliminary screening of the patients, tachypnoea can be forecasted, which would act as first-order diagnostics (Cascella et al., 2020). In different countries, mobile phone or cellular devices have been used for monitoring the infected COVID-19 patients, some of these devices have implanted sensors in them which could be used for monitoring of the COVID-19 patients. These mobile phones have also been used for the collection of a survey for probably infected patients (Srinivasa Rao and Vazquez, 2020). Epidemiological SIR model has been used for the containment measures in berlin; the government utilized this model for the implementation of quarantine, lockdowns, and social distancing solutions (Hamzah et al., 2020). Similarly expanded SIR model (Gan et al., 2018), considering the data collected from china has been implemented for creating GLEAMviz ("GLEAMviz.org," n.d.) epidemiological model and Metabiota ("Metabiota: Epidemic Tracking and Data Science," n.d.) epidemic tracker for tracking the spread of infection and for forecasting the spread of infection. The tracking of the infection helps the authorities to design working plans and models that can be used to deal with pandemic (Wim Naudé, 2020).

#### *6.2.2.5 Prediction of patients health condition*

A novel methodology was proposed for prioritizing high-risk patients and separating them from general or low-risk patients by combining the reports from patients' clinical data and blood test reports; this method is used to reduce the mortality rate of the patients (Yan et al., 2020). Apart from this, a separate model was developed for assessing the patient's mortality; this model uses XGBoost calculation. Three clinical pointers were determined for assessing patient mortality, namely lactic dehydrogenase, lymphocyte, and high affectability of C-receptive proteins. The advantage of this method is that this method is interpretable and also corresponds to significant factors in pathophysiological progress, such as inflammation, cell immunity, and cell injury (Chen and Guestrin, 2016). In different reports, an AI was trained to forecast the duration of the stay of the patients in the hospital, the AI was trained on CT imaging data and was known as UNet (Qi et al., 2020). The methods mentioned above can be used to recognize the patients according to their care plans and deal with the patients more efficiently and adequately. These models can be enhanced by increasing the output of the data combined with research and clinical investigation.

#### 6.2.2.6 Computational biology

Computational biology can be defined as the branch which utilizes mathematical modeling, data analytical, and computational simulation for biological studies. The scientists or researchers associated with this field are responsible for creating disease models and apply these models for finding appropriate medication. Disease dynamic models help in the apprehension of the effect of parameters responsible for the spread of infection and the prediction of the impact of medication on controlling the spread of infection (Ferguson et al., 2020). It is observed that when the virus infiltrates the deceased cadaver, then both the lungs start to exhibit ground glass and infiltrates. For the identification of the point of illness and treatment of infected patients with existing drugs, data-driven drug repositioning approaches have been studied and applied in practice (Richardson et al., 2020).

#### 6.2.2.7 Prediction of the protein structure

It is observed that when the virus infiltrates the body, it gets combined with the protein production unit, for the duplication of the RNA molecules. RNA replicating molecules known as polymerases are the target molecules for treatment (Joynt and Wu, 2020). The role and purpose of the protein can be evaluated by genetically encoded amino acid sequence and their 3-dimensional structure (DeepMind, 2018). The prediction of protein structure can be made in two ways: template-free modeling, this model is used for prediction of the protein structure that has unknown related structure and another prediction model is template modeling in which the structure of the protein is predicted using similar proteins as the template (Yu and Koltun, 2015). A model was developed using amino acid sequences and in which parallel amino acid sequences were taken out using multiple sequence arrangement for prediction of the distance and dispersal of angles between amino acid residues, this model is known as Alpha model and is mainly dependent upon ResNet architecture (He et al., 2016). This model was used to identify the protein structure of SARS-CoV-2, and six proteins were identified, namely, membrane protein 3a, Nsp2, Nsp4, Nsp6, and papain-like proteinase (DeepMind, 2018). These predictions can help in discovering various physical properties and can also lead to the discovery and improvement of the cure for COVID-19.

#### 6.2.2.8 Drug discovery

It was observed that Coronaviruses is effective when it binds with the ACE2 receptor; therefore, a group of scientists at Massachusetts Institute of technology is synthesizing decoy receptors or proteins which would obstruct the virus and can be taken as medication. AI model is trained on data about the ACE2 receptor to predict the connection between the baits and viruses (Busse et al., 2020). Another group of researchers is using an exclusive pipeline for SARS-COV-2 to discover novel compounds that can act as an inhibitor for 3C protease (Zhavoronkov et al., 2020). Three data sets are required for these kinds of the model, crystal structure of the protein, co-crystallized ligands, and the homology model of proteins, and for each data set separate generative autoencoders, and generative adversarial networks are utilized (Makhzani et al., 2015).

## 6.3 Digital technology for social awareness

Communication with the general populace for the broadcasting of information is established through the use of social media platforms. However, overutilization of social media platforms has led to a crisis of misinformation, and people are becoming overwhelmed with the information through national and worldwide associations. For overcoming this problem, WHO has set up Information Network for Epidemics (EPIWIN) for communicating important and legit data to key partners (Zarocostas, 2020). Facebook promotions identify the content regarding infection and analyze the given information. The Facebook ad library scans all the commercials with catchphrase COVID-19 and Coronavirus; these outcomes are analyzed and combined so that the spreading of the misinformation can be prevented, and the data is collected from 34 countries with 923 outcomes in which majority of the contributors were from USA and EU. Different types of sensors located on the smartphones are utilized for the collection of the information, and this data is cross-referenced with the existing database (Maddah and Beigzadeh, 2020). In a different approach, the microphone of the smartphone is utilized for the collection of sound information for the analysis of cough through voice samples (Nemati et al., 2019). This collected information is used for AI calculations for the prediction and early detection of the high-risk cases, which require quarantine and immediate care, resulting in the reduction of infection in vulnerable populations (Allam and Jones, 2020). Drones are utilized for many purposes, such as identification of the people not following COVID-19 guidelines and not wearing masks along with that these drones are used to broadcast information to large crowded areas and also to sanitize the open spaces. A small multi-copter drone was developed by Shenzen based company for city-wide transportation of medical and clinical supplies and quarantine material, thus decreasing the traffic, which results in a reduction of infection transmission (Marr, 2020). To restrict the transmission of viruses in India administration has launched the Aarogya Setu application, which utilizes Bluetooth and GPS framework as a proximity sensor for the detection of suspected cases. The application color codes the individual according to the location history of the person. This application also notifies all the government guidelines to the users and is used as self-assessment tool for COVID-19 (The Economic Times, 2020).

## 6.4 Risks and challenges associated with the use of digital technology

The use of digital health technology could amplify the socioeconomic inequalities and imbalance in the health care system as the use of digital technology requires active internet connection and smartphones. In a survey, it was discovered that internet usage is higher in high-income areas as compared to the medium and low-income areas. It was seen that 4 billion people used the internet worldwide in 2019, but the ratio of usage was skewed 82 percent in Europe vs. 28 percent in Africa (GSMA, 2019). It the high-income countries, every individual might not have access to the internet, broadband, smartwatches, the low-income neighbourhood, or remote regions of the area might be a susceptible group. For the implementation of digital technology globally, multiple attempts have to be made such as broadband access, which requires governmental and private sector investment in technology and infrastructure, these investments must be tailored according to the target region (Riband, n.d.; Wallis et al., 2017). For the people at the regional level, different attempts such as subsidized internet plans, free public wifi hotspots, loaned devices, and training could provide short term solutions for these discrepancies (Torous et al., 2020; Velasquez and Mehrotra, 2020). In the regions where infrastructure and funds are not available automated applications and devices may be implemented, which does not require constant internet connectivity can be installed (Wallis et al., 2017). The digital devices that are used to enforce quarantine can infringe upon the privacy of the individual and these devices may also be the cause of mental illness and instill fear and threaten civil liberties. The contact tracing devices or databases are efficient only when there is an extensive database, and a large section of the population is using these devices. There will be no data available if the individual does not carry the device. European authorities have proposed that the collected data should be retained for 14days, during the duration of the possible viral outage, and these nonessential data measures would be lifted, and data would be erased after the pandemic ends (DeCell, 2020). The challenges associated with the use of AI is that the models formulated with the AI are as efficient as the input data. If the input of the data is biased or the sample size is less then these models cannot be implemented. The models that are formed must be flexible and have scope of data entry so that they may be developed as and when required.

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# CHAPTER 7

# Challenges and future aspects of COVID-19 monitoring and detection

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## 7.1 Introduction

The coronavirus pandemic has plummeted the development of the human population and has come up with newer challenges regarding hygiene and healthcare that require immediate attention. Some infected patients experienced common symptoms (dry cough, fever), and some developed non-common symptoms (nasal congestion, sore throat, running nose, aches, and pain (Albahri et al., 2020) (Saadat, Rawtani and Hussain, 2020). Hence, to curb the further spreading and control of infectious sources, it is important to develop accurate, cheap, and rapid diagnostic methods (Das Mukhopadhyay et al., 2021). Two detecting methods are commercialized so far namely, molecular test and antibody test. Molecular tests can detect the virus by its genetic materials but require complex clinical practices to avoid false-negative results. Serological tests are blood-based tests that can detect the presence of antibodies (Afzal, 2020). (Fig. 7.1) demonstrates the diagnostic methods for COVID-19.

The real-time polymerase chain reaction is considered a widely recommended method for the COVID-19 disease, but its primary drawbacks are longer analysis time and higher operating costs. Therefore, advances in diagnosis methods are crucial in overcoming the limitations of conventional methods. Hence, in a molecular test, other approaches are under study for rapid and cost-effective detection like LAMP, CRISPR, Microarray, and LSPR. Emerging methods in a serological test like SPR and GEFT are providing enhanced performance and efficiency, sensitivity, and real-time monitoring. Rapid improvements in bio-sensing techniques have improved the sensitivity towards detection of the pathogen, resulting in the reduction of operating costs and boosting up analysis speed. Hence, these emerging techniques have successfully countered the challenges faced by the employment of conventional diagnostic methods. In addition to above mentioned diagnostic methods, biosensor-based techniques have emerged in the wake of COVID-19, such as paper-based biosensors, electrochemical-based biosensors, immunosensor, these techniques have been discussed in detail in the later sections

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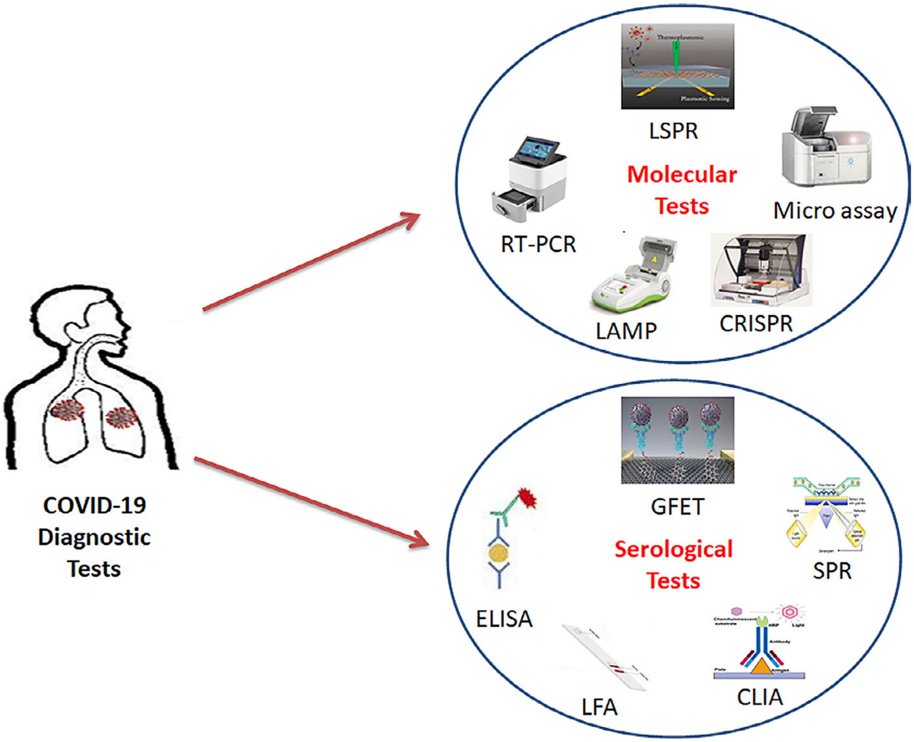


**Fig. 7.1** ***Diagnostic methods for COVID-19.***

of the chapter. Another emerging technology includes the use of artificial intelligence. Numerous AI classifications have been reported by researchers. Despite the many advantages of AI techniques for COVID-19, it is challenging to choose a proper method that can deliver exact outcomes (Albahri et al., 2020). Thus, here in this chapter, rapid advances of alternative modern technologies are envised that will be successfully helpful to combat COVID-19 and future pandemic outbreaks (Chen et al., 2021).

## 7.2 Classification on basis of molecular and serological tests

There are many technologies available for COVID-19 detection. Among them, two main detection techniques are Molecular test that reveals the current infection by detecting antigens or Antibody test that reveals if a patient is already exposed to infection by detecting antibodies. Both detection methods are significant and supplement one another. The detection of the viral RNA can help diagnose the early stage of infection whereas the antibody tests can only detect evolved antibodies after being fully recovered from COVID-19 infection (Sheikhzadeh et al., 2020).

### 7.2.1 Molecular diagnostics

Molecular diagnostics are informative and useful tests indicating active infections and are designed to detect the pathogen by its genetic material. Polymerase chain reaction (PCR) based methods provides rapid monitoring and greater sensitivity (Ali et al., 2020). Nucleic acid amplification tests (NATTs) include RT-PCR. NATTs identify pathogens by targeting specific nucleic acid sequencing (Taleghani and Taghipour, 2021a). Other molecular-based techniques are LAMP, CRISPR, LSPR, and microarray methods.

The real-time reverse transcriptase Polymerase Chain Reaction is known as the "gold standard" for the diagnosis and detection of viral RNA. In this technique, viral RNA is extracted from the body fluids of the infected person, and conversion of cDNA from the real amplification process is done (Das Mukhopadhyay et al., 2021).

#### *7.2.1.1 Reverse transcription-polymerase chain reaction*

RT-PCR has been the most recommended method for SARS CoV-2. In RT-PCR, firstly viral RNA is extracted from specimens and then amplified, identifying the sequence existing in a sample. This test can detect viruses from swab samples (nose/throat), bronchoalveolar lavage fluid, or lower respiratory tract aspirates (Bossuyt, 2020). Though it shows the rapid screening of virus detection, there are some limitations of this test such as the generation of false negatives (due to factors like improper sampling collection and storage, cross-contamination, or technical errors), instability at different temperature ranges (Pérez-López and Mir, 2021; Suleman et al., 2021a). Besides, it is an expensive method and requires complex laboratory facilities (Farasani, 2021).

#### *7.2.1.2 LAMP: loop mediated amplification isotherm*

One of the emerging methods for detection of COVID-19 is RT-LAMP in replacement to RT-PCR kits, which is cheaper, unlike RT-PCR. The only difference between LAMP and RT-LAMP is, amplification of DNA is done by a single-tube technique in LAMP, whereas, RT-LAMP is combined to LAMP with an additional reverse transcription step to detect RNA (Zalzala, 2020). In this test, the temperature is constant throughout the reaction, i.e. between 60–65° and ~$10^9$ DNA copies per hour are generated (Kilic, Weissleder and Lee, 2020). Other advantages of this test include lesser time, direct analysis without RNA isolation from swabs, rapid analysis, and conditions such as pH, temperature are sustainable (Pérez-López and Mir, 2021). Equipment like thermal cycler is not required, resulting in ease for using such a method (Thompson and Lei, 2020). But the major challenge of this technique is to design primer sets, as it utilizes four to six primers (Kilic, Weissleder and Lee, 2020).

#### *7.2.1.3 CRISPR systems*

Clustered regularly interspaced short palindromic repeats systems are used in the identification and annihilation of DNA of bacteriophages (Zalzala, 2020). Variants

CRISPR-12 show robustness against single-stranded DNA and CRISPR-13 show towards RNA targets. Also these two variants are combined with LAMP and are used in detecting different viral infections. (Das Mukhopadhyay et al., 2021) reviewed about ability of CRISPR-12 to identify five to eleven copies per microlitre of viral RNA in 90 min. (Zalzala) mentioned about DETECTOR test in which SARS-CoV-2 from viral RNA can be detected by CRISPR-Cas12 assay. Hence, tests like DNA Endonuclease Targeted CRISPR Trans Reporter (DETECTR) and Specific High sensitivity Enzymatic Reporter Unlocking (SHERLOCK) have also gained importance, because of rapidness and ultra-sensitive visual detection method (Das Mukhopadhyay et al., 2021). Though, there are many advantages like amplification in shorter time, easy to use and no additional thermo cycling steps, it is still a developing technology which needs to be implemented in clinical setup (Ali et al., 2020).

#### *7.2.1.4 Microarray based methods*

Microarray based method is highly efficient technique in detection of SARS-CoV-2, in which mRNA molecule is hybridized to its parent DNA template (Bukkitgar, Shetti and Aminabhavi, 2020). In this method, it is mandatory to create cDNA from the RNA by reverse transcription method. Well stacking of cDNA is done following hybridization by successive steps of washing. The discovery of CoV RNA is trailed by utilizing indicated tests. (Jalandra et al., 2020) mentioned about 60-mer oligonucleotide microarray method for identifying COVID-19 that can provide complete information regarding genetic material of the virus. Advantages of this method over conventional techniques are precision, robustness and explicitness (Das Mukhopadhyay et al., 2021). Some unavoidable limitations of this method include high cost and high sensitivity to temperature variations.

#### *7.2.1.5 LSPR: localized surface plasmon resonance*

Biosensors are other emerging methods adopted for diagnosis and monitoring of COVID-19, for quick and accurate detection. LSPR detects nucleic acid by combining photothermal effect and plasmon sensing. LSPR sensor detects localized effect of nonmaterial by utilizing light (Taleghani and Taghipour, 2021b). Plasmonic photothermal effect was also utilized, thus increasing the diagnosing accuracy (Chen et al., 2021). Therefore, combining photothermal effect and LSPR sensing, different viral sequences like ORF1ab COVID, E genes and RdRp-COVID from corona virus were detected (Sheikhzadeh et al., 2020). Thus, advantages of this method include sensitive bimolecular detection technology and eliminating need of the sophisticated equipments (Chen et al., 2021). Despite above mentioned advantages, it faces some challenges in improving limit of detection and in constructing the device for detection.

## 7.2.2 Serological / antibody tests

The test for COVID-19 antibody is blood test which can diagnose whether an individual has SARS-CoV-2 antibodies. The people who have been infected by COVID-19 or recovered from the infection can be identified by this test. According to some reports, it is unestablished that whether the existence of antibodies will be immune to the corona virus in future, or how long it will last if one is immune (FDA, 2020). There are several antibody tests either under progress or available for SARS-CoV-2 antibodies detection.

The techniques used for COVID-19 testing are mainly Lateral Flow Assay, Enzyme-linked Immunosorbent Assay and Chemiluminescent Immunoassay. These tests mainly work with the platform of IgM and IgG antibodies. The testing material used for ELISA is mainly plasma samples from human blood or from upper respiratory tract swab while for LFA it is human blood.

### *7.2.2.1 ELISA*

In Enzyme-linked Immunosorbent Assay, on a solid phase layer, viral proteins are immobilized, and samples of patient are added by inserting microplates. If the sample of the patient produces antibodies to the antigen, a plate reader may detect them as color shift or fluorescence. This procedure is available commercially and generate either a quantitative or qualitative response. It can be automated and several samples of patients can be evaluated at a time. The time for the result varies by the type of examination typically 1 to 5 h (Carter et al., 2020a; Theel et al., 2020). The key benefit of this test is that, it is an entrenched technology which relinquish higher accuracy (Xiang et al., 2020). There are some disadvantages such as high-cost, time-consuming analysis process and the sample volume needed is high. Delivery of sample to specially designed laboratories and skilled personnel is also required (Vogl, Leviatan and Segal, 2021; Pérez-López and Mir, 2021).

Three ELISA kits have been created by the Beijing Wantai Biological Pharmacy Enterprise Co. Ltd that are designed to work with the total antibodies for SARS-CoV-2 of COVID-19 (Lassaunière et al., 2020). On the basis of the double-antigens sandwich ELISA, the ELISA for total antibodies has been developed which employs the mammalian cell-expressed recombinant receptor binding domain (RBD) of SARS-CoV-2's spike protein and the HRP-conjugated antigen. To recognize the IgM antibodies through the similar HRP-conjugated antigen, the IgM $\mu$-chain capture ELISA has been used (Lassaunière et al., 2020). An indirect ELISA kit based on a recombinant nucleocapsid protein has been used to evaluate IgG antibodies (Lassaunière et al., 2020).

### *7.2.2.2 LFA*

In lateral flow assay, without the aid of additional forces (capillary action), a sample solution (or its extract) containing the substance, analyte travels through separate zones of polymer strips to which molecules are attached that may interfere with the analyte (Katarzyna M. Koczula and Gallotta, 2016). The main advantages of this technique is rapid Point of Care (POC), cheaper cost, easy to operate (Carter et al., 2020a) and the results can be acquired in a period of 15 min (Suleman et al., 2021b). But there are issues of reliability and it does not give quantitative results (Djaileb et al., 2020). It also has other limitations like low sensitivity, less accuracy and sample pretreatment (Katarzyna M. Koczula and Gallotta, 2016).

For testing of COVID-19, the principle of this test is on the basis of the nucleocapsid proteins and receptor-binding domain (RBD) of the virus spike. The cassette has a pad of dye consisting of colloidal gold combined with nucleocapsid protein recombinant of novel corona virus 2019 and another dye pad containing colloidal gold conjugated with Spike Protein recombinant of novel corona virus 2019 (Ragnesola et al., 2020). Negative and positive IgM/IgG band determinations are need to be made by visual interpretation (Ragnesola et al., 2020).

#### *7.2.2.3 CLIA*

The chemiluminescent immunoassay works on a similar principle to that of ELISA test, in which samples collected from a patient are incubated with the viral proteins in order to assess the production of antibodies by the sample. The virus protein is used to mask the magnetic micro particles, and a luminescence transition in the reaction is observed by a reader (Theel et al., 2020). This test is also available commercially. A kit has been manufactured to carry out chemiluminescence immunoassay by Diazyme Laboratories, USA for qualitative assessment of IgM antibodies against SARS-CoV-2 from human plasma and serum (Gregg, 2020). Acquirement of quantitative results is the main advantage of this technique. Moreover, like ELISA, it can be automatic, multiple evaluations can be carried out at a single run with more accuracy, and the time for result varies by type of examination which is normally 30 min (Asif et al., 2020; Theel et al., 2020). The disadvantages are longer process time, requirement of specialized laboratory equipment and personnel (Vogl, Leviatan and Segal, 2021).

The challenges of conventional tests can be fixed if other rapid tests are developed and deployed (Zalzala, 2020b). Two such emerging tests are GFET and SPR.

#### *7.2.2.4 GFET*

In Graphene-based Field-effect Transistor, graphene is established as a sensing platform in the Field-effect transistor system which comprises of source, drain and gate. Graphene has high conductivity and hence, it takes less response time giving quick results of presence of SARS-CoV-2 (Sengupta and Mustansar, 2021). The sample is layered on the graphene and if the virus or the viral protein are present in the sample, then the change in electric potential is detected by the sensor (Parkhideh, 2020).

(Seo et al.,) have developed a biosensor based on GFET which can detect the SARS-CoV-2 present in nasopharyngeal swabs from the patients of COVID-19, in lesser than a minute. The sensor can differentiate between the samples from sick and healthy patients without any preparation of the sample (Seo et al., 2020).

##### 7.2.2.4.1 Advantages of GFET

1) **Enhanced performance and efficiency**: Graphene has high electrical and thermal conductivity which gives outcome as losses of low resistance and better heat dispersion. Thus, graphene transistors provide better performance, efficiency and less response time (Kingatua, 2020).
2) **Less Molecular Defects:** Good precision and accuracy can be obtained. Moreover, effectively created two-dimensional material like graphene, can have much fewer surface defects which can result in high sensitivity and will overcome the problem of false positives (Bolotsky et al., 2019).

##### 7.2.2.4.2 Disadvantages of GFET

Proper preparation of sample is required for valid detection. Non-specific interactions can cause issue to the sensitivity of the sensor resulting in, reduced efficiency of binding between the viral protein and its antibody (Sengupta and Hussain, 2021).

#### *7.2.2.5 SPR*

Surface Plasmon Resonance is a technique that monitors disturbance at a solid demarcation line with incident light owing to local fluctuations like antibody or antigen adsorption (Carter et al., 2020b). SPR sensor, on the basis of the change on particular binding layer of the spectra of reflectance can detect large biomolecules (Chen et al., 2021).

In identification of nucleic-acid and even for analysis of viral disease, this technique is widely applicable. The SPR-based sensor has recently been reported for identification of nucleocapsid antibodies specific to SARS-CoV-2 in pure human serum rather than oropharyngeal swabs (Samson, Navale and Dharne, 2020a). This SPR sensor is covered with monolayer peptide and bound with recombinant protein SARS-CoV-2 nucleocapsid which detects COVID-19 antibodies in nanometer range (Samson, Navale and Dharne, 2020b). It is free from labeling and can analyze the sample in 15 min of contact with sensor (Samson, Navale and Dharne, 2020b).

##### 7.2.2.5.1 Advantages of SPR

1) **Label-free detection:** the ability to assess the association between the analyte and the ligand without wasting time and resources on high-cost labeling reagents (Helmerhorst et al., 2012).
2) Compound samples: surface Plasmon Resonance can be used for diagnosis of human serum analysis.
3) **Instantaneous monitoring:** techniques like ELISA can give detailed information like affinity for binding, but it has intricated and prolonged labeling steps. Surface Plasmon Resonance gives detailed information regarding on and off rates under the surface of yes or no affinity and binding values (Schasfoort, 2017).

4) **Reproducible assessments:** the technology for SPR would give precision of the data, as repeated sample injections reliably produce repeatable results (Helmerhorst et al., 2012). This technique is user friendly and has high sensitivity and accuracy (Abid et al., 2021).

#### 7.2.2.5.2 Disadvantages of SPR

Although this method has many advantages, it also has some limitations like small quantity samples cannot be analyzed. Moreover, the cost of the assay is high (Chen et al., 2021).

The advantages of emerging tests can enhance COVID-19 monitoring and detection but instrumentation compactness and further research for stability of the test is required. In addition to above mentioned emerging tests, biosensors and artificial intelligence are also gaining attention in COVID-19 diagnosis.

## 7.3 Other emerging methods for diagnosis and monitoring

### 7.3.1 Biosensors: paper-based biosensors

Since conventional methods have some limitations like, time consuming and requiring complex laboratories with qualified personnel, it is essential to develop new methods to overcome the aforementioned limitations. Paper based biosensors are emerging methods for point of care COVID-19 diagnosis. Paper based micro fluidics chip are invented for the purpose of diagnosis and amplification of DNA or RNA. Paper is used as substrate due to its affordability and disposable quality. There are various production techniques for paper biosensors like polydimethylsiloxane (PDMS) plotting, plasma treatment, photolithography, etc. (Shen, Anwar and Mulchandani, 2021). Points of interest of paper fluidic based LAMP sensor is because of its sensitivity, simplicity and user-friendly properties. Other advantages include possibility for asset restricted zones, transportation and safe removal by means of incineration. (Hui et al., 2020) presented LFA, one of the types of paper-based device for detecting CRISPR and LAMP reaction products, in diagnosis of SARS-CoV-2. In addition to this, lateral flow immunosorbent strip on paper is integrated with smartphone-based biosensor. These smartphone-based devices can detect viral gene and are promising methods for point of care and health aspects.

### 7.3.2 Electrochemical methods combined with biosensors

Electrochemical sensor is one the significant method for detecting infection in early stages of SARS-CoV-2, providing accurate results. Electrochemical Biosensors comprises of bio-receptor, transducer component and electronic system. It can be a system of two electrode or three electrode namely conductometry and potentiostat respectively (Bukkitgar, Shetti and Aminabhavi, 2020). Biosensors consist of gold or platinum electrodes. Selection of a suitable material for fabricating the sensors is pivotal for detecting virus or pathogens. (Srivastava et al.,) demonstrated electrochemical biosensors combined with Au-NPs for detecting COVID-19 (spikeS1 protein) antigen. Operability was matched with COVID-19Ab immobilized screen-printed carbon electrode (SPCE). Outcomes exhibited good selectivity for COVID-19Ag. This sensor can be used thrice and can diagnose COVID-19A up to 120 fM (Srivastava et al., 2021). Similarly, (Navakul et al., 2017) mentioned about electrochemical biosensor utilizing electrode made of gold integrated with graphene oxide for detection up to 0.12 pfu/ml. (Yakoh et al.,) reported paper based electrochemical to detect COVID-19 immunoglobulins (IgG and IgM). This device consists of three parts for construction i.e., ePADs for working, counter and closing. Technique like square wave voltammetry was utilized for monitoring. It proved to be very efficient point of care (PoC) technique in diagnosing of COVID-19 antigen (Yakoh et al., 2020).

### 7.3.3 Immunosensors

Immunosensor is small wireless object, that can detect antigen and antibodies of desired target (Behera et al., 2020). It can be useful for determining the severity of the disease. There are various immunosensor techniques for SARS- CoV2 detection, including LFA, ELISA platforms, and micro fluidic point of care immunosensors (Pérez-López and Mir, 2021). Major advantages of this technique are rapid detection, cost effectiveness, high sensitivity, wireless remote and multiplexed sensing (Behera et al., 2020).

## 7.4 Future aspects of IT applications in monitoring of COVID-19

### 7.4.1 Artificial intelligence

Artificial Intelligence (AI) can be utilized in two sections of COVID-19 such as diagnosis and monitoring of disease in patients. AI also plays a major role in utilization of facial identification cameras to trace the infected individuals, robots to distribute food, medications and disinfect places. AI is a less time-consuming technology in comparison of Human Intelligence as it can diagnose the disease through Computerized Tomographic or X-Ray images by utilizing cognitive processes. It is used on a large scale to minimize the burden on the Healthcare system and to achieve more accurate detection of COVID-19 in patients.

AI can be applied in activities such as epidemiology, diagnosis and therapy of COVID-19 (Chang, 2020a):

#### *7.4.1.1 Epidemiology of COVID-19*

Forecast of disease transmission depends on two kinds of models:

##### 7.4.1.1.1 Statistical model

This model uses machine learning algorithms to project deaths and transmission of infection. IHME (Institute of Health Metrics and Evaluation at the University of

Washington) model is a statistical model functioning on this methodology and it was highly praised to detect this disease spread during the beginning stage of COVID-19. It detects spread of the disease by using mobile phone data and estimates the level of contact by social distancing rules.

#### 7.4.1.1.2 Mechanistic model

This model offers information about ongoing and future transmission synopsis of disease. Susceptible, Exposed, Infected, and Recovered (SEIR) or Susceptible, Infected, and Recovered (SIR) models are utilized by epidemiologists as it provides data regarding spread of this infectious disease. Prediction of COVID-19 infection rates and trends can be performed through SEIR model whereas SIR model ensures that recovered patients are not again susceptible to coronavirus through prediction of population migration (Alanazi et al., 2020). The prediction models should be more dynamic and real-time with more non-linear approaches, to expand the prediction accuracy of confirmed cases.

### *7.4.1.2 Diagnosis of COVID-19*

The current method of testing COVID-19 in patients is RT-PCR combined with DNA sequencing yet, this is costly and highly time-consuming method. So, AI can be useful in medical image interpretation and viral and antibody testing. Innovations fueled by artificial intelligence (AI) consists of machine learning, deep learning algorithms and image interpretation that are utilized for early recognition, infection analysis and rapid discovery of drug for development of new remedies (He, Zhang and Li, 2021a).

#### 7.4.1.2.1 Medical image interpretation

AI associated techniques such as Deep Learning (DL) and Convolutional Neural Network (CNN) of chest X-rays and Computerized Tomographic (CT) or Magnetic Resonance imaging (MRI) of lungs can be useful in radiological imaging of COVID-19 (Dorr et al., 2020).

**7.4.1.2.1.1 Deep learning (DL):** DL model has potential to attain solutions for COVID-19 upheaval, outbreak projection, tracing of infection spread, virus determination and treatment, research of drug and vaccine development. DL additionally helps in faster and accurate diagnosis of complex medical images and disease detection (Bhattacharya et al., 2021). Lung nodules in Computerized Tomographic images can be identified by utilizing multiscale DL. Doctors have to observe the patient's report for diagnosis which is highly time consuming. Hence, by opting DL manual, workload can be reduced and better outcomes can be observed.

**7.4.1.2.1.2 Convolutional neural network (CNN):** CNN algorithm can be used for image processing and analysis. It is used for land marking medical images and evaluation of 3D image datasets because of its higher accuracy. Multi-layer CNN is constructed by assorting various high-resolution images (Bhattacharya et al., 2021). It can also analyze lesions of soft tissue from CT and positron emission tomography images before applying image processing. To detect interstitial lung disease and lymph nodes, CNN with triple cross-validation can be utilized (Shin et al., 2016).

**7.4.1.2.1.3 Generic machine learning:** To build accurate diagnosis model, AI algorithm uses Computerized Tomographic images, clinical symptoms, contact history and research center testing to analyze coronavirus infected cases. Information is to be collected from the patients and to classify the confirmed cases of COVID-19 (Lalmuanawma, Hussain and Chhakchhuak, 2020). Random forest models can also be utilized to classify COVID-19 patients because these are ensemble learning techniques for characterization, regression and various tasks. These tasks function by developing a large number of decision trees and producing class mode (classification) or mean/average individual prediction (regression) (Cobb and Seale, 2020). Hence, Machine learning algorithms provide experimental design and resources for discovery of various viral species and subspecies of SARS-CoV-2 (Metsky et al., 2020).

**7.4.1.2.1.4 XGBoost model:** It is a multilayered classifier of clinical and mammographic datasets. This model can predict and assess criticality of COVID-19 patients through general, severe and mortality rate. This model uses three major clinical features such as High-sensitivity C-reactive protein, lymphocyte and lactic dehydrogenase (LDH) from a pool of more than 300 features (Yan et al., 2020). By utilizing this model, coronavirus infected patients can be grouped into sub categories such as gender, symptoms and based on levels of serum lymphocytes and neutrophils in immune cells (Tayarani N., 2021).

#### 7.4.1.2.2 Viral and antibody testing

SARS-CoV-2 detection is done mainly by viral RNA, antigen and antibody. It is majorly performed by three detection techniques:

**1)** During active infection, Molecular RT-PCR test is utilized for determination of viral RNA.
**2)** During active infection, for detection of explicit proteins on the viral surface, Antigen test is utilized.
**3)** During past infection, COVID-19 antibody based serological test is utilized for detection.
**4)** Combined Test pooling-machine learning method is utilized to diagnose COVID-19. In this method, samples of many individuals are combined into a single sample for analysis. If result of that combined sample is negative, then it is interpreted that all individuals are not infected. Risk assessment can be performed by machine learning through acquiring data from multiple sources to find group classification strategies (Chang, 2020b).

#### *7.4.1.3 Therapy of COVID-19*

By utilizing AI and Deep learning in the AlphaFold software from DeepMind system consists of prediction of quaternary protein folding and structure to discover drugs that have potential to destruct the viral proteins (He, Zhang and Li, 2021a). Artificial Intelligence empowered strategy can be utilized for design and development of vaccine by using different combinations of viral proteins and reverse vaccinology equipments for an efficient immune reaction (Chang, 2020b).

### 7.4.2 Future AI techniques to combat COVID-19

To live a healthy life in future, regular tests should be mandatory to acquire information regarding infection. Hence, by assistance of AI, regular tests can be performed within few seconds with wirelessly automated data entry. To trace and identify infected people, an epidemiological map is used to monitor the body temperature and locations. By utilizing Monto Carlo tree search (MCTS) and Deep reinforcement learning, containment areas can be identified and public health measures can be immediately implemented (Chang, 2020b). Multi-agent modeling process can be utilized in tracing of viral contamination. Drones attached with food and medicines can be sent to containment areas without being in physical contact. In future, AI enabled 3D printed equipments such as masks, gowns and intelligent Robots can be utilized to attend the patients suffering from COVID-19 (Budd et al., 2020).

### 7.4.3 IT applications for COVID-19 monitoring

Innovative utilization of arising technologies can assist in diminishing the community transmission of COVID-19, condition monitoring of infected individuals, treatment rectification of infected patients and development of vaccines and medical treatments (Johnstone, 2020). Some new technology applications such as Telemedicine, Robotics, Internet of Things (IoT), Mobile phones and 3D printing have been recently developed to fight this pandemic (Fig. 7.2).

#### *7.4.3.1 Telemedicine*

Telemedicine is the method of electronic communication between healthcare system and patients to maintain physical distance. Telemedicine can be beneficial for the patients suffering from COVID-19 because it permits proper clinical monitoring, detects criticality of the infection at early stage and it contributes to lower rate of infection among medical services staff (Cassar et al., 2021). During a pandemic, it can also resolve the challenges such as insufficient beds, and personal protective equipment for healthcare staff by using digital communications for treatment. An infected individual is required to submit reports of their body temperature and oxygen saturation by using a thermometer and pulse oximeter provided to him by healthcare system on daily basis (Abdel-Wahab et al., 2020). The active attitude, reaction to alarms, and the calls

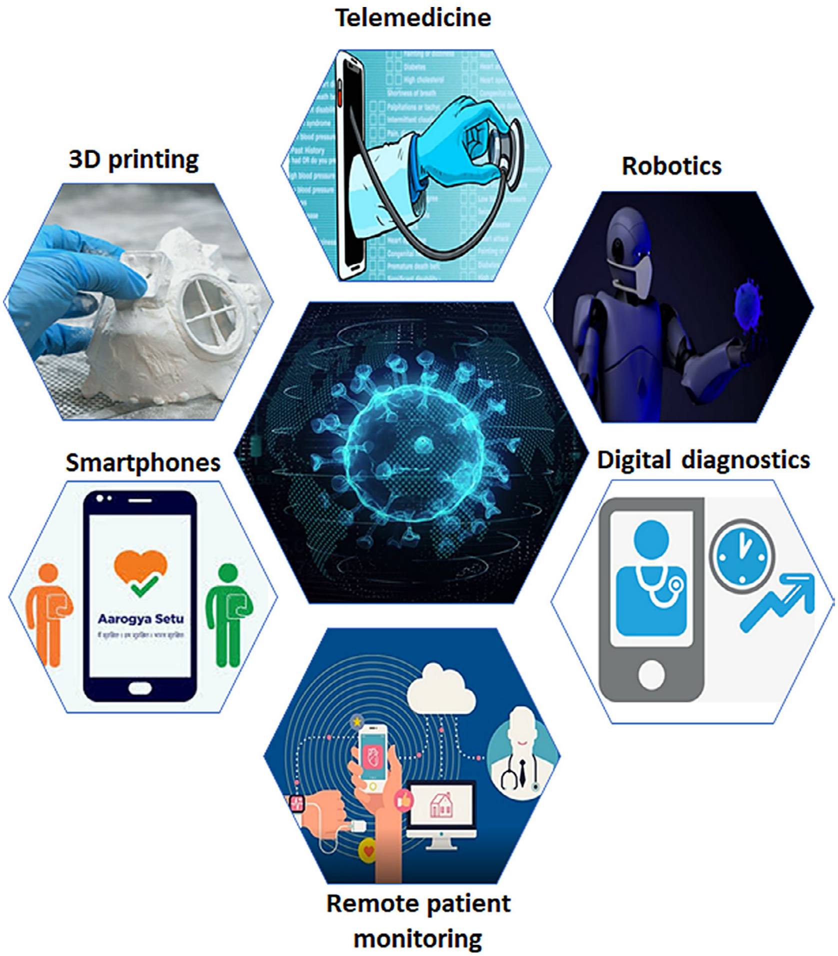


**Fig. 7.2** ***Future aspects of IT applications in monitoring of COVID-19.***

to patients within specific timeframes impart a sensation of control and surveillance. Therefore, monitoring of infected individuals by utilizing telemedicine is clinically beneficial and is considered as a safe system for healthcare professionals. Thus, telemedicine can play a vital role in present and future pandemics (Martínez-García et al., 2020).

#### *7.4.3.2 Robotics*

Robotics can be used to prevent the outbreak of COVID-19. Robots can be beneficial in hospitals for delivering food and medicine and disinfecting rooms without direct human contact with patients suffering from the novel coronavirus disease. In addition to that, the major issue regarding insufficient personal protective equipments and health care workers facing viral exposures can be solved by Robotics. In an Intensive

Care Unit (ICU) patient room, collaborative robot system has the potential to perform duties of healthcare professionals because it can operate ICU equipments such as ICU monitors, ICU alarms, oxygen flow-rate regulators, ventilators and intravenous pump machines (Freeman et al., 2020). By utilizing robotics, oropharyngeal and nasopharyngeal swabbing can also be performed. Drones can also be used to convey medical supplies, surveillance of containment areas and tracing of quarantine mandates (He, Zhang and Li, 2021b).

#### *7.4.3.3 Internet of things*

Internet of Things (IoT) is a network of interconnected tasks consisting of the components such as software, hardware and network availability. Integration and information exchange between the person with requirement and the service provisioner is also permitted by IoT. It can be utilized for the inspection of COVID-19 infected individuals to reduce the disease transmission (Singh et al., 2020a). It is an arrangement of interconnected computing strategies, digital and mechanical devices having the capability of data transmission over the characterized network without human inclusion at any stage. The primary components of IoT include:

**1)** Data collection: IoT installed in mobile phones, health monitors or robots can be utilized for data collection and this data is forwarded to cloud server for processing, examining and decision making.

**2)** Data Analysis: this methodology can also analyze temperature and biometric estimations such as heartbeat, blood pressure and glucose level. This analysis is feasible by means of wearable Internet of Things (IoT) sensors such as Electroencephalogram (EEG) sensor, Electrocardiogram (ECG) sensor, Pulse oximeter Electromyogram (EMG) sensor and Blood pressure sensor. These sensors are associated through internet so constant correspondence of clinical information is achieved which is less tedious process (Swayamsiddha and Mohanty, 2020).

**3)** Data Transfer: after analyzing, this data is transmitted through cell phones to the doctors for monitoring, tracking and diminishing the possibility for COVID-19 inflections (He, Zhang and Li, 2021a).

**4)** Data storage: the captured real-time medical data of infected patient from various locations is managed using the virtual management system.

By utilizing statistical method, IoT is beneficial in predicting impending circumstances so that we can create a better environment to confront such pandemics. Further applications of IoT technologies have been discussed in Table 7.1. These technologies incorporate utilization of smart wearable gadgets connected through internet for the purpose of early determination, isolation period, and post recovery of COVID-19 (Nasajpour et al., 2020).

**Table 7.1** Major applications of Internet of Things (IoT) in COVID-19 Pandemic (Singh et al., 2020b).

| Sr. No. | Applications | Description |
|---|---|---|
| 1 | Internet-connected hospital | The implementation of IoT to support pandemic like COVID-19 needs a complete integrated network within hospital premises |
| 2 | Inform the concerned medical staff during any emergency | This integrated network will allow the patients and the staffs to respond more quickly and effectively whenever needed |
| 3 | Transparent COVID-19 treatment | The patients can avail the benefits offered without any partiality and favours |
| 4 | Automated treatment process | The selection of treatment methods become productive and helps the appropriate handling of the cases |
| 5 | Telehealth consultation | This especially makes the treatment available for the needy ones in the remote locations via employing the well-connected teleservices |
| 6 | Wireless healthcare network to identify COVID-19 patient | Various authentic applications can be installed into smartphones, which can make the identification procedure smoother and more fruitful |
| 7 | Smart tracing of infected patients | The impactful tracing of patients ultimately strengthened the service providers to handle the cases more smartly |
| 8 | Real-time information during the spread of this infection | As the devices, locations, channels, etc. are well informed and connected, the on-time information sharing can be done, and cases can be handled accurately |
| 9 | Rapid COVID-19 screening | As the case arrived/found at first instance, the proper diagnosis will be attempted through smart connected treatment devices. This ultimately makes the overall screening process more superior |
| 10 | Identify innovative solution | The overall quality of supervision is the utmost goal. It can be achieved by making innovations successful to the ground level. |
| 11 | Connect all medical tools and devices through the internet | During COVID-19 treatment, IoT connected all medical tools and devices through internet which convey the real-time information during treatment |
| 12 | Accurate forecasting of virus | Based on the data report available, the use of some statistical method can also help to predict the situation in the coming times. It will also help to plan the government, doctors, academicians, etc. to plan for a better working environment. |

#### *7.4.3.4 Mobile phones*

Mobile apps by means of cell phones and video-conferencing devices are utilized for movement tracing of people, alerting people from entering high containment COVID-19 hotspots, assists doctors to analyze patients through telemedicine/telehealth and uphold people with online shopping, e-learning, online meetings and telecommuting (He, Zhang and Li, 2021b). To overcome and make the citizens and healthcare workers more concerned regarding the COVID-19 disease spread, the Indian government has developed a network-powered application widely known as ArogyaSetu, which is meant to develop a connection between the significant medical care administrations and Indian population. Main objective of this application is to show the closest corona infected individual so that more precautions could be taken during travelling in the surroundings. Through these framework, medical services authorities can distinguish any remaining cellphone operators who were inside a specific distance of the contaminated individual for particular time. Medical services divisions can contact those possibly tainted individuals, instruct them regarding the infection and disease transmission and guide them to get tested for the infection and self-isolate depending on the situation (WHO, 2020).

#### *7.4.3.5 printing*

3D printing technology can be utilized to produce face masks, face shields and Personal Protective Equipments (PPE) for health care laborers and civilians to prevent disease spread. 3D printed rayon wrapped nasopharyngeal (NP) swabs can be manufactured on large scale for COVID-19 testing, because these swabs are made within few minutes and are much faster at collecting samples from individuals (He, Zhang and Li, 2021b).

## 7.5 Conclusion

The standard global health and hygiene regulatory measures have gained a brighter spotlight due to the onset of COVID-19 pandemic. It has instigated the scientists to create quick and proficient techniques for detection of the virus. Timely diagnoses of the infection expand the prospects of being relieved and sustain oneself from the disease. Hence, detection methods are pivotal in the speed and nature of observing, surveillance and quantitative microbial danger appraisal and impacts actualizing the accepted procedures to prevent dangers. Therefore, researchers are developing new advancements in current technologies to combat the current challenges. Detection methods basically comprises of Molecular and Antibody Tests. Currently, reverse transcription polymerase chain reaction is a method of choice for COVID-19 detection, but to improve clinical and detecting practices, many new alternative techniques such as CRISPR, LSPR, LAMP, RT-LAMP, are evolving to overcome the limitations of conventional methods in terms of lesser time, cost effectiveness and more rapid diagnosis of COVID-19. Every method is compared based on functionality in performance and modified accordingly to meet the future challenges of next potential viral outbreaks. Biosensors are emerging techniques for early detection or diagnostic assays. Digital techniques such as artificial intelligence have been optimized to take on future challenges and they have been playing a very crucial role in identifying, monitoring, tracing and curbing of the virus. Thus, AI techniques prove to be essential techniques in both health and economic aspects. Also, ArogayaSetu app has been in limelight which is helpful in terms of concerned authority if a person shows symptoms of COVID-19 disease. Countering the challenges in the wake of COVID-19 and the regulation of health and hygiene guidelines is really a challenging task. Scientists and researchers from all over the world are working continuously to develop and evolve new diagnosis and testing strategies for COVID-19. Thus, emerging methodologies and their coupling with biosensors or artificial intelligence is likely to have great utility and will replace the conventional methodologies for COVID-19 testing hence, eliminating the possible challenges that could be faced in the future.

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## PART 3

# Impact of COVID-19 on Socio-Economic Environment

# CHAPTER 8

# Socio-economic impact of COVID-19

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## 8.1 Introduction

The world is facing different challenges induced the highly infectious disease called as Corona Virus Disease (COVID-19). This highly contagious disease is caused by a novel strain of a Corona virus (CoV-19) that has made its epicenter in Wuhan city at Hubei province, China (Zhu et al., 2020) at the end of 2019 and progressively it spread across the world almost in still all 220 countries, areas or territories (WHO, 2020a, 2020e). This highly contagious disease has so far killed over 1,289,730 people out of the total infected 52,440,433 cases as on 12th November 2020 (Worldometers, 2020; WHO, 2020e). Although, 36,676,552 people found to be recovered from the disease, the disease has still its tight grip over many countries including USA, Brazil, India, Italy and Germany. The COVID-19 outbreak and its severity are the highest in community health jeopardy that triggered by a similar respiratory virus since 1918. It is a highly contagious and many people could die if mankind does not mitigate the spread of infection (Ferguson et al., 2020). As people get infected so faster by this virus CoV-19 disease, it may perhaps only be time before the healthcare system becomes weighed down and forces physicians to sort treatment among critically ill patients (Mar 16 JTP. 2020). Without an intrusion, it is to be expected that resources to care for the ill people are very less in this pandemic time (CDC, 2020a). But through awareness people can somehow minimize the contamination in the community. So, there are two ways to control the contamination. 1. For asymptomatic case, by practicing to wearing mask, maintain social distancing, that is spacing of 6 feet away, and also keeping them in the quarantine are the main measures to decrease the chance of spreading the illness 2. For symptomatic cases the individual actions include working tenuously, avoiding public transportation, and staying home and keep oneself in isolation.

According to the CDC, these classic methods such as social distancing, quarantine and isolation decrease the spread of COVID-19 (CDC, 2020a). This COVID-19

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pandemic situation's infectious rate was very high according to the WHOs globally risk assessment. The contamination rate of the disease is so fast, which causes the number of the infected cases and allied mortality increasing day by day and due to the deficiency of therapeutic and production of vaccine option impelled, many countries governments to execute strict measures to combat the pandemic. So, WHO has suggested many major precautions including community lockdown, restrictions of travel, and the events and non-essential gatherings are cancelled to stop spread of COVID 19 in community and many of the countries follow the steps and keep the complete lock down in their respective country (Ebrahim et al., 2020). And, due to this lockdown most of the people lost their job and subsequently hampered in many sectors: such as socio-economic sector, transportation sector, educational sector and religious sector (Kanitkar, 2020; Shafi et al., 2020; WHO, 2020a, 2020c). So, it can be said that this outbreak has steps forward with remarkable impact on human life, society, education and economy and environment too (Panda, et al., 2020; Paital et al., 2020a, b, c). If analyzed the data, the major step of social lockdown implemented in many countries initially, which may have helped in decreasing the rate of spread of the disease in one hand but resulted into pulling down their epidemic curves on the other hand (Fisher et al., 2020; Lee et al., 2020). There are many countries with previous experience of coronavirus outbreaks, notably Severe Acute Respiratory Syndrome-CoV (SARS-CoV) for example: Singapore adopted the early intervention and implemented the lock down (Lee et al., 2020).

The present problem of is highly contagious in nature and faster infection rate of COVID-19 have made the disease pandemic and a very serious problem of the world which seems as unsolved till now. But as per the data the vulnerability of the disease and the mortality rate is very high in-between the age of 60–80 and above (Fig. 8.1, Business insider, 2020) and it also affected much to pre- existential disease persons (Fig. 8.2, Business insider, 2020) pregnant women and children. However, it is very difficult to know, the deprivation rate of physical and mental health that affected by the long-term consequences of COVID-19 lockdown which created a major problem i.e., social isolation. It is too general that the uncertainties and worries about a pandemic created excessive of anguish and harm to social and occupational functioning. But it is a kind of situation from which people can come out of it and should have with a strong desire to succeed. Humankind has to realize that the ability to cope up with the situation lead to success. As Pandemic creates many socio-economic problems, which very much seen in the present COVID-19 situations, that imposed many socio-economic problems cause to break the social relations; people are staying isolated, and sacrificing their emotion, affection, love, entertainments, etc. And due to this conditions, many people also loss of employment, formal educational opportunities, freedom and support. It has also collapsed the economic system, so, people are becoming unemployed, and poor to poorer in many economically weaker countries. People are struggling for survival; it means there is no way left to earn to survive (OECD Interim Economic Assessment 2020). Mass shutdown

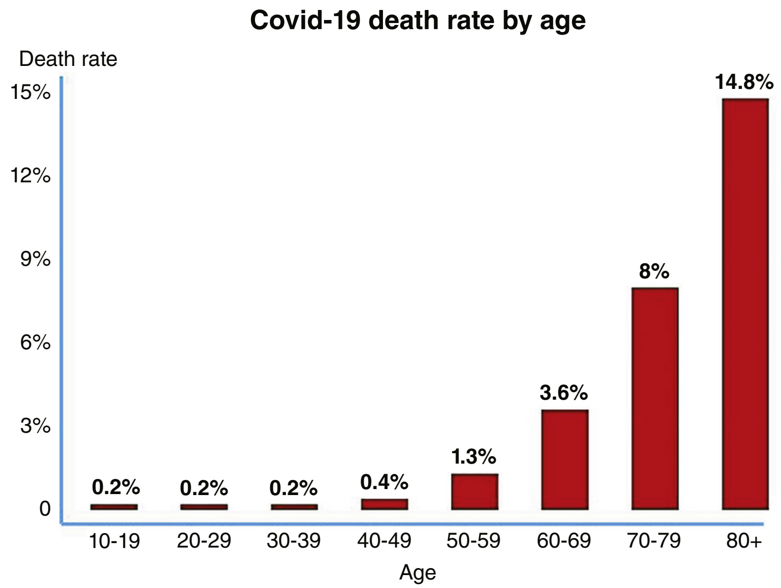


**Fig. 8.1** COVID-19 affected most in the age group (Source: Chinese center for disease control and prevention, business insider) Google images. https://www.businessinsider.in/science/news/the-coronavirus-death-rate.

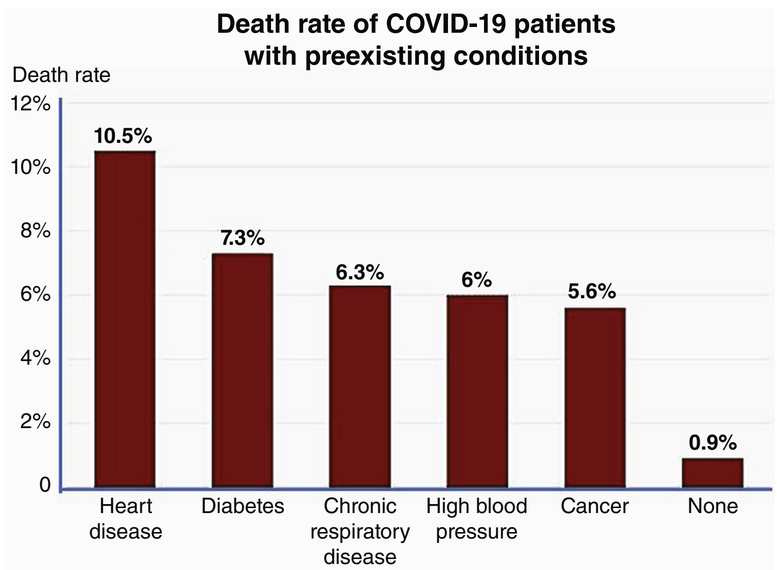


**Fig. 8.2** COVID-19 affected co-morbidities such as heart disease or diabetes patients and made them more vulnerable to severe illness or death (Source: Chinese center for disease control and prevention, business insider) Google images https://www.businessinsider.in/science/news/the-coronavirus-death-rate.

of industries and allied sectors are the sole reason behind it. As it is known, more than 50 percent of people in countries such as India work in private sectors. So, if all these sectors will be closed for longer time, it will be difficult for their servility. It's true that the COVID-19 has broken the back-bone of the daily workers, small as well as big business peoples, factories, companies, etc., the world economy is also severely affected by this pandemic (Fig. 8.3, WEF, 2020). Stock markets are declined with a never seen manner putting the whole tragedy together to the affected 216 countries.

Another big problem is being created in educational sector, due to this pandemic; all educational institutions are closed. Students and teachers can loss their formal educational opportunities, freedom and support. They are only engaged in online teaching learning system that makes difficulty in practical approaches of study. Internet is also not accessible by all students and their families as well all teachers, is another drawback that severely felt during the pandemic. Student and teacher's relationship through online teaching, working from home, and distancing both socially and physically have unexpectedly broken up many important opportunities related to both physical and mental health. And in other things opened with inequalities in the education systems. Those who have equipped with technology get better facilities and those who have poor and

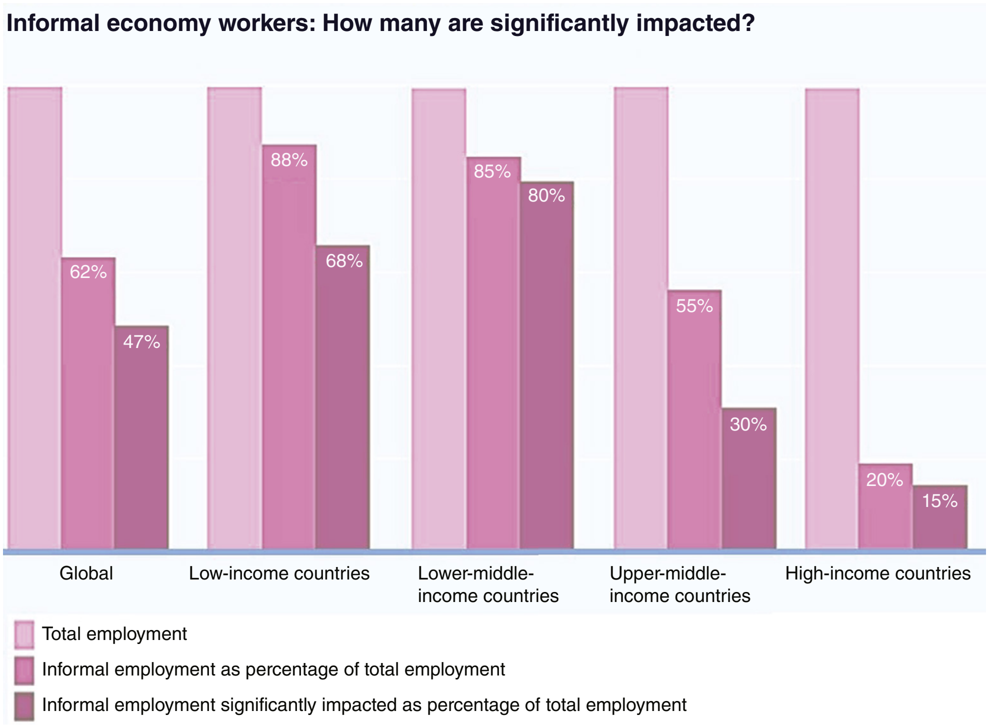


**Fig. 8.3** COVID-19 affected Global employment (Source: Google images, https://www.weforum.org/agenda/2020/05/coronavirus-unemployment-jobs-work-impact-g7-pandemic/).

not equipped to enter into this process. But as there is no any other way to get out of this present situation, It must swiftly absorb from flourishing active plans to continue and construct social resources and flexible to build and endorse a sense of positivity in the society.

There is another and least but not the last problem observed under the pandemic is socio-religious imbalance. As it is known that countries such as India and USA, constitute a multi-religious system where people live in the country belonging to many religions. Many religious people maintain their family life by depending on religious activities. And all religious people believe in the existence of God and Goddess, so they go to temple, church, Masjid, etc. for their prayer and the tranquility of their mind and heart. People believe that worship to God and Goddess in their respective places gives them peace and prosperity. It is thought in many places that the primary duty of human being is to believe and worship super power that makes the life smooth. It is very unrealistic to be believed but such believes exist below the canopy of scientific advancements (Das, 2016). And such feelings are making their strong epicenters in religious places by observing the failure of science to discover medicine or vaccine against CoV-19. Although many people do not understand the issues with science and the problems behind the failure to develop vaccines or medicines against COVID-19, SAR-CoV or Middle East respiratory syndrome-Corona virus (MERS-CoV), believing no/yes type phenomena under emergency is always simple for them. Therefore, there is not a medicine or vaccine still discovered yet after 3 months of the pandemic makes a religious thought to believe still COVID-19 is a plan to mask mankind. Having the religious bent of mind sometimes people always do not miss the chance to challenge science. On the other hand, this pandemic makes a situation to come in their life they bind their body by the strongest rope of mind. It means the pandemic is pressurizing human to keep silent and sit in home and maintain social distancing. However, the family string is becoming stronger due to availability of time for each other's (Das, 2017). People should take it seriously, systematically and also positively to handle the situation and without this procedure it not possible to overcome from this situation and cannot defeat COVID-19.

Practice makes a man perfect. Therefore, human should take COVID-19 to experience its pros and cons to make a hierarchical strategy for such future conditions rather to make knee down under the pandemic. Without facing the problem human cannot experience anything, learn anything, cannot become wiser and stronger too. The present condition is very challenging, as the therapeutic vaccine and medicines of COVID-19 are under processed till now. Now it is time to people must ready to face the problem, challenge it, but not to ignore or escape from the pandemic rather to chase the pandemic by adopting social distancing and hand sanitization types of prevention. Rather than to take a back step from the disease, human must become the front-line fighter. Then only there is possibility for the achieving the normal growth in human life and learn the lesson to face and deal with serious problems.

Owing to the above discussions, this chapter was written to emphasize the effects of COVID-19 outbreaks on global to individual health care system, socio-economic sectors, educational systems, and religious responses in global context.

## 8.2 COVID-19 outbreaks and its effects on global health care systems

In the history of mankind The COVID-19 pandemic has created a huge distraction globally to the health care system and community development. The outbreak has laid bare the deficiencies in the public health system. Many countries had felt that they made an epidemiological transition from communicable to non-communicable diseases before the nineties; and went ahead and partially dismantled their capacity to deal with outbreaks of infections. The focus was to prevent infections from reaching their shores. But this pandemic caused so much economic and social upheaval simultaneously in so many countries. Many things happen at a time to managing this disease. All countries, Government's institutions are continuing to fighting with this contagious disease in many ways such as i. supporting the frontline workers ii. Carrying social services, and iii. Shielding the livelihoods and iv. Protecting the resources as these four are the most important for the very center of the world's attention. But the organizations faced many obstacles as never before to access, maintain the safety of the people, supply chain logistics, and financial stress. Everywhere across the world, humankind faced many challenges and struggled that related to short-term consequences of this vulnerable disease but it almost very challenging to face the long-term consequences. But now the point is that how people can overcome with these current obstacles and also to rethink to reshape health and development of the institutions, occupations, and priorities.

All the countries are now trying to develop the vaccine of this coronavirus very rigorously (Paital et al., 2020a, 2020b). But till now no country has the success regarding the vaccine as therapeutic (Paital, 2020). There are few drugs which can contextually give the treatment but not with a very high success because of less clinical experiences (Cao et al., 2020; Gautret et al., 2020; Das et al., 2020; Gordon et al., 2020; Ko et al., 2020; WHO, 2020d). Hence there is no specific drug for the treatment of COVID-19 as per the WHO and every country trying to develop the vaccine. The only thing has repurposed many anti-malarial, anti-cancer drugs and macrolides against COVID-19 (Paital et al., 2020a, 2020b). Now at this time point it is said that, most of the developed countries like Italy, the USA, the UK, the Spain and the France with a better healthcare system have failed to save their people completely from the COVID-19. Presently across the world, the developed countries compared with other countries for high morbidity rate of these diseases. As this virus is very high in contagious the old methods such as social distancing is only work to prevent this outbreak from community transmission (Wilder and Freedman, 2020). By separating the people to interrupt in community transmission is to prevent person to person spread of disease which is the main focus of this technique/method. . These techniques are 1. Isolation, 2. Quarantine and 3. Community containment (Table 8.1, Cetron and Simone, 2004) and adding to the

**Table 8.1** The table is adopted after (Cetron and Simone, 2004 and Wilder et al. 2020 under creative common attribution license).

| Techniques | Definition | Objective | Setting | Challenges | Remarks |
|---|---|---|---|---|---|
| **Isolation** | Separation of ill persons with contagious diseases from non-infected persons | To interrupt transmission to non-infected persons | Effective for infectious diseases with high person-to-person transmission where peak transmission occurs when patients have symptoms | Early case detection is paramount | Largely ineffective for infectious diseases where asymptomatic or pre-symptomatic infections contribute to transmission. |
| **Quarantine** | Restriction of persons who are presumed to have been exposed to a contagious disease but are not ill, either because they did not become infected or because they are still in the incubation period | To reduce potential transmission from exposed persons before symptoms occur | Quarantining is most successful in settings where detection of cases is prompt, contacts can be traced within a short time frame with prompt issuance of quarantine | Quarantined persons will need psychological support, food and water, and household and medical supplies | Financial compensation for work days lost should be considered. Voluntary is preferred over mandatory quarantine, but law enforcement may need to be considered if quarantine violations occur frequently. |
| **Community containment** | Intervention applied to an entire community, city or region, designed to reduce personal interactions and movements. Such interventions range containment from social distancing among (such as cancellation of public gatherings, school closures; working from home) to community-use of face masks to locking down entire cities or areas (cordon sanitaire) | To reduce intermixing of unidentified infected persons with non-infected community members. | Social distancing is particularly useful in settings where community transmission is substantial. | Ethical principles and codes are needed to guide community containment practice and policy Community to protect the population's health potentially conflicts with individual rights of liberty and self-determination. | Law enforcement is needed in most settings therefore such restrictive interventions should be limited to the actual level of risk to the community. |

Classical techniques without medicine in public health interventions to control infectious disease outbreaks.

compulsory use of mask and hand sanitization. These classical techniques have utilized by China and India, being the first and second largest populous counties, respectively, and the results were known to the world.

Showing after the successive result of China, many countries took these three major techniques by the governments to restrict the movements of the people to decrease the spread of COVID-19. Through isolation, it will measure that separation from an ill person with contagious disease to non-infected person and basically, this takes place in hospital settings (Cetron and Simone, 2004; Nishiura et al., 2012; Li et al., 2020). After that quarantine has mandatory to restriction moments of people who have been supposed to be exposed with the contagious disease but are not ill. This technique is also very old. Italy is one of the countries that took this method in the 14th century to fight against the plague (40 days quarantine) with logic that an asymptomatic becomes symptomatic and therefore the case will be identified (Cetron and Simone, 2004). During this period of quarantine, the contact tracing of infected persons is more important which is followed by many governments. After that "social distancing" has measured as mandatory for reduced interaction between large parts of communities (CDC, 2020b; Das and Paital, 2020, 2020; Paital et al., 2020b). It reflects slow down the spread of the contagion, limits infections and casualties, and alleviates the chance of putting one-time pressure with huge infection on health service providers (Scherbina, 2020). As people were not experience before that these types of provisions include cancelling group events, mandating people to work from home, closing schools/colleges and universities and commercial activities, and limit people's freedom to leave their homes As public mandate to relies on these steps, which shows the effectiveness of these measures (Maharaj and Kleczkowski, 2012). Due to social isolations, mankind paid severe cost of loss for both (economic and psychological) crisis and it also created numerous factors that may affect compliance for public. Because people were not aware of the provisions, as result they gave severity of penalties for contraventions, the nature towards the authorities that enact them. So, it's all about the government's interruption for public to obey these major steps. As this vulnerable disease originated in Hubei province of China and spread here first, the authorities forced to took a strict version of social isolation, i.e., the prohibition of leaving one's home, without setting a defined end date (Yang and Kubota, 2020; Hessler, 2020).

When this highly contaminated disease spread so fast, countries like Italy Canada, France, the United States, United Kingdom and India, bound to take these major strict steps and announced that strong social distancing measures (including stay-at-home mandates) would be in place for a defined period. Without government instruction no one can take any moment. At this time point, most of the countries' health care systems have been facing a great and unprecedented challenge due to the COVID-19 pandemic. For example, healthcare workers like medical and paramedical staffs those who worked in frontline for others in the society, the risk of infection to them is one of the greatest vulnerabilities worldwide. As asymptomatic cases are most and healthcare workers are unable to work remotely strategies could made for these workers as well as others (Scherbina, 2020). This type of crisis occurs and patients were not got the treatment as before due to shortages of protective equipment including N95 face masks, and low medical capacity, intensive care unit beds and ventilators at one time have ultimately exposed weaknesses in the delivery of patient care. Panic buying of mask and sanitizer has another issue through which most of the Governments dealt with (Fig. 8.4). It is shows that in US, the uninsured individuals who may at their jobs increased the risk factor due to this viral infection and the illness created a huge difference in financial consequences (Tanne et al., 2020). Most of the countries invest their economy to build the massive disease prevention infrastructure for healthcare systems to give better treatment to their citizens. To stronger the pharmaceutical part countries are depended with each other. For ex: the No.1 country USA depends on many countries such as: India (18 percent) and the EU (26 percent), while China accounts for 13 percent for imported of largely active pharmaceutical material. The biggest (39.3 percent) share of many medical devices was exported from China to US. This leads to a big difference in production growth that slow-downs and created limited supply. It would fortuitously lead to revenue loss (COVID-19 USA, 2020). Another developed county UK predict


**Fig. 8.4** ***Representing figure showing shelves in a pharmacy in Japan.*** Surgical masks and other medical and equipment sold out by third February 2020 due to panic buying in Japan. The shelves are found to be empty in almost all medicine shops by the first week of February 2020 (Source: http://www.wikiwand.com/en/COVID-19_pandemic_in_Japan, reproduced under common creative attribution license).

that the revenue growth 2020 is very much affected by this vulnerable disease COVID-19. In India, this disease has also affected many sectors in larger scale to gross domestic product rate of 2020 (BBC News 2020c).

### 8.2.1 A big peril in physical and mental health

The coronavirus effects have provoked action globally and changed the entire world in a very short period. Every country all over the world have bound to practice the major step "social distancing" due to this outbreak which creates a challenging mode for humankind. The unusual behavioral patterns in the nation due to social isolations and shutdown, the usual day resulting in changes day-to-day functioning. Although the above steps are restricted for some time to spread the disease in the community but it will have different consequences for psychological health and physical health in both the short and long term. There are changes in behavioral aspects that create stress, depression, etc. Many mental and behavioral disorders like post-traumatic stress disorder (PTSD), substance uses disorder (SUD), created violence among the people's mind (Neria et al., 2008). This pandemic situation bound to close the schools and other premises which extensively increase the rate of anxiety and depression, in the both parents and children. It also increased loneliness, and domestic violence, and child abuse. Again In this present crisis it was reported that the adult has experienced more stress and anxiety (Fig. 8.5). As this is the alarming situation of world the UK has issued psychological first aid guidance for Mental and behavioral Health (Mental Health UK, 2020). But as the power of innovation spirit in mankind, digital technology is a gift to humankind by humans. The very friendly use of Digitalization Bridge the gap of physical distancing

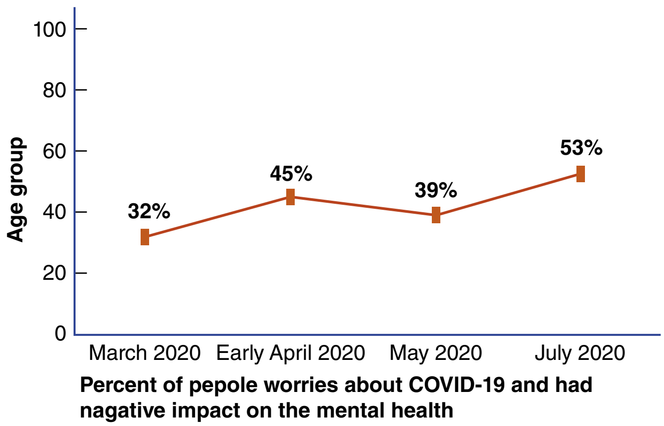


**Fig. 8.5** This figure represents the report of mental health that affected by COVID-19 19 of the adult. (Source: https://www.kff.org/coronavirus-COVID-19/issue-brief/the-implications-of-COVID-19-for-mental-health-and-substance-use/).

measures is in place (Merchant and Lurie, 2020). In a normal time where people gather in worship places like temples, churches and mosques, or gyms, and yoga, but through online activities on a scheduled similarly to what was in place before social distancing. As physical distancing made the part of the life in current situation the digitalization is the only way to work places where people can connect over video connections and also work over there. So, they are not feeling alone although they are not physically meeting. It is responsibility of employers, that to maintain social contact through a supervisor or buddy system, each employee receives daily outreach during the workweek.

At this time point definitely, humankind has to understand that there is a big difference between physical distancing and social isolation. Physical distancing is mandatory to avoid the critical situation but no to social isolation. Keeping each other safe and connected is everyone's responsibility in society that highly required at the present time. Physical distancing is not social isolation. In this difficult situation of COVID-19 strengthen the mental health system is very much challenging to deal with unavoidable circumstances. It's the work of healthcare system to maintain and delivering the most effective heavy treatment to least resources and at the same time they can developed the more resources for patients need as a useful method (Cohen et al., 2017).

For a better treatment and care the whole system may both prepared and well designed to take care of the patients, from physically and mentally which will arise from this pandemic (Galea et al., 2020). A well deigned treatment and tactics in a system need creative thinking in this present crisis. Therefore, it's the responsibility of a whole communities as well as Government organizations to taken up different policies like l giving training to non-traditional groups to provide psychological first aid, helping them and teach the lay public to check in with one another and provide support As public awareness is very much necessary and if with this preparedness a very small signs that someone cares could make a difference in the early stages of social isolation. As the total system may change with digitalization and to communicate and give better stepped care to public there will be technological platform that helped people in different perspective such as: Telemedicine, mental health visits, group visits, and delivery of care via technology platforms will be important components during the acute crisis supervision and more routine communication and support. Some of the healthcare has already in a position to extend the treatment of the patients through tele-mental health services which includes mental health counseling and virtual visits with psychologists and social workers. It also reflects in both the public and private sectors that will need to develop mechanisms for refill and delivery of essential medicines, including psychiatric medicines (Telehealth, 2020). It is very much obvious that in this difficult time it is the opportunity to advance and learn many things through virtual mode and get ready to focused on psychological first aid and mental health care, with a new ways to do that emerge from this pandemic (Galea et al., 2020).

## 8.3 COVID-19 and its effects on international socio-economic sector

The present time is ruining humanity in every part of the world due to devastating Coronavirus disease. Although 216 countries have been affected by this outbreak but indirectly, this pandemic affected billions of people globally. There are asymptomatic cases are increases more, and it shocking that several people likely to stem from under-reporting, and it may probably rise alarmingly in the coming weeks ahead. The only way to restrict the transmission in the community is to complete lockdown which is the only steps that can take by many affected countries. Foremost the international flights have been cancelled in different countries. After that, all the domestic flights, railway service (except goods trains), bus, trucks and vehicle transports are suspended. But the essential commodities of vehicle transports are allowed with special permission obtained from the government.

Again, the entire educational, commercial sports and spiritual institutions are closed as lockdown is strictly followed. Those who have associated with the tourism and transportation industry are also facing most difficulties. Many of the industries are suffering a great loss and in some cases the production level has very low. Pandemics have had significant social and economic costs to humanity over centuries and also the crisis is constantly changing, countries are distracted to flattening the curve for COVID-19. Due to this changing situation around the world, most of the countries are facing a great loss. This COVID-19 pandemic has put the world economy at major risk indubitably. Most of the powerful countries first give their importance to the treatment and care of the COVID-19 sufferers and their families. It is increasing unemployment and lack of productivity and excessive expenditure which is the major threat of high inflation (OECD Interim Economic Assessment, second March 2020). Already it is shown that the de-globalization is starting for the result of this outbreak as per the analysts. However, it will again reflect the World War I and II which causes recession period and global losses according to some observer.

### 8.3.1 Asian countries

The epicenter of the novel coronavirus pandemic of 2019 was in China, the largest populated country in the world and also took the strategy to social lockdown. In the last week of January 2020, China initiated the social lockdown in Wuhan city the main spot of the COVID-19 outbreak. All the public transportations were cancelled and its population was entirely isolated to other parts of the country (Godzinski and Suarez, 2019; Guan et al., 2020). To prevent the spread of the contagious disease the Chinese government moved swiftly after took the initial step that is unprecedented quarantine in Wuhan (WHO, 2020a, 2020b, 2020c). China may fastest overcome from this outbreak through a combination of high-tech scanning and tracking of its population, and fixed with strict controls over public as to work from homes and make less moments and travel. This step has praised by WHO to China as "perhaps the most ambitious, agile and aggressive disease containment effort in history" (WHO, 2020a, 2020b, 2020c). But in the other city like Hong Kong, Beijing it was a little different than schools were closed and public gathering was banned and it followed the compulsory mask-wearing and maintain social distancing. There are some major steps has taken by the Chinese government to stay open in businesses, like restaurants, with strict protocols in place on to maintain distancing between people (The Diplomat, 2020). There has a huge disturbance to experience in a supply and demand chain due to lockdown. . When China took the lockdown steps primarily, the restrictions dealt with a serious decrease in product supply by the factories of Chinese. Then again, another major protocols like quarantine and self-isolation decreased consumption, demand and utilization of products and services (Yap, 2020). When other parts of the world have been affected very seriously the only country China will start to recover faster and strengthening its trade negotiating power against the US. This outbreak hampers the stock market severely in the western counterparts as a result Chinese companies will be in a gainful position because they have dealt with most of the western counterparts (Imperial News, 2020).

In the East Asian side, the most advanced countries like Japan, Korea, also controlled the pandemic somehow in a very challenging manner. Japan draws the attention in the January 2020 through a cruise ship named Diamond Princess which was docked in Yokohama and the COVID-19 symptoms were detected in many persons. In this case, Japan Govt. took very strict regulations to restrict community transmission. The Govt. has also stated to begin a strategy that those who have been returning reported to the Japan Govt. from abroad and mainly from China. The Govt. also closed the schools in early March and tells people to work from home. The awareness of the community and the protocols called by the Government people and to follow the Government appeal with their best possibility, as a result, it controls the spread of COVID-19 and the number of deaths. Thus, the governmental plans and self-discipline within the people have led to desirable results. The Prime minister of Japan having passed two packages of small business loans, one $4.6 billion package in February, and a $15 billion one on March 11, 2020 and these timely updates reached to people through virtual mode (Djalante et al., 2020). Again, the Japan Government, took the another steps to developed and share information regarding automobile parts of car manufacturers, auto part and component suppliers which has the collaborative work between Japan Automotive Manufacturers Association (JAMA), and Novel Coronavirus Countermeasures Examination Automobile Council to help the workers in this outbreak. These advanced countries are in process of learning with a greater hope to maintain a balance between to control the rate of spreading the disease, death and growth of the financial part of the country. Another developed country Korea like Japan parallel increases and give importance to get control the spread of the virus through, extensive testing, location tracking, and contact tracing which has helped the country in a massive surge cases. As this outbreak is unprecedented and challenging for every country across the world, in the meantime countries around the world have been asking for advice from Korea for success to take steps to control the pandemic to develop the new technologies like testing kits and other alternatives (The Diplomat, 2020). To strengthen the economic activity in this emergency period the country assigned more than $13 billion funds.

This outbreak heavily affected the South and Southeast Asian countries towards health or otherwise. Singapore, Malaysia, Philippines and Indonesia countries took strict monitoring method to control the pandemic such as: quarantine, tracing infected people's movement etc. By restrict people's moment and increase the tracing number succeeded drastically to limiting the number of infected people. Many countries like Singapore has set aside 5.6 billion Singapore dollars ($4.02 billion) in the coming year, and Indonesian Government has prepared a budget of Rs 1 trillion, or around $70 million as declare the emergency giving fund to help the public in business, households, care and treatment. But in Iran the outbreak response has different in mode of action. In the primary stage the lack of response by the Government of Iranian, and the inadequate public awareness as created the contamination risk and lack of self-isolation which create a high death rate as compared to China.

It is fully measured and stated that the risk factor of present pandemic which fall on economies and livelihood of people. Its consequences have tremendous hazardous that needs response and complex answer, particularly in many helpless communities and social groups, and countries with breakable economies and poor healthcare systems. It also affected the communities that belong to too much suffering from social taboos like humiliation of women, marginalized and aging groups (Egger and Mirjana, 2020).

In South Asia, Bangladesh took the strategy of social distancing very late in the last week of March followed by the ten days holiday in the country. In the meantime, a part from the essential services it was directed to shut down all industries (TGI, 2020). Every people has concerned and in very uncertain to their job. For ex: In Bangladesh one-in-four workers were being jobless in a garment manufacturing sector as global demand to reduce the workers capacity due to this pandemic. But in the meantime, the Govt. support them to announced a package with an $8 billion which representing 2.5%percent of GDP (The Diplomat, 2020). Sri Lanka Government also had declared the holiday in the entire country first to restrict the Coronavirus in the community. Govt. has declared curfew and strictly follow the steps as people have not been aware of the meaning of social distancing or they didn't want to lose their freedom in a very short period initially (Daniyal, 2020). But before the lockdown was announced the govt. tried to help their public as much as they can like to run the special trains and buses and allow its residents to reach their own villages and cities without facing much trouble (The Morning, 2020). For this outbreak the World Bank has shown its concern to Srilanka and declared to providing $128.6 million in financing to support for emergency healthcare systems on second April, which was one of the largest announcements by the World Bank (The Diplomat, 2020).

But at the same time Pakistan Govt. thought against the idea of lock down as not to affect the socio-economic status of the country. Because the Govt. has faced a huge economic crisis during the COVID-19 period as its Ministry of Planning has assessed that the country could face the unemployment problem, around 18.5 million people will be jobless. However, to restrict the contamination in different parts like Sindh the Govt. took measure steps to lockdown seriously in the latter period (Malik, 2020). Initially the Govt. of Pakistan has more concerned to its residents reached their hometown safely before lockdown. But some places like Sindh, declared the shutdown on 18th March, within the city and restrict the travel moments. On the other hand the Pakistan government had allowed moving for 1 week to all the residents to reach at their respective places as a result before lock down people will reach their natives (Azam, 2020).

As India is the second largest populated country after China, and the Government of India concerned with huge responsibility, seriousness and awareness treated the outbreak as taking safety measures initially. For example, a total restriction of foreign arrivals by air and announced total lockdown throughout the country followed by Janata Curfew. The Govt. also bans the transportations (excluding the essential commodities) within the country and 14 days self-quarantine mandatory those who were from abroad. As the most unhygienic lifestyle (Naidoo et al., 2018; Paital et al., 2020a, 2020b) it was cleared that the pandemic will take it's one of the great places. As a result, the Govt. had succeeded to restrict the community transmission in a highly populated country. India has recorded 74,281 cases so far with 2,415 deaths as on the second week of May, The WHO also praised the Govt. of India for its early and strict decisions of lockdown (World economic forum, 2020). It is very challenging time for all, as this COVID-19 pandemic stated the huge divesting in the livelihood due to mass unemployment, created poverty, hunger and but the COVID-19 pandemic is haunting the world. It has been devastating the lives of people due to mass unemployment, poverty, hunger and misery. These conditions are increasing the rate of socio-economic inequalities in the country due to the sudden lockdown of the country. Working people have not prepared both in physically and mentally to accept these huge challenges in life in a very short period of time (Fig. 8.6).

Globally workers have been faced painful challenges due to COVID-19. It is harsher for the millions of workers of India fight for the livelihoods and health. Initially they have forced stayed in camps, forget about the comfort of family, food which is took them from mental peace. As it has very painful sarcasm to see these workers after sacrificing many things they have been asked to assume, not to maintain the physical distancing. Laborers and workers are the play major role to developed India's growth rate but they strengthen instead of lost the rights in this pandemic period. While the world is focus on primarily on the impacts of the COVID-19 crisis on developed countries in the Global north, developing countries will not be immune to the economic fallout with migrant workers expected to be particularly hard-fit by this crisis. Migrants send

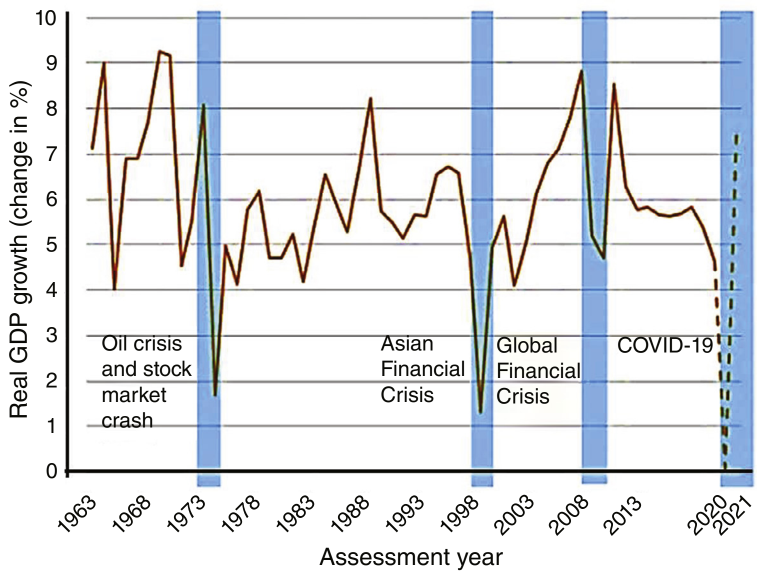


**Fig. 8.6** ***The COVID –19 crises is expected to inflict steps decline in output across Asia.*** It is calculated that (Source: modified after Staff calculations of IMF, https://www.imf.org/en/Research, reproduced under common creative attribution license).

home billions of dollars to family members in the form of remittances, which serve to stimulate local economic activity. Declining remittances will result in many houses holds falling back under the poverty line as well as cutting back on expenses including health care and education. In addition to decline remittances, communities of origin will need to absorb an increasing number of returning labor migrants who are unable to find work in countries of destination. But the insecurity in job and improvement of livelihood aggrieved these workers in the informal sector. It is now the question of overcome from this crucial period and the only answer to this present situation is to assuring them to give a better livelihood and strengthen the income sources (Paital and Das, 2021). In this crisis among the workers, the daily wages and migrant workers have very much affected. It has reported that due to hunger, their life getting miserable and death rate increases in this vital period. So, future will uncertain for unemployed young mass, students and children due to strict lockdown continued and after over. As a developing country and a huge population, the lockdown obstacle in India has created a very difficult situation among the people of the country the migrants' workers and daily laborers. It has reported by the International Labor Organizations (ILO) that 40 crores of workers in India are at risk due to poverty, which is an alarming period for all. Still the Central Government of took the measure steps to fight against the COVID-19 simultaneously the government declared the packages to secure the socio-economic sector. There are lots of packages declared by the govt. for the poor and migrant workers.

And the biggest part of this package has the `20 lakh crore economic incentive packages that were announced by Prime Minister on 12th May 2020 to recover the financial crisis from the coronavirus pandemic (Hindustan Times, 2020).

### 8.3.2 European countries

The epicenter of the novel coronavirus pandemic has not only moved China and East Asia but also affected European countries and other Western nations including the USA most of the European countries have affected such as Germany, France, Spain and Italy. The particularly severe outbreak in Italy has centered. Italy tried to adapt social lockdown and was listed as the second country after China to follow the restrictions to control the contamination. On 21st February 2020, North Italy as it was covered 50,000 people, announced the lockdown for not to spread the disease (Paital et al., 2020b). But unfortunately, the country was not able to control the disease practically and predicatively In the meantime the Italian Government had broadcasted the whole country lockdown on ninth March 2020 with essential services like allowing public transport move partially with pass system to ride bus and board flight on an emergency basis (BBC, 2020a; Fig. 8.7). Again, the Italian Govt. and France Government have between their politicians and commentators on a discussion that whether they continued for lockdown with an extension mode in a specified period or indefinite mode tills the disease will vanish (Galluzzo, 2020; BBC, 2020b). From the standpoint of socio-economic policy, most of the European countries especially in Italy have stood


**Fig. 8.7** ***Mainlining social distancing in a lift in Italy.*** A highly representative example to combat COVID-19 with social distancing even during very a short term movement in a lift. Noteworthy to mention that social distancing and hand sanitization are the only preventive measures available till now to combat COVID-19. (Source: https://www.weforum.org/agenda/2020/04/coronavirus-social-distancing-how-long/, reproduced under common creative attribution license).

the higher in position in terms of the standards health system. As the general health system, in European countries was very strong and advanced it would be easier for the govt. to control the virus and give proper care to the people in comparison to Asia. But the problems with these countries are they take COVID19 completely underestimated. The demographic structure of these countries stated high numbers of elder people and they affected by this contagious disease more and its implications reflected on the advanced health system not to control the disease through underestimate and poor management (Taddei, 2020). Finally, after the country faced the high rates of infection and deaths that has impelled the European Commission to manage the outbreak with common rejoinder to determine the action to strengthen the public health sector and parallel announced the different packages for COVID-19 fund like: French announced $49 billion, Italy announced a $28 billion plan on 11th March to be divided over two separate spending packages, while the UK announced a £5 billion, to reinforce the socio-economic side. UK also took the resources from of police forces to help mitigation measures through training to adequate and supply the personal protective equipment (Mousazadeh et al., 2021; Djalante et al., 2020; PPE ILO, 2020).

### 8.3.3 The United States of America

Today the United States of America is suffering the high rate of COVID-19 positive cases and high death rates. But when it was first reported on January 14, 2020 (CDC, 2020), followed by government interventions in travel restrictions. Officially on 11th March, the COVID-19 declared the global pandemic (WHO, 2020a), and the beginning of a series of governmental decisions to restrict social and economic behavior began. The most affected country in this pandemic was America as the high percentage of migrants frequently international travel, and less strict on social lockdown by the government moments and also in another side they took it casually of its citizen towards their social movement (Rasheed et al., 2020; Das and Paital, 2020b). Later on, the American govt. extended the lockdown period to control the spread of infection of COVID-19 and death to add 30 more days on 29th March up to 30th April 2020. The alarming situation occurred when the experts from public health warning that the death rate of people touched to 200, 00 million people in the US since then the social distancing has extended. According to Trump government "The better you do, the faster this whole nightmare will end. Therefore, we will be extending our guidelines to April 30th to slow the spread." Owing to the lack of ventilators in some public hospitals in the USA, Mr Trump directed that "hospitals not using ventilators will have to release them and that there was hoarding of the devices" (Rasheed et al., 2020). The Director of National Institutes of Health (NIH) has suggested the citizens of USA to maintain social act voluntarily with social distancing manner (Collins, 2020). The pandemic disturbs the whole stock market, and capital market to disruption the supply chain. For example: US stock exchange hampered, the Dow Jones Industrial Average and the Nasdaq fell dramatically until the US government secured the Coronavirus Aid, Relief, and Economic security (CARES) Act, with the indexes rising by 7.3 percent, 7.73 percent and 7.33 percent, 10 years treasury bond yields have dropped to 0.67 percent respectively. Furthermore, 10-year US Treasury bond yields have dropped to 0.67 percent (Daily IB, 2020). This has shown in different mode such as: 'Panic buying'. This issue reflected the shortage of items in supermarket shelves (Fig. 8.8). In one hand many low-income people were not afford the healthcare as they had uninsured in USA and on the other hand millions of low -income workers have lost their jobs and unemployed (Thompson, 2020). Firstly, the Trump Govt. has declared $2 trillion 'virus-aid package'- the CARES Act to secure to support the economy on the 27th March 2020 (USA News, 2020).

Overall, all the countries took significantly different approaches in handling the pandemic. To save people's live and also the socio-economic sector every government took


**Fig. 8.8** ***COVID-19 induced panic buying at the Sams Club in Lufkin, Texas on 13th March 2020.*** During the March first and second weeks in 2020, many cities had experienced panic buying by the consumers in different shops starting from medicines to grocery in response to the coronavirus pandemic. The representative figure indicates such an example in Texas. (Source: https://commons.wikimedia.org/wiki/File:Panic_buying_in_Texas_in_response_to_the_coronavirus_pandemic.jpg, reproduced under common creative attribution license).

dynamic actions. This unprecedented outbreak taught and experienced many things like: strengthen the vigilance, taken up the safety protocols like testing and isolation, public awareness related to strong and weak section, maintain self-discipline, etc. The social stigma and other cultural issue linked the risk of socio-economic structure of the country an community in this outbreak but in a robustly interconnected world it is responsibility of the global standard to maintain strict on a protocol, build mechanisms that decrease the infection risks for the betterment and safety of the every nation.

## 8.4 COVID-19 and its effects on the educational sector

The educational systems have affected worldwide due to the serious COVID-19 Pandemic, as a result, the total closures of schools, universities and colleges. While approximately 1.725 billion students and learners are currently affected due to school closures in response to the pandemic as the report on 27th, April 2020. According to the report of United Nations International Children's Fund (UNICEF), initially 186 countries have applied nationwide closures and also eighty have implemented local closures, impacting about 98.5%percent of the world's student population (UNESCO, 2020a). As a result, the impacts on the closures of educational sector, reflected not only the creel on students, teachers, and families but increased the economic and societal consequences. To overcome from this devastating situation of school closures, different organizations such as:United Nations Educational, Scientific and Cultural Organization (UNESCO) has endorsed the virtual mode of teaching like the use of distance learning programs and open educational applications have the platforms that schools and teachers can use to reach learners remotely and limit the disruption of education (UNESCO, 2020a).

### 8.4.1 Impact on formal education

To inclines formal education which indicates schools, colleges, universities and training institutions (Coombs et al., 1974). Formal education defined according to the report of World Bank on 1974 as the following:

"*Formal education*: the hierarchically structured, chronologically graded 'education system', running from primary school through the university and including, in addition to general academic studies, a variety of specialized programs and institutions for full-time technical and professional training" (UNESCO, 2020a). After this pandemic the data came from that the number of students and learners have squeezed as the closure of formal education system (Fig. 8.9). There are many things happened which hampered the educational systems and increase the distancing mode like: maintain the space between the desks, restrictive the nonessential visitors, making and monitoring the separate heath offices places for the children with flulike symptoms. And also cancelling field trips, assemblies, and other large gatherings such as physical education or

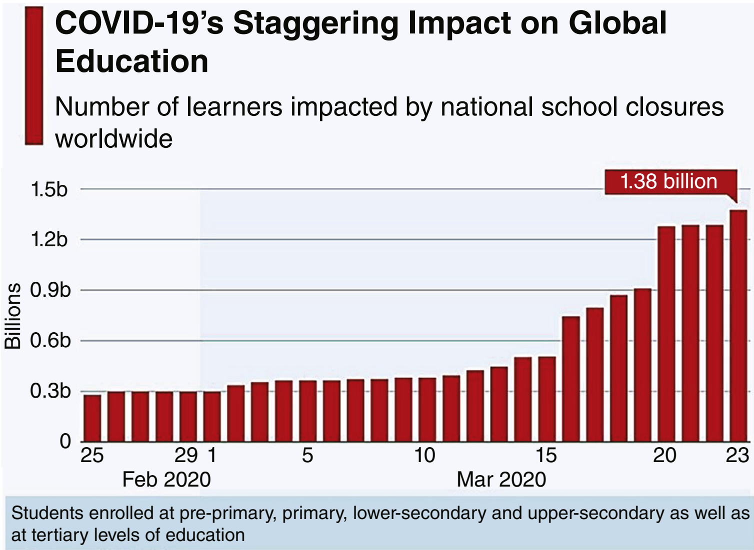


**Fig. 8.9** This figure represents that the global education of formal education system has affected by this pandemic. (Source: google images, https://www.weforum.org/agenda/2020/03/infographic-covid19-coronavirus-impact-global-education-health-schools/).

choir classes or meals in a cafeteria. Many countries like higher developed countries experienced lockdown but reopened the schools in a very delicacy mode. Since it shows the inequalities in educations systems and also faced many challenges. But to overcome with these challenges the education systems have to be equipped with digitalization. But the problem is that lots of parents and teachers do not understand technology. Lots of families have not use the internet services. But schools have to prepare with better services and infrastructure. So, emails and messengers services that protect education little bit (Carillio and Flores, 2020).

The Corona crisis has realized the students that how much schools needs to be done. Most classes and schools use the analog tools and learning materials to change and overcome from the crisis. Money has to be needed to develop the infrastructure and make it digitalize (Beaunoyer and Guitton, 2020).

### 8.4.2 The time for reflecting and reach out a change in the purpose of learning

To develop the process of knowledge, learning is the different mode of achievement in this context. The process can change from traditional method to highest potential method of the brain. But how cans this huge gap will remove? This is the chance for both students and teachers to experience the new learning process. The teaching and learning process through online base in education systems strengthen the teacher's

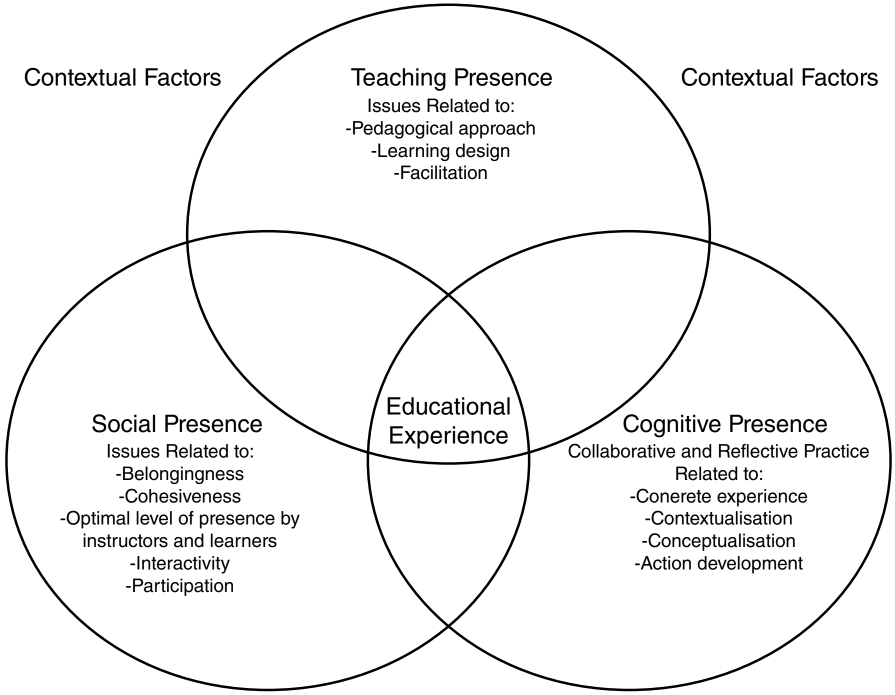


**Fig. 8.10** ***This represents Factors impacting online teaching and learning practices, and to better equipped with teaching methods.*** (Source: Carmen Carrillo & Maria Assunção Flores (2020) COVID-19 and teacher education: a literature review of online teaching and learning practices, European Journal of Teacher Education, 43:4, 466–487, DOI: 10.1080/02,619,768.2020.1821184 https://www.tandfonline.com/doi/full/10.1080/02619768.2020.1821184).

education and somehow bridge the gap between the traditional and the current times teaching method as well as it enhanced the quality of teaching (Fig. 8.10). In the context of COVID-19, filled with uncertainties around 2020 made all different in many ways. Online education was one of those differences taking students in preparing to think beyond in creative education and getting well equipped with technologies. There is a big hope to keep the tradition of excellence even at this pandemic hour. Therefore the methods like combined learning and experiential learning, through the help of technology with greater implementation will power the future the education in schools.

### 8.4.3 A friendly environment with technology

To maintain the connection with each other in this crippling pandemic, the mode of digitalization and current technology played a very vital role to save the world in many ways. Without communication life becomes paralyzed and technology has appeared that maintains the connection among the people (Paital et al., 2020c).

In education systems connectivity of two things that is creating the content and delivers that content is the most important part which can only be possible through the technological mode. May be what people thought that the rigid systems are more necessary but now the time has come to give more flexibility and accessible to the education system (Sahlberg, 2020) through a connection of technology world. So to overcome from this challenging period of COVID-19 there are many alternatives in education system suggested by the UNESCO (UNESCO, 2020b). They are as follows:

**i.** Choose the most relevant tools through which teachers and students are getting connected. Like digital learning platforms, video lessons, Massive Open Online Courses (MOOCs), to broadcasting through radios and TVs. Organize the training session and orientation related to the digital tools through which parents, teachers can equip with the new methods. New methods have helped teachers to prepare the basic settings to use the internet data and provide the live streaming of lessons.

**ii.** As social isolation and physical distancing is mandate, and to overcome from this vital period it addressed the psychosocial challenges before teaching. To connected with each other, it organized the available tools and to get connected with schools, parents, teachers, and students with each other. So regular interaction through create virtual communities made through virtual mode can address and empower the social caring measures when students may face isolation.

**iii.** Other possibilities of virtual program reflect to maintain the study scheduled through distance mode where every can organize the program and made the discussion with the stakeholders and also examine and focus on teaching new knowledge and enhance the knowledge of the students. In the same time avoid the learning methodologies that require face to face communication.

**iv.** In this regard, many cognitive sights can be collected together through which students can be connected with their studies and utilized the time. Because post pandemic-period is going to very crucial and in this pandemic outbreak situation most of the students are not free from stress and anxiety with their careers. So if students are connected with the teachers they can free from the other psychological disorder and it will also give them the strength to fight against this vital period.

### 8.4.4 Factors affecting the evolution of the education system in India

The country India is well known globally for the knowledge of scientific innovations, values, and develops justifiable technologies and medicines. The traditional knowledge systems like: yoga, Indian medicines, architecture, hydraulics, ethnobotany, metallurgy and agriculture should be integrated with a present-day mainstream university education to serve the larger cause of humanity.

Through the help of virtual mode in this time of crisis, the educational practice can enhanced the young minds. It will develop skills that will drive their employability, productivity, health, and well-being in the decades to come, and ensure the overall progress of India (Das & Paital, 2020; Das, 2020a). But the lockdown initiation has impacted the future of the education system. The impact was more severe for underprivileged children and their families, causing interrupted learning, compromised nutrition, childcare problems, and consequent economic cost to families who could not work (UNESCO, 2020a). Lack of publicity about online teaching and learning, the poor, homeless and hungry children do not have access to any such facilities. May be education post-COVID- 19 will embrace learning from science and emphasize a greater focus on issues that endanger our health, society, life and earth.

## 8.5 COVID-19 and its effects on the religious sector

All human beings know that they have many characteristics but believe in religion and do religious activity is very important and very regular for them too. But it is not the case that people don't do religious activity isolatable. So, it is very common to mankind that from the very beginning of civilization mankind have been doing in this way that for a religious activity people must together. This is a situation in the society means in the world, religious activities are must be stopped and there should be maintained social-distancing by the people. No Church, Temple, Masjid can be opened because there is a risk to spread coronavirus, it means coronavirus is attacking such a way that the mortality rate is erasing the moral power within the human and forget about the religious belief power just think about how to safe from COVID-19. So, it is an unforgettable challenging step to safe from this danger. It is known that in society there are large numbers of religious institutions in each corner of the world and there are large numbers of people also working for God. But this is a kind of situation born in the world that everything is a lockdown, people are in quarantines, nothing is possible rather than living in quarantine in this situation (Valson, 2020).

### 8.5.1 Religious services during COVID-19 pandemic: service to humankind is the true religion

Generally, it claims that those who believe in God and religious text they are a religious person. In this context, it is very clear that to be religious is to keep faith in God and do some kinds of spiritual and ritual practices. If this is the case then how can the religious persons do their religious activities? Due to the COVID-19 Pandemic everywhere lockdown and no religious institutions are open. But one thing people can do that in their own home they can do religious activities. But to understand religion in a broader manner it is a very different and critical way. "Service to mankind is service to God" is the best understanding of religion. So, this is the critical conception of religion which is applicable in every place and every situation. In this critical pandemic period, people are performing their religious activity or religious duty which is nothing but social services and helping others. The doctors, nurses, social workers and some other authorities are very rigorously working for needful persons (Valson, 2020). Here it is found two versions of religion; one is very ordinary and another one is a very crucial and critical version that is functioning in this pandemic condition of the society. In comparison to the former version of religion the later version is more practical which is practiced by doctors, nurses, social workers, etc. in this pandemic. The duty of doctors, nurses, and social worker is the real religion. Without this duty, no duty or activity can be considered as a religion. Here the term religion is substituted by social services or the social welfare duties. This contention is to provide a new approach of religion which will show a new path to the new generation for their worth-living.

It's a time which is teaching mankind a new lesson that must be appreciated; that the nature of true religion is performing duty, selfless services to society, give cooperation and kind messages, etc. This is the most essential part to do by all human being. But there are certain people can call as blind believers, their job is to do something in the religious institutions (Church, Temple, Masjid, Girija, etc.) apart of this job they don't have any other work which is helpful for the social welfare rather the people those who belong to this kind of institutions they extract money from the innocent people like leeches extracts blood form the people. Especially in this pandemic situation, they are also fighting against the social workers those who are doing something for the benefit of others and doing something for the safety of others life (Valson, 2020). There are several cases people have already seen through the medium of news. Some temple worshipers of the Hindu community and some moulans in Muslim community are arguing that God, Goddesses, and Allah are almighty can help people and safe their life from this pandemic situation so people should come to temple or in Masjid and worship to God and Goddesses and for the Namaz. But they forgot the risk factor of coronavirus how that is spreading from person to person and there is no vaccine or medicine for the treatment. There is another issue with regards to this aspect of religion is that there are political biases that are creating social violence which is so and so dangerous in the normal situation but what shall people say more if that happens in this pandemic situation.

It's a very bad and shame thing for each individual and the government of the country because there are certain politically biased people and politicians, they need this kind of problem for their political agenda which is so and so harmful for the public. Here the point there is a crisis of right knowledge, proper training, and in the root right person. And another crisis is self-knowledge and self-awareness, self-realization which is must essential for the right person to do the right action. In this present scenario, social distancing is mandatory to save from the situation (CDC 2020c; Das and Paital, 2020a; Davies and Diver, 2020; BBC News 2020c; Mar 16 JTP. 2020; OECD Interim Economic Assessment 2020). But it doesn't mean that people are far away from each other and one is different from other, no it's not the case rather it is a way of creating relationships among people for everlasting of the relationships where there is no caste, race, gender, community, rich and poor, in the eyes of all humanity is one and the aim is one to safe form the problem as soon as possible. And it is also not just for this critical situation but for forever. It should be the motto of all the individuals' mentality then only mankind can feel the real sense of "Vasudhaiva Kutumbakam". This is the real energy that can defeat everyone, what coronavirus is killing mankind that will go very soon if people stand by feet of this aspect of religion (Valson, 2020).

### 8.5.2 COVID-19 and religion US response

It is noticed the US situation due to coronavirus millions of people have lost their lives and millions of people are struggling for survival. How it is happening? What is the deficiency in the US? The central problem is the greedy of money, unawareness of the diseases, and the practice of religious activities in a grouping. As a result, all these cases become the real weapon of their demise, and the rest of the people are at full risk. Because in the preliminary stage of the COVID-19, the people of the US thought that this is nothing, even if this is something critical but our money and economy are more crucial than this critical disease. So they continue to earn economy in the preliminary stage of this disease due to this ignorance and greedy of the economy today the situation is out of control. Presently, the people those who belongs to religious sectors they are getting some sort of irritation due to the cessation of in-person worship. Though people have already experienced such kind of situation but not what exactly the present pandemic has created a situation which is so far different from the previous pandemics in many ways. With regard to ritual practices and religious activities, people are in full edgy because it's a kind of practice and activity in which social distancing is a very big question. But social distancing is sure for the survival, it's a kind of fight for the existence. In U.S. it has created a new history because there were no such situations though the people of U.S. already faced such kind of pandemic but not like this situation among people during the pandemic period. With regard to religious activities, people of the U.S. are so panicky since they are attending a new pattern of worship (virtual worship), it is only due to the virus situation. But, by heart they are not ready to do it because they are also thinking that it's not a proper way of doing worship. So, sometimes they are feeling that we are not doing anything for our God which means we should not live in this world if are not able to do something for our God. But, what can they do, it's a civil imposition or civil suggestion and guide line of health organization that social distancing is must to stay away from this devil activities of this virus? Therefore, the regions practitioners are forced to maintain the new pattern of worship (Newport, 2020).

But the basic question is that how far this new pattern will continue, it's for short time or it became a pattern for permanent? If it is for permanent, then what will be our social integration? Is in-person worship being a complement to virtual worship? Is in-person worship being a replacement to virtual worship?

Though, the religious programs were displaying through digital devices before present pandemic but that was happening in both the ways; offline as well as online. But the present case is totally different from the previous one because there is no question of social gathering which is must important for the religious programs. So, now it is only through online and the religious guru himself telling something in the program and we all are listening even if that is not so convenience to internalize as an intellectual and rigorous religious practitioner. So, many of the religious leaders considered that virtual worship is not a replacement to in-person worship rather it's a complement for in-person worship (Newport, 2020).

There is no alternative way to move our thought for the shake and securing of the religion as well as religious activities and ritual practices as well. So, most of the religious sectors already started broadcasting their services on the whole radio stations, television channels, cable and satellite networks are devoted solely to religious program. There are some religious groups they have also developed some sort of new technology of online broadcasting, and individual pastors and churches have been using the internet as a way of reaching an audience for present year. Therefore, there is no such difficulty for this current transition, in-person worship to virtual worship (Newport, 2020).

With regard to social integration, social distancing is a 'Lakshman rekha' to stay away from the difficulties for the safe and healthy life of human. Though it's not a way to think about to do something for the society but is a way of learning to do something for one and all in the period of difficulties. As we know a smaller religious institutions and local community of religion cannot continue their activities for long time as per the new pattern of worship (virtuous worship) suggested. Because, their understanding of social integration is different form the larger religious sectors. Therefore, they are facing more difficulties to adjust with the situation not only due the problem of pandemic but also due to the lack of infrastructure.

According to Baylor, Byron and Thomas, the traditional roles of religious individuals and religious entities have been to serve a positive, integrative, pro-social, charitable function in a crisis (Das and Paital, 2020a). But it has to be admitted that if there is any social disorder then the communities of faith must have to play an important role in working toward solutions. Though we don't have such sufficient evidences regarding religious individuals and religious organizations whether they are working to help others in their communities affected by the virus, although there is circumstantial evidence suggesting this is the case (Newport, 2020).

Religious Americans could also affect the current virus situation in less directly perceptible ways, through prayer. President Donald Trump established March 15, 2020, as a National Day of Prayer "for all Americans affected by the coronavirus pandemic and for our national response efforts." Trump said: "I urge Americans of all faiths and religious traditions and backgrounds to offer prayers for all those affected, including people who have suffered harm or lost loved ones." Pew Research recently asked Americans (March 19–24) about their prayer behavior in this situation and found that over half of all Americans, 55 percent, say they have prayed for an end to the spread of the coronavirus situation, and among some groups that percentage is significantly higher. This includes about eight in 10 evangelical Protestants and black Protestants, and about two-thirds of Catholics (Newport, 2020).

### 8.5.3 COVID-19 and religion India's response

India is a secular country with respect for many religions. But the countries current situation excavating the religious between Hindus and Muslims. As diversity and democratic nation India forward with safeguard the religious harmony. Though the situation of maintains the relation of Hindu-Muslim have long been tense and the communal riots and violence created many a times (TOI, 2020). In the background it is very difficult to overcome from this out brake of corona virus that led to people's fear over health and connected this with religion-based mis-trust social stigmas and discrimination. Primarily in India many cases of COVID-19 reported were linked to a Muslim congregation held in Delhi in the month of March by an Islamic sect called Tablighi Jamaat. It was a biggest gathering of Muslim communities that Indian authorities identified during that period and many people that muslim communities for that cluster to cause of the spread of the disease (Slater and Masih, 2020; Minj, 2020). It was questioned that how it be possible to spread the disease by Muslims in India? This pandemic started blaming the Muslims community and it turned into another Islamophobic conspiracy theory. So, this was the opportunity to attack on the Muslim Community. Again, it would happen through this outbreak that the Muslim community was blamed physically, verbally and mentally in Indian Society that they were the carrier of this contagious disease. So, they have prohibited to in and restricts in their moments in the nation. Restriction made on Muslim Vendors not to sells product on the street and also huge superstitions made against them that they were spilt on the people and in the roads, in the products etc. to spread the disease etc. Many viral false videos uploaded against the Muslim communities which cased people in different religion maintain the distancing and not to connect with them (Slater and Masih, 2020; Minj, 2020).

The Government of India took it seriously and creates awareness on people to create separate stake of Tablagi Jamaat related cases in daily briefings. According to Saugato Datta, a behavioral and developmental economist, highlighting the large proportion of overall positive cases that are linked to the New Delhi event is misleading, given that the authorities did not aggressively trace and test people from other gatherings like it. "This is sampling bias: Since people from this one cluster have been tested at very high rates, and overall testing is low, it is hardly surprising that a large proportion of overall positives are attributed to this cluster," Datta said (Slater and Masih, 2020).

As human being is rational being full of many good and bad qualities the heartedness of different religion takes man to a different mode that is irrational mode. And retreat and respect for all religions take mankind to close with the divinity. In this unprecedented crisis created by the Coronavirus, many thoughts that the social and political discourses will rise above religious lines and build a strong national unity to combat the pandemic. However, it is unfortunate that religion-based hatred refuses to retreat from our society even at a time when unity across religions and castes is needed the most (Pathak, 2020; Minj, 2020).

Therefore, a diversity and unity approach between the religions requires fighting against this pandemic. Faith on God and respect for all religions with the humanitarian ground and encourage every people to re-analyses the guidance and religious practice with a humble and surrender manner is very much necessary to defeat the COVID-19 (Pathak, 2020; Minj, 2020). There are different ways to get connected virtually and continued with hope and believe and to slowdown the spread of the virus with the help of social medias, radios and mobilize and aware the people to strengthen and harmonize the mind through daily prayers, worship and serve elderly and others who are at risk. People have engaged in discussions surrounding personal well-being and found new ways to communicate to our communities the importance of listening to the safety guidelines promoted by governments and the WHO.

"The ability to go to your church or synagogue or mosque in a hard time is really important to people," empathized Rabbi Sharon Brous in the Los Angeles Times. Nevertheless, she practiced social distancing and engaged with her community via virtual platforms, as recommended by medical and government authorities. She exhorted her synagogue members to find "resilience and level-headedness and kindness and cooperation precisely in their moment of greatest vulnerability (Elsanousi et al., 2020).

India is a land of mixed cultures where people from diverse groups coexist. India has given refuge to foreign invaders, with many people adopting new cultures and has a long lineage of traditions. India is home to large community-based institutions that are involved in charity and social work. Temples, Gurudwaras, Church, Mosque adorn every nook and corner of cities and villages in India. They also command participation of large strata of affluent people who contribute to keep them running. In these times of crisis created by Coronavirus, many of the religious institutions have come forward to assist in cash and kind to prevent the spreading of the virus. A −15-year-old student Abhinav wrote a letter to PM asking him to mandate all religious trusts, irrespective of religion, to donate 80percent of 'God's wealth' to PM Cares fund, so that it can be used to help people who are affected most due to the COVID-19 lockdown.

Sri Ram Janmabhoomi Teerth Kshetra Trust donated 11 lakh Rupees to the Prime Minister's Citizen Assistance and Relief in Emergency Situations (PM CARES) Fund, setup to fight coronavirus outbreak in the country. Golden Temple in Amritsar has decided to bear the cost of all PPE kits and ventilators required in Punjab during the coronavirus pandemic. Gurudwara Bangla Sahib is serving food to approximately 40,000 needy people in Delhi and has offered for its rooms to be used as quarantine centers in these times.

Such initiatives by religious institutions can play a key role in mitigating the spread of the virus (India legal live, 2020). Some suggestions for all religious institutions to play an effective role during a pandemic are given below: -

Avoid overcrowding: Religious institutions can help in preventing the spreading of the virus by restricting people from gathering in their premises during festivals and religious occasions.

Distribution of masks: Many religious places in India require people to enter after covering their heads by wearing a scarf that they provide. Also, now they can keep masks and gloves so that people don't touch each other or come in contact.

Temperature testing: For all employees of religious institutions, temperature testing at entry should be made mandatory.

Pooling financial resources: Religious organizations should pool their financial resources and donations and assist the Government and law enforcement agencies financially.

Ensure hygiene and cleanliness: Management of religious institutions should ensure that there are proper cleaning and sanitization of the premises of religious institutions.

Dialogue and discussion: Religious leaders of all sects should engage in dialogues and discussions which encourage people to cooperate and supplement the government efforts in combating the Coronavirus.

Encourage the study of science and medicine: Many religious people in India also discourage the use of scientific methods and techniques while affirming faith in God. This pandemic has proved that the development of scientific temper is essential to save humanity from any calamity and its use should be encouraged by religious leaders (India legal live, 2020).

## 8.6 COVID- 19 and its effects on the social system

Form the very beginning of human life they have been facing many contagious diseases. But this a kind of virus infection disease which is coronavirus infection disease that is primarily spreading among people only those who are closely contacting with each other and often via small droplets produced by coughing, sneezing, and talking. It's a very strange case that the virus is not able to survive in the air or on the land but it is so dangerous and becoming very active and multi-celled if it is transforming to the human body and again it is not surviving similarly in every human being (Paital and Agrawal, 2020). It is varying from person to person and the symptom of the disease is changing from day by day. There is no common point through which one can identify the spreading capacity of the virus and can control that. But with the number of people infected by the 2019 novel corona virus, which is rapidly increasing worldwide (Tang et al., 2020) public anxieties and worries are elevated in many regions. As the COVID-19 outbreak is on-going, a wave of fear and worry in the society has arisen (Davies and Diver, 2020).

Another social discrimination has created in several communities due to this outbreak with fear and anxiety. As they thought that they will get infected with this dangerous virus and it is very natural. Everyone has right to concern with their own health and following mental peace. But it created so many misconceptions related to societal systems (Kobayashi et al., 2020). Fear and stigma toward the epidemics of COVID-19 may lead to negative consequences of disease control, as prior SARS and Ebola outbreaks are vivid evidence (Cheung, 2015; Maunder et al., 2003; Person et al., 2004). Therefore, it advocates that there is a need to design an effective anti-stigma program that breaks the misperception of COVID-19, increases the public's knowledge in COVID-19 (CDC, 2020c), and spreads encouraging positive and supportive messages (Lin, 2020). In this pandemic, another silent crisis is taking shape. Frustrated by the sudden lockdown people cannot survive and take this crucial situation differently.

There is lots of domestic violence, depression; anxiety and suicidal case are reported. Lockdown and social distancing measures to prevent the spread of the Coronavirus have heightened fears of increasing domestic violence, which includes physical, emotional and sexual abuse (BBC News, 2020a, 2020b, 2020c). Another bad impact reflect in this pandemic is that to increase the rate of use of video-gaming industry. With many individuals self-isolating and/or remaining home under strict governmental regulations, online gaming has seen the emergence of record numbers of players, which has facilitated a boost in revenue for many companies (News coronavirus-world, 2020). The mentally ill are always more vulnerable to the effects of any health crisis (Das, 2020b). This is more so in the situation of an infectious disease pandemic. It is important to bring in a sense of cohesiveness and togetherness. The medications and psychotherapies which are important for such individual may not be available, as all available health resources are diverted towards controlling the infection. This will lead to relapses of several common and severe mental illnesses. It will be important for mental health professionals/hospitals to attempt contact with such individuals to ensure that they are reassured, and enable them to source medications locally. People with pre-existing illnesses need to ensure that whatever treatment they are on currently is continued until the next possible consultation (Ghosh, 2020).

## 8.7 Conclusion

The world is still struggling to develop a specific medicine against COVID-19 and therefore, a different level of social lockdowns is adopted by different counties to prevent the disease COVID-19. Yet the vaccine is in process of trial of third stage in some country where to spread the control over the disease the lock down and social distancing is only hope but on the other hand the negative impact hard-hit on social and economic side. The post COVID-19 crisis just shaken the world with tremendous changes in people's mind, their job prospects their education, and their religious aspect. In replying to these COVID-19 crises everyone should take their own steps and coming forward with the kindness to others and the major role will be taken by the Government and the communities at large. So, the Govt. and the communities can implement the programs that can significantly restrained the negative impacts of crisis by:

1. Endorsing financial/economic inducement
2. Enhanced Social Solidity
3. Addressing and to s shutout the phase of rising unemployment

To stimulating the nation as well as local economic activity the time-bound programs are need to be designed to inspire and incentivize the sending of payments can secure to improve remittances and can be put in place to make it easier to incentivize the use of payments towards education, business start-up or energy efficient, home renovation through matching grant-programs at the individual or community levels. Again, the awareness towards the people at large number, information campaigns and community programs are to be addressing stigma and negative stereotypes between returnees and the broader community are needed to facilitate social reintegration. Job matching services need to be expanded which linking returnees and other with opportunities not only within the local community but also in incites throughout the country. Govt. in countries of destination should avoid reactionary measures that shut their labor markets to foreign workers. Government should also increase the flexibility of work permit conditions of migrant workers already in the country to allow them to seek employment in sectors seeing rising demand. Finally, govt will also need to consider programs that quickly regularize and manage seasonal migration. In the previous recessions people have seen, significant shortages in both high and lower skilled occupations that can create with high rates of unemployment at the national level which is no doubt a negative sign of the country's growth.

Initially social lockdowns has tremendous effects on controlling the disease as countries like China and India seemed to be successful to control the death rates of the patients. Social distancing will provide the chance to buy time to delay the spreading of disease in one hand. It has beneficial results that the health system will get rid of getting huge single time load of COVID-19 patients. However, on the other hand, lockdowns or shutdowns to achieve social distancing found to have many negative effects on the socio-economic state of almost all countries. Not only social impact imparted by COVID-19 but also educational, religious sectors is also found to be severely affected. However, entire world must learn lessons form from the disease at the current state to make future hierarchical strategies to fight any such situation in near future.

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# CHAPTER 9
# Impact of COVID-19 on industries

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## 9.1 Introduction

The United States (US) is still in the midst of one of the largest pandemics in the history of this country. As of November 5, 2020, the U.S. death rate had reached approximately 720 deaths per million people, which is the thirteenth-highest rate worldwide. Throughout March and early April of 2020, several states, cities, and counties enforced 'lockdown' or 'stay at home' quarantine orders on their populations to reduce the spread of the virus. The recent Coronavirus, the SARS-CoV-2 (severe acute respiratory syndrome coronavirus 2) or COVID-19, has made a long-term financial impact on U.S. industries. According to the April 2020 Report of the U.S. Bureau of Statistics (USBLS, 2020a), "total nonfarm payroll employment fell by 20.5 million in April, and the unemployment rate rose to 14.7 percent. The changes in these measures reflect the effects of the coronavirus (COVID-19) pandemic and efforts to contain it. Employment fell sharply in all major industry sectors, with particularly heavy job losses in leisure and hospitality."

The global pandemic from the spread of COVID-19 has generated an unprecedented amount of uncertainty due to the massive growth of hospitalizations, deaths, and quarantine related crises (Saadat et al., 2020). COVID-19 is now considered to be the greatest economic threat since the Great Depression; it has increased mortality and morbidity rates, negatively affected mental health conditions, and had an enormous, negative economic impact. A recently published journal estimated the overall cost of the virus would be greater than $16 trillion (Cutler and Summers, 2020). This study aims to perform a robust before-after analysis by collecting historical employment data from the U.S. Bureau of Statistics. The findings of the study will be beneficial in understanding the temporal influence of this pandemic on several industrial sectors in the US.

## 9.2 Literature review

There has recently been a tremendous growth of COVID-19 related published articles. However, there has been a limited number of studies conducted about the impact of COVID-19 on different industries in the U.S. and other countries.

By examining the U.S. stock market data, Baek et al. (2020) determined a regime change in market volatility due to the COVID-19. The results indicate a substantial increase in total risk for the US stock market. Baker et al. (2020) also stated that

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COVID-19 had the greatest impact on stock market volatility in the history of pandemics. Maneenop and Kotcharin (2020) explored the short-term impact of the COVID-19 on 52 listed airline companies by performing an event study methodology. The results show that traders in Western countries react more responsively based on data than the rest of the world. Kim et al. (2021) examined the impact of Asian American employment due to the COVID-19 outbreak. The empirical results showed that Asian Americans are more adversely affected by this pandemic than other racial groups. Using Household Pulse Survey data (Ganson et al., 2020), estimated the associations between job insecurity and depression thresholds among U.S. young adults during the COVID-19 pandemic. Dang and Viet Nguyen (2020) explored the impact of COVID-19 on gender inequality by using a six-country survey. The results showed that women are 24 percent more likely to lose their job due to the COVID-19 outbreak. Huang et al. (2020) examined the impact of the pandemic on the hospitality industry. The findings showed that the rise of the pandemic is highly associated with the continued deterioration of this industry.

Cutler and Summers (2020) estimated a $16 trillion (nearly 90 percent of the annual gross domestic product or GDP of the US) economic loss due to the outbreak. Since the beginning of the outbreak in March 2020, 60 million people in the U.S. filed for unemployment insurance. Although a human life is invaluable, economists employ a measure known as 'statistical lives' to estimate the value of a human life. This study provides an estimate of cumulative financial costs due to the pandemic by evaluating the lost output and the decline of health conditions.

## 9.3 Methodology

### 9.3.1 Data collection

The USBLS Current Employment Statistics (CES) survey is the most trustworthy source of employment related data on the U.S. labor market (Ghanbari and McCall, 2016). The CES survey collects data, an indicator of Principal Federal Economic Indicators, each month on employment frequencies, hours of employment, and earnings. The USBLS publishes these preliminary estimates at the national level by 12 major industries (in addition of four broad categories), usually on the first Friday of the subsequent month, with amendments to be published in the following two succeeding months (USBLS, 2020b). To achieve reliable data, preliminary data published for August to October in 2020 were not used. This study collected data for April to July of 2018 and 2019, and January to July of 2020. The industries included in the CES data are as follows:

1. CES7000000001: leisure and hospitality (seasonally adjusted)
2. CES8000000001: other services (seasonally adjusted)
3. CES1000000001: mining and logging (seasonally adjusted)
4. CES5000000001: information (seasonally adjusted)
5. CES4200000001: retail trade (seasonally adjusted)

6. CES6000000001: professional and business services (seasonally adjusted)
7. CES6500000001: education and health services (seasonally adjusted)
8. CES2000000001: construction (seasonally adjusted)
9. CES3000000001: manufacturing (seasonally adjusted)
10. CES9000000001: government (seasonally adjusted)
11. CES5500000001: financial activities (seasonally adjusted)
12. CES1021100001: oil and gas extraction (seasonally adjusted)
13. CES0500000001: total private (seasonally adjusted)
14. CEU0500000001: total private (not seasonally adjusted)
15. CES0000000001: total nonfarm (seasonally adjusted)
16. CEU0000000001: total nonfarm (not seasonally adjusted)

Table 9.1 lists the measures of number of jobs by the sixteen sectors. The difference between job frequencies of 2018–19 (the mean of 2018 and 2019 job data by sectors from April to July) and 2020 (April to July) shows that majority of the sectors were impacted during the COVID-19 pandemic (in exception of oil and gas extraction sector). The

**Table 9.1** Measures of Number of Jobs by Different Sectors (April to July).

| Code | Industry | Year | Apr | May | Jun | Jul |
|---|---|---|---|---|---|---|
| CES7000000001 | Leisure and hospitality | 2018–19 (mean) | 16,362 | 16,391 | 16,418 | 16,439 |
| | | 2020 | 8549 | 9954 | 11,933 | 12,566 |
| | | Diff | 7813 | 6437 | 4485 | 3873 |
| | | Percent Change | 47.75 | 39.27 | 27.32 | 23.56 |
| CES8000000001 | Other services | 2018–19 (mean) | 5852 | 5856 | 5870 | 5867 |
| | | 2020 | 4571 | 4816 | 5182 | 5340 |
| | | Diff | 1281 | 1040 | 688 | 527 |
| | | Percent Change | 21.89 | 17.76 | 11.72 | 8.98 |
| CES4200000001 | Retail trade | 2018–19 (mean) | 15,732 | 15,728 | 15,705 | 15,700 |
| | | 2020 | 13,287.6 | 13,673.5 | 14,531.5 | 14,785.4 |
| | | Diff | 2444.4 | 2054.5 | 1173.5 | 914.6 |
| | | Percent Change | 15.54 | 13.06 | 7.47 | 5.83 |
| CES0500000001 | Total private (seasonally adjusted) | 2018–19 (mean) | 126,958 | 127,132 | 127,318 | 127,464 |
| | | 2020 | 108,527 | 111,763 | 116,492 | 118,018 |
| | | Diff | 18,431 | 15,369 | 10,826 | 9446 |
| | | Percent Change | 14.52 | 12.09 | 8.5 | 7.41 |
| CEU0500000001 | Total private (not seasonally adjusted) | 2018–19 (mean) | 126,504 | 127,382 | 128,422 | 128,492 |
| | | 2020 | 108,159 | 111,866 | 117,311 | 118,808 |
| | | Diff | 18,345 | 15,516 | 11,111 | 9684 |
| | | Percent Change | 14.5 | 12.18 | 8.65 | 7.54 |
| CES0000000001 | Total nonfarm (seasonally adjusted) | 2018–19 (mean) | 149,442 | 149,623 | 149,824 | 149,989 |
| | | 2020 | 130,303 | 133,028 | 137,809 | 139,570 |
| | | Diff | 19,139 | 16,595 | 12,015 | 10,419 |
| | | Percent Change | 12.81 | 11.09 | 8.02 | 6.95 |

**Table 9.1** (Cont'd)

| Code | Industry | Year | Apr | May | Jun | Jul |
|---|---|---|---|---|---|---|
| CEU0000000001 | Total nonfarm (not seasonally adjusted) | 2018–19 (mean) | 149,380 | 150,187 | 150,835 | 149,733 |
| | | 2020 | 130,317 | 133,432 | 138,502 | 139,076 |
| | | Diff | 19,063 | 16,755 | 12,333 | 10,657 |
| | | Percent Change | 12.76 | 11.16 | 8.18 | 7.12 |
| CES1000000001 | Mining and logging | 2018–19 (mean) | 732 | 734 | 735 | 733 |
| | | 2020 | 653 | 633 | 626 | 620 |
| | | Diff | 79 | 101 | 109 | 113 |
| | | Percent Change | 10.79 | 13.76 | 14.83 | 15.42 |
| CES2000000001 | Construction | 2018–19 (mean) | 7346 | 7372 | 7390 | 7404 |
| | | 2020 | 6556 | 7012 | 7171 | 7202 |
| | | Diff | 790 | 360 | 219 | 202 |
| | | Percent Change | 10.75 | 4.88 | 2.96 | 2.73 |
| CES3000000001 | Manufacturing | 2018–19 (mean) | 12,731 | 12,744 | 12,763 | 12,776 |
| | | 2020 | 11,489 | 11,729 | 12,062 | 12,103 |
| | | Diff | 1242 | 1015 | 701 | 673 |
| | | Percent Change | 9.76 | 7.96 | 5.49 | 5.27 |
| CES6000000001 | Professional and business services | 2018–19 (mean) | 21,047 | 21,084 | 21,121 | 21,153 |
| | | 2020 | 19,254 | 19,414 | 19,725 | 19,887 |
| | | Diff | 1793 | 1670 | 1396 | 1266 |
| | | Percent Change | 8.52 | 7.92 | 6.61 | 5.98 |
| CES6500000001 | Education and health services | 2018–19 (mean) | 23,792 | 23,826 | 23,874 | 23,924 |
| | | 2020 | 21,805 | 22,193 | 22,760 | 22,979 |
| | | Diff | 1987 | 1633 | 1114 | 945 |
| | | Percent Change | 8.35 | 6.85 | 4.67 | 3.95 |
| CES5000000001 | Information | 2018–19 (mean) | 2842 | 2845 | 2851 | 2852 |
| | | 2020 | 2609 | 2569 | 2576 | 2565 |
| | | Diff | 233 | 276 | 275 | 287 |
| | | Percent Change | 8.2 | 9.7 | 9.65 | 10.06 |
| CES9000000001 | Government | 2018–19 (mean) | 22,484 | 22,491 | 22,506 | 22,525 |
| | | 2020 | 21,776 | 21,265 | 21,317 | 21,552 |
| | | Diff | 708 | 1226 | 1189 | 973 |
| | | Percent Change | 3.15 | 5.45 | 5.28 | 4.32 |
| CES5500000001 | Financial activities | 2018–19 (mean) | 8633 | 8647 | 8659 | 8674 |
| | | 2020 | 8566 | 8585 | 8605 | 8620 |
| | | Diff | 67 | 62 | 54 | 54 |
| | | Percent Change | 0.78 | 0.72 | 0.62 | 0.62 |
| CES1021100001 | Oil and gas extraction | 2018–19 (mean) | 144 | 145 | 146 | 146 |
| | | 2020 | 155.4 | 153.5 | 153.6 | 155.2 |
| | | Diff | −11.4 | −8.5 | −7.6 | −9.2 |
| | | Percent Change | −7.92 | −5.86 | −5.21 | −6.3 |

leisure and hospitality sector was hardly impacted, with half of job reduction in April compared to the average number of jobs in this sector in April of 2018 and 2019. The job loss measures improved in May and July due to people's intention to return to work as many industries have started to operate partial or full starting from May or June in 2020.

The percentages of job losses during COVID-19 months are shown in Table 9.2. The overall trend shows that the reduction is higher in the early months (April or May) compared to the late months (June or July) during this pandemic. Two sectors (information and manufacturing) show a slightly opposite trend with greater job losses in the later months compared to the job losses in the earlier months. The overall month by month trends and the upticks of these two sectors are also visible in Fig. 9.1. Fig. 9.2 shows the number of COVID-19 cases and related deaths from January to July of 2020. Although the number of cases and deaths are higher during the summer months, the stay home orders and lockdowns were in place during the earlier months (March and April), which were associated with the high number of job losses during April and May (see Table 9.2).

Table 9.3 lists the number of average jobs during the first three months and the last four months of January to July job market data in 2020. There are job reductions in all sectors in the later months. However, the impact varies widely by sectors. The most impacted sector was 'leisure and hospitality,' with a 35.23 percent reduction of jobs. The least impacted sector was 'oil and gas extraction' with a job reduction of only 1.28 percent.

## 9.4 Difference in differences

Difference in Differences (DID) is a robust observational before-after study. In DID, or double difference approach, a treatment qualification variable occurs in a way that the

**Table 9.2** Percentage Change in Number of Jobs by Different Sectors (April to July).

| Code | Industry | Apr | May | Jun | Jul |
|---|---|---|---|---|---|
| CES7000000001 | Leisure and hospitality | 47.75 | 39.27 | 27.32 | 23.56 |
| CES8000000001 | Other services | 21.89 | 17.76 | 11.72 | 8.98 |
| CES4200000001 | Retail trade | 15.54 | 13.06 | 7.47 | 5.83 |
| CES0500000001 | Total private (seasonally adjusted) | 14.52 | 12.09 | 8.5 | 7.41 |
| CEU0500000001 | Total private (not seasonally adjusted) | 14.5 | 12.18 | 8.65 | 7.54 |
| CES0000000001 | Total nonfarm (seasonally adjusted) | 12.81 | 11.09 | 8.02 | 6.95 |
| CEU0000000001 | Total nonfarm (not seasonally adjusted) | 12.76 | 11.16 | 8.18 | 7.12 |
| CES1000000001 | Mining and logging | 10.79 | 13.76 | 14.83 | 15.42 |
| CES2000000001 | Construction | 10.75 | 4.88 | 2.96 | 2.73 |
| CES3000000001 | Manufacturing | 9.76 | 7.96 | 5.49 | 5.27 |
| CES6000000001 | Professional and business services | 8.52 | 7.92 | 6.61 | 5.98 |
| CES6500000001 | Education and health services | 8.35 | 6.85 | 4.67 | 3.95 |
| CES5000000001 | Information | 8.2 | 9.7 | 9.65 | 10.06 |
| CES9000000001 | Government | 3.15 | 5.45 | 5.28 | 4.32 |
| CES5500000001 | Financial activities | 0.78 | 0.72 | 0.62 | 0.62 |
| CES1021100001 | Oil and gas extraction | −7.92 | −5.86 | −5.21 | −6.3 |

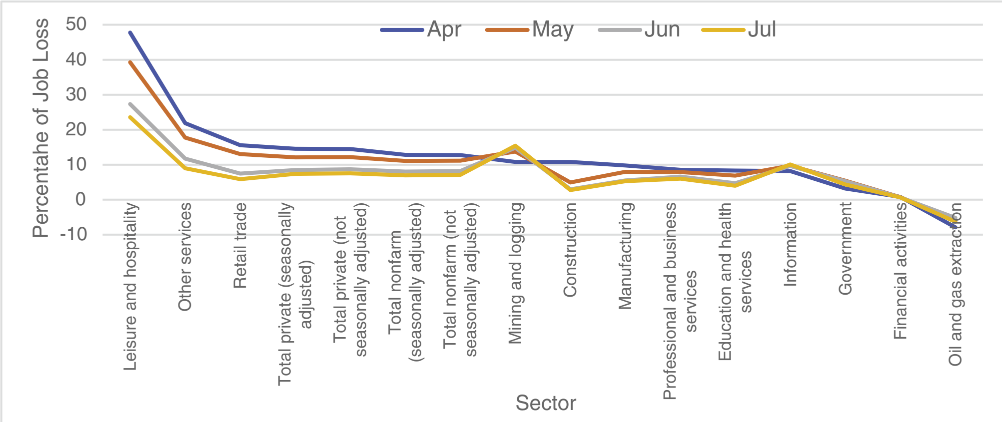


**Fig. 9.1** ***Monthly trends of the percentage of job loss during COVID-19.***

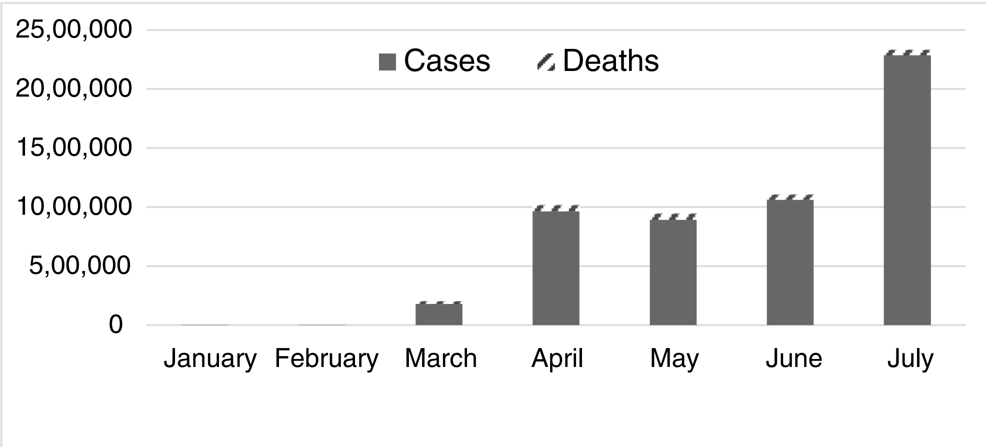


**Fig. 9.2** ***COVID-19 cases and deaths in the U.S. from January to July 2020.***

treatment group is considered at some time point, but the control group is never considered. While before-after studies use the difference of the treatment group before and after the treatment, DD uses the difference between the two before and after differences across the treatment and control groups (Lee, 2016).

To understand what is essentially identified by DD, suppose that the treatment is a law implemented at $t = t_0$ to affect possibly everybody, not just those with $Q = 1$, and

$$Y_{it} = X_{it}^{1}\beta_x + 1[t_0 \le t]\beta_0 + Q_{it}1[t_0 \le t]\beta_q + U_{it} \tag{9.1}$$

where $Q_{it}$ is a time-varying qualification dummy. Here $\beta_0$ is the treatment effect for everybody, but if there are other changes at $t_0$ affecting everybody (e.g., a weather 131

**Table 9.3** Measures of Number of Jobs by Different Sectors (January to July 2020).

| Code | Industry | Jan-Mar | Apr-Jul | Diff | Perc |
|---|---|---|---|---|---|
| CES7000000001 | Leisure and hospitality | 16,600 | 10,751 | 5849 | 35.23 |
| CES8000000001 | Other services | 5909 | 4977 | 932 | 15.77 |
| CES0500000001 | Total private (seasonally adjusted) | 129,193 | 113,700 | 15,493 | 11.99 |
| CES0000000001 | Total nonfarm (seasonally adjusted) | 151,922 | 135,178 | 16,744 | 11.02 |
| CES1000000001 | Mining and logging | 711 | 633 | 78 | 10.97 |
| CES5000000001 | Information | 2892 | 2580 | 312 | 10.79 |
| CEU0500000001 | Total private (not seasonally adjusted) | 127,535 | 114,036 | 13,499 | 10.58 |
| CES4200000001 | Retail trade | 15,643 | 14,070 | 1573 | 10.06 |
| CEU0000000001 | Total nonfarm (not seasonally adjusted) | 150,434 | 135,332 | 15,102 | 10.04 |
| CES6000000001 | Professional and business services | 21,510 | 19,570 | 1940 | 9.02 |
| CES6500000001 | Education and health services | 24,509 | 22,434 | 2075 | 8.47 |
| CES2000000001 | Construction | 7602 | 6985 | 617 | 8.12 |
| CES3000000001 | Manufacturing | 12,834 | 11,846 | 988 | 7.7 |
| CES9000000001 | Government | 22,729 | 21,478 | 1251 | 5.5 |
| CES5500000001 | Financial activities | 8832 | 8594 | 238 | 2.69 |
| CES1021100001 | Oil and gas extraction | 156 | 154 | 2 | 1.28 |

132 Matching, RD, DD, and Beyond change), then $\beta_0$ will pick up the effects of the other changes as well. In contrast, $\beta_q$ is the extra effect only for those with $Q_{it} = 1$. Hence, $\forall t \geq t_0$,

$$E(Y_{it} | Q_{it} = 1, X_{it}) - E(Y_{it} | Q_{it} = 0, X_{it}) = \beta_q$$

Under

$$E(U_{it} | Q_{it} = 1, X_{it}) - E(U_{it} | Q_{it} = 0, X_{it}) \quad (9.2)$$

What is identified in DD is not $\beta_0 + \beta_q$, but the extra effect $\beta_q$ on the subpopulation $Q_{it} = 1$, which is the effect of the interaction between $Q_{it}$ and the time dummy $1[t_0 \leq t]$ for the post-treatment or "treatment-on" periods. The condition involving $U_{it}$ is the aforementioned removal of the unobserved confounder effect (Lee, 2016).

## 9.5 Results and discussions

To examine the impact of COVID-19 on job frequencies, this study used DID, a function used in open source software R package 'fixest' (Berge, 2020). This packed offers a special tool to add interactions in estimations. In this method, the variable 'job frequency by month (January to June 2020)' was interacted with the values taken by 'job frequency in March 2020' by specifying it as a reference value. Table 9.4 shows the

**Table 9.4** Estimates of Difference in Difference Models.

| | Estimate | Std. Error | t-value | Pr(>\|t\|) |
|---|---|---|---|---|
| Month: Jan | −632.31 | 51.493 | −12.28 | < 2.20E-16 |
| Month: Feb | −161.47 | 35.413 | −4.5597 | < 5.29E-06 |
| Month: Apr | −1068.7 | 64.226 | −16.639 | < 2.20E-16 |
| Month: May | −1589 | 88.765 | −17.901 | < 2.20E-16 |
| Month: Jun | −1113.8 | 78.743 | −14.144 | < 2.20E-16 |
| Adj. $R^2$ | 0.79882 | | | |
| $R^2$-Within | 0.09424 | | | |
| Log-likelihood | −35,994.75 | | | |

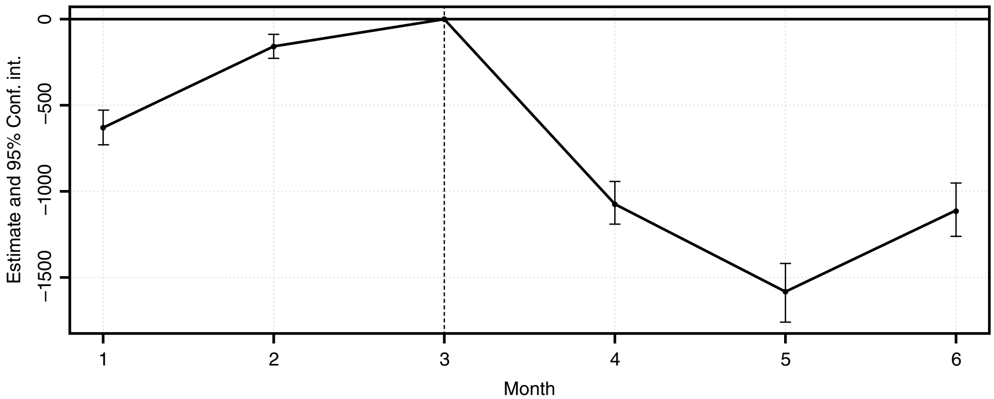


**Fig. 9.3** ***Interaction plot of job measures from January to June 2020.***

results from the difference in difference method. The adjusted $R^2$ value of the developed model is 0.80. The estimates for each month are statistically significant. The estimates indicate that there is a growth of total jobs from January to February. By keeping the 'job frequencies in March 2020' as the reference, the study showed a drastic reduction in jobs in April and May of 2020. The estimates for June 2020 show lower job loss compared to May 2020. The descriptive statistics also provide similar evidence. Fig. 9.3 illustrates the estimates of the month-based job frequencies.

## 9.6 Conclusion

The impact of COVID-19 on the U.S. economy is enormous. Many top economists consider this outbreak as the most disastrous economic recession since the Great Depression. The laid off workforce needs to spend less due to their job loss, which will impact other businesses in the long run. With the loss of subsequent business opportunities, economic growth will decline. As the virus is still not contained in the US, this loss will stay longer, and full recovery is not expected in the near future. This study collected historical CES data from the USBLS and showed the highly impacted sectors (leisure and hospitality, other services, and total private) by performing both year-based and month-based analysis. Additionally, this study applied DID, a sophisticated before-after observational study, to show the statistical significance of job loss during the COVID-19 pandemic. By using data from all sectors, the DID results show a large decline of jobs during April and May and a slight recovery in June.

The current study has some limitations. It has used only data until July 2020 as the rest CES data are preliminary estimates. Additionally, the DID analysis was limited to all job losses. There is a need for sector based DID analysis, which was not performed in this study.

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## PART 4

# Environmental Impact and Risk Management of COVID-19

CHAPTER 10

# Environmental impact of COVID-19

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## 10.1 Introduction

On December 31, 2019, in the hospitals of Wuhan, China where several cases of pneumonia was observed which is connected to the animal market that sells bat, poultry, fish and other animal products to the citizens of Wuhan this attracts the global attention (Saadat et al., 2020). After few days a new variant of coronavirus was pin out by World Health Organization (WHO) which was given a name as severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). SARS-CoV-2 is part of a group of viruses mostly affecting human beings through zoonotic transmission (Chatterjee et al., 2020). Coronavirus belongs to the species Betacoronavirus, such as the Middle East Respiratory Syndrome Coronavirus (MERS-CoV) and severe acute respiratory syndrome coronavirus (SARS-CoV) (Khanna et al., 2020). The SARS-CoV-2 has infected many peoples over the globe and has led to thousands of deaths. It spreads rapidly due to international travelling and lake of awareness among people (Khanna et al., 2020) and due to inadequate waste management. On January first 2020 around 1,75,000 people traveled from Wuhan to different countries (James Glanz, 2020). Such as 900 people traveled to New York and 15,000 to Bangkok likewise thousands of people flew out from Wuhan (James Glanz, 2020). The first case after Wuhan, China was observed in Thailand on 13th January 2020 and then subsequently in Japan and Korea (WHO, 2020). In India the first case reported in Kerala on 30 January 2020. On late January 2020 the World Health Organization (WHO) declared the outbreak to be a Public Health Emergency of International Concern (PHEIC) and subsequently, on March 11th, it was declared a pandemic and on May 21st of the same year it had spread to 188 countries and regions (Peng et al., 2020).

In this chapter we are going to discuss some pros and cons of covid-19 on environment as during lockdown many countries had reduce human activities, as industries are on halt, reduced vehicular use, restriction on cross boundary movement and reduced waste recycling process. To stop the transmission of covid-19 people are also following social distancing among themselves (Zambrano-Monserrate et al., 2020). This led to positive impact in the environment as this practice lowers down the pollution level across the globe. Certain Greenhouse gases, Sulphur dioxide, Nitrogen dioxide, $PM_{2.5}$, and $PM_{10}$ concentration has been decreased in the time of lockdown so air quality is improved (Lokhandwala and Gautam, 2020) and also it was observed that ozone layer is

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recovered Zambrano-Monserrate et al., 2020a. Some more impacts have been observed as clean water bodies and beaches, and also animals are roaming freely in their natural habitat due to lack of tourism. The outbreak has bring havoc for the world but also it brought positive impacts for environment with it (Chakraborty and Maity, 2020). As everything has pros and cons so similarly COVID-19 also cause some negative impacts on human being as well as on environment as recycling of waste has been stopped for the well-being of workers, this led to increase in domestic and other waste volume (Yvonne, 2020), also there is increase in biomedical waste in hospitals, private clinics etc. this creates hazard for environment and can infect living being (Mihai, 2020). Also, natural habitat left unobserved causes illegal hunting and illegal cutting of trees from government reserved areas (Hamwey, 2020). On the other side, single use plastic has been on high demand by the food retailers for health concern of customers and beside these more protective gears are manufacturing day by day for protection from corona virus (Hamwey, 2020). Also this pandemic has affected the world economy including the individual household (Nicola et al., 2020). All impacts of COVID-19 on environment are shown in Fig. 10.1.

## 10.2 Positive impacts of COVID-19

### 10.2.1 Impact on air quality

The lockdown brought a drastic change for the environment. As there is seen a global decline in air pollutant concentration such as $PM_{2.5}$, $PM_{10}$, and $NO_2$, $SO_2$, and Green House Gases in the atmosphere. The human activities with the use of planes, ships, motorbikes are the primary cause of $NO_2$ emission in cities as this all use fossil fuel which is a significant source of $NO_2$ (Chakraborty et al., 2020). But due to lockdown the restriction on transportation led to decrease in NO2 concentration. The satellite imagery from the Copernicus Sentinel-5P satellite shows the worldwide decrease in NO2 concentration in varies parts of the world (Zambrano-Monserrate et al., 2020) such as China where concentration decreases up to 65 percent in the end of January 2020 as compared to 2019 data (Bourzac, 2021) with the quarantine measures (Poetzscher, 2020). Similarly in North Italy (Saigal, 2020), North America and Europe the concentration lowered in the end of February and March 2020 (Poetzscher, 2020). Other than this India's lockdown also turned to a positive impact with decrease in $NO_2$ concentration, in its major metro cities as Delhi the $NO_2$ levels was 90 μmol/$m_2$ from the first day of lockdown to May second 2020 (Poetzscher, 2020). In Barcelona the carbon and nitrogen dioxide concentration declined by 45–51 percent (Tobías et al., 2020) and also In Portugal, Croatia, Spain, Norway, France, Italy, and Finland greatest reduction in NO2 has been seen (Myllyvirta, 2020). The carbon emission of the globe has decreased due to reduced transportation and shut down of factories (Hamwey, 2020). In Bay area's carbon emission decreased

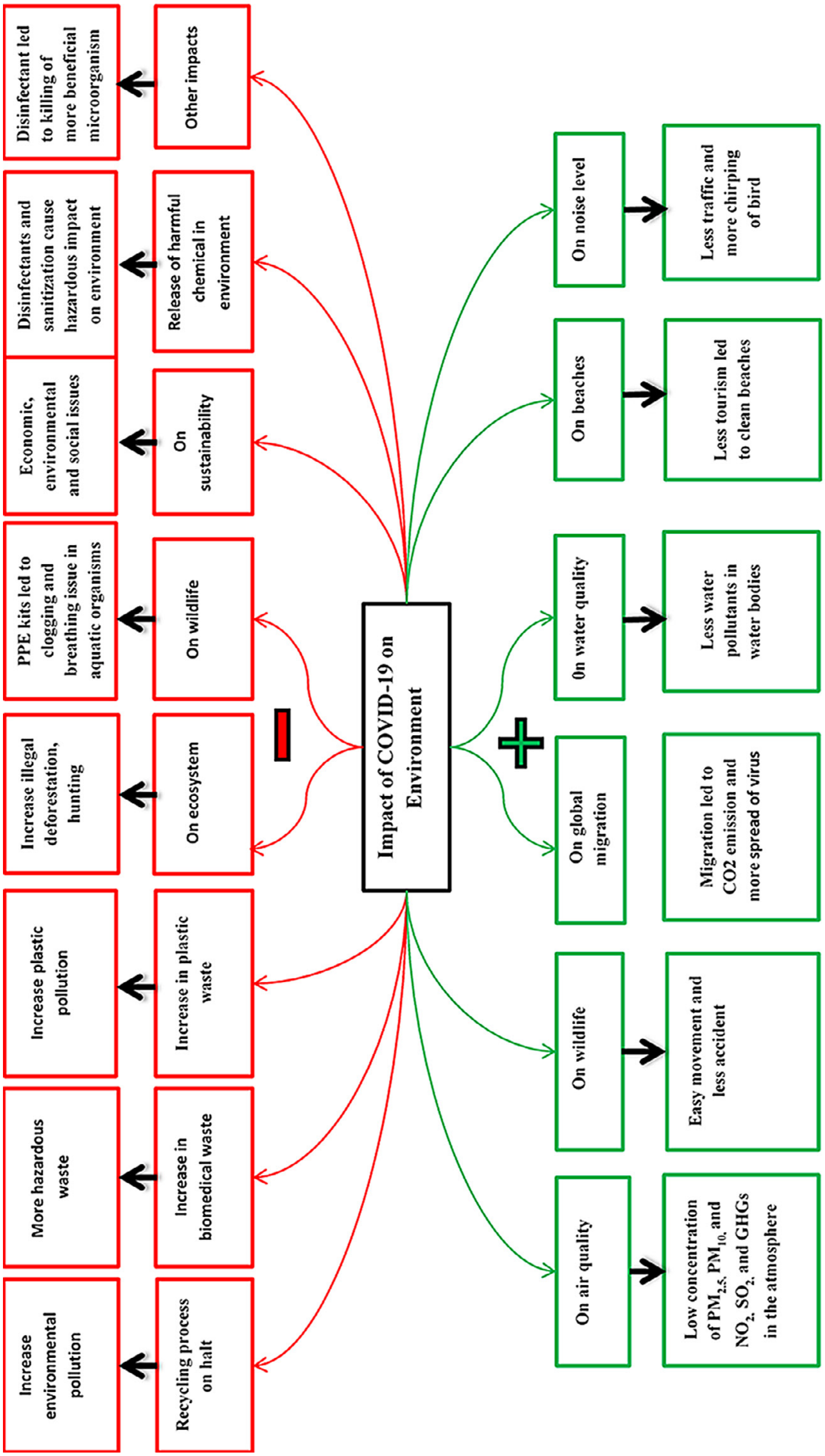


**Fig. 10.1** *Showing positive and negative impacts of COVID-19 on Environment.*

by 28 percent (Bourzac, 2021). In China there is 25 percent drop in carbon emission during the pandemic (Wang and Su, 2020). In New York the reduced transport drop down the carbon monoxide concentration up to 50 percent (Shutterstock, 2020). In Wuhan, china the strict quarantine measure reduces the particulate matter concentration in atmosphere as PM2.5 to 1.4 μg/m3 (Zambrano-Monserrate et al., 2020). In Malaysia during the lockdown the PM2.5 concentration drops by 58.4 percent (Shakil et al., 2020). A 10 percent reduction in PM2.5 concentration can led to a reduction in 11,000 deaths caused due to respiratory problem (Rupani et al., 2020). The reason for decrease in PM2.5 concentration is due to less consumption of coal and oil (Myllyvirta, 2020). Greece had leaded first in reduction of particulate matter concentration and other countries which also contribute in major reduction are Norway, Poland, Portugal, Finland, Sweden, and Spain (Myllyvirta, 2020). The level of ozone is raised between 33 percent and 57 percent during lockdown in Barcelona (Shakil et al., 2020). The concentration of $O_3$ increased remarkably by 37.35 percent in Delhi while in Mumbai an increment of 20.65 percent was observed (Kumari and Toshniwal, 2020). In Wuhan, China the ozone concentration is increased by 116 percent (Lian et al., 2020).

### 10.2.2 Impact on wildlife

Covid-19 can have negative impact for human beings but it turns to be a positive outcome for wildlife as the whole battle has changed, now the human beings are inside the house due to lockdown and the wild animals are on the streets. The lockdown wildlife tracker has been launched by the Wildlife Institute of the India to track the wildlife movement in public resigned areas (Paital, 2020). Also less traffic will led to fewer accidents of animals (David Waetjen, 2020). Many animal species has been seen roaming on the streets such as wild boars are seen in Haifa, Israel, similarly In Albania, pink flamingos are seen flourishing in lagoons on the country's west coastline, and the number raised to 3000 (BBC, 2020). The Dears and Coyotes are spotted in USA, Peacocks are roaming in the streets of Ronda, in Spain a group of goats are wandering around a seaside town in north Wales (Rupani et al., 2020). But on the other side, some animal requires human interference for staying alive. For example now the African government is providing vital measures to protect the species as well as the areas near Mount Kilimanjaro (Rupani et al., 2020). The China has provided full stop on the trade of wildlife especially on animals like wolfs, pangolins, bats. for the well-being of citizens (Eslami and Jalili, 2020).

### 10.2.3 Global migration and COVID-19

Migration has also lead to negative impact by releasing carbon dioxide in the atmosphere (Komatsu et al., 2013) as due to lockdown workers are returning to their homes which rises the migration rate with indirectly increasing the carbon dioxide emission by using more transportation facilities (Ru et al., 2015). And after unlock the migrants are again coming to their work city this also cause more use of vehicles so more pollution on other side the migrants who are coming from rural to urban area has different pattern of energy consumption and utilization then the urban residents (Rupani et al., 2020). Global migration during COVID-19 outbreak is somewhere related to the changes in environment parameters. The international migration is also increased from the main five COVID-19 affected regions as most of the migrant worker used to live their only (Liem et al., 2020) this can trigger the spread of COVID-19. The statistics of migration shows that there is increase in migration among countries due to loop hall in laws and health administration (Rupani et al., 2020). Hence, this irregularity increases the spread of the virus and also it increases the risk of transmission across the countries.

### 10.2.4 Impact on water quality

Anthropogenic activities are the key drivers of water pollution (Yunus et al., 2020). The water pollution include the pollution of oceans, lakes, groundwater and rivers, the main cause behind its pollution is industrialization, rapid urbanization and over use of natural resources etc. but the strict lockdown in different countries have come up with the positive impact on the hydrosphere as industries are on halt so no mixing of dyes, crude oils, and heavy metals (Häder et al., 2020) also less Suspended Particulate Matter (SPM) in water, another is that urbanization rate is also decreased (Yunus et al., 2020). In Venice, Italy the arrival of COVID-19 turns the canals of Venice so clear and transparent with more visibility of aquatic species (Clifford, 2020) as compared to period before COVID-19 (Saadat et al., 2020). Similarly in Vembanad Lake, India the SPM concentration decline by 15.9 percent as observed by the Landsat-8 OLI (Yunus et al., 2020). The sacred river Ganga, India also shows some positive impacts of lockdown as it seems more clean then before (Mani, 2020). The report by Scripps Institute of Oceanography told that there would be reduction in fossil fuel usage all over the globe due to lockdown (Monroe, 2020).

### 10.2.5 Impact on beaches

During lockdown people are not allowed to go outside this strategy turns to be a best result for less pollution on beaches. And beaches are the beautiful natural attraction found in the coastal region (Zambrano-Monserrate et al., 2020). Beaches plays an important role as they provide tourism, recreation activities, sand and land (Lucrezi et al., 2016) and this all are linked with the economy of that region. If beaches are clean then they attract more tourist so high economic growth of that region. But the lack of knowledge and irresponsible behavior of public turns the natural assets into hazardous pollution problem (Partelow et al., 2015). However, the lockdown helps in rejuvenating the coastal region with less human interference (Zambrano-Monserrate et al., 2020).

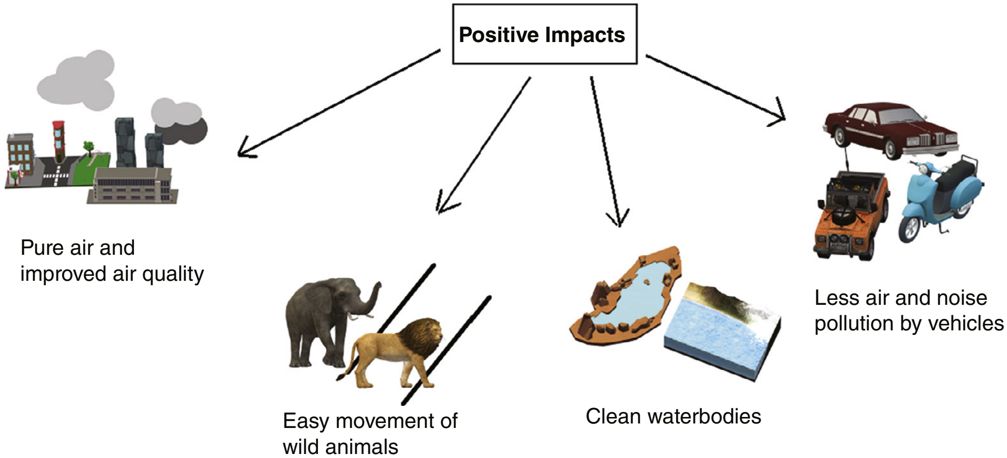


**Fig. 10.2** ***Positive Impacts of COVID-19 on environment.***

Beaches of Barcelona, Spain, Salinas, and Ecuador (Ormaza-González and Castr-Rodas, 2020) are looking more clean then before lockdown.

### 10.2.6 Impact on noise level

Noise pollution is mainly caused due to honking, whirring of vehicular engines, and use of loudspeakers at high volume (Mohammad Ibrar, 2020). This is the main factor behind many health related issues, discomfort in human beings and alteration of environmental conditions (Zambrano-Monserrate and Ruano, 2019). But the lockdown measures has helped in solving this problem and dropping the noise level as people are ordered to stay at home this lead to decrease in transportation, aviation and shut down of factories and mills all over the COVID-19 prone areas (Zambrano-Monserrate et al., 2020). According to (Mohammad Ibrar, 2020) in residential area before lockdown the diurnal decibel level is 55db at day time and 45db at night but after lockdown their come a decrease in its number as 30 db and 40 db whereas now the chirping of bird is easily hearable at the range of 40–50 db. For example in Delhi, India due to less anthropogenic activities the noise level has decreased drastically (Mohammad Ibrar, 2020). High noise level can also change the behavioral nature and transport of many species in aquatic system such the green turtles avoid to come to the place of high noise level (Jacob, 2020). Some positive impacts of COVID-19 on environment are shown in Fig. 10.2.

## 10.3 Negative impacts of COVID-19

### 10.3.1 Recycling of waste on halt

Recycling of waste is the golden way to reduce the pollution and conserve the natural resources (Zambrano-Monserrate et al., 2020). But the lockdown leads to stoppage of the recycling process as to break the transmission cycle of COVID-19 among workers. However, this is indirectly affecting the environment by increasing the hazardous waste in nature causing harmful and deadliest impact on living beings and environment. For example, the USA have kept its recycling process on halt for breaking the chain of COVID-19 transmission (Staub, 2020). Similarly Italy has banned the sorting of infected residential waste (Yvonne, 2020). In Europe also the European plastic recycling industry has closed the production because of the pandemic (Plastic Recyclers Europe, 2020).

### 10.3.2 Increase in biomedical waste

Biomedical waste is increasing in healthcare centers as COVID patients are increasing (UNDP, 2020). The biomedical waste include hand gloves, medicated masks, blood soaked cotton pads, used syringes, medications, drain bags etc. (Varmani, 2020). The usage of this materials leads to increment in biomedical waste that can lead to health issues in human beings and it also alter the environmental conditions (Rume and Islam, 2020). In Wuhan, China the medical waste produces per day in hospitals is 240 metric tons during the pandemic (Eroğlu, 2020). Again, in Ahmedabad, India, the medical waste generated during first lockdown was 1000 kg/day (Rume and Islam, 2020). Similarly in Dhaka, Bangladesh 206 tons of biomedical waste are produced per day during lockdown (Rahman et al., 2020). In Barcelona 1,200 tons of medical waste is generated (Sarkodie and Owusu, 2020). While in lockdown other cities like Bangkok, Manila also shows the increment of waste by 154–280 metric tons per day (Ahmadi, 2020) According to Environmental Pollution Control Authority (EPCA) the biomedical waste generated in Delhi, India is around 350 tons per day (Soumya Pillai, 2020). Sudden increase in medical waste has created risk for the person who is sorting it (Varmani, 2020). Also as per the guidelines by WHO the virus has long life span on plastic, cardboards and steel so it is very important to dispose the medical waste properly (van Doremalen et al., 2020).

### 10.3.3 Increase in plastic waste

COVID-19 pandemic has boosted the plastic waste as use of PPE, sanitizer bottles and plastic bags is increased (Sarkodie and Owusu, 2020). The pandemic has emerged with the increase demand of masks, hand gloves and groceries indirectly linked to the use of more plastic bags for packaging as to stop the transmission (Recycling magzine, 2020). Also, the hazardous plastic waste is increasing at world level during the outbreak (Singh et al., 2020). To fight with COVID-19,China has increased the production of face masks to 14.8 million (Fadare and Okoffo, 2020). According to WHO per month 16 million hand gloves are used on worldwide scale (Iyer, 2020). In India the manufacturing rate of face mask is increased by 15 million per day (Buisness standard, 2020). Similarly in Barcelona the masks and hand gloves production is increased by 350 percent (Sarkodie and Owusu, 2020). In USA also the demand of personal protective equipment has increased (Calma, 2020). The manufacturing of N-95 masks is increased all over the globe but it does not have only positive impact as this mask are made from polypropylene which causes micro plastic pollution in environment especially in aquatic environment (Rume and Islam, 2020). Other than this, the outbreak brings more usage of single use plastics in different aspects as, during lockdown the home delivery and online shopping pattern has been raised by the people which causes more use of plastic for packaging (Klemeš et al., 2020). Indirectly this cause harm to natural resources as more transportation led to more usage of fossil fuel (Yvonne, 2020). In Singapore during 8 week of lockdown the packaging material waste has been increased by 1400 tons (Adyel, 2020). Other than this, the main problem arises during dumbing of hazardous plastic waste as, the waste collector and other workers does not have sufficient knowledge, this led to improper dumbing and segregation of waste (Rahman et al., 2020).

### 10.3.4 Impact on ecosystem

The lockdown practices left all-natural habitats to be unmonitored as forest official are at home. This point can be taken in advantageous form by the hunters and poachers who are now illegally hunting and poaching in the protected zones. Ecotourism has also been stopped due to COVID-19 as lockdown has been come in force to stop transmission. This affects the economy of particular area as less tourism led to low economic growth (Hamwey, 2020).

### 10.3.5 Negative impact on wildlife

The outbreak not only causes positive impact on wildlife as it also causes some negative impacts on them. The main harmful effect it possesses on the aquatic animals as when we dispose the masks and hand gloves. Sometimes with surface water it flows down and end up in the sea. As this protective gears are made up of the polypropylene and polyethylene which causes micro plastic pollution in the water body (Patrício Silva et al., 2020) this indirectly affect the aquatic organisms as some time fishes or other aquatic animals think mask or the hand gloves as a food and they engulfed it which causes clogging and breathing issues in them. In Lantau island 70 face masks are found on sidewalk of the beach out of which 30 washed away on the shoreline (Konyn, 2020). Similarly in Hong Kong the numbers of face masks are increasing day by day and accumulating on the shoreline (India Today, 2020). In Columbia the improper disposal of protective gears and equipment's are affecting the water and soil based organisms (Patrício Silva et al., 2020). Most of the plastic waste generated during pandemic is clogging the landfills and are polluting the oceans (UNCTAD, 2020). The other effects are such as, increased wildlife-livestock contacts and increase population growth, which can trigger the chance of disease transmission among the animals for example the African swine fever which is an animal transmissible disease (Bar, 2020).

### 10.3.6 Impact on sustainability

Sustainability is connected with the three things that is society, environment and economics (Rupani et al., 2020). The pandemic not only impacted the life of human being as it also harms the sustainability. During lockdown economy of several countries is affected, this directly affected the individual's life as in several families it led to domestic violence and it also create social issue among themselves as they feel more distressed and then disconnect themselves from society (Pazzanese, 2016), on the other side, environment is also affected as due to lockdown protected zones are not monitored by the forest officials which led to illegal deforestation and hunting (Rupani et al., 2020).

### 10.3.7 Release of harmful chemical in environment

Sanitizers can deactivate or some time can kill the virus but it's not necessary that they have only positive impact as the sanitizers are made up of chemicals such as triclosan, triclocarban, hypochlorite and acrylate copolymers that can easily cause hazardous impact on environment (Ishmail, 2020). Similarly, disinfectants used now days also release toxic substance that can be harmful to human beings as well as for nature also, the increase use of sanitizer and disinfectants bottles are causing plastic pollution. Due to curfew the agricultural practices were on halt which increases the use of more pesticide and fertilizers to increase the crop yield and to get healthy crop this led to eutrophication in water bodies (UNDP, 2020).

### 10.3.8 Other impacts of COVID-19 on environment

As to protect normal public from the virus, government is disinfecting the roads, streets, residential and commercial areas. The property of disinfectant is to kill the virus and other pathogens but some time it kills the beneficial microorganisms also which can create imbalance in environment cycle (Didar-Ul Islam and Bhuiyan, 2016). The virus can enter the environment through various modes as in Sweden, Australia, India, USA and Netherlands the virus found in patients feces, and in wastewater of municipality. So to get rid of this government has to take specific measure to control it (Rume and Islam, 2020). For example the China has implemented the use of more chlorine in water treatment process but excessive use may led to harmful health impacts on individuals (Zambrano-Monserrate et al., 2020). Some negative impacts are depicted in Fig. 10.3.

## 10.4 Conclusion

The unprecedented crisis has kept the world in challenges by its fast-spreading tendency and putting lockdown on several countries led to decrease in global economy. But as we know everything has pros and cons at the end, similarly COVID-19 also reflects both of it as on one hand it shows decrease in water and air pollution, but on the other hand it reflects more negative impacts as the main effect is the increase in plastic waste

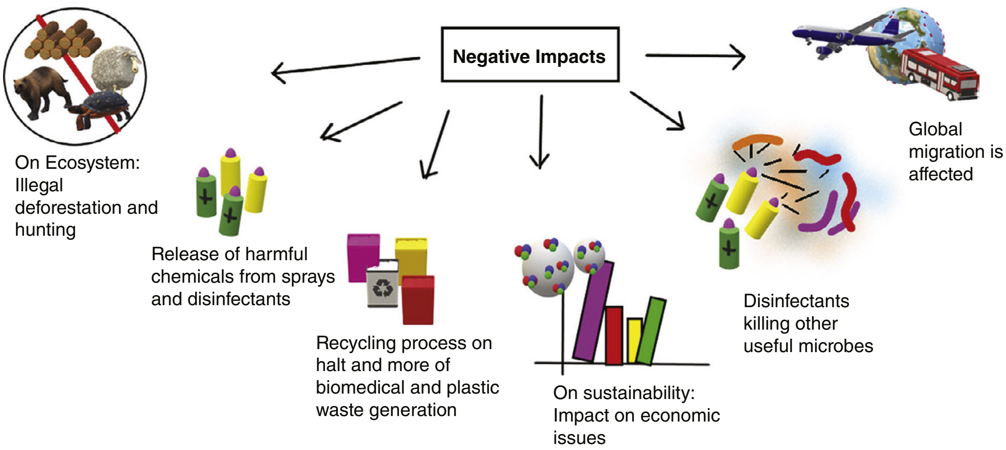


**Fig. 10.3** ***Negative Impacts of COVID-19 on Environment.***

and biomedical waste, improper disposal and management of medical waste and plastic waste that is causing marine pollution as well as depleting the environment and causing harm to humans and animals. So, Special attention should be given on the management and disposal facilities. Proper education and training should be provided to the workers with respect to segregation of the medical waste which can reduce the chances of spread within the hospitals.

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# CHAPTER 11
# Risk management of COVID-19

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## 11.1 Introduction

During the end of 2019, in the Wuhan province of China, numerous pneumonia cases were registered. In the preliminary stages of the infection the reason or the causal pathogenic microbe was not identified and was not isolated. On 30th January 2020, an emergency regarding public well-being was issued by the World Health Organization (WHO) that concerned different government on a global scale and identified the causal pathogen to be a virus that belonged to the *Coronaviridae* family (Peeri et al., 2020). Approximately 1.5 months later i.e., on 12th March the outbreak of the novel coronavirus or the COVID-19 disease was acknowledged as a global epidemic by the World Health Organization (Ducharme, 2020; WHO, 2020a). The order Nidovirales houses the coronavirus family which is additionally categorized into four different genera, namely, the alpha, beta, gamma and delta coronaviruses. The novel coronavirus belongs to the betacoronavirus group and was named as the SARS-CoV-2 (Severe Acute Respiratory Syndrome Coronavirus-2). The replication procedure of the SARS-CoV-2 is carried out in three different steps, the first objective of the viral strain is to attack or attach to an appropriate host at the cellular level, further, the viral strain inserts its genetic material into the cell of the host organism and finally utilizing the host cell capabilities to produce new virions (Pellett et al., 2014). The spike protein, envelope, protein membrane and the nucleocapsid are the four different structural proteins that constitute the morphology of the novel coronavirus (Wang et al., 2020d). The angiotensin-converting enzyme 2 is utilized by the novel coronavirus as the marker to bind to the host cell (Li et al., 2003; Zhou et al., 2020). This feature of the novel coronavirus spike protein enables the novel viral strain to penetrate the cells of the host organism and further use their particular mechanisms to produce further copies of themselves. Further analysis and studies were conducted to enumerate the aspect that the novel strain of the coronavirus is a recombinant one that includes the bat coronavirus and a coronavirus of an unidentified source (Ji et al., 2020; Malik et al., 2020).

In the preliminary stages of the novel coronavirus pandemic, different governments, on a global scale have enforced rigorous measures in order to recede the transmission of the disease. Measures, for example, social distancing, limitations in transport and

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movement and lockdowns have been effective in reducing the risks associated with COVID-19 (Jordan et al., 2020). The risks associated with the transmission of the novel coronavirus disease can be observed in a specific set of population and further, due to the increase in the death rates due to COVID-19 it is crucial to assess the risks associated with its transmission and strategies to counter such risks (Dryhurst et al., 2020). There are two aspects that determine a population's willingness regarding their co-operation to health-preserving behaviors in situations of crisis and in this case the COVID-19 pandemic. These aspects or factors include threat and risk assessment (Floyd et al., 2000). In simpler terms, the crucial step to manage risks associated with any sort of pandemic is to exactly analyze the risks associated with such pandemics (Dryhurst et al., 2020). This chapter aims to educate its readers with the different types of populations associated with the risks of transmission of COVID-19 and their probable management strategies that would provide a better insight in handling and curbing the spread of the novel coronavirus disease. This chapter also focuses upon different global standpoints for assessing and managing risks associated with COVID-19.

## 11.2 COVID-19 associated risks

The month of December in 2019 was the time when, the outbreak of the novel coronavirus began. Subsequently, the outbreak of the SARS-CoV-2 virus in the whole world became an unprecedented crisis for which the world was not prepared for. The death tolls have been high since the beginning of the year 2020 and the sternness of the disease increased at an alarming rate. Frontline defenders, such as doctors, nurses and other concerned authorities have been working tirelessly for limiting the transmission of the novel coronavirus infection. Since then various epidemiologists, researchers, virologists and meteorologists have been studying analyzing the viral strain of the SARS-CoV-2 in order to come up with an appropriate vaccination against the SARS-CoV-2. Several researchers have been also working towards assessing the risks associated with the transmission of COVID-19 virus. Several particular populations such as pregnant women, children and people of young age have been considered to highlight the risks associated with such population. The upcoming sections in this chapter will also enumerate the occupational risks and environmental or climatic risks associated with the transmission of COVID-19. Fig. 11.1

### 11.2.1 COVID-19 risks in particular populations

The onset of the novel coronavirus outbreak has raised serious concern issues in pregnant women regarding its transmission control and prevention and the probable risk of vertical transmission. Studies and more detailed researches are the need of the hour in order to develop accurate and effective clinical and preventive strategies. In one study by (Qiao, 2020) it was stated that SARS infection in pregnant women tends to rather serious complications such as unprompted miscarriage, delivery before due date,

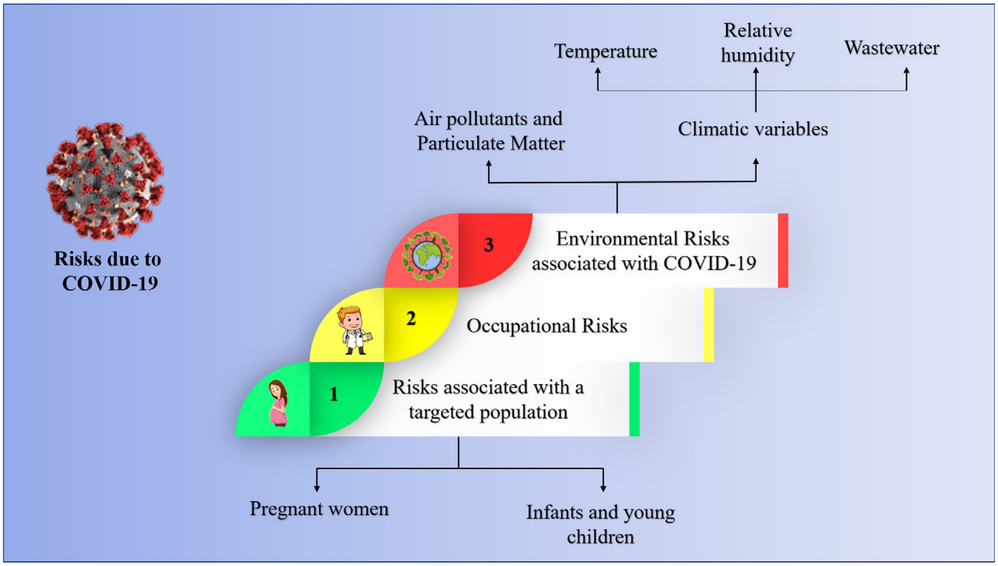


**Fig. 11.1** ***Risks due to COVID-19.***

intrauterine growth restriction, application of endotracheal intubation, renal failure and neonatal complications (Lam et al., 2004; Wong et al., 2004). Further it was established in the study that the complications faced by prenatal women affected with COVID-19 disease causing SAR-CoV-2 viral strain exhibited rather less complications than SARS-CoV-1 infection. To further understand the concept of risks associated between spread of the novel coronavirus disease and pregnant women it is mandatory to comprehend the clinical features of COVID-19 in a prenatal or pregnant woman and the intrauterine vertical transmission of COVID-19 in pregnant women. A research conducted by (Chen et al., 2020a) consisted of approaches such as scrutiny of medical records, laboratory test results and computerized tomography scans of the chest area. Such scrutiny was conducted upon pregnant women with confirmed COVID-19 pneumonia infection. The indications for intrauterine vertical transmission was analyzed in samples such as amniotic fluid, blood samples from umbilical cord and neonatal throat swab samples and breastmilk samples prior to first lactation. These samples were analyzed for the presence of SARS-CoV-2 strain. Subsequent to all the analysis and tests performed it was elucidated that the clinical characteristics of COVID-19 pneumonia in pregnant women are homologous to the clinical characteristics of COVID-19 pneumonia acquired by non-pregnant women and other adults. Further, women exhibiting COVID-19 symptoms in the latter stages of pregnancy did not exhibit any proof of intrauterine vertical infection.

The aspect of COVID-19 infection in children or infants is a lesser explored area. As the paediatric data corresponding to severe COVID-19 symptoms is limited, a study by (Graff et al., 2021) aims to determine all the risk factors associated with COVID-19 transmission in children and young people. In the United States of America approximately 12 percent of the total COVID-19 positive cases that roughly estimates to about 1.3 million cases were reported in children as of early December 2020 (American Academy of Pediatrics, 2020). Studies by (DeBiasi et al., 2020; Parri et al., 2020) emphasizes upon the fact that clinical characteristics due to COVID-19 infection is milder in children when compared to the clinical characteristics of COVID-19 in adults. Moreover, depending upon the severity of the infection, a broad range of illnesses can be seen in children that range from asymptomatic infection to severe respiratory tract ailments to complications due to severe inflammations (Abrams et al., 2020; Cheung et al., 2020). The study by (Graff et al., 2021) specified the risk factors involved in COVID-19 transmission, corresponding to some particular comorbid conditions such as asthma, diabetes and obesity. The final results of this study established a direct link between the prevalence of the aforementioned comorbid factors to that of higher risks in getting infected with the novel coronavirus disease causing SARS-CoV-2.

### 11.2.2 Occupational risks due to COVID-19

Most of the cases regarding the COVID-19 infection are directly linked to exposure at work or commonly termed as occupational risks. As the zootonic COVID-19 virus has crossed species barrier to infect humans, the fact that this SARS-CoV-2 viral strain will affect the occupational class first is evident. The SARS-CoV-2 virus in the most preliminary stages of the outbreak have affected the people working in the seafood and meat sectors in Wuhan (Koh, 2020). In these unprecedented times COVID-19 or the novel coronavirus disease stands tall as a difficult challenge to combat, especially for occupational health. Workers or people of different occupational class are at constant danger of getting infected. In this modern-era there are numerous jobs that requires a person to meet new people or stay in the vicinity of other individuals or a group. This enforces an individual to come in direct contact to them, hence exposing the particular individual to a risk of exposure. Businesses, tour guides, travel and transport personnel, people working at offices, restaurants and fast food shops and courier delivery are to name a few occupations that consists of high risks of COVID-19 transmission and infections. On the contrary, flexibility of many occupations has been extended so that individuals could work from home. This initiative of working from home, to some extent has reduced the rate of COVID-19 transmission (Burdorf et al., 2020).

Another aspect of COVID-19 transmission has been covered in people who pursue ophthalmology as a profession. Ophthalmologists are subjected to tedious hours of dealing with patients that require them to be in close contact. This increases the risk of ophthalmologists to be exposed to aerosols or respiratory droplets from infected individuals, during a slit-lamp examination procedure. Conjunctivitis as an ailment has been reported as a symptom in SARS-CoV-2 infected individuals (Güemes-Villahoz et al., 2020; Ozturker, 2020). Although the prevalence of the SARS-CoV-2 viral strain is evident in conjunctival fluids or tears, the transmission of the novel coronavirus through the conjunctival fluid remains a bigger concern and requires immediate attention (Kuo and O'Brien, 2020).

The tracking of the total COVID-19 cases has been going on all over the world and the aspect of different types of workers contributing to the number of positive infection cases is less addressed. Frontline workers who are directly associated with the treatment of patients infected with the SARS-CoV-2 are also in the verge of getting exposed to the virus. This aforementioned statement brings focus to the vitality of the safeguard, mental and physical well-being of a frontline worker. These said factors of a frontline worker determine a nation's capabilities in order to manage situations of pandemics and in this case the novel coronavirus outbreak. To ensure the safeguard and the mental and physical wellness of a frontline worker some small measures such as provision of personal protective equipments, face masks, face shields and sanitizers etc. and proper counseling can be provided (Sim, 2020).

### 11.2.3 Environmental risks due to COVID-19

Air quality, atmospheric particulate matter, climate conditions and wastewaters are some of the important environmental factors that govern the environmental risks associated with COVID-19 transmission. The following subsections would discuss all of the aforementioned aspects in detail.

#### *11.2.3.1 Air quality and atmospheric particulate matter as mediators for COVID-19 transmission*

Air quality has improved post lockdown measures due to restrictions in industrial processes and reduction in fossil fuel emissions (He et al., 2020). In continents such as Asia, Europe and North America, primary pollutants such as Nitrogen dioxide ($NO_{2,}$) Particulate matter (PM 2.5 and PM 10) and black carbon ($CN^{-}$) levels have seen a rapid decline. Also the ozone levels have increased to approximately 50 percent (Tobías et al., 2020). Major cities across the globes have registered a great decline in the air pollutant levels when scrutinized through NASA satellites and the European Space Agency (ESA) (Dutheil et al., 2020; Nelson, 2020). Improvement in the air quality has generated major health benefits as they directly corelate with the transmission of COVID-19. On the contrary, the resume in the day to day and major economic and industrial activities and the uplifting of restrictions due to the lockdown measures, it has been perceived that the levels of greenhouse gases and major air pollutants are still on the rise which will ultimately have a negative impact upon human respiratory health and will promote COVID-19 transmission (SanJuan-Reyes et al., 2021). A hypothesis formulated by (McNeill, 2020) states that the novel coronavirus has the capability of attaching to particulate matter. This drastically improves the prevalence of the novel coronavirus strain in atmosphere. This association of SARS-CoV-2 with the particulate matter also makes the virus to diffuse precisely through air. This hypothesis has been proven to be accurate in studies of (Zhu et al., 2020a, 2020b) as it states that exposure of particulate matter to the novel coronavirus strain facilitates in the transmission of the virus. On the contrary, studies by (Bontempi, 2020; Setti et al., 2020) state that no correlation has been observed between COVID-19 transmission and its exposure to particulate matter. However, upon extensive researches, while considering air quality and the novel coronavirus's exposure to particulate matter or air pollutants as an environmental aspect, several studies have found a positive correlation between the air pollutants or particulate matter and transmission of the novel coronavirus (Dutheil et al., 2020; Chen et al., 2020b). It can be concluded from the aforementioned aspects that further studies and researches are required to evidently highlight the dominions that govern the routes of diffusion and the spread of the novel coronavirus. Some of the unexplored aspects include examples such as geophysical and climatic characteristics of an area and the association of the population residing in the study area and the levels of atmospheric pollutants over the study area (SanJuan-Reyes et al., 2021).

#### *11.2.3.2 Climate conditions posing as a potential risk factor*

The climatic conditions such as temperature, wind speeds, precipitation and relative humidity can play a critical role in transmission of the novel coronavirus. Ambient temperature as a climatic factor is very essential for the survival of all species in the planet. Ranging from smaller microbes residing in hot springs to sea creatures in the depths of an ocean, ambient temperature plays a very crucial role in their survival. Several studies have evidently correlated the relationship between ambient temperature and relative humidity to the transmission of the novel coronavirus disease or more commonly known as the COVID-19 disease. One such study by (Tobías and Molina, 2020) exhibit that the ambient temperature rather has an negative correlation to the spread of COVID-19. In simpler terms, the rise in ambient temperature negatively impacted the prevalence of the SARS-CoV-2 virus. An incidence rate was inferred in this study which clearly exhibited that 1 °C rise in the ambient temperature exhibited a 7.5 percent decline in the SARS-CoV-2 transmission. Other studies conducted have considered temperature and humidity simultaneously to be compared with the SARS-CoV-2 prevalence. One such study was presented by (Wang et al., 2020b) in which environmental factors i.e., temperature and humidity were considered simultaneously for COVID-19 transmission risks. The study clearly stated that 1 °C rise in ambient temperature saw a decline in the effective reproductive number value associated with the novel coronavirus and the association between COVID-19 transmission and relative humidity was deemed unsubstantial. Other studies supporting the fact that increase in the ambient temperature brigs down the prevalence of the novel coronavirus has been published (Bhattacharjee, 2020). On the contrary, the prevalence of the novel coronavirus was reported the most at temperatures ranging from 0 °C–4 °C and the least survivability was observed at temperatures exceeding 70 °C (Chin et al., 2020). In a study by (Wang et al., 2020c) explored the correlation between COVID-19 survivability and temperature rise. It stated that a decline in 0.86 percent COVID-19 positive cases were recorded for 1 °C rise in temperature. It is probably evident from a study conducted by (Rouen et al., 2020) that an increased ambient temperature dampens the spread of the novel coronavirus and lower atmospheric or ambient temperatures promote the novel coronavirus. Hence, it could be concluded that lower ambient or atmospheric temperatures pose a greater risk of COVID-19 transmission.

A comparative study conducted by (Feng et al., 2020) considered two of the most crucial aspects of the environment that has a serious impact upon the novel coronavirus or COVID-19 transmission. These aspects included wind speed and relative humidity. The impact upon aerosol transport due to different wind speeds is a complex concept and is dependent upon dynamics such as wake flow patterns, localized secondary flow intensities amidst two humans and the steadiness of the wind. Moderate and high levels of relative humidity were also considered in this study. A 99.5 percent relative humidity exhibited a lesser risk of exposure to SARS-CoV-2 aerosols when compared to a relative humidity of 40 percent. In a tropical country such as Brazil, relative humidity and ambient temperature have impacted the transmission of COVID-19. In tropical settings higher mean temperatures coupled with moderate relative humidity levels. i.e., approximately 80 percent, promote the transmission of the novel coronavirus (Auler et al., 2020). A study conducted in the Wuhan province of China estimated the relationship between the COVID-19 mortality rates and concluded that a negative correlation exists amidst the novel coronavirus transmission and temperature whereas the COVID-19 transmission increases with the increase in diurnal temperature range (DTR). The correlation between COVID-19 transmission and low humidity conditions were also sketched out in this study which clearly emphasized upon the fact that low humidity conditions represent as a potential risk factor as they support the transmission of COVID-19 disease (Ma et al., 2020). The fact that higher temperatures and high relative humidity levels can curb the transmission of the novel coronavirus disease is evident and has been proved in the study of (Sarkodie and Owusu, 2020). In this same study a brief emphasis upon precipitation and dew/frost point, as an environmental factor has been given. According to this study, precipitation and dew/frost point can act as confounders of COVID-19 transmission. As higher rates of precipitation bring down the ambient temperature levels, it is rather plausible to conclude that the novel coronavirus transmission will speed up.

#### *11.2.3.3 Wastewater as an environmental risk factor*

During the most preliminary stages of the outbreak of the novel coronavirus, early researches exhibited that the transmission of the novel coronavirus is primarily dependent upon aerosols secreted from a SARS-CoV-2 infested individual. These aerosol secretion or other body fluids from an infected person may come in direct contact with a healthy individual. However, conversely stating, the novel coronavirus strain remnants have been reported in human stool samples and human urine samples (Holshue et al., 2020; Pan et al., 2020; Xiao et al., 2020; Zhang et al., 2020). In a few nations for example, Australia, Netherlands and Italy few studies have specified the prevalence of the novel coronavirus in the stool samples of individuals who were confirmed with COVID-19 infection. Such samples were found in the untreated wastewater and exhibited probable transmission of the virus via faeces (Ahmed et al., 2020; La Rosa et al., 2020; Medema et al., 2020). According to the reports of the World Health Organization (WHO) sewage and drinking water still does not pose as a potential source of COVID-19 transmission (WHO, 2020b). Several studies and hypothesis have been evident enough to exhibit the prevalence of the novel coronavirus that could exceed from few hours to several days. Unprocessed wastewater or household waste from sources where the COVID-19 infection was prevalent may act as a potential source to the transmission of the novel coronavirus and may also contribute towards its community transmission. Considering wastewater as the potential source of the novel coronavirus disease transmission and public-health related issues a consequence, several studies have been reported that evaluate wastewater the possible means to transmit COVID-19 (Daughton, 2020a, 2020b; Sims and Kasprzyk-Hordern, 2020). An efficient strategy that provides early warnings related to infectious disease transmission and outbreak is the Wastewater-based Epidemiology (WBE). This strategy aims to locate the point source of transmission, recognize the potential transmitters and provide effective early warnings. WBE can also act as a potential pandemic surveillance system if linked with an effective response tool (Daughton, 2020a, 2020b; Mao et al., 2020). The working of the WBE involves analyzing the biochemistry markers in untreated and unprocessed wastewater, examples of such biomarkers include, fragment biomarkers for the novel coronavirus. This could be achieved by the application of clinical diagnostic test to the signature collective of entire communities (Daughton, 2020a, 2020b; Venugopal et al., 2020).

## 11.3 COVID-19 risk management: a global perspective

### 11.3.1 Korea

The COVID-19 risk management in nation of Korea was held out in 4 specific sets of lockdowns that existed from 20th January 2020 to the end of May in 2020. Specific strategies such as wide-spread testing of individuals, contact tracing and tracking via the integration of bluetooth and GPS technology and appropriate quarantine and treatment measures have helped Korea to curb off widespread community transmission. During the onset of the COVID-19 outbreak the Korean Centre for Disease Control set up the "Task Force for COVID-19". The SARS-CoV-2 crisis levels were given a specific color code. The news of the COVID-19 outbreak forced authorities to begin monitoring for any pneumonia cases. The crisis was color coded as "blue (Attention)" when there were no cases found. When the first COVID-19 case was reported in Korea the crisis level was color coded as "yellow (Caution)". When an individual was suspected with possible COVID-19 infection, a basic epidemiological survey was conducted the local health related authorities. Further an individual exhibiting body temperature greater than 37.5 °C or any respiratory ailment were quarantined immediately. The first individual who exhibited such symptoms and therefore being a potent carrier and transmitter of the virus was immediately isolated and another individual who exhibited possible symptoms of COVID-19 was isolated and was scrutinized by health authorities. In the preliminary phases of the lockdown in Korea a statutory body known as the "Central Disease and Safety Countermeasures Headquarters" was established whose sole aim was to curb off the community transmission of COVID-19 by following appropriate protocols and deal with every incoming passenger in Korea. The Korean government following their set of protocols were easily able to distinguish between symptomatic and asymptomatic patients and were successfully able to restrain the spread of the virus up to a great extent through cooperation with medical institutions. Further, the Korean government in the second phase of lockdown were able to track 104 positive cases of COVID-19 and "super spreader" cases. Upon the identification of super spreader cases, the crisis levels were raised to "orange (Alert)" and "red (Serious)". Measures such as mass testing were conducted and drive-throughs and COVID-19 safety booths (Walk-through centers) were established. Further digital tools for tracking and analysis of COVID-19 were enforced by the government. Social distancing and the utilization of personal protective equipments (PPEs) were the standard measures that were enforced in all of the phases of lockdown. The digital tools utilized by the Korean government would send emergency alerts via text messages that would show the locations which an individual with affirmed SARS-CoV-2 infection had visited. Also, via monitoring digital handshakes, such tools could notify an individual that whether they have been in contact with an healthy or infected individual (Kim and Ashihara, 2020).

### 11.3.2 The European Union

The European Union for solving the crisis of has a priority-based approach. The leaders of the European Union came into agreement upon the following sets of priorities which included public health and well-being transport and travel, research and development strategies and programs, crisis management, and education. The European Centre for Disease Control a statutory body, emphasized upon restrictions in border movements to control the spread of the novel coronavirus. This measure was initially enforced for 30 days and later it kept getting extended due to elevating crisis (Chinazzi et al., 2020). Apart from this, supply of PPE kits in medical institutions and hospitals were ensured by the leaders of the European Union. Research regarding COVID-19 vaccine development and small scale businesses to support the overall economy was also supported by the European Union (Goniewicz et al., 2020).

### 11.3.3 China

As the novel coronavirus outbreak spread throughout the world, China has been successfully managing the risks associated with the virus transmission. The Chinese universities have made an impeccable influence regarding the pandemic issue. Health rescue unit formation, mental health maintenance, staff mobility control etc. were the primary domains where risk management approaches were enforced. The role of Chinese medical universities in the prevention and control of the COVID-19 outbreak has been significant. Although the enforced approaches have been successful in mitigating the COVID-19 transmission, severe exposure risks were faced by the health rescue units including frontline workers (Zhang et al., 2020b). All these issues and risks were addressed in an appropriate manner and further more befitting approaches were enforced to mitigate the risks associated with the novel coronavirus transmission (Wang et al., 2020a).

## 11.4 Conclusion

The outbreak of the COVID-19 disease has brought day to day life activities at halt. Severe impacts upon industrial and business operations have been seen due to the imposed lockdown measures. Small scale workers and professionals have incurred heavy losses due the onset of the novel coronavirus pandemic. On the contrary, the imposed measures for have proved to be useful in the mitigation of the novel coronavirus transmission and the risks associated with it. It is crucial to assess different types of risks that might be associated with the transmission of the novel coronavirus as it would facilitate to a great extent the frontline workers and health professionals to combat its spread. There are specific population targets who are in the crosshairs of SARS-CoV-2 exposure, all of which has been enumerated in this chapter. Environmental aspects also play a significant role in risks of exposure to the virus. Aerosols, particulate matter and air pollutants specifically enhance the risk of exposure to COVID-19. Lockdown measures, enforced by governments of different nations have, to a great extent, helped in the improvement of air quality as the automobile emissions and industrial activities were restrained. Poor air quality plays a major part in the transmission of COVID-19 as it has been evidentially stated that the novel coronavirus tends to bind to particulate matter. The risks associated with COVID-19 is numerous and an international perspective on how to manage these risks are enumerated.

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CHAPTER 12

# Case studies on COVID-19 and environment

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## 12.1 Introduction

Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) causes coronavirus disease called COVID-19 that had been initially detected in Wuhan of China in December 2019 (WHO, 2020). COVID-19, an infectious disease, rapidly spread over 219 countries, and WHO declared it as a pandemic on 11th March 2020. People's mobility has influential impacts on the fast-spreading of pandemics. Initially, Wuhan was a major source of infection, and therefore, the majority (57 percent) of early cases outside of Wuhan had a renowned travel history to Wuhan (Kraemer et al., 2020). Several studies suggest that human interactions and behavior contribute to the unfold of infectious diseases, especially in the course of pandemics (Belik et al., 2011; Funk et al., 2010; Yan et al., 2018). The risk of transmission of infectious influenza and coronaviruses increases with travel duration and seating proximity to index cases (Browne et al., 2016). Influenza or COVID-19 spreads from human to human through sneezing, coughing, or touching contaminated surfaces (Hotle et al., 2020), while the SARS-CoV-2 may live for many days on surfaces (Gray, 2020) and might be mobile for up to 3 h (Harvard Medical School, 2020). People are often exposed to SARS-CoV-2 at locations where they visit to accomplish their daily activities like school, libraries, workplaces, restaurants, clinics, and hospitals.

To control the spreading of SARS-CoV-2, policymakers implemented some successful interventions such as inter-countries/states travel ban (Gostin and Wiley, 2020), stay-at-home (Engle et al., 2020), social-distancing, curfews, and lockdown (Gostin and Wiley, 2020; Vos, 2020). During a pandemic, few policies may alter a person's travel behavior and will promote public health, e.g., policies inspiring people to be a lot proactive concerning their health, furthermore instructions for self-quarantine may scale back a person's travel once sick and, therefore, may scale back the unfold of the sickness among mass people (Hotle et al., 2020). Reducing the activity of the less-social group and cross-group interaction are foreseen to be the foremost economical ways for dominant the pandemic potential within the case as this group constitutes the bulk of travelers (Apolloni et al., 2014). The travel restriction, implemented in China substantially, that successfully mitigated the spread of COVID-19 (Iken et al., 2020; Kraemer

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et al., 2020). The successful case of travel restriction in China encourages this intervention to be implemented in other countries. Various control measures remarkably affected the travel behavior of the people (Abdullah et al., 2020; Saadat et al., 2020).

Social-distancing, stay-at-home, lockdown, and travel ban are the most common control measures throughout the world which were rapidly implemented globally to restrict the fast spreading of COVID-19. These interventions reduced the travel demand using public transport and people were more inclined to work from home and use private modes of transport (Vos, 2020). Social-distancing would possibly drop travel demand because of remote working, e-learning, and reduced public tasks. In the transport sector, a pandemic caused a reduction in total mileage production of more than 70 percent compared to the pre-pandemic situation (Ruffino et al., 2020). The public transport is probably unable to maintain the social distance. Therefore, governments banned inter-cities/countries traveling and public transport to reduce spreading (Gostin and Wiley, 2020). Travelers would possibly avoid public transports as these could be thought of as a birthplace for viruses and places wherever it would be tough to avoid contact with different passengers (Troko et al., 2011). To maintain the social-distancing and avoid crowd, active traveling (walking and cycling) can be important ways for short-distance traveling (Vos, 2020). New York's Citi Bike experienced a 67 percent increase in visits between first to 11th of March 2020 compared to the identical period in 2019, and ridership in Chicago was doubled within the same period (Eby, 2020). High level publicity of stay-at-home substantially reduced the individuals' travel during the COVID-19. Stay at home order caused reduced travel by 7.87 percent in the USA (Engle et al., 2020). At the end of the march in 2020, people restricted themselves from traveling to save from COVID 19 in the USA, that reduced 87 percent of ridership demand in the subway as compared to 2019 (Eby, 2020).

In COVID-19, anxiety and fear of infection that outbreaks through social media significantly decreased people's mobility. A pandemic MERS in 2015 reduced the number of trips and transits, and tourists avoided subways and inclined to bus as less crowded modes of traveling in Seoul of South Korea due to the fear of infection (Kim et al., 2017). Moreover, people avoided shared mobilities (Eby, 2020), outdoor trips (Balkhi et al., 2020), and locations within which they perceived medium to high risk (Hotle et al., 2020). The SARS-CoV-2 substantially affected people's consumptions along with travel behavior. With social-distancing and perceived health risks in mind, many people turned to online shopping for groceries and foods, and other needs in Australia (Beck and Hensher, 2020) and in U.S. (Chip, 2020; Li et al., 2020; Wright and Blackburn, 2020). SARS-CoV-2 caused very steep changes in the grocery shopping practice within the U.S. The demand for online-shopping has surged due to COVID-19. Instacart's subscriptions for online delivery service increased by 10–20 times in US, and Hema's online orders were increased to 220 percent at the time of Chinese New Year, once COVID-19 started spreading (Wright and Blackburn, 2020). People avoided public gatherings, and therefore, physical shopping. To fight against COVID-19, individuals are more likely to rely on virtual platforms to reduce the risk of infection.

Few studies advise working from home (i.e., limiting home-based work trips), and reduced consumption (i.e., limiting home-based shopping trips) as effective mitigation policies for COVID-19 (Jones et al., 2020). Working from home, virtual teaching-learning, and job losses extremely affect travel activities (Beck and Hensher, 2020). People's travel behavior has been drastically changed to adapt to the control measures of COVID-19. To avoid the catching-up of COVID-19, people adjust themselves with the pandemic culture which develops adaptive travel behavior **(ATB)**, e.g., travel mode choice, remote working, virtual teaching-learning, and online shopping. People look at safer travel modes (e.g., personal vehicles) to avoid infection by touching and proximity of seating. People re-schedule and/or postpone their daily travel to save themselves from infection with safety and social distancing. Both short- and long-distance travel are reduced significantly resulting from the restrictions on public gathering, transport, aviation, and perceived health risks. COVID-19 declines traveling and the number of trips that reduces fuel utilization contributing to climate change mitigation (CCM). Thus, they subconsciously reduce GHG emission. After all, the control measures of COVID-19 and ATB significantly contribute to the reduction of air pollution.

To keep in mind, some studies investigated air quality in different parts of the world. Pollution is decreased in countries tormented by COVID-19, like China, Italy, Asian Nations, and Spain as industries, aviation, and alternative means that of transportation were stopped. In India, the measures of COVID-19 improved the air quality near transport and industrial hubs by about 60 percent (Mahato et al., 2020). In Spain, lockdown reduced the concentration of black carbon to 50 percent (Tobías et al., 2020). Besides, few studies investigated the air quality and GHG emissions from travel restriction and reduced economic activities. The GHG emission and people's mobility are reduced, which enhances air quality and stimulates wild animals to come out and explore the cities (Jauregui, 2020). Mobility ban partially reduced Air Quality Index (AQI), CO, and PM 2.5, while the decrease in SO2, NO2, and PM10 were significantly mediated (Bao and Zhang, 2020). Reduced financial activities and mobility restrictions decreased fossil fuel utilization and GHG emission in China (Wang and Su, 2020). The COVID-19 pandemic has minimal impact on the 1.5 °C target of the ambitious Paris Climate Agreement (PCA) (Forster et al., 2020). A drastic reduction in traffic due to lockdown caused a notable pollution reduction (75 percent) in Madrid and Barcelona (Baldasano, 2020). Cars, trucks, buses and two- and three-wheeler road vehicles account for pretty much three-quarters of GHG production from transport (IEA, 2020). Lockdown reduced air pollution in Trabzon by 20 percent (Kara et al., 2020).

CCM associated with ATB is a vibrant research area with direct and indirect links to sustainable mobility and transport planning regarding pandemics. CCM is excessively dominated by the studies on supply-side vehicle technology and fuel switching as the central theme for this sector (van Sluisveld et al., 2016), and policy interventions (Creutzig, 2016; Zhang, 2020). Previous studies have looked at the spreading of COVID-19, control measures, and impacts of control measures on the travel behavior, e.g., mode shifting, remote working. From CCM perspectives, COVID-19 reduces global air pollution having witnessed China's lesser-polluted cities, wildlife wandering into Welsh villages, and seabirds returning to Venice's cleaner canals (Friend, 2020). Some studies investigated air pollution as a result of control measures of COIVD-19. While there have been many researches on the spreading, control measures, impact on transport and health, the contribution of ATB on CCM has been studied to a very limited extent. Therefore, this study aims to explore the effects of COVID-19 on the reduction of GHG emission in the context of ATB and travel reduction in south Asian countries.

The remainder of this paper is organized as follows. The next section presents the methods, which include details of the questionnaire survey that was conducted to collect required data and methods for the estimation of emission. Then the results obtained through statistical analyses are discussed. This is followed by the discussion. Finally, conclusions and recommendations for further studies are presented.

## 12.2 Methods

### 12.2.1 Sample collection

An online survey was conducted to collect the travel behavior data through the month of May 2020 focusing on the pre-pandemic situation and during COVID-19 in south Asian countries, i.e., Bangladesh, India, Pakistan and Sri Lanka. The target population of the survey included retired persons, students, employees, and businessmen. Total 545 responses, i.e., Bangladesh (167), India (64), Pakistan (130), and Sri Lanka (183) were obtained through an online survey from the targeted countries. The proportion of samples is shown in Fig. 12.1. Sri Lanka and Bangladesh have the maximum proportion of responses among the four countries. In order to collect the data, a snowball sampling technique was adopted. The questionnaire was sent using Email, Facebook Messenger, Line, Viber, WhatsApp and imo as google survey link. Details of the data collected can be found at Abdullah et al. (2020).

### 12.2.2 Travel data

For each respondent, this study considers only roadway transportation and the main purposes of the trips, e.g., work, study, shopping, social activity, recreation, and other purposes. Cross-boundary and air travel were not included in this survey. The participants were asked to specify the modes of travel, trip length, and trip frequency in a week to capture the travel choices. Also, participants were asked to specify the preferred modes choice before and during the pandemic situation. Travel behavior data were differentiated into two categories, i.e., travel behavior before spreading of COVID-19, and travel

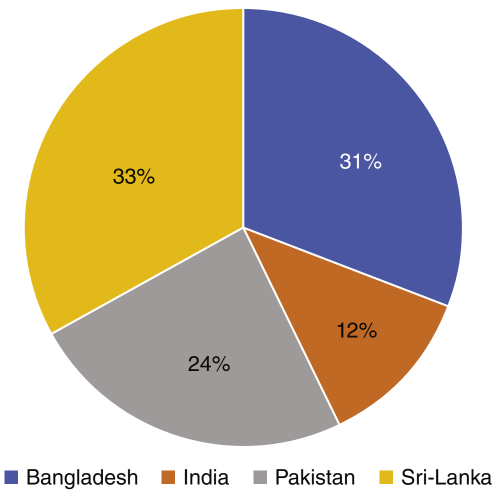


**Fig. 12.1** Proportion of samples from different countries of south Asian region.

behavior during COVID-19. Data on sociodemographic variables such as age, income, education, vehicle ownership, and marital status were also collected. Travel characteristics were extracted by trip length for the different transport modes. The trip length was multiplied by the number of trips to get the total distance traveled. The number of trips was taken as an average of the range to avoid the effects of overestimation on the emission. For instance, if the number of trips falls in the range of 2–4, the average number of trips were 3. As the starting point of these investigations, the authors analyzed the data collected through an online questionnaire survey in several countries to explore the factors, i.e., travel distance, number of trips, and mode choices behavior, that could contribute to the CCM, directly or indirectly in the presence of sociodemographic variables.

### 12.2.3 Emission calculations

Emission factors were used to convert the travel distance to GHG emission for different modes of travel such as public transport (train, bus), car, taxi, motorcycle, rickshaw, tuktuk, bicycles, walking, and so on. This study considered direct emission from the modes of transport, for example, burning of fuels. Active travel modes (i.e., bicycle, rickshaw, and walking), that produce emission indirectly from the consumption of foods, are considered to contribute zero-emission. A rickshaw is a three-wheeler non-motorized vehicle and is shared by two-person. Tuktuk is a gasoline/diesel fired three-wheeler. The collected data focused on the distance traveled by modes for each person. This investigation compared the GHG emission before and during the COVID-19. Country-wise emission factors are not available. Therefore, IPCC 2006 default emission factors are used to estimate the major GHG emission, i.e., $CO_2$, $CH_4$, and $N_2O$, Table 12.1. USEPA (united states environmental protection agency) emission factors have been

**Table 12.1** Emission factors for different modes of travel in terms of vehicle-mile unit.

| Modes of Travel | $CO_2$ (kg CO2/ vehicle-mile) | $CH_4$ (g CH4/ vehicle-mile) | $N_2O$ (g $N_2O$/ vehicle-mile) |
|---|---|---|---|
| Walking | 0 | 0 | 0 |
| Bicycle | 0 | 0 | 0 |
| Rickshaw | 0 | 0 | 0 |
| Motorcycle (gasoline fired) | 0.167 | 0.070 | 0.032 |
| Car/Taxi (gasoline/diesel fired) | 0.364 | 0.031 | 0.032 |
| Tuktuk | 0.364 | 0.031 | 0.032 |

Source: IPCC 2006 default EF; UNFCCC; USEPA.

**Table 12.2** Emission factors for different modes of travel in terms of passenger-mile unit.

| Modes of Travel | $CO_2$ (kg CO2/ passenger-mile) | $CH_4$ (g CH4/ passenger-mile) | $N_2O$ (g $N_2O$/ passenger-mile) |
|---|---|---|---|
| Public transport (bus) | 0.107 | 0.0006 | 0.0005 |
| Public transport (metro/trams/subway) | 0.163 | 0.004 | 0.002 |
| Public transport (equivalent or average) | 0.135 | 0.0023 | 0.00125 |

Source: IPCC 2006 default EF[1]; UNFCCC[2]; USEPA[3].
[1]Intergovernmental Panel on Climate Change.
[2]United Nations Framework Convention of Climate Change.
[3]United States Environmental Protection Agency.

used to obtain the emission factors in the passenger-mile unit as shown in Table 12.2. Other GHG gases are produced in a very little amount that is why the authors relied on $CO_2$, $CH_4$, and $N_2O$.

For this study, the data was not collected on the absolute size of the vehicles. We assume medium size gasoline car/taxi. The normal occupancy for the private car and suv is 1.4, and maximum occupancy is 4 for car and 5 for suv (Mathez et al., 2013). This study assumed single occupancy for the private car, taxi, tuktuk, motorcycle and rickshaw due to social-distancing, and risk perception of users. Hence, vehicle-mile is equivalent to passenger-mile. In the study area, the main public transport is bus, train, and metro. So, an equivalent (average) emission factor for the public transport in terms of bus and metro was derived from the emission factors of bus and metro. Emission factors were expressed in terms of the passenger-mile unit for public transport using Eq. (12.1), and vehicle-mile unit for private vehicles such as cars/taxis and motorcycles using Eq. (12.2). The emission factors are given in Table 12.1 & Table 12.2.

$$E = PMT * \left[ EF_{CO_2} + 0.021 * EF_{CH_4} + 0.310 * EF_{N_2O} \right] \tag{12.1}$$

$$E = VMT * \left[ EF_{CO_2} + 0.021 * EF_{CH_4} + 0.310 * EF_{N_2O} \right] \tag{12.2}$$

**Table 12.3** Global warming potential for time range defined by UNFCCC.

| Period (Years) | $CO_2$ | $CH_4$ | $N_2O$ |
|---|---|---|---|
| 20 | 1 | 56 | 280 |
| **100** | **1** | **21** | **310** |
| 500 | 1 | 6.5 | 170 |

Where,

E: total CO2 equivalent emission

PMT: passenger-miles traveled

VMT: vehicle-miles traveled

EF: emission factor

0.021 & 0.310: conversion factors to $CO_2$

### 12.2.4 Global warming potential

To check the comparative and an aggregated climate impacts of greenhouse gas emission, an emission metric is employed of various species such as $CO_2$, $CH_4$, and $N_2O$ (Aamaas et al., 2013b). For example, the global warming potential (GWP) is developed in the Kyoto Protocol to produce an "exchange rate" between $CO_2$, $CH_4$, and $N_2O$. The metric is applicable in its original form or normalized the other gases to the base carbon-dioxide. The selection of time range, the form of the metric, and pulse or sustained emissions governs the ultimate climate impact. The main characteristics of using the emission metric are the end-point (i.e., forcing or temperature), the kind of emission profile (i.e., pulse, sustained, scenario), and therefore the time range (i.e., 20, 100, 500 years) (Aamaas et al., 2013a). Pulse-emission refers to check impact for a single year. Moreover, sustained-emission refers to study the climate impact for a long period of time horizon. This study used UNFCCC (united nations framework convention on climate change) emission metrics as shown in Table 12.3.

## 12.3 Results and discussions

The study area includes Bangladesh, India, Pakistan, and Sri Lanka. These countries have some sort of similarities in the transportation system, lifestyle, and cultures. The transport modes are rickshaw, auto-rickshaw, tuktuk, bus, taxi, car, and train in the study area. The public transport cover bus and train. There were 545 responses from these four countries. This investigation considered only the main purposes of travel of respondents, e.g., work, study, shopping, social activities, recreation, and family needs. Family needs included grocery shopping, visiting parents and siblings. COVID-19 is causing disturbance across the world, inflicting worldwide health emergencies and imposing economies to bog down that is attributable to the strict quarantine measures. Moreover, the spreading of pandemics intriguingly affected our living sphere. The GHG emission was estimated using Eq. (12.1) and (12.2). Factors explained in Table 12.1 and

Table 12.2 were used for the calculation of emission for different modes of transportation. GWP was considered for 100 years that was defined by the UNFCCC and shown in Table 12.3. The climate impact of ATB is illustrated in the following subsection.

### 12.3.1 Change in main travel purposes

The main travel purposes were investigated to explore the travel choice behavior of people. COVID-19 significantly affected the travel choice for main travel purposes. The main travel purposes in pre-pandemic and during the pandemic are shown in Fig. 12.2 and Fig. 12.3. In the pre-pandemic situation, the respondents identified several activities

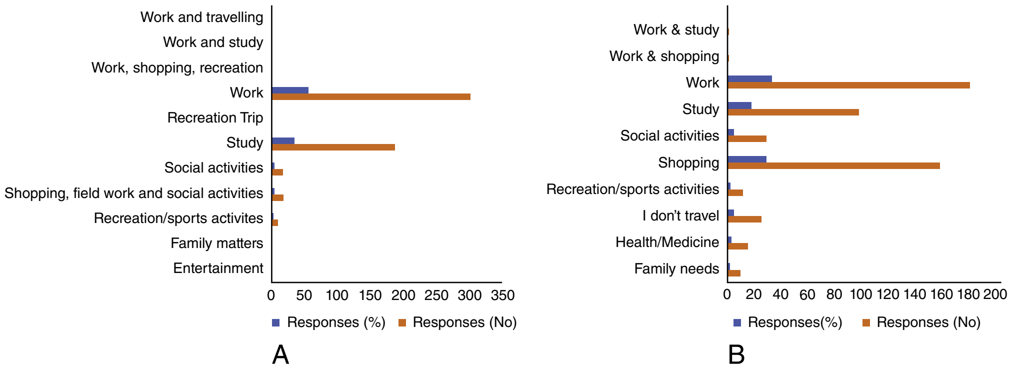


**Fig. 12.2** Adaptation in main travel purposes. (a) before COVID-19; (b) during COVID-19.

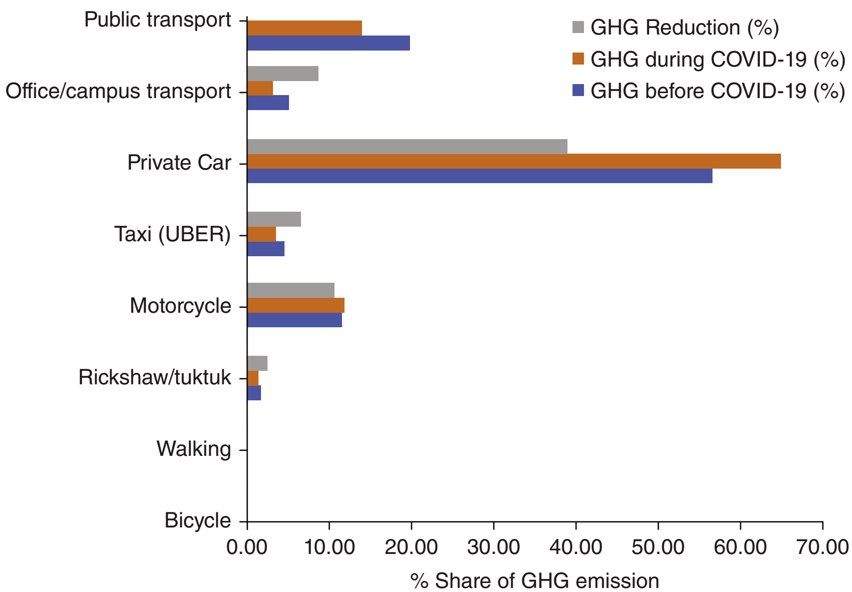


**Fig. 12.3** Contribution of different modes of travel in the reduction of GHG emission.

as their main purpose of travel, i.e., work, study, shopping, social activities, recreation and family needs. Most of the respondents defined work (56.15 percent) and study (34.68 percent) as the main function of traveling. Social activities and shopping were major functions for traveling of 3.14 percent and 3.30 percent of respondents, respectively.

In the course of COVID-19, the main travel purposes were health/medicine, work, study, shopping, social activities, recreation and family needs. There was a remarkable change in travel purposes during COVID-19. During the pandemic, about 34.13 percent of respondents traveled for work, that was 56.14 percent in the pre-pandemic situation. Traveling for study purpose was reduced to 18.53 percent which was 34.68 percent in the pre-pandemic condition. Shopping was increased to 29.91 percent that was only 3.30 percent before COVID-19. Work and study travels were decreased while shopping was increased remarkably. People traveled for visiting doctors, buying medicine, taking relatives to doctors and for other family needs such as food. Travel for recreation (2.20 percent), health/medicine (2.94 percent), and family needs (1.83 percent) were increased as compared with the pre-pandemic condition. COVID-19 created extra travel demand for health and medicine. The length of travel was reduced because travel for work and study was decreased. Short distance traveling for shopping, medicine, sports, and groceries was increased that reduces the travel distance during the pandemic.

### 12.3.2 Travel mode choice

In the interim of COVID-19, governments of different countries implemented full or partial lockdown and some other measures (e.g., social-distancing, travel ban, stay-at-home) to control the spreading of the pandemic. The control strategies and risk perception made people more conscious not to travel at all and contributed to the development of people's adaptive behavior, for example, remote working, online shopping, and virtual classroom/meeting. Pandemic significantly influenced the travel mode choice behavior of people. There is a substantial reduction of trips due to the outbreak of COVID-19. Before COVID-19, 6.79 percent of respondents did not make outdoor trips, where 22.39 percent of respondents restrained themselves from any type of outdoor trips during the pandemic, Table 12.4. In the south Asian region, the demand for non-motorized vehicle was slightly influenced by the COVID-19. More people chose walking during COVID-19 for short-distance traveling, e.g., grocery shopping, purchase medicine. Walking to the destination was increased by 2.75 percent, and bicycling remained almost unchanged. The use of rickshaw and tuktuk was increased slightly during the COVID-19. These vehicles are safe regarding social distancing and risk perception because they can be used as a single-occupancy vehicle. During the pandemic, the usage of the motorcycle and private car were increased by 4.30 percent and 1.10 percent, respectively, but the length of travel decreased (as shown in) that indicated short-distance hauling of such travel modes. The increase in the usage of private vehicles did not ensure the purchase of a new vehicle, but they used their previously owned private car.

**Table 12.4** Effects of COVID-19 on the travel choice of the people.

| Modes of Travel | Before COVID-19 | | During COVID-19 | | Change in choice | |
|---|---|---|---|---|---|---|
| | Responses | Percent | Responses | Percent | Responses | Percent |
| Nothing/I don't travel | 37 | 6.79 | 122 | 22.39 | +85 | +229 |
| Bicycle | 7 | 1.28 | 6 | 1.10 | −1 | −14.29 |
| Walking | 35 | 6.42 | 50 | 9.17 | +15 | +42.85 |
| Rickshaw/Tuktuk | 10 | 1.83 | 12 | 2.20 | +2 | +20.00 |
| Motorcycle | 62 | 11.38 | 68 | 12.48 | +6 | +9.68 |
| Taxi | 15 | 2.75 | 10 | 1.83 | −5 | −33.33 |
| Private car | 148 | 27.16 | 172 | 31.56 | +24 | +16.21 |
| Office/campus transport | 43 | 7.89 | 19 | 3.49 | −24 | −55.81 |
| Public transport | 181 | 33.21 | 80 | 14.68 | −101 | −55.80 |
| Other (NA) | 7 | 1.28 | 6 | 1.10 | −1 | −14.28 |

**Note:** (-) sign represent reduction, and (+) sign indicates increase.

Public vehicles are used publicly and remain as usual for the next passenger to be used. Consequently, the choices of a taxi, office/campus transport, and public transport were decreased as these modes could spread contamination from human to human by contaminated surfaces, the proximity of seating, and period of traveling. Nevertheless, some of the respondents used public transport to commute their work and/or study places. The choice of public transport was reduced from 33.21 percent to 14.68 percent during COVID-19, which was 44.20 percent of the pre-pandemic situation. The pandemic reduced the choice of taxi and office/campus transport by 33.33 percent and 55.81 percent, respectively. The lockdown reduced the availability of public transport. However, people avoided publicly used modes of travel because of unavailability, social-distancing, and risk perception. There will be a growing demand for travel modes that will ensure social-distancing even though there will be no pandemics. Besides, the people's choices for walking, motorcycle, rickshaw/tuktuk, and private car were increased by 42.85 percent, 9.68 percent, 20 percent, and 16.61 percent, respectively, as these modes could be used as single-occupancy vehicles.

## 12.3.3 Travel distance and GHG emission

A comparative travel distance between pre-pandemic and during the pandemic is shown in Table 12.5. The overall length of travel was reduced during the pandemic. The travel distance by all means of transportation was declined except bicycling distance. There was a 40.75 percent increase in travel distance by using bicycle. In the course of the pandemic, travel distance by public transport was reduced by 52.34 percent as compared with the pre-pandemic situation. People avoided walking in 31.16 percent of cases during the pandemic. Travel length of private car was reduced by 22.84 percent. Even though

**Table 12.5** Travel distance covered by different modes of travel and climate impacts.

| Modes of Travel | Travel Distance (mile/week) | | | Climate Impact (GHG Emission) | | | |
|---|---|---|---|---|---|---|---|
| | Before COVID-19 | During COVID-19 | Change in Distance (percent) | Before COVID-19 (kg/week) | During COVID-19 (kg/week) | Change in Emission kg/week | Change in Emission Percent |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Walking | 1763.97 | 1214.28 | −31.16 | ——— | ——— | ——— | ——— |
| Bicycle | 167.70 | 236.03 | +40.75 | ——— | ——— | ——— | ——— |
| Rickshaw/ Tuktuk | 273.29 | 149.07 | −45.45 | 102.37 | 55.83 | −46.54 | −45.46 |
| Motorcycle | 3701.86 | 2583.85 | −30.20 | 660.00 | 460.93 | −199.07 | −30.16 |
| Taxi | 708.07 | 381.98 | −46.05 | 265.22 | 143.08 | −122.14 | −46.05 |
| Private Car | 8633.54 | 6661.49 | −22.84 | 3233.87 | 2495.20 | −738.67 | −22.84 |
| Office/ campus transport | 2689.44 | 1149.07 | −57.27 | 288.22 | 123.14 | −165.08 | −57.28 |
| Public transport | 8366.45 | 3987.58 | −52.34 | 1133.11 | 540.06 | −593.05 | −52.34 |
| Total | 26,304.35 | 16,363.35 | −37.79 | 5682.79 | 3818.24 | −1864.55 | −32.81 |

**Note:** (-) sign represent reduction, and (+) sign indicates increase.

the motorcycle, a single-occupancy vehicle, usage was reduced by 30.20 percent. Travel distance for office/campus transport was declined by 57.27 percent. This reduction in the travel distance could be attributable to the social distancing, perceived health risks, lockdown, travel ban, remote working, online shopping, and virtual classroom/teaching/learning/meeting. People adapted to the control measures exerted due to pandemic, and travel behavior was changed that led to the reduction in travel distance. More specifically, COVID-19 caused a reduction in the length of travel by different modes of travel which indicated the declined travel demand. The demand for public transport and office transport was reduced to 47.66 percent and 42.73 percent. Total travel distance was reduced by 37.79 percent during the pandemic as compared with the pre-pandemic situation.

Before COVID-19, GHG emission (3233.87 kg/week) for the private car was much higher than other modes of travel. Public transport contributed 1133.11 kg/week and the third biggest amount 660.00 kg/week was emitted by motorcycle in pre-pandemic conditions. COIVD-19 caused a reduction in GHG emission for all travel modes. Private car, the highest contributor to GHG, produced 2495.20 kg/week, while public transport (second highest contributor) produced 540.06 kg/week. The motorcycle was again the third highest contributor amounting to 460.93 kg/week. In the case of the private car, GHG emission was declined by 22.84 percent, while GHG reductions were 52.34 percent, 46.05 percent, and 57.28 percent for public transport, taxi, and office transport, respectively. This higher reduction of GHG emission for the public vehicle is attributable to adaptive travel behavior, e.g., social-distancing, risk perception of infection, remote working and virtual teaching-learning. Due to the risk perception of infection, people preferred private and single-occupancy vehicles that is why the GHG emission of private car and motorcycle was not much reduced like public vehicles.

### 12.3.4 Share of GHG of travel modes

The percentage share of total emission for each travel mode in pre-pandemic and during pandemic, and percentage reduction of emission is shown in Fig. 12.3. The emission was much reduced during COVID-19 for public transport. COVID-19 caused a reduction in GHG emission for all modes of travel, but private car showed the highest reduction. Private car and public transport contributed the maximum amount of GHG emission in both pre-pandemic and during COVID-19. Before COVID-19, total GHG emission was 5682.79 kg/week, where private car and public transport contributed 56.91 percent and 19.94 percent, respectively. Motorcycle was the third biggest miscreant in the production of GHG contributing 11.61 percent. Tuktuk produced 1.80 percent, office/campus transport emitted 5.04 percent, and taxi contributed 4.67 percent of total GHG emission. During the pandemic, private car and public transport contributed 65.35 percent and 14.14 percent, respectively. The public transport contributed lower and the private car produced higher GHG emission compared to the pre-pandemic situation. Motorcycle contributed 12.07 percent of total GHG emission. Office/campus transport shared 3.23 percent, while the taxi produced 3.75 percent of emission. Tuktuk contributed a very small amount (1.46 percent) of GHG emission. COVID-19 caused a significant reduction in emission, 1864.55 kg/week, where, the share of the private car, public transport, and motorcycle were 39.62 percent, 31.81 percent, and 10.68 percent, respectively, among all modes. While the share of the taxi was 6.55 percent, office/campus transport shared 8.85 percent of the total reduction of GHG. The private car produced the highest GHG in pre-pandemic and during pandemic, and it had the maximum share in the GHG reduction.

### 12.3.5 Climate impacts

In this study, climate impact was investigated in terms of GHG emission from the change in travel behavior in the course of COVID-19. During the pandemic, people avoided public transport and crowded modes of travel in their daily commuting to maintain social-distancing. Before the pandemic, respondents traveled for 26,304.35 miles/week, that was reduced to 16,363.35 miles/week (62.21 percent) in the course of the pandemic.

COVID-19 reduced people's mobility due to control measures, remote working, virtual classroom/meeting, online shopping, and risk perception, and therefore, it has improved the quality of our environment by decreasing the GHG emission. NASA's satellite images demonstrated air pollution dropped by 25 percent with 4-weeks of lockdown implementation. Emission was estimated in kg/person-week. Before the pandemic, total GHG production was 5682.79 kg/week that was equivalent to 10.43 kg/person-week. Table 12.6 shows a summary of the GHG emission before and during COVID-19

**Table 12.6** Summary of greenhouse gas (GHG) emission.

| Emission ($CO_2$) | Before COVID-19 | During COVID-19 | Emission Reduction | |
|---|---|---|---|---|
| | | | Quantity | Percentage |
| Total (kg/week) | 5682.79 | 3818.24 | 1864.55 | 32.81 |
| kg/person-week | 10.43 | 7.00 | 3.42 | 32.81 |

in the study area. During the pandemic, total GHG emission was reduced to 3818.24 kg/week. COVID-19 reduced 1864.55 kg/week of GHG emission that was equivalent to 3.48 kg/person-week. COVID-19 caused a significant 32.81 percent reduction in the GHG emission in south Asian countries. To control the spread of the pandemic, governments exerted lockdown in cities and countries that greatly affected people's traveling behavior. The Centre for Research on Energy and Clean Air reported that control measures of COIVD-19, such as quarantines and travel bans, caused a 25 percent cutback of GHG radiation in China (Myllyvirta, 2020). A cutback in traveling due to remote working significantly contributed to reducing GHG emissions.

### 12.3.6 Long-term climate impact of COVID 19

As a result of risk perception and control measures (e.g., lockdown, bans on travel, and stay at home) of COVID-19, people are now habituated with remote working, virtual teaching-learning/meeting, online shopping, and other activities. Partial lockdown is still effective in the study area. The effects of lockdown will no longer be available for COVID-19 after 2023 (Forster et al., 2020), but people's behavioral adaptation may exist over a long period. Social paradigm shifts caused by the COVID-19 lockdowns, e.g., remoting working, virtual communication, training, online teaching-learning, shopping, and the use of virtual conference technology, could impose sustainable effects on the far side beyond the short-run cut of transportation usage (Viglione, 2020; Yaffe-Bellany, 2020). Remote working and virtual conference/meeting are the revolutionary adjustments in human behavior due to coronavirus spreading, which cut mandatory outdoor trips every day. In developing countries, online shopping is getting popularity and many people are being used to this service nowadays. Carrington (2020) cited the statement of Dr. Jaise Kuriakose, at the University of Manchester that "people's activities had changed in previously unthinkable ways, with a stop to flying and a shift to virtual meetings". There is a permanent set of such services even though COIVD-19 lockdown is withdrawn, which significantly reduces people's traveling that reduces GHG emissions contributing to the Paris Climate Agreement (PCA). COVID-19 decreases 3.48 kg/mile-person-week GHG emission in the road transport sector in the month of May 2020 in south Asian countries which is equivalent to 33.37 percent compared to the pre-pandemic situation. As a whole, it is a very big amount when considering a total 1786.98 million population in Bangladesh, India, Pakistan, and Sri Lanka.

COVID-19 teaches us in such a way that we can adapt such strategies to combat with climate change. Moreover, behavioral changes due to COVID-19 contributes to the 1.5 °C goal of PCA because it omits lots of GHG emission in the transportation sectors. According to Prof Keith Shine, at the University of Reading, a green recovery from the pandemic is essential to meet the Paris Climate Agreement target (Carrington, 2020). COVID-19 may exist for a few years, but the public willingness for behavioral adaptation to a more sustainable and low-carbon-lifestyle is needed to combat with climate change. "To keep the advantages of this, structural intervention and policies are essential". Global warming hikes severe cyclones as Mc Carthe defines the temperature to generate cyclone seed as 26 °C (Shahin et al., 2020). COVID-19 decreases the GHG thus global warming. Therefore, global disaster, e.g., cyclone and storm surge will be reduced which are intensified by global warming. Foster et al. (2020) suggested that the lead climate impact of pandemic control strategies is negligible, with a cooling of around 0.01 ± 0.005 °C by 2030 compared to a control case. They emphasized on the green stimulus and declined fossil fuel investments that would reduce global warming by 0.3 °C by 2050. Foster quoted that "It is now make or break for the 1.5 °C target". Moreover, global $NO_x$ emissions were reduced by 30 percent in April 2020. To limit global warming, it is required to cut at least 7 percent per year till 2050 (SMC, 2020).

The COVID-19 gives an experience that major structural improvements in the transport and energy systems are of utmost necessary things. Policymakers are requested to establish changes those took already places by transferring the transport sector to low-carbon as soon as possible. COVID-19 proves that we must switch energy manufacturing away from non-renewable sources very fast to ensure continuous year-after-year cut to GHG emissions. Both measures are expected to ensure clean air and clear skies that were discovered on lockdown and to save many lives. COVID-19 shows the need to scale up investments in and access to updated technologies, financing techniques, and capacity-enhancing measurements to better manage disaster and avoid damages for building resilient societies. For instance, forecast-based financing can save lives, reduce damage, and speed up recovery. In developing countries, $800 million investment on early warning systems would avoid $3 to $16 billion per year in losses (UNFCCC, 2020). In the development planning, we should consider the behavioral adaptation resulted from COVID-19 control strategies to enhance a healthy environment.

## 12.4 Conclusions and future research

This study investigated the climate impact in terms of GHG emission from the travel behavioral data using an online questionnaire survey. Main purposes of travel, number of trips, length of trip and choice of travel modes were collected with sociodemographic variables.

Social-distancing, stay-at-home, travel ban, and risk perception of COVID-19 caused changes in people's travel behavior. During the pandemic, 22.39 percent of people did not make any travel, which was 229 percent higher than that of the pre-pandemic situation. The choice of public transport, taxi, and office/campus transport were dropped by 55.80 percent, 33.33 percent, and 55.81 percent, respectively, due to control measures and risk perception of pandemic. Moreover, walking, private car, and motorcycle choices were risen by 42.85 percent, 16.21 percent, and 9.28 percent, respectively. COVID-19 caused a reduction in travel distance for all other travel modes while bicycling distance was increased by 40.75 percent.

During the COVID-19, the average length of travel was 30 miles/person-week that was 48.26 miles/person-week in the pre-pandemic situation. Before COVID-19, GHG emission was 10.42 kg/person-week, where COVID-19 reduced GHG emission to 7.00 kg/person-week in the month of May 2020 in the study area. It reduced 32.81 percent emission for the main purposes of travel. Private car, public transport and motorcycle produced a significant amount of GHG among all modes of travel in both pre-pandemic and during pandemic. The emission of public transport, private car, office/campus transport, taxi and motorcycle were declined by 52.34 percent, 22.84 percent, 57.28 percent, 46.05 percent, and 30.16 percent, respectively, attributable to COVID-19.

A societal paradigm shift (e.g., remoting working, online shopping, virtual teaching-learning and conferences, and stop flying) induced by control measures of COVID-19 (Viglione, 2020; Yaffe-Bellany, 2020) will eventually decrease the GHG emission and contribute to the 1.5 °C target of PCA. This study must promote the reduction of 35 percent of GHG emission as compared with its baseline by 2050 that is assigned to the transport sectors by PCA. The GHG reduction will indirectly reduce natural disasters (e.g., floods, cyclones and storm surges). Outcomes of this study could be useful in transport planning, decision, and the policymaking process to encompass the travel demand in pandemic situations.

In the 21st century, several pandemics/epidemics have occurred since 2000, e.g., SARS (2003–ongoing), H1N1 (2009–10), MERS (2012–ongoing), and COVID-19 (2019–ongoing) (Muley et al., 2020). COVID-19 is not the last pandemic, hence, transport planners must consider such types of events in future planning to combat with climate change. Demand for risk-free public transport, and social-distancing should be introduced in the concurrent development planning. This study only considers road transport that could be extended for waterways and airways for better scenarios to be presented and estimated. The estimation of the GHG emission is based on a few key assumptions that give limitations to our study.

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## PART 5

# Waste Management of COVID-19

# CHAPTER 13

# Impact of waste generated due to COVID-19

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## 13.1 Introduction

The pandemic of COVID-19 has caused rifts in the global population and peace that has forced governments around the globe to take necessary steps to ensure the safety of their citizens. Multiple precautionary measures have been taken by various governments and organizations in order to curb the spread of virus.Social distancing is followed, personal protective equipment is in use and screening tests are conducted to ensure people's health and to limit COVID-19 spread resulting in negligence of the ecosystem (Muhammad, Long and Salman, 2020).

The COVID-19 lockdown has reported reduction in noise and atmospheric air pollution, refined biodiversity and tourist places (Saadat, Rawtani and Hussain, 2020). On the other hand, there emerges to be the situation of emergency of waste because of the abnormal waste production from households and health facilities due to the accumulation of protective clothing and equipment. The transmission of the virus via secondary means may surge if the waste produced from health centers and households is not properly managed. The unbridled burning of wastes and their dumping causes deterioration in air quality and health issues (World Health Organization, 2020). When the waste is combusted in open area, the toxic gases formed as by product can spread in surrounding. These gases when inhaled by people living nearby can result into serious respiratory illnesses. Inappropriate dumping can cause leaching and contamination of groundwater. Therefore, the challenge is to use available waste processing facilities to handle the waste sustainably, while reducing air emissions, avoiding secondary virus spread and eliminating possible health risks (Keith Alverson, 2020). Additionally, underdeveloped and developing nations are bound to face severe consequences as they lack standard technologies for waste management and strategies for waste emergency to tackle the challenges faced due to waste production during the pandemic. Several guidelines have also been proposed by Occupational Safety and Health Administration (OSHA) as well, ranging from (Sarkodie and Owusu, 2020): (1) Using hygiene practices to avoid infection and cross-contamination, recycling of waste. (2) Proper handling of waste water by inactivating ultraviolet irradiation and oxidizing peracetic acid and hypochlorite. (3) effective handling of urban solid waste with use of personal protection devices, protection standards and controls for

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regulatory and engineering aspects. (4) Administering the COVID-19 infected medical waste as regulated healthcare waste (Sarkodie and Owusu, 2020).

Consequently, the rise of COVID-19 pandemic has burdened waste management sector. The occurrence of the pandemic of COVID-19 resulted in the implementation of social distancing and that caused hand gloves, face masks, food, sanitizing supplies, hand sanitizers to be purchased in panic. During this time, the purchasing of protection equipment, goods and groceries increased by more than 20 percent in one grocery store alone (Sarkodie and Owusu, 2020a). The dumping of putrescible goods and leftovers, which gradually produces tonnes of waste, was increased by this panic buying.

In the lockdown phase, the use of disposable plastic has expanded to prevent disease transmission. The life process of plastics, that is from extraction to disposal is perilous and hazardous to the environment (Sarkodie and Owusu, 2020). The competitivity of plastics that are recycled has decreased because of low oil prices and demand, thereby impacting the new plastics' cost. An interim prohibition of transfer to cross-border affects developed nations which rely on international technologies to recycle waste and, thus, much of the COVID-19 waste is disposed instead of recycled. Increased plastic use during lockdown and quarantine measures acts as a passage for infection for humans due to improper disposal. There have been estimates of more than one million plastic face masks and gloves on pavements that have polluted towns (Edmond, 2020) which end up in oceans. As the aquatic habitat mistakenly consumes the single use plastic (polypropylene) of face masks assuming it as food, life under water gets disturbed. Irregular disposal of face masks to the natural ecosystem thus presents a significant threat to animals as well as sea life.

Improper medical waste disposal will lead patients, healthcare staff and workers in waste sector to wounds, illnesses, lethal effects and air emissions (Saadat, Rawtani and Hussain, 2020). Medical waste is categorized into hazardous and non-hazardous waste (WHO, 2018). Management of waste is therefore a major community service needed to curb the transmission of COVID-19 (UNEP, 2020).

In this chapter, we have discussed about different types of wastes generated due to COVID-19 and its impact on the ecosystem. The types of waste generated in COVID-19 is mainly on the basis of source of generation. The by products from incineration of solid waste has a great impact on atmosphere and human health. The effect of COVID-19 waste on water resources and marine organisms due to improper disposal is also described.

## 13.2 Types of waste generated from COVID-19

During the pandemic the quantity of waste produced from different sources has increased. The main sources of waste generation are residential areas and health centers. According to (Pruss, A, Giroult, E, Rushbrook, 1999), the COVID-19 waste can be classified as household waste and healthcare waste. The healthcare waste can be further categorized as hazardous and non-hazardous waste. Fig. 13.1 shows the classification of types of waste generated due to COVID-19.

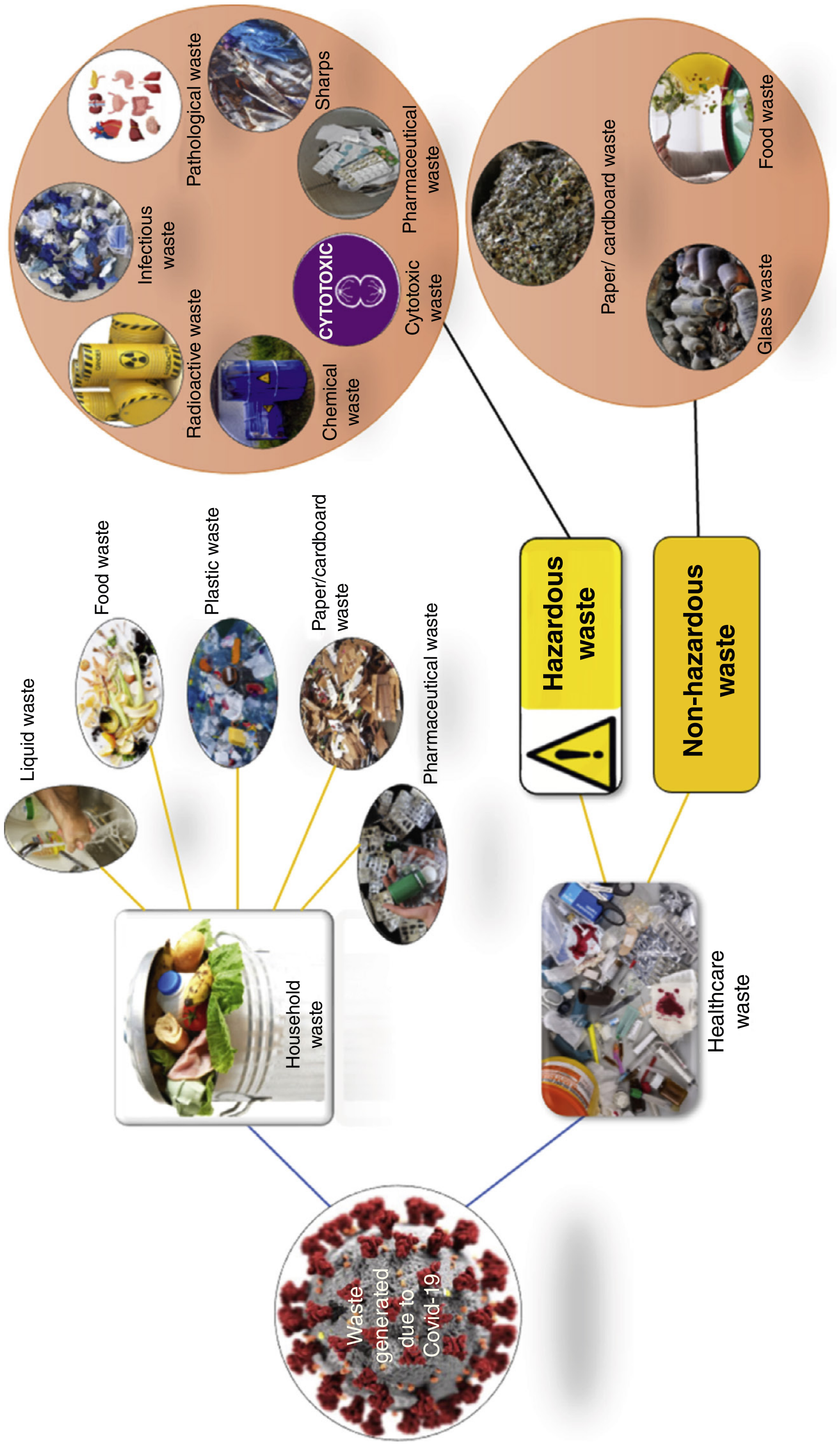


**Fig. 13.1** Types of waste. (Source: Pruss et al., 1999).

## 13.3 Household waste

Household waste is the debris that individuals collect on a daily basis as a result of purchasing economic commodities. The qualitative and quantitative factors are based on citizen's lifestyles and living conditions. The production of waste and its composition may also be affected by a shift in habits after an economic or health crisis (Ouhsine et al., 2020). During the lockdown, activities such as wearing masks and gloves have risen to guard against the novel coronavirus. As a consequence, the presence of such waste in the garbage cans of the households is easily noticeable. A study revealed that 87 percent of residents dispose the masks and gloves in single bin with household waste (Ouhsine et al., 2020) which leads to contamination of other waste. When mixed with medical waste of any amount, household waste becomes toxic. As a result, household solid waste, such as medical and pharmaceutical waste, may contribute to the transfer of diseases (Taghipour et al., 2014).

Conversely, the consumer economy, which has directly affected the production of household waste, is transforming eating and living patterns in general. In addition to eating habits, during the time of lockdown, the ceasing of restaurants and dairy creamer greatly impacts the total weight. The pharmaceutical waste from residential areas due to quarantine has also contributed to the amount of COVID-19 waste. Moreover, during lockdown the qualitative aspect of the waste like the management of household waste during lockdown creates a detrimental effect on health of humans because the waste is merged with the personal protective equipment (Ouhsine et al., 2020). This encompasses the effect on shopping habits and way of living, the number of sales and the form of products bought prior to and after the time of the lockdown, the waste disposal from the bins, waste handling due to the risk of pollution and the assessment on the tonnage of waste produced during the period of lockdown (Sarkodie and Owusu, 2020b). A study found that the lockdown of COVID-19 had a major impact on the consuming patterns of the research area's residents (Ouhsine et al., 2020). As a result, in lifestyle change caused due to the pandemic, there is reduction in the volume of waste when comparing 2019 and 2020. Thus, the study found that the remains of protective equipment are not well handled by citizens; they are combined with domestic waste, posing a risk to collection staff.

The household waste can be categorized into the following:

### 13.3.1 Liquid waste

Liquid waste typically found in households consists of trapped rainwater, detergents and other liquid chemicals (Syed, 2006). Due to the pandemic, washing of hands with soap or handwash has escalated which has increased the amount of liquid waste from residential areas.

### 13.3.2 Food waste

It is mainly produced whence residential areas. As the households often mismanage the excess food, the practice of stockpiling can be considered as a source of increase in waste. Nevertheless, there are additional variables which can reduce food waste from domestic areas in the course of COVID-19. Households experiencing salary reductions are expected to have reduced waste because food waste is favorably linked to remuneration. Moreover, during the pandemic, increasing food prices are also linked to decrease household waste at all income groups. The net influence on household food waste is uncertain, but substantial variation among households is expected to exist (Ellison and Kalaitzandonakes, 2020). When this waste is disposed in landfills, it produces methane while decomposing. Methane, a greenhouse gas which can contribute to global warming.

### 13.3.3 Plastic waste

Containers, jars, toys and many other items are included in recyclable plastic waste. They need to be segregated from regular waste because plastic is not biodegradable. These products should be properly collected and put in the household recycling bin or shipped for proper disposal to the waste recycling facility (Letcher, 2020). There is an increase in use of hand sanitizer, masks and gloves. The packaging is plastic which increases the plastic waste from residential areas. Moreover, masks and gloves disposed from households are also considered as plastic waste but are not recyclable. This waste if not disposed properly in bins can end in seas which causes death of marine organisms due to choking.

### 13.3.4 Paper/cardboard waste

Paper waste like old newspapers, magazines, different packaging materials, cardboard are included in this type of waste which are recyclable. Due to the COVID-19 lockdown, businesses that generally recycle large quantities of paper and cardboard are not in a position for recycling (Allen, 2020). Household recycling is more relevant than ever because of the lockdown. According to the EPA, we are all sitting at home and getting more packages in cardboard boxes and making more waste than usual, much of which can be recycled (Allen, 2020). For anything from the manufacture of fresh goods to boxes to the transport of products and other essential commodities, recycled materials are vital for the daily needs of hospitals, grocery stores and supermarkets (Allen, 2020). For all raw materials in the manufacturing supply chain, particularly paper and cardboard are used more.

### 13.3.5 Pharmaceutical waste

Pharmaceutical waste includes prescribed used or unused or obsolete drugs, personal care items for home use and over the counter medications. Due to increasing COVID-19 cases there was scarcity of beds in the hospital and thus people with less severe symptoms were asked to get home quarantined. This led to rise in pharmaceutical waste from households (Shannon and Woolridge, 2011).

## 13.4 Healthcare waste

According to the (WHO, 2013), healthcare waste consists of broad scope of items, such as discarded needles,blood, syringes, soiled dressings, body parts, diagnostic testing, medications,toxic materials, pharmaceuticals and medical instruments (WHO, 2013).

Healthcare waste compriese of all the waste generated from healthcare facilities and researchlaboratories. Furthermore, it alsocontains waste from “minor” or “scattered” sources, which include wasteproduced from the residential areas during health care (dialysis, insulin injections, etc.) (Pruss et al., 1999). The main sources of healthcare waste are hospitals and other healthcare centers. Other sources include laboratories, centers for research, morgue, centers for post-mortem, laboratories for research and testing on animals, blood banks and senior retirement homes (WHO, 2018).

### 13.4.1 Hazardous waste

Biomedical hazardous waste can be elucidated as waste that needs biological material to be inactivated in an authorized way before final disposal (“Bio-Medical Hazardous Waste”, 1999). Around 15 percent of healthcare waste is considered dangerous and can pose many health hazards (Pruss et al.,1999). The chapter further illustrates the subcategories of hazardous waste consisting of chemical waste, sharps, radioactive waste, infectious waste, pharmaceutical waste, genotoxic waste and pathological waste.

#### *13.4.1.1 Infectious waste*

Thiswastecontains pathogens such as fungi, bacteria or viruses in sufficient quantities or concentrations to induce disease toreceptive hosts (Pruss et al., 1999). Highly contagious waste pertains to stocks or cultures of highly infectious agents, autopsy waste, bodies of animals and additional contaminated waste, inoculated or in contact with such agents (Pruss et al., 1999).The PPE used by healthcare workers can be considered as infectious waste. They wear the PPE to stay safe from the corona virus because they are more susceptible to such environment. This type of hazardous waste has added more to the total amount of COVID-19 waste.

#### *13.4.1.2 Pathological waste*

It stems primarily from surgical procedures or research involving the removal of organs, tissues or parts of the body. Within this definition, identifiable body parts of humans or animals are often referred to as pathological waste. This typeis regarded as subclass of infectious waste, although it can also contain bodily parts that are healthy (Pruss et al., 1999).

#### *13.4.1.3 Sharps*

Sharps are things which can inflict wounds or puncture injuries.Theseobjects are normally regarded as very hazardous medical waste, whether they are infected or not (Pruss et al., 1999). COVID-19 infected patients were treated in hospitals. In the treatment, needles, syringes, blades and other sharps were discarded which resulted in increase of medical waste.

#### *13.4.1.4 Pharmaceutical waste*

It comprises of unnecessary, unused, infected, spilled or expiredpharmaceuticals, vaccines, medications and serums and need to be appropriately discarded (Pruss et al., 1999). It also involves discarded things used in the management of pharmaceutical waste, like residue boxesor bottles, gloves, masks, connecting tubing, and vials for drugs (Pruss et al., 1999). During the pandemic, the amount of masks, gloves and other pharmaceutical waste increased.

#### *13.4.1.5 Genotoxic waste*

This category of waste is extremely hazardous and can have properties of mutagenicity, teratogenicity or carcinogenicity (Pruss et al., 1999). This poses major security issues, within hospitals and also after the disposal, and particular attention must be paid (Pruss et al., 1999). As the healthcare waste increased during COVID-19, the handling and treatment has been not done properly. In this mismanagement genotoxic waste can affect the organisms and humans in future.

#### *13.4.1.6 Chemical waste*

This type comprises of liquid, gaseous and solid chemicals that are discarded, such as from diagnostic work and experiments and procedures for housekeeping,cleaning and disinfection (Pruss et al., 1999). This type of wastecan be non-hazardous or hazardous; it can be considered to be hazardous in the context of health protection if it has at least one of the following properties (Pruss et al., 1999):

- toxic
- corrosive like bases of $pH>12$ and acids of $pH<2$
- flammable
- reactive
- genotoxic (*e.g.* cytostatic drugs).

In COVID-19, more disinfectants and chemicals for cleaning were used to ensure cleanliness in healthcare centres. This contributed to increase of healthcare waste.

#### *13.4.1.7 Radioactive waste*

Any liquid, gaseous or solid substances which are radionuclides-contaminated are considered as radioactive waste (Pruss et al., 1999). This type of waste is generateddue to processes like body tissue analysis and fluid in-vitro, localization and imagingfor tumoursof in-vivo organ and different investigative and therapeutic procedures (Pruss et al., 1999).

In healthcare, radionuclides used are usually in open or sealed sources (Pruss et al., 1999). Liquids specifically applied and uncoveredin course ofapplication are typically sources that are unsealed; sealed sources are contaminants of radioactive material found in machinery or instruments pieces or encased in non-breakable and impermeable items, like needles or seeds' (Pruss et al., 1999). Waste in the structure of sources that are sealed are relatively having high activity, yet limited quantities are produced mainly from larger medical and scientific laboratories (Pruss et al., 1999).

The COVID-19 waste is a highly infected waste and needs to be treated properly. The most appropriate method for treatment is incineration. Table 13.1 describes the examples included in different types of hazardous waste and their treatment and disposal methods. The effects of the method on the environment are discussed further in the chapter.

### 13.4.2 Non hazardous waste

According to (WHO, 2017), waste that do not present any specific chemical, biological, radioactive or physical hazard is non-hazardous or general waste (WHO, 2017).

This type of waste is not exposed directly with patients. Generally, it is not infective. It is like household waste which involves packaging of plastic, food waste, paper and other waste.Nonhazardous chemical waste is generally composed ofcertain organic and inorganic salts, sugars and amino acids (Pruss et al., 1999).

Around 75 percent of the healthcare waste produced is non-hazardous or "general" healthcare waste and this comes primarily from activities of housekeeping of health facilities (Pruss et al., 1999).

Non-risk HCW incorporates any waste which has not been contaminated, such as packaging, general office waste or food leftovers (WHO, 2002). They are like ordinary household waste, and municipal waste services can manage them (WHO, 2002). They represent 75 percent−90 percent of the total quantity of HCW that medical centres generate (WHO, 2002). There are three groups:

- **i.** A1. *Recyclable waste:*It includespaper, plastic, cardboard or metal and recyclable cans or glass which are not contaminated (WHO, 2002).
- **ii.** A2. *Biodegradable HCW*: This category of waste, for example, includes compostable foodleftovers or yard waste (WHO, 2002).
- **iii.** A3. *Other non-risk waste*:This category of wastewhich unrelate to A1 and A2 categories is included in this category (WHO, 2002) This category of waste includes glass.

On average, countries with high income produce till 0.5 kg per day per hospital bed of hazardous waste, whereas low-income countries generate an average of 0.2 kg per day of hazardous waste (WHO, 2018). Though, medical waste is mostly uncategorized into non-hazardous or hazardous waste in low-income countries, rising the actual amount of hazardous waste excessively high (WHO, 2018). COVID-19 has surged the total waste production and because of lack of management the actual figure of total waste cannot be calculated. However, some studies have been carried out which provides data regarding used face masks and total healthcare waste generated during COVID-19.

**Table 13.1** Types of hazardous waste and their treatment and disposal methods (Source: Pruss et al., 1999).

| Classification of hazardous waste | Type of waste | Treatment methods | Disposal methods |
|---|---|---|---|
| Infectious waste | laboratory cultures, equipment, materials, human tissues contaminated with body fluids or blood, waste from isolation ward of infected patients or undergoing haemodialysis, waste from laboratories of infected animals, materials and instruments contaminated with infected animals or patients. | Single-chamber incinerator<br>Rotary kiln<br>Drum or brick incinerator<br>Pyrolytic incinerator<br>Wet thermal treatment<br>Chemical disinfection<br>Microwave irradiation | Sanitary landfill<br>Safe burial on hospital premises |
| Pathological waste | Blood, body fluids, bodily parts and fetuses | Pyrolytic incinerator<br>Rotary kiln<br>Drum or brick incinerator<br>Single-chamber incinerator | Safe burial on hospital premises |
| Sharps | Needles, syringes, blades, infusion sets, broken glass, scalpel, knives, infusion sets, saws, broken glass, and nails | Pyrolytic incinerator<br>Rotary kiln<br>Single-chamber incinerator<br>Wet thermal treatment<br>Drum or brick incinerator<br>Microwave irradiation<br>Chemical disinfection | Encapsulation<br>Safe burial on hospital premises |
| Pharmaceutical waste | Expired or not needed pharmaceuticals; items like bottles and boxes contaminated by or containing pharmaceuticals | Inertization<br>Rotary kiln<br>Encapsulation<br>For smaller quantities-Pyrolytic incinerator; | Safe burial on hospital premises<br>Sanitary landfill<br>Discharge to sewer |
| Genotoxic waste | Waste containing cytostatic drugs (often used in cancer therapy); genotoxic chemicals, urine, vomit, faeces from patients undergoing treatment with cytostatic chemicals and drugs, chemicals, radioactive material. | Inertization<br>Rotary kiln | For smaller quantities-encapsulation |
| Chemical waste | Expired or unnecessary disinfectants, film developer, laboratory reagents, solvents | Rotary kiln<br>For smaller quantities-Pyrolytic incinerator; | Encapsulation<br>Safe burial on hospital premises |
| Radioactive waste | Liquids that are unused from radiotherapy or laboratory research, contaminated glassware, packages, or absorbent paper, urine andexcreta of patients undergoing treatment or tested with unsealed radionuclides, sources that are sealed | Low-level infectious waste-<br>Rotary kiln<br>Pyrolytic incinerator<br>Single-chamber incinerator | Low-level liquid waste- Discharge to sewer |

**Table 13.2** Evaluated face mask use and healthcare waste in some Asian countries and the confirmed COVID-19 cases.

| Sr. No. | Countries | *Population | *Total COVID-19 cases | Total face masks used daily (pieces) | Healthcare waste (tons/day) |
|---|---|---|---|---|---|
| 1 | India | 1,38,10,85,714 | 16,43,416 | 38,11,79,657 | 6,491.49 |
| 2 | Iran | 8,40,77,062 | 3,01,530 | 5,06,48,022 | 1,191.04 |
| 3 | SaudiArabia | 3,48,55,542 | 2,74,219 | 2,33,67,155 | 1,083.17 |
| 4 | Bangladesh | 16,48,20,045 | 2,34,889 | 9,91,55,739 | 927.81 |
| 5 | Iraq | 4,02,88,721 | 1,21,263 | 3,09,73,969 | 478.99 |
| 6 | Qatar | 28,07,805 | 1,10,460 | 13,41,008 | 436 |
| 7 | Indonesia | 27,37,53,080 | 1,06,336 | 15,92,14,791 | 420.03 |
| 8 | Kazakhstan | 1,87,94,372 | 89,078 | 86,75,482 | 351.86 |
| 9 | China | 1,43,93,23,776 | 84,292 | 98,91,03,299 | 332.95 |
| 10 | UAE | 9,899,794 | 60,223 | 7,919,835 | 237.88 |
| 11 | Japan | 126,443,231 | 33,049 | 92,758,754 | 130.54 |

*Data retrieved of 31st July 2020 from https://www.worldometers.info/coronavirus/ (Source: Sangkham, 2020).

(Sangkham, 2020) (Sangkham, 2020) Sangkham performed a study to evaluate the amount of face masks used and the healthcare waste generated in Asian countries in COVID-19 (Sangkham, 2020). Some Asian countries have been included in Table 13.2. The country-wise COVID-19 medical waste generation of some Asian countries are shown in Fig. 13.2.

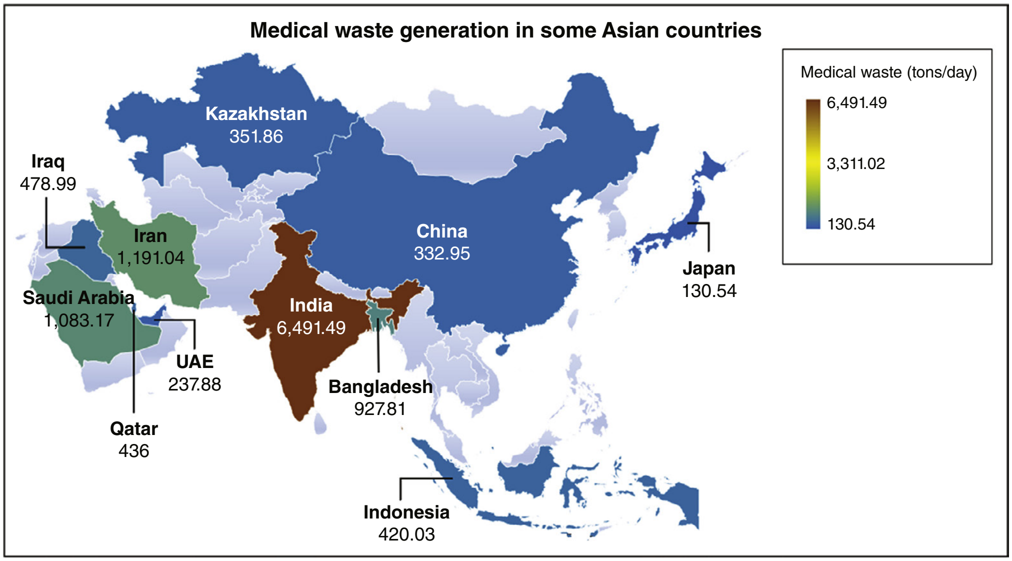


**Fig. 13.2** Evaluated waste in some Asian countries with confirmed COVID-19 cases (Source: Sangkham, 2020).

The impact on waste management sector and environmental components due to different waste produced during the pandemic is discussed further.

## 13.5 COVID-19 impact on waste management

The waste generated fromCOVID-19 has a parlous effect on the environment. The quantity of biomedical waste has increased over all other types of waste produced in the pandemic. Global environmental health is impaired by biomedical waste, particularly in developing countries of lower-middle-income group like India and Bangladesh. Globally, there is an estimation that at least 5.2 million people, including 4 million children, die annually because of diseases caused by unregulated medical wastes (Rahman et al., 2020). In view of global outbreak of COVID-19 exorbitant healthcare waste has been a significant new challenge to public sanitation as well as the environment. The SARS-CoV-2 transmission to health workers and those who treat the waste can be exacerbated by improper handling of hospital waste (Rahman et al., 2020).

A substantial proportion of medical waste is made up of personal protection devices (PPE), including face guards, caps, gowns, accessories and head gears. These are basically single-use plastics (SUP) that are used by frontline medical professionals. It falls into the scope of biomedical waste that winds up in landfills or deep burial incinerators.

Proper segregation and disposal are necessary for wastes generated due to COVID-19. Used PPEs generated from COVID-19 isolation wards at healthcare facilities should be isolated and sent to common disposal facilities. However, used masks and gloves made in general households, commercial firms, institutions, etc., must be processed appropriately for disposal along with solid waste after cutting or shredding.

In developing countries, solid waste management (SWM) techniques also suffer from inadequate collection, mishandled dumping areas and limited tariffs. Developing countries spend $35 per ton on waste management, according to the World Bank, compared to over $100 per ton in high-income countries (Rajesh Sinha et al., 2020).

The outcome of inappropriate disposal of waste are astounding. Insufficient waste disposal raises the possibility of disease spreading directly from the uncollected or discarded waste or from water pollution and crop contamination. Inadequate waste disposal operations are expected to result in between 400,000 and 1 million deaths annually in developed nations; this order of magnitude would be many times the loss of productivity due to sickness (Rajesh Sinha et al., 2020). Moreover, the waste sector results for approximately 5 percent of global greenhouse gas emissions (mainly methane, mostly due to inadequate waste disposal) (Rajesh Sinha et al., 2020). In developed countries, the waste management sector depends on informal employees, typically the poorest and the most vulnerable in society, who earn a living by collection and selling of goods to waste collectors. There is an estimation that more than 15 million people worldwide, living in unhealthy conditions without any social security, match this description (Rajesh Sinha et al., 2020).

### 13.5.1 Impact of COVID-19 on the waste sector

Based on research till date, COVID-19 does not appear to be spread due to the waste value chain. The SWM sector has, however, faced implications (Rajesh Sinha et al., 2020).

Welfare of SWM workers: The lockdown greatly affected the living of informal workers who rely on the waste management sector. The crisis of COVID-19 has revealed, even during regular times, the extraordinarily unstable conditions in which they operate (Kaza, 2020).

Redistribution of waste generation: During the lockdown, waste production was migrated to residential areas from commercial and industrial centers. The quantity of medical waste has surged to about 40 percent (Rajesh Sinha et al., 2020). Waste generated from industries and commercial areas has reduced dramatically due to the decline in industry activities. After lockdown, the waste generated shifted back to industrial and commercial centers. Hazardous waste production has increased with greater demand from the pharmaceutical and medical industries. In developing countries, current hazardous waste treatment capability is expected to be overrun, leading to stockpiling and ultimately insufficient disposal. The quantity of municipal waste has risen, constructively undermining the current collection of waste and recycling procedures. A drop in recycling activities has further exacerbated concerns in the collection and handling of the municipal waste (BIR, 2020). Changes in disposal operation for waste. The government insists on waste storage and transportation away from cities centers (Kapoor et al., 2020).

Changes in waste management activities: The government insists on the waste storage and transportation away from the cities. The processing of plastics and other materials has significantly slowed down. While the potential danger of COVID-19 delivery is the immediate cause for the decline, supply chain disruptions and reductions in industrial and commercial activities are other key factors (Schmidhuber, Josef, Qiao, 2020). It is expected that the global trough, integrated with low energy prices, will exacerbate reliance on cheap new raw materials rather than recycled feedstock. Landfill disposal has grown, partly because more recyclable products are being shipped to municipal waste outlets, such as plastics (Inga Heiland, 2020). The majority of the waste collected is sent to landfills or accumulated in temporary dumps. The use of single-use plastics (SUP) is on the rise. A resurgence has been seen in the previous drop of SUP dependence, followed largely by expanded usage of single-use plastic personal protective equipment (PPE) like face masks, hand gloves, goggles, disinfectant tubes and packaging materials (Rajesh Sinha et al., 2020).

For the sake of waste prevention, we cannot sacrifice the utilization of PPE kits by compromising the lives of health staff. But in minimizing private use of disposable masks and N95 face masks, the society will play a crucial role.

## 13.6 Impact on environment

The COVID-19 waste mainly comprises of biomedical waste and plastic waste which can result into serious environmental threat if not treated properly. The waste or the

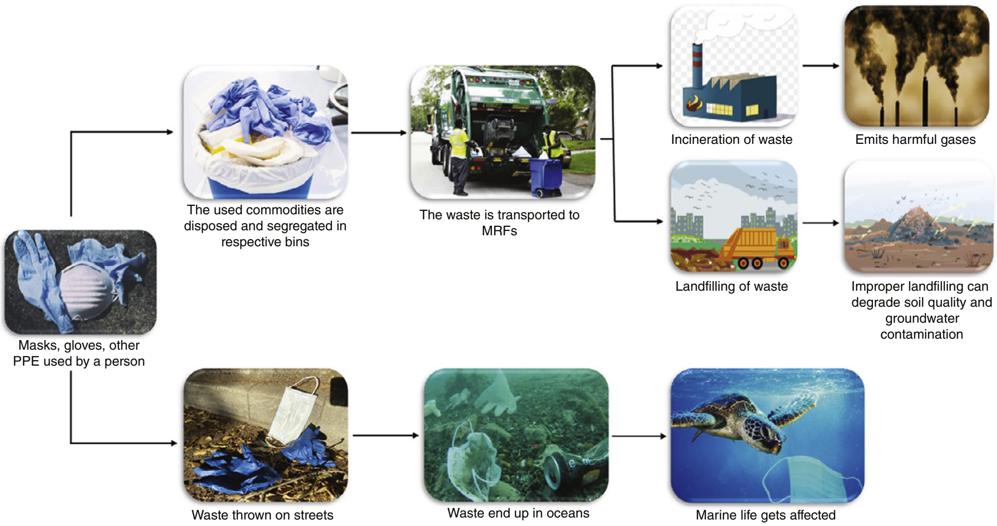


**Fig. 13.3** Flowchart of waste and its impact.

product remaining after the treatment gets disposed in environment naturally. As shown in Fig. 13.3 the waste thrown on streets can affect the marine habitat. Treatment method like incineration can either pollute the atmosphere due to combustion of waste or disposing ash in unlined landfill can leach into groundwater. Improper landfilling can degrade soil quality and contaminate groundwater by leaching. Every component is interrelated in the biosphere because one way or the other the effect on one sphere affects the other spheres.

Irregular segregation of biomedical waste and numerous streams of medical waste from the point of origin will create a domino-like environmental effects that poses risks to humans, wildlife, soil and water supplies.

In several different shapes and types, and by various ways, plastics are introduced into our watershed environments, including drains for storm water, wastewater treatment plants, garbage contamination, runoff from agricultural areas, commercial waste and scrap, insufficient waste management practises and litter (Catherine van Reenen, 2020).

Improper segregation and treatment of biomedical waste can contaminate freshwater supplies, which can, in consequence, infect both humans and animals. Biomedical waste must be safely transited to landfills to protect from birds, rats and stray animals which can act as carriers of diseases. To prevent this, proper packaging and labeling is required. This increases the packaging and marking which can help stop the transmission of contamination through air, soil or water by human and animal communities (Edmond, 2020).

Ecological risks associated with unsafe management of healthcare waste may contaminate the air we breathe by hazardous airborne contaminants if not adequately contained, isolated and incinerated by on-site or off-site incineration (Edmond, 2020).

Radioactive particles produced by diagnostic technologies have the potential to enter a landfill or other environmental areas, particularly airborne particles. Air pollutants distributed through wide regions of populated land have the ability to cause a variety of diseases. In addition to this, more individuals have been driven online by the quarantine economy, resulting in greater packaging waste from deliveries (Li, Mirosa and Bremer, 2020). Further, it is discussed how COVID-19 waste can have impact on hydrosphere, lithosphere, atmosphere and biosphere.

## 13.7 Impact on water resources

These surface waters frequently end up with solid waste as garbage, litter and waste, despite conservation regulations which safeguard the lakes, rivers and wetlands (Richmond and Clendenon, 2000). Ultimately, something spilled or windblown into a watershed can join the drainageway as surface waters collect in low-lying areas. In major cities, waste and litter which generally includes dry solid waste are repeatedly brought by runoff of stormwater. These items are also intentionally poured directly into a water body or wetland or discarded in urban and rural areas near river beds or lakeshores (Clare Shine and Cyrille, 1999).

As disposable PPE inundates the ocean, coronavirus waste has become a modern source of contamination. On the sea beds and washed up on our beaches, waterlogged caps, hand gloves, tubes of hand sanitizer and bottles and other COVID-19 waste are also reported, joining the daily refuse of the ocean habitats (Edmond, 2020). The masks and gloves thrown on the streets find their way to the water. They can be carried to rivers or lakes by wind as they are low density plastic items or by flooding due to rain. These rivers and lakes flow into the sea. Even storm drains will release drainage into natural bodies of water directly (McMurtry, 2020).

Medical waste is labeled as pollutant of land and water supplies if it is not safe until buried on land or disposed of in water (Manzoor and Sharma, 2019). The development of the medical sector around the world has provided to vast quantity of healthcare waste produced in tandem with the rise of single-use healthcare commodities used (Manzoor and Sharma, 2019). Improper discarding of biomedical waste can have an adverse effect on quality of water, as leaching of different pollutants into the groundwater can occur from the dumping sites of waste (Oluseyi, Adetunde and Amadi, 2014).

Healthcare waste incineration produces ash with high concentrations of polycyclic aromatic hydrocarbons (PAHs) and heavy metals can contaminate surface and groundwater, contributing to unsafe concentrations of toxic materials (Heera, Kunal and Rajor, 2014). Therefore, before disposal into landfills or reuse, it is necessary to remove the toxicity of ash. The heavy metals occurrence via biomedical waste in landfill leachates creates an environmental danger, particularly in landfills which are not lined where leachate could be dissipated in groundwater (Al-Raisi et al., 2014).

Environmental factors like wind, precipitation, tides and sun over time allow plastics to disintegrate to minute parts called microplastics (< 5 mm) (RENNIE, 2017). The research of microplastics has evolved enormously over the past few years, but much remains unclear concerning their temporary and permanent ecological consequences. More such studies on origins and consequences of microplastics is important as a surging menace to fresh-water ecosystems with possible public hygiene inference (Catherine van Reenen, 2020). The single-use plastic face masks are the main cause of microplastic fibers in the ecosystem (Fadare and Okoffo, 2020). While the production of biodegradable or recyclable masks is now being investigated, even a transient rise in plastic waste will lead to permanent effects on freshwater ecosystems (Catherine van Reenen, 2020).

In May 2020, when founder Laurent Lombard went on a dive to gather plastic, Operation Mer Propre in France brought to light the issue in the Mediterranean Sea, finding that coronavirus waste was dominant. During the dive, 10 latex gloves, four surgical masks, six beverage cans and four glass bottles were found (McMurtry, 2020). The NGO cautioned that coronavirus litter could "become a true environmental nightmare", and could rise if more people made their way to the beach. Lombard said that the air emission levels during lockdown fell rapidly. Noise pollution got controlled instantly. But if we think of plastics, their persistence is one of the aspects that makes it difficult to manage (McMurtry, 2020).

(UCL Plastic Waste Innovation Hub, 2020) conducted a study of the environmental dangers of employing single-use face masks as part of a COVID-19 exit strategy. It reported that if each individual used a face mask per day for a year in the UK alone, a supplemental 66,000 tonnes of infected waste will be produced and tenfold more climate change effect can be observed (UCL Plastic Waste Innovation Hub, 2020). Millions of other masks and gloves find their way into the water, contributing to the approximate 8 million tonnes of toxic waste pouring into the seas each year (McMurtry, 2020). The disposable masks and latex hand gloves have been seen around the world continue to be found on many shorelines, above and below the waves, also in parks, on public transit and on our highways (Dr Teale Phelps Bondaroff, 2020). According to the U.S. The Environmental Protection Agency, from the climate perspective, it is the worst end-of-life management strategy possible for plastics. Global warming is a significant menace to the aquatic habitat and oceans (Gaia, 2019).

The product from decades of improper construction, usage and disposal is what we have in our oceans and we are adding more to it.

## 13.8 Impact on soil and soil quality

The COVID-19 waste mainly comprises of biomedical waste and plastics. The number of gloves and masks lining the streets is rising (McMurtry, 2020). They are basically plastic. Plastic takes almost 1,000 years to decompose. This causes accumulation of plastic debris and with time, formation of microplastics occur and leaching of toxic additives takes place. All this degrade the soil quality.

The soil quality near waste landfill sites can be changed due to inappropriate and unscientific dumping of biomedical waste. Various contaminants can mix with the soil and can alter the soil ecosystem's chemistry and biology. Heavy metal contamination of soil samples has been reported from the bottom ash of incinerators and industrial landfill areas (Auta and Morenikeji, 2013). The declining condition of the soil and the decrease in the abundance of plants is due to biomedical waste disposal. There has been significant impact on chemical and physical properties of soil near dumping sites (Ali et al., 2014). The accumulation and future effects on the climate and local culture of heavy metal pollution of soil near open landfills (Gebre and Debelie, 2018). Groundwater may become polluted by dumping of ash from incinerator in unlined landfills (Al-Raisi et al., 2014).

Soil contamination due to biomedical waste is often caused by unused pharmaceutical drugs from infectious waste (Pandey, 2016). By being consumed by plants, heavy metals found in the waste join the ecosystems, contaminating the food chain (Dwivedi, Pandey and Shash, 2009). If trace nutrient elements are found in significant amounts, they are ultimately toxic to crops, animals and even to human beings (Pandey, 2016).

## 13.9 Impact on air and human health

Greenhouse gas emissions and particulate pollution from landfill sites for urban solid wastes pose challenges that require immediate attention. The incineration of medical waste at such landfill sites is a huge commination to the ecosystem as well a health of humans. It emits dangerous contaminants among the inhabitants that cause different kinds of respiratory problems. Their analysis has shown that the main particulate matter *i.e.* PM10 and PM2.5 species are ashes, black carbon, ammonia, sulphate, and nitrate (Karthikeyan, Balasubramanian and Iouri, 2006). It has been observed that the concentration of Pb and Zn in hospital waste is comparatively higher concentrations than the other elements in many studies (Sabiha-Javied, Tufail and Khalid, 2008). These heavy metals have primary source as ash from incinerator and the existence of poly vinyl chloride in the waste. Ethane, propane, carbon monoxide hydrochloric acid, propylene and ethylene are found in the emissions from incinerators (Allen, Brenniman and Darling, 1986). This is regarded as a serious health issue.

Biomedical waste is 10–25 percent of the total waste produced by healthcare facilities (Sharma et al., 2013). Proper hospital waste treatment and all related hazardous waste management is crucial otherwise it can have important environmental and health impacts. The conventional method for the disposal of infectious waste is incineration. However, depending upon the nature of waste, incinerators emit a broad range of toxins (Manzoor and Sharma, 2019).

Higher occurrences of symptoms of respiratory disorders and cancer, hormonal abnormalities, inborn malformations, and sex ratio changes are the potential consequences of combusting healthcare waste (Sharma et al., 2013). Medical waste should be handled by incineration and protected landfill. High-temperature incineration for the treatment of COVID-19 waste is granted priority (Sangkham, 2020). This is the most popular, biologically safe and acceptable approach for removing high-furnace temperature remains of the virus and setting the incineration temperature to 1100 °C for three minutes (Kanemitsu et al., 2005). The incineration of hospital waste emits dioxin which induces mercury contamination (Lekwot[1] et al., 2012). The ash is made of heavy metals, dioxins and furans that are poisonous compounds. Air emission systems are only effective at eliminating particulate matter, so the fly ash toxicity increases. The incineration method will only turn solid and liquid hazardous waste into particulate matter with gaseous pollutants, sulphur oxides and nitrogen oxides. Acute symptoms like lung and eyes inflammation can be caused by this (Manzoor and Sharma, 2019).

Incineration, which involves pyrolysis, gasification and plasma arc, is dangerous and not a suitable alternative to process plastic waste (Gaia, 2019).

Plastic and other waste burning releases toxic chemicals in the atmosphere and ash residues like heavy metals, persistent organic pollutants and other toxic substances (Verma et al., 2016). Experience with some industrial-scale pyrolysis, plasma arc installations and gasification which actually treat municipal solid waste (compared to treating other substances) indicates that these processes will release the same contaminants as incinerators for burning in large quantity (Dong et al., 2018). These pollutants lead to cancer, asthma, endocrine dysfunction, and the risk of disease growth on global level (Darbre, 2018). Organic pollutants that are enduring migrate long ranges gradually deposit on polar ice caps and oceans, whither other synthetic aquatic waste and microplastics may be adsorbed, bioaccumulating the food chain, affecting marine and human health (Gaia, 2019).

Using new technologies for incineration such as pyrolysis, plasma arc and gasification several industries claim to heat plastic and convert it into oil or electricity. They can be exorbitantly costly and also cause toxic plastic waste chemicals to be emitted into the air and into the ash residues (Gaia, 2019).

Incinerators in the areas where they are installed create environmental injustices that bear the overwhelming brunt of ozone emissions and radioactive ash (IEER, 1993). These areas are often negatively affected by the climate change.

Burning of healthcare waste containing chlorine emits dioxins and furans. They are highly toxic and can bio-accumulate (WHO, 2017). They can cause reproduction and growth problems, affect the immune system, interact with hormones and are carcinogenic. Plastic polyvinylchloride (PVC) used in medical devices is a source of chlorine in health-care waste (WHO, 2017). Gloves or blood bags, for instance, may consist of PVC (WHO, 2017).

Due to COVID-19, the biomedical waste has increased and, in many cities, incinerators are overutilized than the actual capacity. The capacity of incinerator of the plant in Mumbai is 24,000 kg per day that has been underused heretofore (Deshpande, 2020). Prior to COVID-19 outbreak, Mumbai produced 10,000 kg-17,000 kg of biomedical waste per day that was transported here (Deshpande, 2020). Since biomedical waste and COVID-19 waste rose from 10,000 kg-17,000 kg to over 24,000 kg a day since June 2020, the facility is now overused (Singh, 2020). Biomedical waste (including COVID-19 waste) soared over the 24,000 kg per day treatment facility limit in Deonar a suburb in Mumbai India in July (Singh, 2020). Biomedical waste (including COVID-19 waste) reached 30,000 kg per day in July and August (Singh, 2020). In Wuhan, China in March 2020, the processing capacity for daily healthcare waste rose to almost 214 tons from 50 tons which is more than four times prior to the pandemic (Yu, 2020).

Another method for treatment of biomedical waste is pyrolysis. The pyrolysis process requires the superheated oxidation of organic matter that is carbon-intensive in the oxygen deprivation condition to create combination of pyrolysis oil (bio-fuel), char (ash) and synthetic chemical (syngas), a gaseous mixture of hydrogen, methane, carbon dioxide and carbon monoxide (Sorenson, 2006). In addition, an air purification facility is required for the further treatment of flue gases from pyrolysis (Once, 2018). Based on the amounts in the to-be-processed flow, produced ashes have a high heavy metal content. These ashes are treated and must therefore be disposed of as radioactive waste. Gases, liquids and ashes are released, which may theoretically damage the atmosphere (Once, 2018).

Pyrolysis generates potential hazardous sediments such as passive volcanic ash, inorganic compounds and unchanged carbon. This approach has the potential for a range of possible toxic air pollutants to be produced such as nitrogen oxides, sulphur dioxide, particulates, acid gases, dioxins and furans, etc. (Fortuna et al., 1997). Hence, the waste does not directly affect the air but the products formed during processing of the waste harms the atmosphere.

Autoclave is another technique for waste disposal. However, semi-volatile and volatile organic chemicals, mercury, large animal cadavers, chemotherapeutic waste, heat-resistant enclosed containers, other hazardous chemical and radiological waste, etc. cannot be treated (ISWA, 2020). If there is improper ventilation, odours can be an issue around autoclaves. Low concentrations of alcohol, formaldehyde, phenols and other organic compounds can be released into the atmosphere by inappropriately segregated waste (ISWA, 2020). Waste requires further processing for final disposal (ISWA, 2020).

Restrictions on imports and exports, as well as decreases in the supply of freight transport, mean that vast volumes of food have now been lost. And greenhouse emissions can be emitted when this organic waste decays (Edmond, 2020).

Other challenges related to biomedical waste burning are acidification, eutrophication, global warming and photochemical ozone or smog production. New developments such as plasma pyrolysis and hydro claves for incineration of medical waste contribute to decreased environmental deterioration, minimal impacts on health, healthy processing of processed waste, lowered operating and repair costs, reduction of microorganisms more efficiently, and cleaner disposal (Sorenson, 2006).

## 13.10 Impact on marine life and other organisms

The waste and its products from disposal cause serious harm to organisms and humans. Issues for humans and the environment are created by waste produced by medical operations. Waste generated in health care facilities has a huge influence on the health of the public, the health of healthcare staff and the environment (Manzoor and Sharma, 2019). Infectious and toxic waste saturates the waste that comes from numerous hospitals and care homes (Abd El-Salam, 2010). BMWs haphazard and disorganized disposal subjects individuals and medical workers to multiple ailments and thus needs particular treatment and regulation before its ultimate disposal (Hossain et al., 2011).

Usually, medical and household waste is combined until it hits the place of disposal. In the long term, this causes various kinds of health conditions. In economically developing countries, the population and staff are unaware of healthcare waste treatment (Khan et al., 2019). The population at large, including municipal employees, health workers, and rag pickers engaged in waste recycling, could be affected by the possible health hazards. Owing to unsafe treatment of hospital waste, waste handlers and the population that has close interaction with waste collection and handling are at risk of touching communicable diseases (Singh, 2020b). Exposure can be by contact with the skin, injection, and inhalation. Inappropriate sterilization of containers and plastic materials until recycling can transmit communicable diseases. The processing of chlorine-composed plastic waste can produce dioxins known as human carcinogens (WHO, 1999).

The waste, even if disposed inland somehow ends up in oceans through various environmental forces. Household garbage, comprising of plastic cups, bottles, containers, polythene bags, food wrappers and packaging items is the most prevalent litter in waterways. Plastics for animals can be terribly problematic. They can be either swallowed, inducing internal organs collapse, or bring about slow strangulation, depending on their appearance (Richmond and Clendenon, 2000).

To make matters worse, as reported by John Hocevar, the oceans campaign director at Green peace, the discarded PPE poses an especially horrible issue for aquatic life because of how it is made (Zeldovich, 2020). Hocevar said "Gloves, including plastic bags, can be assumed as jellyfish, for instance, or different form of sea turtle food," (Zeldovich, 2020). The cords on the face masks occurs to be threat for entanglement. According to the 2015 estimates, approximately 300 million tonnes of plastic is generated per year and 5 to 13 million tonnes of it is washed into ocean (Katsnelson, 2015). The same study listed that around 269,000 tonnes of plastic circulating in the ocean (Eriksen et al., 2014). The plastic waste produced as a result of COVID 19 has increased significantly.

Fish, turtles and avian misinterpret this as food and ingest it as larger plastic waste splits into small fragments, which is unfortunately a normal phenomenon. This can cause death of organism due to piercing in their stomachs, damage to their intestines, or deprivation of food (WWF, 2019). A fresh coating of personal protective equipment (PPE) mingling with coral, aquatic life and the normal plastic covering the seabed has also been found by scuba divers in Spain (McMurtry, 2020).

The danger posed by plastic waste to marine life is crucial. Sea plastic adsorbs toxins and chemical compounds, which ensures the pollutant particles bind like a toxic coating to the surface of the plastic. As a result, it is also possible that marine animals may get poisoned by ingestion of plastic. It may destroy them immediately, or degrade them, leaving them more vulnerable to other attacks (Gallo et al., 2018). Ingested plastic can affect the fertility, development and growth of young ones. Floating plastic can act as a carrier to transmit intrusive diseases, poison and choke corals, and to interact with aquatic organisms, leading to reduced movement, illness, amputation of the limbs, malnutrition, suffocation and death (Katzenberger, 2015). It has been observed that algal development can also allow sea turtles to consume marine plastic as a consequence of plastic contamination in aquatic ecosystem (Nelms et al., 2016). It does not dissolve until plastic reaches the aquatic world, but disintegrates into smaller pieces, creating disruption in the food web (UNEP, 2014). A single face mask can take hundreds of years to deteriorate into microplastic, the type of microplastic that is used for human consumption in fish, sea salt, and also sea spray (Fadare and Okoffo, 2020).

Greenpeace International (2018) recorded that in a survey of 2006 called Plastic Debris in the World's Oceans, over 267 distinct animal species were estimated to have encountered plastic debris entanglement and ingestion (Godswill and Gospel, 2019). It is evaluated that at least 400,000 aquatic species will die annually because of pollution from plastic in the oceans (Godswill and Gospel, 2019). The Ocean Conservancy found that plastic waste pollution affects at least 600 different wildlife species (Mallos, 2010). Around 8 million tonnes of plastics used to enter the oceans each year, contributing to the approximate 150 million tonnes hitherto flowing in the marine environment (Mallos, 2010).

The gloves and goggles would ultimately arrive in the ocean when it floods if they're thrown on the field. Human beings live on land but still endure from ocean toxins. In a week, we eat a spoonful of plastic has been found in a research (Zeldovich, 2020). Plastic also leaches into our potable water. Plastic percolates into the drinking water, too. And the microscopic plastic pieces embedded in the ocean water compete with Prochlorococcus's balanced work, the unseen woods of the ocean that contain 10 percent of all the oxygen we breathe (Tetu et al., 2019).

Researchers believe that other plastics pose threats to aquatic organisms that might get trapped or eat parts that are mistaken for food. And even though there is no significant damage incurred by a single piece of plastic in the sea while it is intact, the ultimate destiny is to split into thousands or millions of small bits and transform them into tiny microplastics (ROYTE, 2018).

## 13.11 Conclusion

The COVID-19 has indeed affected the world in different ways, in terms of economy, trades and environmental health. The different types of waste generated due to COVID-19 from households and hospitals has a great impact on air, water, soil as well as humans and other organisms. The waste if not treated properly, can cause severe long-term effects on the environment. This is the concern which need to be paid much attention.

Neglecting the waste management guidelines can prove to be fatal for both aquatic life and humans. The developing countries already lack proper waste treatment facilities and the burden of increasing waste due to COVID-19 has affected more. The amount of waste generated is very high and the solution to this problem is use of reusable things instead of using single use plastic and producing waste. Discarding the different types of waste in their respective bin scan ease the processing and treatment. Moreover, proper air pollution control systems can help reduce the release of hazardous gases from chimneys of incinerators. Lining the landfill sites with appropriate liners and proper maintenance can prevent leaching of heavy metals into groundwater. There can be significant improvements in marine habitat due to proper waste disposal.

There solutions to the waste management problems need to be implied effectively in order to safeguard the environment. The world is already facing environmental issues and waste management is one of the aspects which needs immediate actions. The pandemic has increased the problem. Thus, there is a significant need to manage the waste generated due to COVID-19.

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## CHAPTER 14

# Management of COVID-19 waste

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## 14.1 Composition of COVID-19 waste

The COVID-19 Pandemic has greatly influenced waste management sector due to large-scale patient care, diagnosis, treatment and isolation (Sharma et al., 2020). Health-care waste comprises of the waste arising from healthcare facilities, research centers as well as laboratories associated with medical procedures. Waste produced during health care undertaken at home also includes in healthcare waste (WHO, 2019a). While the principal source of health-care waste or bio-medical waste are the health-care establishments like hospitals and laboratories, other sources could be home quarantine facilities, temporary establishments, sample collection and testing centers, graveyards, crematoriums etc. COVID-19 waste essentially comprises of:

- Anything that may have come in contact with a COVID-19 infected person.
- Items coming in contact or discarded by a healthy person has been in close contact with a COVID-19 infected person.
- PPEs discarded by healthy or asymptomatic persons (such as masks, gloves etc.)

Any waste that is generated from a facility where a COVID-19 patient is undergoing treatment or by a person exposed to the coronavirus, can be considered as infectious medical waste (Ed and Ym, 2020). In other words, bio-medical waste, MSW from home quarantines where COVID-19 patients are receiving treatment and discarded PPEs from households and by general public could be collectively treated under the category of COVID-19 waste Fig. 14.2. An exhaustive list of items which may be considered as COVID-19 waste is given in Table 14.1 and Fig. 14.1.

## 14.2 How COVID-19 waste differs from other waste

COVID-19 waste may have the tendency to spread infections if not handled and treated properly. Nations across the globe have clearly defined and differentiated between bio-medical waste and municipal waste. Both have separate methods and procedures for handling, treatment and disposal. COVID-19 waste could comprise of both municipal waste as well as bio-medical waste depending on the source of its generation. For instance, any waste originated from households in which a person infected from COVID-19 has been isolated and is undergoing treatment from home is categorized as COVID-19 waste. Conversely, bio-medical waste generated from any healthcare facility

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**Table 14.1** List of items categorized as COVID-19 waste (Source: WHO, 2019a; CPCB, 2020).

| | |
|---|---|
| Infectious or potentially infectious waste | Used masks (including N95 mask, surgical mask, etc.), head cap/cover, shoe cover, disposable linen gown, coverall suit, splash proof apron, face-shield, hazmat suit, nitrile gloves, feces from COVID-19 confirmed patient, body fluids or blood soaked tissues/cotton, microbiology, biotechnology and other clinical laboratory waste, viral transport media, plastic vials, vacutainers, Eppendorf tubes, plastic cryovials, pipette tips, used syringes, urine bags, drain bags, medicine vials, ampoules, broken or discarded and contaminated glassware |
| Pathological waste | Human tissues, organs or fluids of COVID-19 confirmed patients |
| Sharps waste | Needles, discarded and contaminated metal sharps, syringes with fixed needles |
| Pharmaceutical waste | Expired, unused drugs and contaminated vaccines used during diagnosis or treatment of COVID-19 patients |
| Non-hazardous or general waste | Waste that does not pose any particular hazard which may include wrappers of medical items, fruit peels, empty or used bottles, waste-paper, carton boxes of medicines, disinfectant bottles, left-over food, disposable cutlery, packaging material etc. |


**Fig. 14.1** Composition of COVID-19 Waste (CPCB 2020).

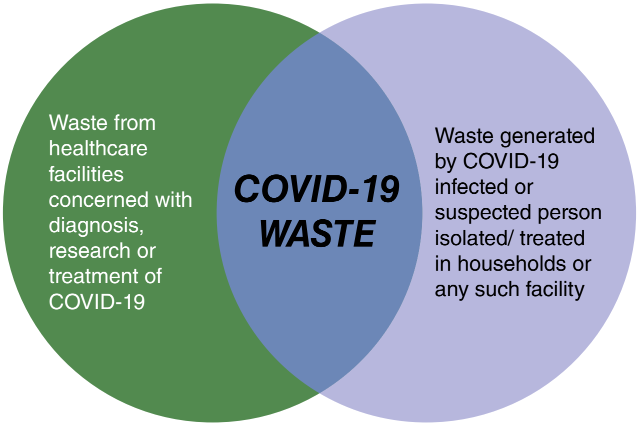


**Fig. 14.2** Classification of COVID-19 Waste.

which is not related to any COVID-19 related activity (diagnosis, research or treatment) does not fall under COVID-19 waste. Another notable difference is in the quantity of waste. During the pandemic, the quantum of potentially infectious waste is enormous which requires special care to handle and dispose. The quantum of such waste is quite less during normal scenario (Chen and Guo, 2020).

## 14.3 Why it is necessary to manage COVID-19 waste?

A humongous amount of waste is being generated during the pandemic and those originating from healthcare sector are of utmost concern. There are high chances of such waste being potentially infected with the virus. If not managed and treated scientifically, the risk of secondary transmission of the virus increases (UNEP 2020a). The frontline staff coming in contact with the waste could get infected if it is improperly handled (Singh et al., 2020). Uncontrolled dumping in the open could further elevate the chances of spreading to other groups such as waste pickers and general public.

The pandemic has led to enormous utilization of personal protective equipment (PPEs), especially face masks. In 2020, 2.4 billion surgical masks are expected to be used (UNICEF 2020). A huge chunk in PPEs is plastic and their uncontrolled burning would result in release of toxic gases and fumes in the environment. Unmanaged dumping could pollute ecosystems like rivers, beaches and oceans (UNEP 2020a).

As of now, it is not known whether COVID-19 virus transmits through direct or unprotected contact during handling of health-care waste (WHO 2020). But, the risk of transmission during sorting or handling at healthcare facilities or scavenging at waste dumpsites cannot be neglected, especially in low and middle income countries (WHO 2018).

Over and above, it is necessary to have a well-executed and coordinated strategy to deal with COVID-19 waste in order to maintain progress towards achieving various Sustainable Development Goals such as Goal-3 good health and wellbeing, Goal-6 clean water and sanitation, Goal-8 decent work and economic growth, Goal-12 responsible consumption and production and Goal-13 climate action (Singh et al., 2020).

## 14.4 Risks and challenges associated with waste management during COVID-19 pandemic

The numbers of COVID-19 cases have kept increasing with each passing day since its first occurrence in December 2019. For the sake of providing treatment and medical assistance to rising number of patients, the healthcare infrastructure has been expanded to a large extent globally. People all over the world have been using masks and gloves to protect themselves from getting infected. All these changes over a short span of few months has resulted in a sharp rise in the amount of waste meant for disposal. Some countries have even reported upto 10 times increase in the waste generation during the pandemic scenario as compared to pre-pandemic scenario (Abu-Qdais et al., 2020; Sarkodie and Owusu, 2020). Obviously, the existing waste management systems are not designed to handle such surge of waste and therefore, safe handling and disposal of such waste is viewed as one of the biggest challenges.

Before the pandemic, access to waste collection was not available to 2 billion people globally while around 3 billion lacked controlled waste disposal facilities, which reflects the state of waste management systems, especially in developing nations (Sharma et al., 2020; UNEP 2020b). At times when enormous waste is generated, cases of open burning and uncontrolled disposal of waste cannot be ruled out. This would in turn lead to more littering, pollution and environmental degradation, including higher chances of secondary transmission of the virus from such waste.

There is poor segregation at source, especially of municipal waste, which has resulted in an increased amount of mixed waste. Because of lockdowns and promotion of work from home culture, people have been staying at home due to which the quantity of household waste generation has increased. Another reason for the increase is the rise in the use of disposables and packaging items. The services of waste collection and recycling have been disrupted leading to piling up of waste which further raises hygiene concerns (UNEP 2020c).

The risk of transmission of the infection to the waste handlers while handling COVID-19 associated waste cannot be neglected (Sharma et al., 2020). Safety of waste handlers needs to be ensured as the role of waste handlers has been treated under essential services by various countries because timely and proper collection, treatment and disposal of waste is of paramount importance during the pandemic. In developing countries, where the waste handlers are not equipped with requisite PPEs, the extent of risk would be high (Sharma et al., 2020).

Another section of people which are at even greater risk are the waste pickers who may contract infection from improperly dumped infectious waste such as masks, gloves and other infectious municipal waste.

The scientific fraternity and governments across the world had little knowledge about the nature of the pandemic and its associated impacts. To make our waste management systems robust and resilient, we need to have thorough information about the extent of waste generation and its spatial as well as temporal variation (Sarkodie and Owusu, 2020).

## 14.5 Sources of COVID-19 waste

The sources of COVID-19 waste could be multiple and the type and quantity of waste generated varies for each source. The sources are briefly explained below and also represented in Fig. 14.3:

**i. Hospitals, COVID-19 wards, ICUs, Clinics etc.**

Separate isolation and quarantine wards have been set up to admit COVID-19 confirmed as well as suspected patients in large bedded hospitals. Some patients may require intensive care and thus apart from isolation wards; intensive care units, critical care units, dialysis facilities, laboratories etc. can be the sources of COVID-19 waste within a hospital. Infact, hospitals are the biggest source of COVID-19 waste among all other sources.

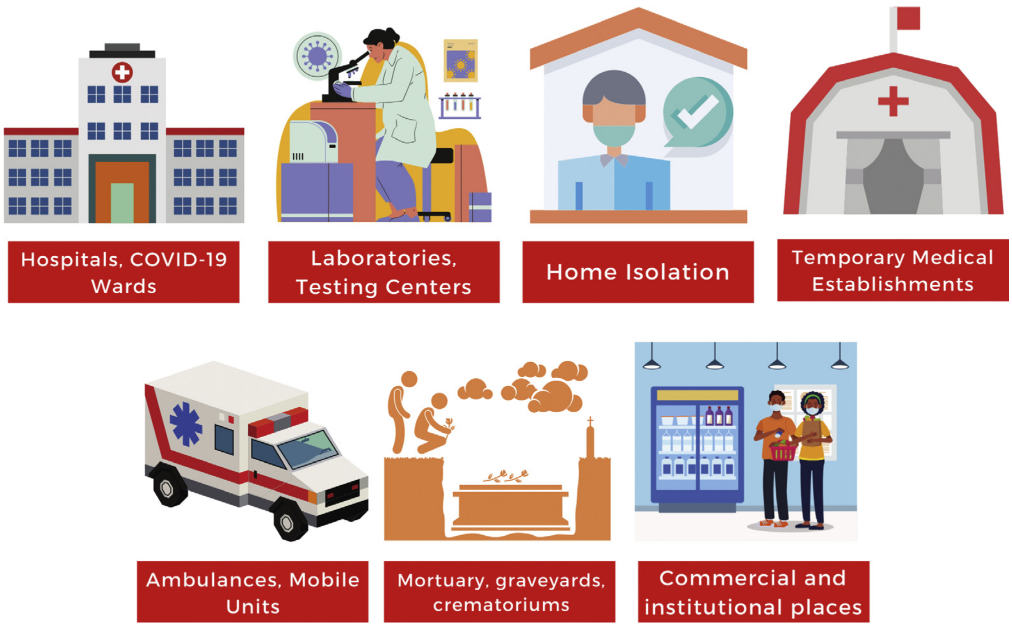


**Fig. 14.3** Sources of COVID-19 Waste.

**ii. Testing centers, laboratories and sample collection facilities**

Countries have been striving to ramp up the testing services so as to isolate as many COVID-19 positive patients as possible in order to avert further spread in the communities. In doing so, testing centers, community testing booths, laboratories, sample collection facilities, mobile testing units have been set up and mobilized in large numbers. All these testing related infrastructure contribute significantly to COVID-19 waste.

**iii. Households where COVID-19 confirmed patients have been isolated (Home Quarantine)**

COVID-19 confirmed patients with mild or no symptoms at all are not required to be admitted to an isolation facility in a hospital. Such patients are isolated in their respective households itself where they receive medical assistance either remotely or through visiting health professionals. Waste generated by them comprise of used masks, gloves, tissues and other infected municipal waste which in terms of quantity is very small.

**iv. Temporary medical establishments**

Due to massive increase in caseloads, existing hospitals and healthcare establishments were running at full capacity and soon became overwhelmed, due to which governments across several countries had to provide makeshift and temporary isolation facilities over very short period of time. Facilities like stadiums, convention centers, community halls and even railway coaches were transformed into COVID-19 isolation wards.

**v. Ambulances, mobile diagnosis and testing units**

To take care of logistics, vehicle fleets are being deployed as ambulances and also as mobile diagnosis and testing units in a large number.

**vi. Mortuary, graveyards and crematoriums**

Health workers are required to shift the body of deceased person to a mortuary and finally to graveyard or crematorium for respectful burial or cremation as the case maybe. The waste arising from these sources are the personal protective equipment (PPE) doffed by health workers.

**vii. Commercial and institutional establishments**

After the lockdown restrictions were eased, various commercial and institutional establishments resumed operations. COVID-19 waste from these places are only the masks and PPEs discarded by people.

## 14.6 Practices recommended by World Health Organization

World Health Organization advocated that application of WASH (Water, Sanitation and Hygiene) and waste management practices are critical to avert spread of COVID-19 and issued guidelines for their implementation.

WHO stated that additional treatment or disinfection over and above the routine or prescribed waste management procedures are not required specifically for COVID-19 waste since waste arising from healthcare facilities with and without COVID-19 patients is not different.

WHO stressed on segregating waste since general and non-infectious waste is a major chunk of waste in healthcare facilities and they shall be disposed as general municipal waste. WHO recommends on-site treatment of infectious waste generated in the course of treatment of patients preferably through high temperature, dual chamber incineration or autoclaving.

The need for ramping up the waste treatment infrastructure through alternate technologies has also been addressed by WHO in view of the sudden surge in the quantum of waste, especially the discarded PPEs. Until more sustainable options are implemented, as an interim solution, safe burial of healthcare waste may also be practiced. However, manual disinfection is not a recommended option for treating waste since it is unreliable and inefficient (WHO 2020).

## 14.7 Global practices: COVID-19 waste management practices in different countries

**i. United States:**

- The Occupational Safety and Health Administration of the United States did not categorize COVID-19 as Category-A infectious substance. It recommends that infectious medical waste related to COVID-19 should be managed as regulated medical waste, for which CDCs Guidelines for Environmental Infection Control in Health-Care Facilities are to be referred. It recommends placing and containing the waste in a leak-proof and sturdy bio-hazard bag for disposal. For containment of sharps, syringes and needles, puncture-proof containers are to be used.
- OSHA advocates following standard engineering and administrative controls, safe working practices and use of PPEs to prevent exposure of the workers to any type of infectious waste as well as any contaminants in the items being managed. Such controls would safeguard workers from injury due to sharps or other items that may cause injury or expose the workers to infections.
- Contaminated or potentially infectious general waste (municipal waste) should be managed similarly to that of non-contaminated municipal waste (CDC 2019).

**ii. European Union**

Excerpts of guidelines issued by European Union based on the advice of European Centre for Diseases Prevention and Control (ECDC) are as follows:

- According to ECDC, there is no established proof to conclude that routine waste management practices are unsafe or insufficient to spread infection of COVID-19 and neither household waste could transmit SARS-CoV-2 or other respiratory viruses.
- A waste bag should be available in the patient's room who is self-isolating at home, items such as paper tissues, masks etc. discarded by the patient must be promptly

placed in the bag. Another waste bag should be for the caretaker for discarding his used face masks and gloves. These bags shall be placed in a separate garbage bag.

- Waste arising from healthcare facilities, laboratories and other activities related with COVID-19 patients should be managed as per the provisions of EU law on waste and concerned national regulations related to infectious waste as well as instructions delivered by ECDC and national health authorities (European Commission 2020).

**iii. China**

Basel Convention Regional Center for Asia and the Pacific published the detailed guidelines titled *"Handbook of Emergency Disposal and Management of Medical Waste in China"* for management of medical waste during the COVID-19 pandemic in China. It says,

- Collection of waste generated from fever clinics and ward rooms for treatment and diagnosis of COVID-19 patients shall be as per assigned classification of medical waste.
- Waste should be packed and sealed in double-layer bags and labeled properly.
- For emergency disposal during the pandemic, the waste should be disposed category-wise and through decentralization. Waste not meant for emergency disposal should be disposed through centralized medical waste disposal facilities. Waste PPEs generated from COVID-19 related activities shall be treated and managed as medical waste. They shall be segregated as per the prescribed standards and collected and disposed within 24 h.
- Waste generated in households by COVID-19 patients such as used masks and other waste shall be managed as medical waste, collected in sealed bags and disposed through incineration (Chen and Guo, 2020).

**iv. India**

For India, the Central Pollution Control Board (CPCB) published the *"Guidelines for Handling, Treatment and Disposal of Waste Generated during Treatment/Diagnosis/Quarantine of COVID-19 Patients"*. It laid down detailed responsibilities and duties of various stakeholders engaged in management of waste, from generators to regulatory bodies. According to the guidelines:

- Isolation wards and temporary establishments should keep separate color-coded foot operated bins for segregation of bio-medical waste as per provisions laid down in the Bio-medical Waste Management Rules, 2016. Dedicated bins labeled as 'COVID-19 Waste' should be used. Use double-layer bags for waste collection.
- General waste generated in healthcare establishments should not be mixed with bio-medical waste. It should be collected and managed separately in accordance with the provisions of the Solid Waste Management Rules.
- In case of quarantine camps, home quarantine and home care facilities where COVID-19 patients are isolated for treatment, only used masks, gloves, swabs, tissues, syringes etc. shall be handled as bio-medical waste and stored in yellow colored bags.

- Used masks and gloves discarded by persons who are not infected with COVID-19 should be stored for a period of 72 h in a paper bag and they shall be disposed as general waste. They must be cut prior to disposal so as to avert their reuse (CPCB 2020).

## 14.8 Management of COVID-19 waste generated from different sources

While certain procedures and techniques for collection, treatment and disposal of COVID-19 waste vary from country to country, the basic underlying principle of their management remains the same as most of the national legislations have been based on the following:

**i.** Technical Guidelines on the Environmentally Sound Management of Biomedical and Healthcare Wastes adopted in 2002 under the Basel Convention

**ii.** Safe management of wastes from health-care activities – A WHO Publication

**iii.** Water, sanitation, hygiene, and waste management for SARS-CoV-2, the virus that causes COVID-19

**a)** Healthcare facilities such as COVID-19 Hospitals, COVID Clinics, COVID Care Centers etc. (facilities where COVID-19 patients are diagnosed and /or isolated for treatment)

- Based on the end fate (disposal or recycling) and potential hazard, segregate the waste at source itself in coded bags / bins.
- For additional safety and strength, use double layered bags (Chen and Guo, 2020) (CPCB 2020).
- Avoid mixing general solid waste and bio-medical waste.
- In most countries, treatment followed by disposal of infectious waste is done at a central disposal facility or a common facility. In such cases, waste should not be stored on-site beyond a specific period of time, which in most cases is 48 h, or even less in some countries.
- Dedicated and adequately trained staff should be deployed for handling and collection of waste, including on-site treatment and transport.
- Ensure the availability of items in adequate numbers such as bags, bins, trolleys, PPEs for waste handlers etc.

**b) Testing centers, laboratories and sample collection facilities**

- The entire waste collection handling and management process for testing centers, laboratories and sample collection facilities is similar to that of other healthcare facilities as mentioned above.
- Potentially infectious consumables such as viral transport media, plastic vials, vacutainers, Eppendorf tubes, plastic cryovials, pipette tips etc. are specific to sample collection and testing facilities. They shall be adequately pre-treated before their final disposal (CPCB 2020).

**c) Home quarantine and home care centers**

- Countries that already have strict and safe disposal measures for municipal waste have not recommended separate special provisions for COVID-19 waste from households (where COVID-19 confirmed patient has been isolated at home) (OSHA 2020).
- Developing countries like India has specifically stated that potentially infectious COVID-19 waste from home isolation (e.g. used masks, gloves, tissues and other items that may have infected with blood or body fluid of a COVID-19 patient shall be deemed as bio-medical waste and shall be handled and disposed accordingly (CPCB 2020).
- Waste from such households should be sealed in appropriate bag, stored temporarily shall be collected at the first opportunity, its treatment and disposal should be prioritized.
- The agencies collecting waste should make sure that collection is not disrupted and periodic collection of waste is done. Waste handlers must be given proper training along with adequate PPEs and should also help in spreading awareness to the community regarding proper segregation, storage and handling.
- In no case, open burning and/or uncontrolled dumping of waste should be done (UNEP 2020d).

**d) Temporary establishments**

- Temporary establishments have been described earlier in section. Measures for waste management in such establishments would be similar to that of healthcare facilities.
- Certain aspects to be considered while setting up a temporary establishment include storage requirements for on-site storage, waste collection route, availability of items such as bags, bins, trolleys etc. and pre-treatment facilities.

**e) Ambulances**

- Ambulances and emergency vehicles should have bins and bags of adequate size and numbers for collection of waste, while also ensuring proper segregation.
- Necessary protocols should be in place to hand over and empty the bins at a designated place and also replace with new bags/bins.

**f) Graveyards and crematoriums**

Procedures should be prescribed to safely collect and dispose PPEs, masks and gloves doffed by health workers and visitors at graveyards and crematoriums (CPCB 2020).

## 14.9 Treatment and disposal of COVID-19 waste

**Factors to be considered to decide the treatment technology**

Several economic, environmental and social factors of a country or region would govern the selection of an appropriate technology to treat and dispose potentially infectious COVID-19 waste. The following factors would decide the selection of technology:

- Waste characteristics
- The prevailing national and local laws governing medical or healthcare waste
- Available technologies to treat and dispose healthcare waste
- The existing treatment capacity.
- Waste volume expected to be generated considering worst case scenario
- Availability of alternative 'best available technology' (for example waste to energy plants, industrial hazardous waste incinerators, sanitary landfills) overwhelms the available treatment options
- Availability of sufficient trained and skilled manpower to operate the existing equipment
- Availability of manpower and infrastructure to collect and transport waste safely.

**Preferred Technologies**

According to UNEP, the technology adopted for treatment should be compliant to the Guidance Manual by UNEP IETC, the Stockholm Convention Guidelines, and WHO guidelines (UNEP 2020e). WHO recommends that ideally infectious COVID-19 waste should be treated on-site followed by safe disposal. High temperature, dual chamber incineration or autoclaving are the preferred treatment options. An interim solution could be to safely burry healthcare waste until more sustainable options are made available (WHO 2020).

**i. Autoclave**

Autoclaving is a steam based low-heat thermal process widely used mainly to sterilize medical equipment. Since it destroys micro-organisms, it is also used to treat infected or contaminated medical waste before further treatment or disposal (International Finance Corporation 2020). Except anatomical waste (human tissues or body parts), autoclave is capable to treat any kind of infectious waste. It is a metallic vessel with a sealed door. It is capable of withstanding high pressure. A mechanism for steam inlet and outlet is made within the vessel (WHO 2019a).

To achieve effective disinfection, a suitable combination of three parameters – temperature, pressure and exposure time is required. A minimum temperature of 121 °C, pressure of 2.05 bar and exposure time of 30 min is recommended by WHO (WHO 2019a).

**ii. Microwave-based technologies**

Another steam-based technology commonly employed to treat bio-medical waste uses microwave which operates at a frequency of around 2450 MHz and wavelength of 12.24 cm (WHO 2019a). Microwave energy causes the moisture contained in the waste to rapidly heat up. Waste is kept in a chamber which is subjected to microwave energy generated from a microwave generator and heated upto 100 °C (WHO 2019b). After treatment, the waste can be further disposed or recycled according to the type of waste.

**iii. Dual Chamber Incineration**

Incineration is a dry oxidation process in which waste is subjected to high temperature. Organic and combustible fraction of waste gets converted into inorganic substance. A significant reduction in volume and weight of the waste is also achieved. The temperature ranges from around 200 °C to more than 1000 °C. One of the serious drawbacks is that it generates by-products in the form of gaseous and particulate emissions as well as residual ash. They are required to be disposed of carefully (WHO 2019a). The incineration technology should be designed and operated such that it complies with Best Available Technology (BAT) and Best Environmental Practices (BET) relevant to Article 5 and Annex C of the Stockholm Convention on Persistent Organic Pollutants (UNEP 2020f).

**iv. Brick built De-Montfort Incinerators**

These are simple and low-cost dual chamber incinerators made of refractory bricks. These can be used as temporary stop gap solution for burning medical or municipal waste arising due to COVID-19 activities, particularly in developing counties (UNEP 2020e; International Finance Corporation 2020). >850 °C temperature will ensure complete combustion of waste while forming bottom ash and particulate and gaseous emissions as by-products. Depending on design, its capacity ranges from 12–50 kg/hr. A 6-hour cycle would incinerate one batch of waste, thus it can handle upto 3 batches per day (De, 2004; UNEP 2020e).

**v. Barrel incinerators with air induction**

It could act as a temporary stop gap solution when existing waste treatment measures are overburdened or at remote locations or temporary medical camps where certain type of waste is required to be disposed of immediately or transportation for treatment and disposal is not feasible. The capacity is in the range of 8–25 kg per hour. It can act as a mobile unit and can be easily mobilized from one place to another. It burns at a slightly lower temperature of around 650 °C which may result in higher emissions (UNEP 2020e; UNEP 2020 g).

**vi. On-site Pit Burial**

This option should be the least preferred for waste disposal and should be employed only during lockdown situations or when no other alternative is available. An excavated pit should have a fixed metal covering to prevent vermin and rodents from entering the pit. Around 5–10 tons of waste can be dumped in a single pit and if required, multiple pits may be created. Site selection should be done very carefully such that it is away from water abstraction points, water resources, crops and communities. The bottom should be made impermeable for placing plastic liner or compacted clay. The site should be properly secured with clearly marked hazard signages and access to waste pickers and scavengers should be restricted. Each layer of waste should be covered with 5–10 cm of soil cover and waste should be disinfected with 0.5 percent sodium hypochlorite prior to placement. In no case, open burning of waste should be carried out (UNEP 2020e; UNEP 2020 g).

## 14.10 Special consideration to used masks and PPEs, its management and disposal from residential, commercial and other establishments

Traditionally, only the staff in healthcare settings have been using masks and PPEs to safeguard themselves from potential disease-causing infections. The global pandemic of COVID-19 has forced each one of us to wear a mask in routine life (Ogunseitan, 1989; Singh et al., 2020). Governments across the world have been advocating and enforcing wearing of masks to prevent human to human spread of SARS-CoV-2 virus with a view to secure public health, for which mass awareness drives have been undertaken. Apart from knowing why and how to wear a mask, it is equally crucial to know how to dispose it off (Rhee, 2020).

Although there is no established proof of SARS-CoV-2 virus transmission to human beings through COVID-19 waste (WHO 2020), traces of the virus were detected on the outer surface of surgical face mask even on day 7 (Di Maria et al., 2020; Chin et al., 2020). On the other hand, a case of transmission of the coronavirus without coming in direct contact of an infected person was detected in South Korea. A person got infected with the virus through a used face mask which was lying on a table (Rhee, 2020). Apart from all this, health workers and citizens regard such waste as a perceived threat, making its safe disposal even more critical. The threat is not just about further spread of the virus but also the disastrous impact it would have on the environment.

As much as 75 percent of the used masks, and other waste associated with the pandemic is anticipated to end up either in landfills, or dumped in the seas. In areas of tourism and fisheries, this would cause a financial damage of around $40 billion, in addition to the environmental damage (UN News, 2020). A Report by WWF claims that, even if 1 percent of the masks are disposed improperly, 100 million masks per month would end up in the environment (Kumar et al., 2020). It is estimated that in 2020, a whopping 2.4 billion surgical masks are going to be used (UNICEF 2020). Looking at the quantum of waste that would be amassed from the used PPEs, it is quite apparent that the existing waste management systems are going to be overburdened (Kumar et al., 2020; Infection Control Today 2020).

Used masks and other PPEs used by healthy individuals (those who are not infected with COVID-19 should be sorted so that the risk of cross-contamination of the entire waste stream as well as picking up by scavengers is minimized. They must be securely packed and earliest possible collection of the waste should be ensured. The most appropriate method to dispose the used PPEs is incineration (Di Maria et al., 2020; WHO 2020).

Single use masks are made from mixed polymers and comprise of multiple layers of plastic which makes them quite difficult to recycle which will ultimately adversely affect the environment (Vanapalli et al., 2021). Various technologies are being tested to explore the prospects of reusing used PPEs through disinfection. These include, methods such as hydrogen peroxide vapor infusion, ultraviolet or gamma-irradiation, ethylene oxide gasification, spray-on disinfectants, and infusing base materials with antimicrobial nano-particles (Singh et al., 2020; Price et al., 2020). However, the most sustainable approach towards management of waste due to PPEs and masks should be based on the concept of circular economy (Singh et al., 2020).

## 14.11 Waste recycling

**Implications of COVID-19 pandemic on recycling**

The imposition of lockdown to contain the spread of virus has adversely impacted economy and trade, including the waste recycling sector. Recycling of plastic and related items has declined considerably. Due to the apprehension of transmission of the virus, plastic waste is being directly dumped, either through incineration or landfilling. Another reason for decline is disruption of supply chain and suspension of commercial activities (International Finance Corporation 2020). The reduced oil prices have further made virgin plastic more affordable than recycled plastic (Sarkodie and Owusu, 2020). Globally, the magnitude of plastic recycling is already less and recovery of recyclables from PPEs and other healthcare waste is a huge challenge (Singh et al., 2020). Recycling will continue to suffer as demand in the market for single-use plastics, disposables and packaging material will lead to an increased production of virgin plastics during the post-pandemic period (International Finance Corporation 2020). Most of the waste recyclers fall under the category of Small and Medium Enterprises (SMEs) which are under huge financial stress owning to the lockdown and market uncertainty. This would cause shutting of operations, which would further amplify the concerns of recycling sector.

**Changes in waste generation and management scenario**

Although temporarily, the pandemic has altered the affairs of the waste industry in many ways. The bulk of healthcare waste generation has escalated manifolds and their disposal is being given more priority and attention than any other waste. Lockdowns have forced people to stay at home and working from home is the new trend. This has resulted in a spurt in the volume of municipal solid waste. The characteristics of industrial hazardous waste has also altered since only essential industrial sectors related to pharmaceutical and medical items were fully operating during lockdowns while other sectors are functioning partially and reviving slowly. As discussed previously, incineration and landfilling of waste is preferred over recycling (International Finance Corporation 2020).

**Impact on informal sector**

Roughly between 12.5 to 56 million work in informal sector of waste management across the world (Linzner and Lange, 2013). They are among the most deprived sections of the society. Due to their unhygienic and hazardous nature of work, they are prone to several infections and diseases and are not able to receive the necessary medical assistance. The COVID-19 pandemic has made them susceptible to greater health as well as financial risks (COVID-19 Related Wastes and the Informal Waste Recycling Sector). Informal sector is a crucial link in the recycling business, especially in developing counties. The slump in recycling sector because of the pandemic has severely affected the informal sector. Waste pickers, who represent a large section of the informal sector will fail to get the desired price of the commodities from the dealers as the demand for recycled items is quite low and it is envisaged that it will remain low in the coming years. Millions are going to face financial crisis and they are unlikely to receive any support from the government since this sector is completely unorganized in many countries (COVID-19 Related Wastes and the Informal Waste Recycling Sector).

## 14.12 Management of sewage and wastewater

A clear linkage exists between COVID-19 and wastewater (UNEP 2020h). Although infectious SARS-CoV-2 has not been detected so far in treated or untreated sewage, RNA fragments of the virus in trace levels have been identified in a couple of instances wherein the sewage was untreated or partially treated (WHO 2020).

The likelihood of transmission of the virus through sewage would be minimized through routine wastewater treatment systems comprising of physical, biological and chemical processes. Disinfection at the final stage may be done if the existing treatment systems are not capable to eliminate viruses (WHO 2020).

## 14.13 Assessment, inventorization, legal and policy interventions

The significance of a sound, robust and effective waste management system (also referred as 'system' in this section) has been realized during the pandemic period. An ideal waste management policy during this pandemic should,

**i.** be capable of safely tackling the waste generated in a manner that there are no odds of transmission due to the waste

**ii.** ascertain that the treatment and disposal of waste causes environmental impact, and

**iii.** strive to achieve sustainable development goals (SDGs) and other international obligations

The vulnerabilities in our existing waste management systems have been exposed during the pandemic as they were never designed to withstand such an emergency situation. Strict laws and regulations in place alone will not guarantee that the system is resilient to deal with such a sudden upsurge in waste. They must be supplemented with effective utilization and optimization of the infrastructure and the services at hand. It is important to recognize that the continuity and uninterrupted functioning of the waste management services is critical in battling the pandemic (Scheinberg et al., 2020).

The first step towards a sound waste management is assessment of waste, and that is where countries have been struggling in the course of the pandemic. There is no or insufficient data about the estimated waste to be generated, due to which the governments are unable to formulate strategies to deal with it (UNEP 2020i). In such cases, the estimates made by WHO and UNEP should be used.

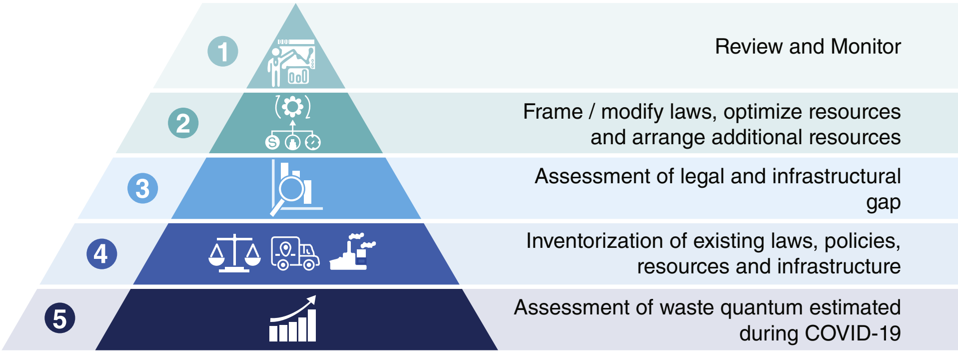


**Fig. 14.4** Stages of legal and policy interventions to deal with COVID-19 waste.

In the next step, an inventory of the existing laws, policies, sources of waste, logistical resources, treatment capacities and other related infrastructure shall be made so as to assess the country or region's existing competency and readiness towards handling the enormous quantum of waste (UNEP 2020i). This will also assist in pointing out the gaps in the existing framework.

In case a gap is pointed out in the legal or policy framework to deal with waste during emergencies such as the COVID-19 pandemic, the same must be rectified which would pave way for a smooth execution. This would tell us how the existing resources and facilities can be optimized and what extent of additional facilities are required to be arranged.

In view of the large amount of waste associated with the pandemic, particularly the used PPEs, their treatment and disposal is not a long-term sustainable option. This will lead to extraction of huge quantities of natural resources. The concept of circularity or circular economy should be part of the government policies which should promote the concept of 4Rs (Reduce, Reuse, Recycle, Recover) (United Nations Environment Programme, 2020). The stages of legal and policy interventions to deal with COVID-19 waste are represented in Fig. 14.4.

## 14.14 Conclusion

The pandemic is once in a century kind of phenomena and has had a lasting impact on the lives of each and every human being living on this planet. Waste management has never received such prominence as it has received during the pandemic period. Sound waste management is one of the tool to combat and avert the outspread of the virus. A well-executed and coordinated strategy at par with global standards, timely put in place could save the communities from the ill-effects of the waste generated during this pandemic.

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## PART 6

# COVID-19: A Burden or Relief for Environment

# CHAPTER 15

# Environmental policies and strategies for COVID-19

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## 15.1 Introduction

COVID-19 has reshaped our world in a short span of one year. The pandemic situation has seriously affected our day-to-day lives and its impact can be visualized on economy, personal life, healthcare and environment. COVID-19 is a worldwide health crisis and has made everyone realize that our lifestyle and economy are very much connected to the global health. It clearly implies that global health is the building block of worldwide welfare of businesses and individual (World Economic Forum, 2020). Activities pertaining to economy and society have decreased because of COVID-19 which according to experts have impacted positively on environment. The impact is quantifiable as the level of pollution and emission in greenhouse gases have decreased significantly. A temporary break, because of adverse effect of human-induced activities, is observed globally due to present situation. Nations have to function strategically towards green economic activities to overcome fall in current economic activities (Gulf Business, 2020). As world combat with this pandemic and go ahead to think about recovery both economically and environmentally, businessmen can expect for stronger and well-thought-out environmental strategies.

## 15.2 Environmental regulations worldwide and impact of Covid-19

Environmental laws and regulations have always proven efficient towards consistent quality of our surrounding and environment. Ethically they redefine the association of humans with nature. These laws prevent and control pollution and aid to circumscribe the depletion of natural resources, that too on scaffold of sustainability. Particularly the important aim of imposing environmental regulations is to reverse the outstanding disregard to natural resources which cause its serious degradation. In early 20th century, environmental regulations were enforced at state or provincial level, leading to discrepancies between jurisdictions. However, in 1970s, it grown in to adulthood from its infancy because of major increase in environmental awareness in 1960s (Bruch, 2006). Environmental Protection Agency (EPA) saw a proliferation of novel environmental

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regulations in USA wherein the states had to execute measures for pollution control, water issues and to deal with solid wastes.

### 15.2.1 Progress of environmental regulations across world

Environmental regulations at global scale cover climate change, ozone depletion, biodiversity, air quality, land degradation, water management, toxic and hazardous wastes, e-waste, marine resources, desertification (MERM, 2017). The growth of environmental regulations can be classified in three phases as shown in Table 15.1 which roughly corresponds to initial gleams of elementary agenda development, worldwide environmental laws, development and association with various fields of global law. The

**Table 15.1** Evolution of Environmental Regulations (Weiss, 2011).

| Periods of Evolution of Environment Regulation | Type of the period | Highlights during the period |
|---|---|---|
| 1900–72 | Early Glimmers | (a) Early 20th century: Four agreements to safeguard species of commercial value, including migratory birds, birds beneficial for agriculture, fish and wild animals, fur seals and birds in Africa<br>(b) 1930s & 1940s: Many treaties focused on safeguarding animal and plant species in particular areas<br>(c) 1950–70: Numerous treaties associated to curb oil pollution in seas and oceans<br>(d) 1971: Canada-USA: Agreement for the safeguarding Migratory Birds in the USA and Canada etc. |
| 1972–92 | Development of Basic Framework | (a) 1972: The United Nations Stockholm Conference on the Human Environment<br>(b) Post Stockholm conference: More than 1100 international agreements associated with environment |
| 1992–2011 | Maturation and Linkage | (a) 1992: The United Nations Rio Conference on Environment and Development<br>(b) Linking global environmental law with other region of law<br>(c) Rise of players excluding States in shaping worldwide environmental law<br>(d) Development and refinement of novel international principles and rules of worldwide environmental law and the rise in illegally binding instruments<br>(e) Emphasis on implementing and obedience with worldwide environmental agreements. |

two demarcations for these periods are 1972 UN Stockholm conference on human environment and 1992 Rio De Janeiro conference on Environment and Development (Weiss, 2011).

Since 1972, there is approximately 38 times growth in environmental acts and regulations but are yet to be implemented fully. Enforcing these regulations has been a major task to alleviate climate change, control pollution and protecting and conserving bio species. Numerous challenges are faced to fulfill these regulations effectively because of ideological opposition among regulatory bodies and interference of market economics (McManus, 2009). Especially, the extent of provision of laws among public sometimes inspire governments to deregulate the existing laws. But principally these environmental laws should be contributory from the government bodies, industries, general public and environment organizations equally. Environmental law directs conserves and safeguards the environment and its resources but indirectly aids clean and competitive economy that creates vacancies and generate environment goods and services in the market.

### 15.2.2 Present status of environment regulations and effect of Covid-19

Environment preservation is integrated with the country's overall development. Environmental laws have got a thrust due to public health concerns and increasing consciousnesss about conservation of natural resources. Till 2017, environmental framework was a vital part of 176 countries which was implemented by hundreds of ministries and agencies. 187 countries had legal instruments requiring environmental assessments for projects impacting the environment and more than 50 percent of the total countries having adopted legislations to access environmental information (UNEP, 2019). The environmental laws at present principally in addition to protect air, water and land are also amended and being stringent towards using plastics, carbon emissions, biodiversity, climate change and industrial pollution too. Entire world is debating on strict execution of environmental laws and variability in standards for industrial environmental practice in different countries. Industries often claim that the directive standards are stringent to impact their competitiveness and sometimes survival (Ottewell, 2012) whereas environmentalists claim them as too low and it seriously affect the public health and quality of environment. Such everlasting debates need political intervention for greater level of environmental protection with its impact on innovation, sustainability and competitiveness (Gouldson et al., 2014).

The prevailing pandemic situation has pushed back several environmental regulations. Several environmental policies have been relaxed or suspended and major environmental events like IUCN World Conservation Congress and 15th Convention on Biodiversity were postponed. On 26th March 2020, USEPA has issued an order "COVID-19 implications for EPAs Enforcement and Compliance Assurance Program" which meant that in the present situation EPA will not levy penalties for environmental management and monitoring works such as sampling and testing violations, laboratory analysis, day-to-day monitoring compliance, training and reporting or certification obligations. Such relaxations shall be applicable if EPA agrees the reason of non-compliance as pandemic situations (Kecinski et al., 2020). Several such relaxations have potential long-term contamination and pollution problems as these pollutants are having a long self-life in the entire ecosystem. Moreover, industries refer the pandemic situation as reason of non-compliance of environmental rules and impeded economy is now a virtue of executing infrastructure projects that were prohibited due to strict environmental regulations in approval process. It may create impacts on flora and fauna, injustice towards culture and native activities and price of assets located close to source of pollution (Greenstone and Fan 2018; Zentner et al. 2019).

## 15.3 Post COVID-19 environmental strategies

The state of environment in 21st century and the degradation of ecosystem and natural resources, seriously demand reviewing of present environmental laws. The paradigm shift of industrialization from 1980s to 1990s have raised in mind dreadful images of grime, soot, noise, radiations, lumps of solid wastes, dirty waters and what not. Addressing environmental challenges will involve technical knowledge along with engineering proficiency for providing scientific solutions to alleviate the adverse impacts. Moreover, beyond technological progress, the new era of change in sustainable technology will also involve organizational, political, societal and financial endeavor (Soderholm, 2020). The environmental laws for future will involve sustainable practices and investments (both from government and private firms) in green along with low carbon emissions to attain the sustainable development goals for the century.

### 15.3.1 Green economy

As stated by UNEP, green economy is involving investments from both government and private sectors, leading to development that is focused on decreasing carbon emissions, controlling pollution, boosting up resources and energy efficiency and preventing the biodiversity losses. These economic investments need to be supported by policy amendments and regulation changes. Also, the reforms must support the sources of revenue and ensure wellbeing of underprivileged public who are completely reliant on nature, thus, natural resource can be especially regarded as a vital economic asset and source of public benefits. There are three sets of activities in the Green Economy Initiative:

1. Promotion of the reports and related materials related to green economy. This will aid macroeconomic industries to examine their funds and processes, sustainability practices, and green investment to diminish poverty.
2. To some nations, advice-giving services can be provided on green economy to shift towards sustainability.
3. Engaging large variety of researchers, businessmen, NGOs, and partners from United Nations (UNEP, 2016).

Oxford university and Colombia university recently-published investigation by top economists showcasing potential COVID-19 economic recovery strategies. The study explains that 'green recoveries' are the most economically-feasible recovery strategies for nations affected by COVID-19. It involves many actions include shifting towards clean energy setups along with retrofitting of already established structures to improve efficiency (Earth.org, 2020). For businessmen, the connection between COVID-19 and environmental degradation is a chance to obligate their capitals in serving the world – for instance to alleviate environmental losses, planting of trees can be done (World Economic Forum, 2020).

The chief element of green economy is the development of economy with a vital asset being natural resources as the foundation of public benefit. Green economy aims at empowering growth of economy and investment along with enhancing social comprehensiveness and quality of environment (Green Growth Knowledge Platform, 2020). Green economy identifies the necessity to consume resources in a more efficient way, complementing policy consistency with nexus sectors. This green development plays an important role, seeing to the rising demand for water, food and energy worldwide.

### 15.3.2 Green recovery

In relation with the ideologies of green economy, this would involve engaging production plans and integrated policy approaches which will aid economic activities to head towards environmentally sustainable businesses and practices. A green recovery would mean passing on investments towards decarbonizing the economy and production recovery in broader welfare. Integrating green economy ideas and efforts for recovery will also open up mutual benefits like novel greener job opportunities, enhancing energy safety, better public health and environment. Currently, businesses have the opportunities to check their approaches, which will engage them more socially and environmentally.

UN suggests both government and private driven businesses to remodel their recovery plans based on Sustainable Development Goals. Such initiatives may become robust and more resilient by reviewing the numerous action plans for economic recovery, which will prospect to promote in financial transformations and scientific innovations to improve society sustainably. This would inspire private enterprise to switch their investments from the linear economy to circular economy, which surely will cut down the generation of waste, result in sustainable mobility, improve the energy efficiency and focus on renewables and smart agriculture. Such developments are crucial for capacity building of societies. Moreover, mobilizing these financial resources encourage investments in workforce and skill development, which will create green occupations and well-trained workforce. The COVID-19 pandemic has offered the humankind an opportunity to reset and rebuild a new normal. As these financial recoveries are associated to a green and climate-friendly methods, world will be one step nearer to reach sustainable development and success (Gulf Business, 2020).

Capitalizing in green recovery makes economic sense. Studies illustrate that investing in renewable energy can produce 2.5 times more career opportunities than non-renewable energy. It is reported that cleaning of air to reduce the problem of air-borne diseases may cost upto 7 percent of the GDP for some countries (UNEP, 2020b). In a post-pandemic world, only a strengthened multilateralism can bring the best return for these investments which offers a pollution-free planet having a stable climate and nature. Fast-tracking the change towards renewable and cleaner energy is crucial if country wants to attain a green recovery, nevertheless, the present situation has triggered the questions on intensifying the green energy investment and deployment. According to the reports of BloombergNEF, there exist a 37 percent reduction in new investments in green energy around the globe from late 2019 to early 2020 because of pandemic. Thus, COVID-19 policies for recovery need to offer a supreme prospect to develop cleaner, greener and better world. A robust green recovery strategy must motivate three important areas: 1) intensifying the accessibility of capital; 2) nurturing innovation; and, 3) creating jobs (Climate Investment Funds, 2020).

### 15.3.3 Low-emission economy

The worldwide lockdowns have ruined the financial activity, as the transportation sector and industrial activities were on halt, which led to decrease in greenhouse gas emissions. For example, industrial shutdowns in China, are valued to have triggered a 25 percent drop in carbon dioxide emissions in the February month of 2020, in comparison to February 2019. Similar trends were observed because of pandemic restrictions in many countries. The global energy demand observed a fall by approximately 4 percent in early 2020s. Energy demand declination have affected the global coal, oil and gas demands by downfall of 8 percent, 5 percent and 2 percent respectively (IEA, 2020).

Climate change can be supported by economic policies by two important ways: by changing the energy composition based on sources of high-emission and low-emission, and by focusing total energy usage. For illustration, a tax on carbon makes non-renewable fuels more costly, which motivates energy customers to change their consumption towards greener fuels. Thus, overall energy consumption will fall. Whereas, policies that objects to make green energy inexpensive and profuse rises the share of low-emissions energy. The overall energy demand can be stimulated or kept consistent by making energy cheaper which can be achieved through green energy subsidies (IMF, 2020). Noteworthy, decrease in carbon emissions is the one optimistic impact of COVID-19. Figs. 15.1 and Fig. 15.2 clearly depict the variation in CO2 emissions in worldwide ground transport sector and worldwide power sector from January 1, 2020 to November 30, 2020 as compared to the same phase last year, being a gift of stringent enforcement of shut down during Covid-19 era.

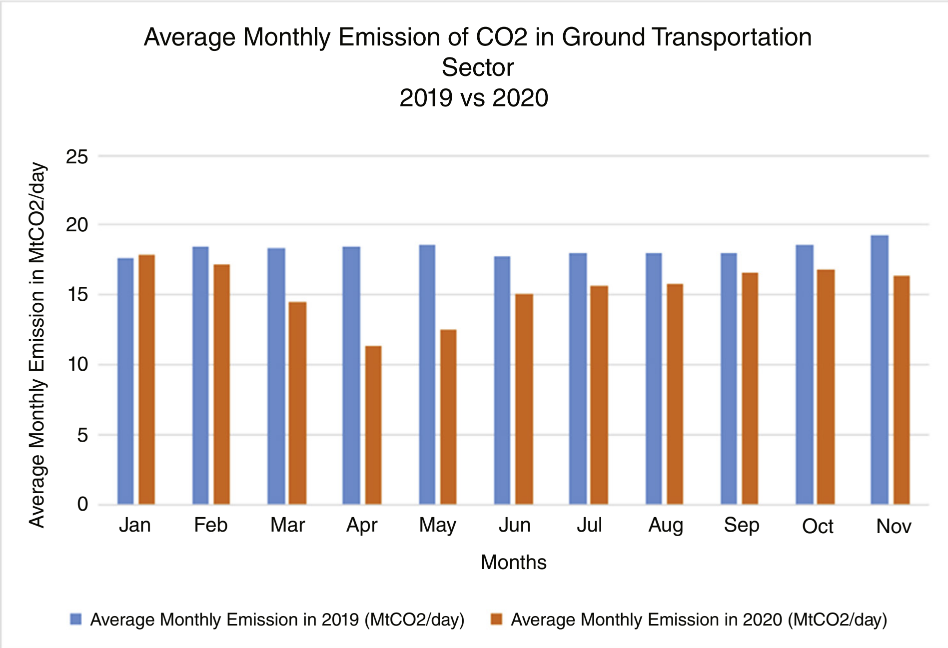


**Fig. 15.1** ***Average Monthly Emission of CO2 in ground transportation sector 2019 vs 2020 (Carbon Monitor, 2020).***

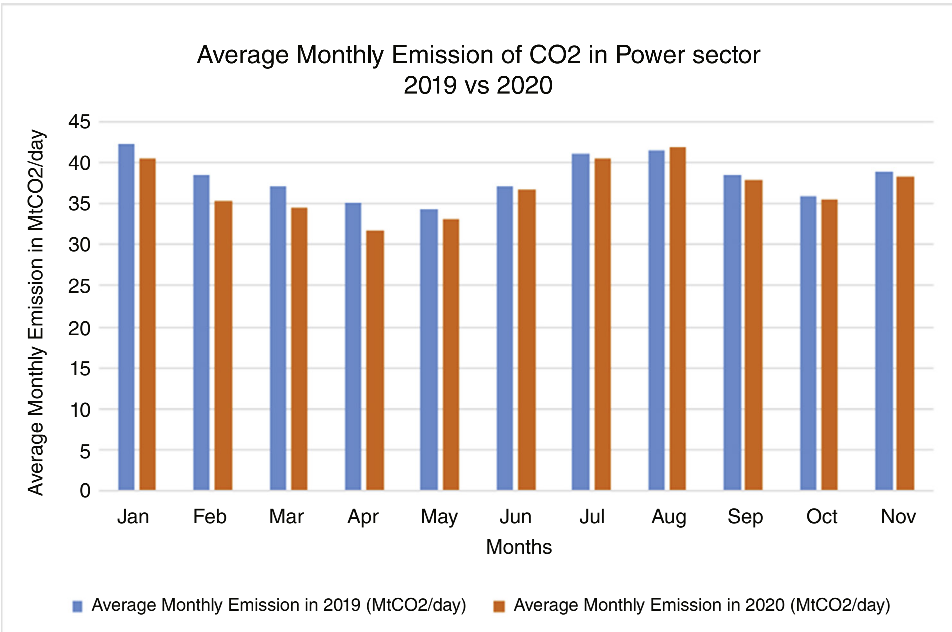


**Fig. 15.2** ***Average Monthly Emission of CO2 in Power sector 2019 vs 2020 (Carbon Monitor, 2020).***

Nevertheless, long-term drop in emissions require external funding from public and private fraternities. To achieve pacts of Paris Agreement, innovative technologies with low-carbon economy are necessary. New startups involving young innovators are major drivers of such essential innovation as they are severely shaken by the COVID-19 crisis because of poor access to required capital (OECD, 2020a). Emission drop triggered by economic recessions seems to be temporary and tends to rise in emissions as these economies attempt to get back on track. Governing bodies play a vital role in setting out healthy, well-structured and sustainable investment strategies as these investments will create new vacancies and many benefits related to environment, society and economy. For example, many social and economic benefits were laid by "The American Recovery and Reinvestment Act of 2009" which roughly created 9,00,000 jobs in clean energy sectors in the US from 2009 to 2015 (WRI, 2020a). For India, recovery solution will be subject to end non-renewable fuels subsidies, supporting poor workers and households, providing unemployment insurance to the unwell and those who are not able to work from home, implementing nature-based solutions in social assistance programs, stimulating climate-smart agricultural (CSA) practices (Rijsberman, et al., 2020). As COVID-19 pandemic will eventually end, the effect of growing greenhouse gas emissions will still remain to destruct earth's climate unless industries and businesses pledge to lower emissions (Oliver Wyman, 2020).

### 15.3.4 Strong sustainability policies

Development and recovery plans based on sustainability are only imaginable when thorough plans and policies related to environment are justifiably formulated and executed. There are adequate opportunities for governments to concurrently emphasis on environmental aims and guarantee that this recovery leads to overall sustainable outcomes. According to the estimation of World Economic Forum, a novel green economy can generate business opportunity worth more than USD 10 trillion per annum and 39.5 crore opportunities of job by 2030. Also, as per the estimation of The International Renewable Energy Agency, India's 2022 goal of producing 175 Giga Watts of renewable energy will create 10 lakh new vacancies in solar and 1.8 lakh vacancies in wind energy sector.

Government capitals can influence private investments if they strategically push financing decisions and investments in the right track. Rearrangement of subsidies related to energy will be crucial. Still in many countries, alternate energy subsidies are less than 10 times the non-renewable energy subsidies. There exists no future to be built on coal. One of the major areas for saving costs of import and curb the harmful environmental impact is to move towards electric vehicles. As per the estimation of NITI Aayog, by shifting transportation towards green energy, INR 6,000 crores could be saved with a reduction in 100 crore tons of carbon emissions (UNEP, 2020a).

It is seriously required to increase accessibility of clean water, clean air and primary health care which will improve life expectancy and enhance physical and economic flexibility. Recycling, repair and reuse promoting policies can add on to a circular economy and help in waste reduction through current business models. Motivation for work-from-home policy can reduce road traffic congestion and overall air pollution.

Moreover, future comeback and resilience mechanisms can be very well supported by larger employment in the e-commerce sectors, inclusive of innovative technologies. But it is also important that proper regulations are framed to ensure data privacy and consumer protection (WRI, 2020b).

## 15.4 Conclusion

The experience with COVID-19 crisis has been an eye opener for the world to reconsider and redesign the national policy focus. There is a serious need to frame strategic policies to strengthen preparedness for such potential future crisis along with comeback from this massive impact of COVID-19. This involves designing of effective plan and better capacity building strategies. The policymakers should take into account long-term and short-term vision for restored preparedness plans. The recent experiences of the fight against pandemic indicates that both of above aspects are not well organized and executed. Post COVID-19 outburst, the set for economic and environmental recovery should have principally focused on making economy greener or pro-environmental.

## 15.5 Way forward

### 15.5.1 Social economy

The social economy has established to be a pioneer in recognizing and executing social inventions and alternate paths of shaping financial activities. These inventions are channelized and accepted by the rest of the economy. Examples of social economies are fair trade, organic food movements or ethical finance. These novelties shall promote renovations related to economy and society and should play a significant part in post COVID-19 world. Social economy emphases on economic practices leading to sustainability through following ways: (i) concentrating on societal needs; (ii) establishing local level economic activities; and (iii) performing in with additional economic drivers and stakeholders.

The COVID-19 crisis demands for effective economic re-balance and resilience. Conventionally, it has been observed that the persistence of the social economy is to "repair" social problems like homelessness, labor market exclusion. Nevertheless, the social economy can perform a bigger part in the post COVID-19 phase to motivate alteration to a more comprehensive and sustainable economy and society.

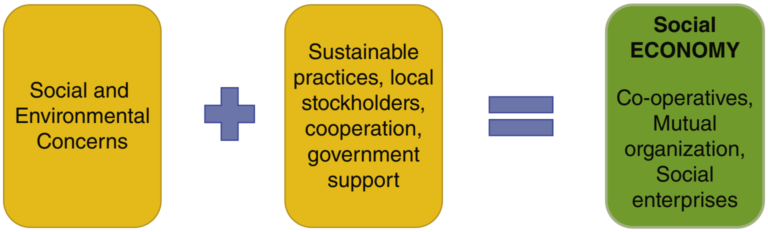


**Fig. 15.3** ***Elements of Social Economy.***

Social economy establishments develop social invention to curb societal and environmental challenges. It can be achieved by concentrating on social impact and functioning with neighboring investors (researchers, society, entrepreneurs, citizens, policymakers) that encourage the usage of novel practices. National and subnational governments have come out with a clear vision to reconstruct a better economy and society with active anticipation of social economy organizations. They also intent to develop a strategic plan to attain a changeover development model towards sustainability with a clearly incorporating social economy. They operate to achieve the mutual goal of protecting overall interest of welfare of community by organizing different activities (OECD, 2020b).

As shown in Fig. 15.3, Social economy organizations put foremost attention on social and environmental concerns of their commercial model, and thus prioritizing social impact over profit maximization.

The social economy backbones the flexibility of society and economy with the help of their models of business which are organized to a greater extent to resist shocks. Primarily, to aid local community and society to manage such crisis, these organizations provide number of activities in healthcare sector, communal facilities and work integration. Additionally, some precise business model structures of the social economy intensify the capability to beat complications during a calamity or crisis (OECD, 2020b).

## 15.5.2 Policies changes including decentralization of medical services and growth of public private partnerships (PPPs)

The COVID-19 financial impacts have put a great burden on stakeholders, users, project, private corporate sector, and public sector. Especially the PPP models can aid in decentralization of medical services which helps the appropriate distribution of medical aids and financial viabilities for medical consultations. This may also help in one stop solution for patients from different society gradients in quicker and cheaper way. For example, COVID-19 positive patient can be issued vouchers for testing at any empaneled private laboratories, generating e-vouchers by tele-health call centers can subsequently be reimbursed by the government, etc.

Transportation sector has observed significant challenges in generating revenue during worldwide lockdown. The income loss includes reduction in tolls tax collection due to citywide quarantine, shipping fees loss, loss of gate fees at airports, etc. PPP projects can aid transportation sector in economically viable way.

### 15.5.3 Global solidarity

Solidarity can be defined as acknowledging all the individuals as an integral part of one family irrespective of their political, ideological, national, racial, economic, and gender differences. COVID-19 has triggered extreme and irreversible damage on healthcare, education and nutrition systems, for children and society. The existing healthcare system certainly requires capacity building to withstand the world in post pandemic era. COVID-19 has also proved itself as development crisis along with humanitarian crisis. Although, UN Development agencies are helping countries to overcome from the crisis but the efficiency of this response relies on suppleness offered to them in funding and operational procedures (UNDP, 2020). Focus on tackling the healthcare emergency will remain on top priority which will be followed by social impact and economic response and recovery.

Apart from goals focused on politics or economy, global solidarity should work on prioritizing public health including a precise focus on nations with least capacities and also for women, exposed to infection in their duties as front-line healthcare workers. Global solidarity should be a wakeup call for the entire world along with their social and economic restoration.

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# CHAPTER 16

# Environmental implications of pandemic on climate

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## 16.1 Introduction

Covid-19 pandemic has adversely affected all the aspects of life in adverse manner. It is a menace in terms of health, economy, social well-being etc. In order to minimize the viral spread and reduce the death rate, National authorities of most of the affected countries initiated lockdown. The positive impact of restricted human activities amid lockdown appeared to be a delight in the critical condition of the pandemic and certainly a lesson to learn. Millions of population was put on lockdown during the pandemic, 1380 million in India, 760 million in China, 297 millions in United States, 165 millions in Bangladesh, 142 millions in Russia, 100 millions in Philippines and more than 50 million in UK, France, Italy, South Africa and Colombia (Fig. 16.1). In India, the lockdown was implemented in different phases (Table 16.1), where all facilities except emergency services (like medical, food supply, national security, fire etc.) were put on hold to restrict the movement of people. The public transport facilities were suspended except for transport of essential and emergency items. Similarly, in Italy lockdown was implemented and it is said that the travel restriction were even more extensive than that were placed during second world war (Cellini et al., 2020). It is reported that in London the entertainment places like pubs, bars and theaters have been closed to check the spread of virus due to human contact. The lockdown came out as boon for the environment revival owing to restriction on all the industrial activities, mass transportation and tourist activities. The result of lockdown is well visible in terms of decline in the pollutants level in air and water and a decrease in the noise level (Sharma et al., 2020; Mandal and Pal 2020; Bherwani et al., 2020).

There are many reports suggesting the improvement in air quality in terms of air quality index or concentration of various pollutants (Bao and Zhand 2020; Jain and Sharma 2020). During lockdown there was restrictions on travel and transport, a complete limitation in the business in global and local markets, in construction work, food business, mining tourism, etc. However, sometime liberty was given for essential services like medicines, fruits, vegetables, groceries, etc. The direct lateral impact is the dip in the economy observed globally and nationwide, that may take couple of years to return

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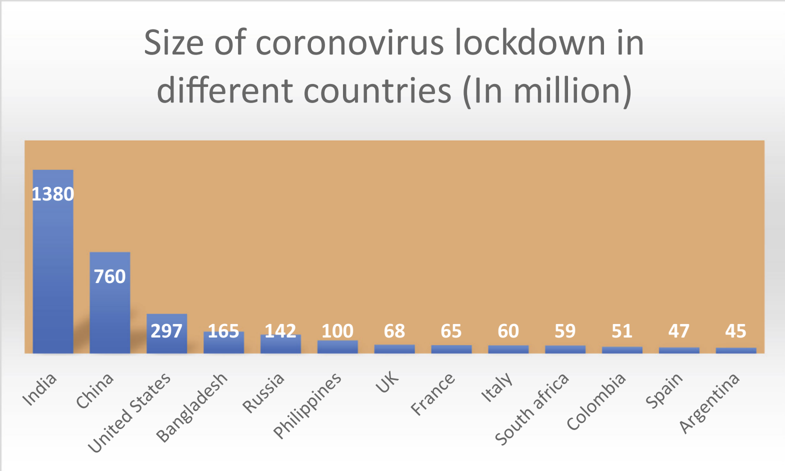


**Fig. 16.1** Number of people placed on enforced lockdown during covid-19 as on 23rd of April, 2020 (*Source*: Buchholz, 2020).

**Table 16.1** Initial lockdown phases in India, with maximum restrictions on the anthropogenic activities.

| Phase | First day | Last day | Total days |
|---|---|---|---|
| First phase of lockdown | 25th March– | 14th April– | 21 |
| Second phase of lockdown | 15th April– | third May– | 19 |
| Third phase of lockdown | fourth May– | 17th May– | 14 |

to the previous conditions. The lockdown has benefited the environment in terms of improvement in water quality, air quality, noise pollution level (Mandal and Pal 2020; Bherwani et al., 2020). Worldwide, many researchers have documented a fading in the air pollution due to restricted economic and social activities amidst lockdown (Bao and Zhand 2020; Jain and Sharma 2020).

## 16.2 Air quality parameters

There are two different categories of air pollutants: primary and secondary. Primary pollutants enter the environment directly from a source. For example, vehicles, directly emit carbon dioxide, into the environment. Other examples of primary air pollutants are nitrogen oxides and Sulphur oxides (Aranha, 1994). Whereas, reaction of primary air pollutants lead to the formation of secondary air pollutants. Ozone and particular matter fall under secondary air pollutant type (Fig. 16.2).

The effect of lockdown on the variation in concentration of Sulphur dioxide, oxides of nitrogen, particulate matter and ozone has been reported, primarily.

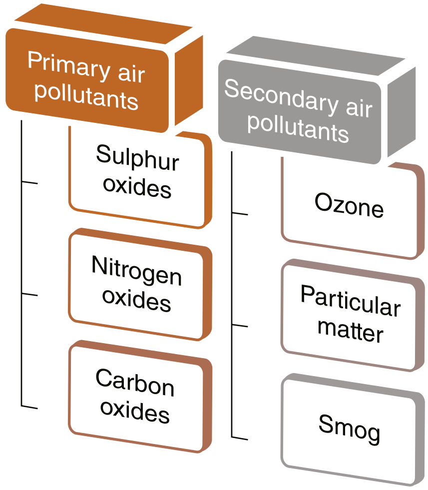


**Fig. 16.2** Classification of air pollutants.

The main sources of sulfur dioxide ($SO_2$) are industrial emissions, combustion of conventional fuels, burning of agriculture wastes. Sulphur dioxide is a primary pollutant and considered to be dangerous for human health with its exposure above 100 ppm. Sulfur dioxide is responsible for acid rain formation also.

Combustion of fossil fuels, biomass results in formation of oxides of nitrogen ($NO_x$) like nitrogen dioxide ($NO_2$). It is also primary pollutant and involved in production of ozone in the atmosphere. Carbon monoxide is formed due to incomplete combustion of carbon in fossil fuels, biomass industries etc.

Ozone ($O_3$) is produced by free radical reactions of nitrogen oxides in the atmosphere. Smog is formed by combination of smoke and fog. The particulate matter, includes solid, liquid and particulates suspended in the air. The particles can be of organic or inorganic like metals, acids, soil. dust etc. formed by brake down of large solid particles obtained from incomplete combustion of fossil fuels, agricultural courses, mining, construction of building or roads etc.

There is one other way to convey the information about air quality known as Air quality index (AQI). This helps us to avoid the protracted conventional method of comparison of concentration of various air pollutants, individually. A typically AQI is constructed on air pollutants criteria. With the help of aggregation method a sole index is calculated by converting the weight of an individual air pollutant (CPCB report, 2014).

AQI formulation is two-step process i) Formation of sub-indices function and ii) Development of AQI using sub-indices

**i)** Formation of sub-indices function for air pollutants. Sub-index function ($I_i$) is expressed as per Eq. (16.1) for n number of pollutants.

$$I_i = f(X_i), i = 1, 2, 3, 4, \textit{upto } n \quad (16.1)$$

**Table 16.2** Sources of different air pollutants in India.

| Pollutant | Sources of pollutant | References |
|---|---|---|
| $PM_{2.5}$ | Burning of agricultural wastes/open biomass burning, Bio- and fossil-fuel combustion, Household cooking, Road dust, Emission from vehicle exhaust, Industrial processes. | Guttikunda et al., 2016; Sharma and Dikshit 2016; Singh 2018; Lelieveld et al., 2015 |
| $PM_{10}$ | Burning of farm residue/biomass burning, Cement industries, Lime kilns, Slab polishing, Industrial processes, Windblown dust, Building construction Marble stone evastating, Bio- and fossil-fuel combustion, Vehicle travel on paved and unpaved roads, Dust from open fields and farmlands. | Singh 2018; Sheikh and Najar 2018;Yadav et al., 2014 |
| $SO_2$ | Diesel driven personal vehicles, freight vehicles exhaust (vehicular traffic), Diesel generator sets, Burning of fossil fuels in industries Industrial activities occurring in<br>• iron and steel smelting unit,<br>• production of basic metals, metal products and machinery,<br>• fertilizer unit and<br>• cement unit | Guttikunda et al., 2019; Sheikh and Najar 2018; Pant et al., 2018 |
| $NO_2$ | Industries, Burning of fossil fuels, Construction activities, Vehicular emission | Guttikunda, et al., 2019; Pant et al., 2018; Sheikh and Najar 2018; Sahu et al., 2012 |

Sub-index function *(fi)* relates pollutant concentration variable ($X_i$) and respective sub-index $I_i$.

**i)** Development of AQI using sub-indices *(I)*

$$I = F(I_1, I_2, I_n) \tag{16.2}$$

Here, F is the function of sub-indices ($I_1$, $I_2$, $I_3$, $I_4$, *upto* $I_n$)

For AQI, we have made a comparative analysis from the air quality before lockdown period (1–25th March of every year) with the phases of lockdown (first, second and third phase) (Table 16.1).

For the comparative study on the concentration of four criterion of pollutants, we chose March as the month before lockdown and the two months April and May after lockdown. The study will give a crisp analysis of the effect of lockdown on the air quality of Agra. The continuous ambient quality data for the selected city has been acquired through the Central Pollution Control Board, New Delhi (CPCB, 2020).

## 16.3 Water quality parameters

The water quality mainly depends upon the source, influence of different wastes like domestic, agricultural and industrial (Ojekunle et al., 2000 and Ayeni et al., 2009). The various anthropogenic activity influence the properties of water like pH (a scale to measure the acidic/basic character of water), alkalinity, chloride, Total dissolved salt (TDS), Total hardness (TH) and Dissolved oxygen (DO). In order to understand the overall nature of a water sample, statistical techniques like determination of water quality index and water quality modeling are applied.

## 16.4 Improvement in air quality

Air pollution is a worldwide environment and health problem, particularly in developing countries like India and China. The world has been suffering from high level of air pollutants and decline in air quality. The main sources of air pollution includes industries, transport, power stations, etc. (Table 16.2).

As per reports, more than twenty Indian cities are in the 30 most polluted cities in the world (WAQR 2019; WAQR 2018; CNN 2020). There are different programmes and awareness campaigns announced and implemented to control the air pollution and its harmful effect, however world is still struggling with the problem.

During lockdown amid Covid-19, the air quality showed a dramatic improvement. We were able to see the clear blue sky and significant visibility of nature. The reason is restriction on major pollution sources viz. transport, factories, tourism, etc. The high degree of air pollution is related to lot of respiratory disorders, skin and eye ailments, mental sickness etc. In metro cities, the problem of smog may sometimes lead to austere road accidents also. As per WHO report (WHO, 2016) the deaths from air pollution shares 7.6 percent of all the premature deaths, globally. The WHO also stated that if the $PM_{2.5}$ levels are reduced by 25 μg $m^{-3}$ (from 35 to 10 μg $m^{-3}$), it may control 15 percent of premature deaths (WHO 2005). The impact of air pollution is not as severe as effect of corona virus and it will also not results into instant death, as it is more of chronic phenomenon. However, there is one more aspect that the impact of air pollution is not only on human being but it also adversely affects the flora and fauna. The lockdown can be considered as a perfect strategy to control pollution and thus the adverse effects (Gautam 2020; Sharma et al., 2020b).

As reported by Quere et al. the carbon dioxide emission observed a decline of about 17 percent as compared to the average value of carbon dioxide emission in the previous year (Quere et al., 2020).

Similarly, In India reports have shown a remarkable decline in the concentrations of $PM_{2.5}$, $PM_{10}$, CO, $NO_2$ by 31, 43, 10 and 18 percent respectively. A study based on region wise also showed a dramatic decrease in air quality index (AQI) during the period of lockdown. The northern part of India observed a decline in AQI by 44 percent, southern par 33 percent, eastern par 29 percent, central part 15 percent and wester part 32 percent (Zambrano-Monserrate et al., (2020)).

The improvement in the air quality can be attributed to industrial shut down, a restriction on all mode of transport that also declined the demand of oil and hence energy consumption, worldwide.

According to reports, New York observed a decline of more than fifty percent in air pollution during the restricted activities amid covid-19 (Henriques, 2020). Due to the closure of heavy industries in China, a dip of nearly 50 percent in the concentration of nitric oxide and caobn monoxide occurred (Caine, 2020) (Fig. 16.3).

There is evidence of decline in the air pollutants level are evidence in the pictures published by National Aeronautics and space administration (NASA) and European space agency (ESA). As per a report, there is a major reduction in the average concentration of nitrogen dioxide over India during the lock down period as compared to the same time frame of the previous year (2019) (ESA 2020) (Fig. 16.4). Based on the data collected by Ozone monitoring Instruments (OMI) on the AURA satellite of NASA, a 30 percent reduction in the level of nitrogen dioxide was observed in India (Muhammad et al., 2020). Similar reduction of nitrogen oxide is reported in many other courntries like US, Italy, Brazil etc.

The nitrogen dioxide is produced from burning of fossil fuels and it mainly enters the environment form the exit pipes of motor vehicles and smokestacks of power plants. Thus the reduction in the concentration of nitrogen dioxide gives a correlation of the extent of air pollution and various human activities. Therefore, changes in $NO_2$ concentration in environment can be used as an indicator of changes in human activity. Still, an accurate estimation of the effect should be correlated with the meteorological and temporal analysis.

A similar reduction in the concentration of Sulphur dioxide was also observed across the country. As per report and images generated by NASA, 2020 a decline of 12–25 percent was visible in the eastern part of the country (Fig. 16.5). The decline must be due to a down in the electricity generation. However, the concentration of Sulphur dioxide increased in the southern region of India, possible due to higher thermal power generation before the lockdown period.

During lockdown concentration of all other pollutants except ozone declined. The concentration of ozone was found to be increased during lockdown period in various parts of world be it China, USA or various states of India (Xu et al., 2020; Jain and Sharma 2020). The increase in concentration of ozone can be explained by the formation of ozone in the atmosphere. Photochemical reactions are responsible for formation of ozone in atmosphere (Fig. 16.6).

Nitrogen oxides (NOx) and volatile organic compounds (VOC) are the ozone precursors. The ambient concentration of ozone in the atmosphere depends upon the concentration of oxide of nitrogen, volatile components, solar radiation and other

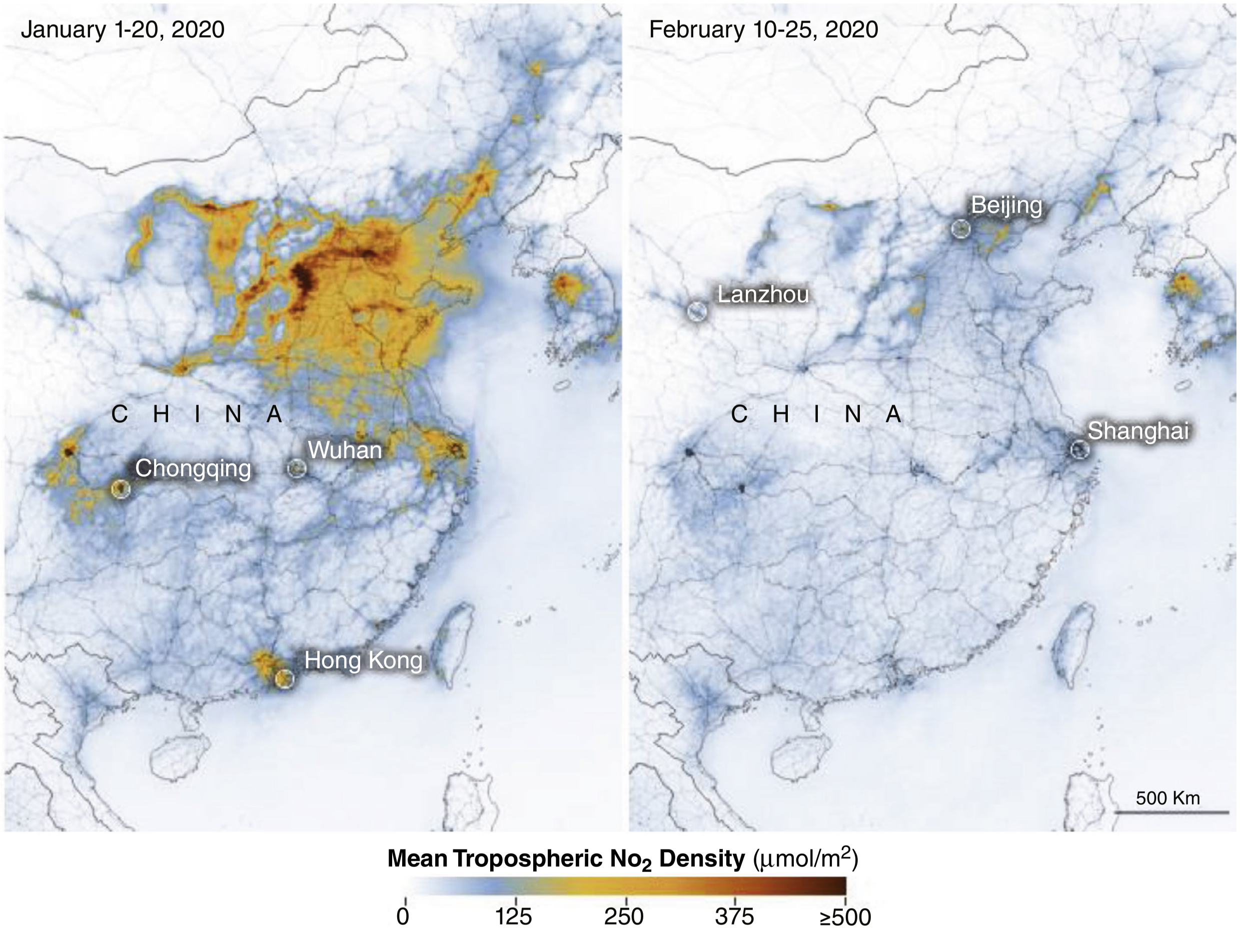


**Fig. 16.3** Satellite maps of China (NASA and European Space Agency (ESA) pollution monitoring satellites have detected significant decreases in nitrogen dioxide ($NO_2$) over China (NASA 2020).

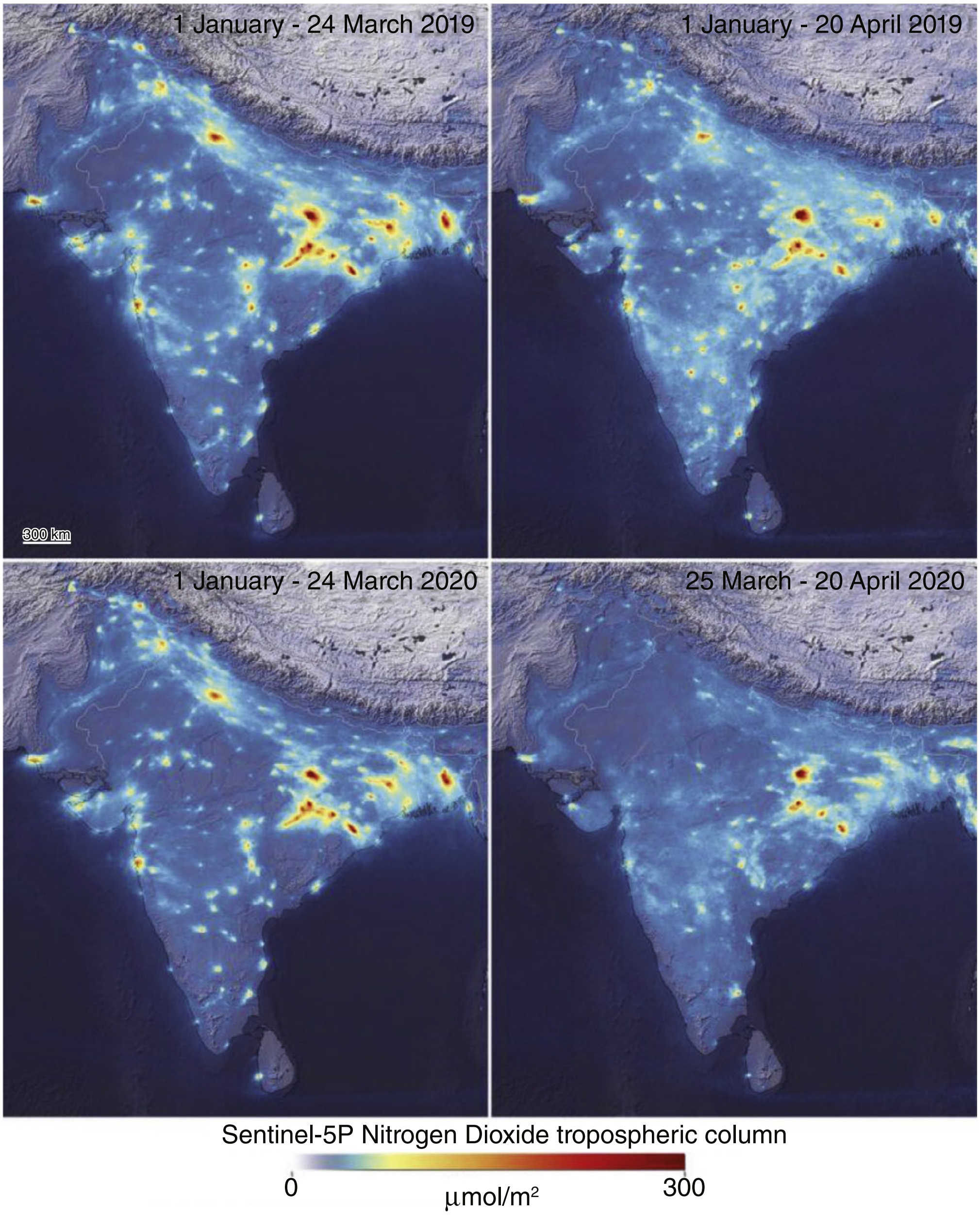


**Fig. 16.4** Satellite maps of India [Copernicus Sentinel-5P satellite], showing averaged nitrogen dioxide concentrations January 1 to March 24, 2020 (before lockdown) and March 25 (the first day of the lockdown) to April 20, 2020 with a comparison to the same time frame of year 2019 [ESA, 2020].

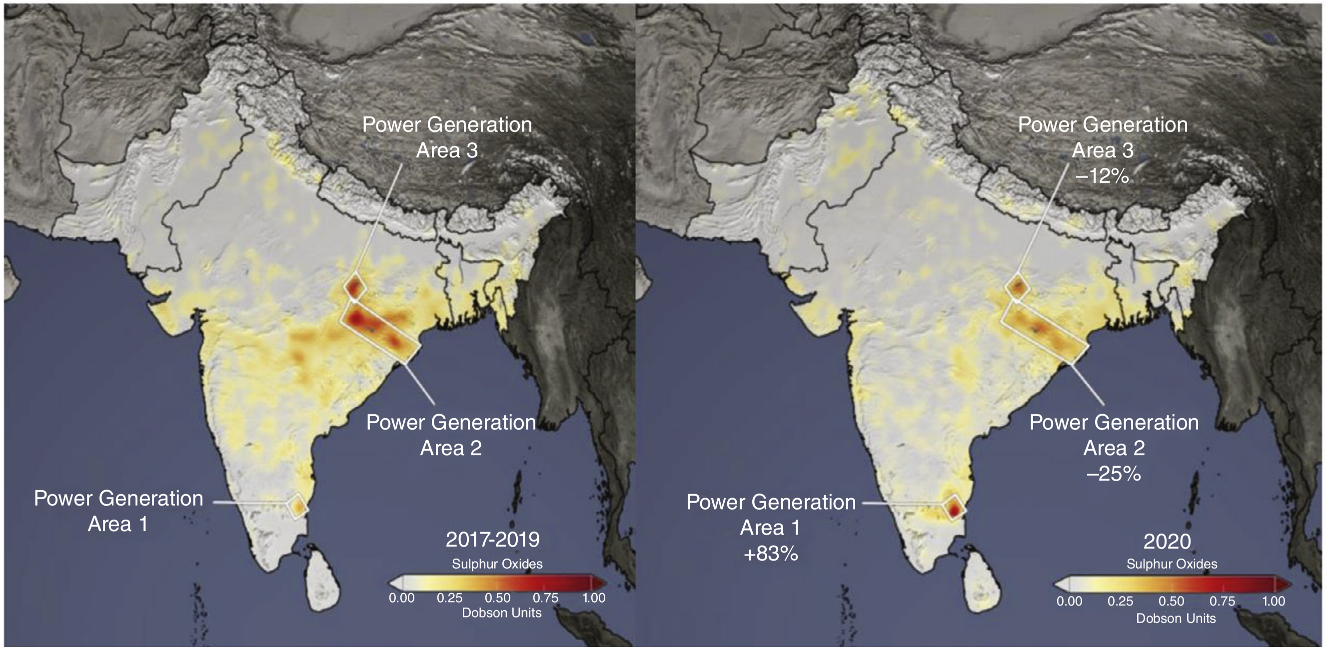


**Fig. 16.5** The comparison of the concentration of Sulphur dioxide in the months of lockdown of year 2020 with the average of concentration of Sulphur dioxide in the previous years (2017–20) over south east Asia [March 25th – April 25th] [NASA AirQuality Analysis, 2020].

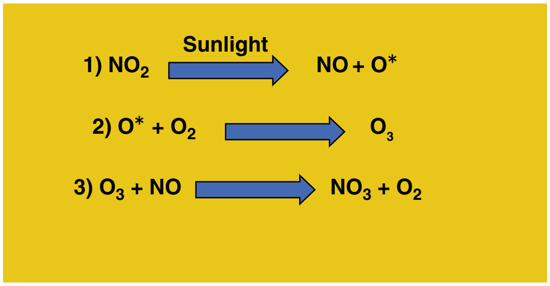


**Fig. 16.6** Photochemical formation of ozone in atmosphere.

meteorological parameters. The concentration of ozone observed a rise during lockdown phase owing to the a complex reaction taking place among NOx and VOCs in presence of sunlight (Srivastava et al., 2005). The effect of restricted human activities on environment is primarily studied for urban regions of the country. The urban part falls under VOC limited region of the country (Seinfeld et al., 1998). It is reported that in the VOC limited environment the ozone concentration is govern by photochemical interactions of oxides of nitrogen and ozone, beside the meteorological factors (Saini et al., 2017). More than 75 percent of nitrogen is released from sources like agriculture, transport (fossil fuel combustion) and industries. As mentioned, during lockdown all these sectors were put on hold resulting a lowering of the concentration of NOx emissions in VOC-limited environment, that in turn responsible for the increase in concentration of ozone (Sicard et al., 2020; Shrestha et al., 2020; Sharma et al., 2016).

## 16.5 Improvement in water quality

There are several studies and analysis showing the adverse effect of various industrial and domestic effluents on the quality of various water bodies in India and across the world (Thakur et al., 2018). The ecosystem is considered balanced and well in function if the air is clear and rivers are clean. During lockdown period, the impact of restricted anthropogenic activities was also observed in terms of water quality. Ganga the major river of India observed a significant improvement in the terms of water quality. It appeared that rivers rejuvenate during the lockdown period amid covid-19 (Dutta et al., 2020).

The data issued by Central pollution control board of India (CPCB) showed that the water of more than 27 points out of 36 points of the Ganga river improved for human beings, wild life and aquatic flora and fauna. The water of the river Ganga was found to be five times more suitable for drinking due to decrease in industrial and domestic waste, anthropogenic activities like washing, bathing, public gathering during fairs and site seeing.

Studies have also showed a dramatic increase in the live storages, during the lockdown period as compared to the average same period of previous ten year more than

80 percent of more storage has been observed. The dissolved oxygen gets increases and the biological demand, total coliform,faecal coliform, dissolved nitrate ions concentration get reduced owing to minimal sewage disposal as run off in the water body like the river Ganga. The agriculture activities were also put on hold and thus the decrease in concentration of nitrate ions was observed.

Yunus et al. studied the effect of covid-19 spread on the hydrosphere with the help of remote sensing data. They studied the water parameters of Vembanad lake and concluded that 18 out of 20 zones of the lake observed a decrease in suspended particular matter (SPM) (Yunus et al., 2020).

## 16.6 Improvement in noise level

Noise is an unwanted sound responsible for obstruction in communication. There are many reports suggesting that vehicular noise is one of the primary source of noise pollution in the country (Banerjee et al., 2008). A higher level of exposure to noise level for a longer run may cause stress, hypertension, mental disorders, irritation etc. (WHO, 2005). The level of noise pollution depends upon the timing or activities around the globe. The noise level were reduced to 35–65 percent from morning to evening. The higher noise level may also affect the wild life.

During lockdown the level of noise pollution also observed a decline, globally. There are reports suggesting a dip of as good as half of the original values during day time, amid lockdown in the country. According to Mahato et al., the noise level reduced in the area of stone quarrying and crushing (Mahato et al., 2020).

Not only the surface even oceans also observed a rejuvenation due to lesser noise level as the anthropogenic sources (responsible for noise pollution in marine ecosystem) like marine transport, traffic noise and industries on the sea shores were shut down during the lockdown amid COVID 19.

### 16.6.1 Effect on marine life

The lockdowns have also shown to have positive effects on the natural world. We witnessed clear skies, mountains, return of wildlife to forests and positive impact on marine life. Oceans suffering from ship traffic notices a quieter time and home to marine life that were forced to migrate to deeper parts of the sea. We could see species that are on the verge of extinction.

According to reports, Adriatic sea observed a positive change due to reduced water traffic and limited movement. There were instances when whales and dolphins swimming in water off the shores. The snorkeling and profusion of fish is the main point of attraction for tourists on Adriatic Sea. However, the excessive pollution, commercial exploration of ocean and traffic affected the underwater visibility and marine life negatively (NCP, 2020).

The pandemic restrictions rebounded the marine life and helped to reemerge the flora and fauna be it dolphins, rare species of fish.

The decline in fisheries, shipping, tourism and crude oil extraction has significantly shown a ray of hope to revive the marine ecosystem.

### 16.6.2 Adverse effects on environment

We can not ignore the adverse effects of various kind of waste generated or increased during this pandemic period. There is a huge increase in the medical waste generation and that is a serious concern for human health and environment. The sample collection of the patients, different diagnosis aids, treatment of patients and disinfection has generated a lot of biomedical waste (Somani et al., 2020, Zambrano-Moserrate et al., 2020). During the time of outbreak, in Wuhan city of China, about one fourth metric tons of medical wastes was produced every day. The normal time medical waste quantity is 190 metric tones less than the pandemic value (Saadat et al., 2020 and Zambrano-Moserrate et al., 2020). In Ahmedabad, India, the amount of medical waste generated reached a value of 1000 kg/ day from 550–66 kg/day (Somani et al.). Rahman and coworkers reported a 204 metric tonnes per day of medical waste generation in Dhaka, capital of Bangladesh (Rahman and Islam, 2016). Asian development bank reported a rise of 154–280 metric tonnes of biomedical waste generation in various Asian cities like Manila, Kuala Lumpur, Hanoi, and Bangkok (ADB, 2020). This sudden escalation in the generation of biomedical waste and its management is a challenge to local waste management authorities. The waste generated during covid-19 needs a special care during disposal owing to high risk of contamination.

The other major source of pollution is safety kits (personal protective equipment, PPE). PPE includes gloves, gowns, mask, filters etc. These PPE kits are made up of various kinds of plastics like polypropylene, high density polythene, etc. The decomposition of these plastics is a slow process and requires hundreds of year for a natural degradation by microbes. There is a high demand and usage of PPE kits by all frontline workers as they provide a rationale protection against the corona virus. However, their disposal is chaotic due to lack of knowledge and ignorance. There are guidelines from national agencies and WHO, however people are throwing the used masks, gloves etc. in open places (Rahman and Islam, 2016) (WHO, 2020). There are reports indicating a rise in trash amount with the increase in production and use of PPE kits in USA (Calma, 2020). The haphazard disposal of these safety equipment results in accumulation in the environment that adversely affects human life, wild life, ocean and marine life. About 80 percent of these safety equipment are made up of poly propylene polymer (PP) that is very difficult to decompose and persists in environment for a very long time. In due course of time PP preleases dioxin and toxic elements.

The solid waste further increased due to increase in municipal waste generation and reduction in recycling. Many countries implemented quarantine amid the pandemic and it has increased the online shopping for home delivery. This has also added in the waste due to package materials (Somani et al., 2020; Zambrano-Monserrate, 2020). And during pandemic, the recycling of waste was put on hold in order to avoid further spread of Covid-19 (Somani et al., 2020).

The rash application of disinfectants in residential and commercial areas to destroy SARS-CoV-2 is responsible for destruction of non targeted beneficial species. This may cause ecological imbalance and thus adverse effect on environment.

## 16.7 Conclusion

It is an opportunity to understand the adverse impact of anthropogenic activities on mother earth. The chapter gives an insight that how the restriction on the industries, transport-tourism, mining etc. may revive the environment.

The lockdown and associated halt on human activities can decrease the level of pollution and thus can help us to overcome the impact of pollution on human health, flour-fauna and environment (Gautam, 2020). The positive impact on environment was a temporary phase as now again the level of pollution is up in the various parts of country owing to unlock phases. However, it is right time to learn, for the government and individual, that we can reduce the pollution by our efforts. We should implement our learning in the form strategies to tame the pollution and its harmful effect. It is desirable to implement firm regulations about the level of pollution causing discharges from various sources and a regular check on the compliance of the regulations. It is we who are destroying our ecosystem and we are not affecting human lives but also the other parts of ecosystem.

### 16.7.1 Suggestive strategies for environment sustainability: a lesson from covid-19

Nature has given us a chance to convert these short term environmental consequences into a long term benefit by strategizing our actions that may result in sustainability of environment. The world is working hand in hand to fight against the deadly virus. Similarly we have to unite our effort, globally, and plan for global environment (Somani et al., 2020).

**a)** ***Environment friendly transport and policies:***
In order to minimize the emission of harmful gases (carbon dioxide, carbon monoxide, nitrogen dioxide, Sulphur dioxide etc.) the people of each country should be encouraged to use public transport, opt pooling, and use environment friendly vehicles like bicycle. These are the steps that can help us to reduce pollution in longer run. Companies should promote work from home, as per their requirement, to reduce traffic.

**b)** ***Renewable energy:***
The use of renewable energy can decrease the excessive demand and usage of conventional fossil fuels like crude oil, natural gas etc. As per reports, when world was

put on hold through lockdown the demand of energy was reduced. The clear consequence was reduction in emission and thus revival of air quality, even in the top most polluted cities of the world. We should work for technologies that can work on solar power, wind energy, hydropower, geothermal energy and biomass. The switch to alternate and greener resources of energy can reduce the emission of harmful gases.

**c)** ***Waste water treatment:***
The domestic and industrial waste should be treated before discharge to reduce water pollution. Strict policies are needed to ensure the treatment of waste water. Also, work is need to be done to develop simpler, economical and effective measure for treatment of waste water.

Waste recycling: The burden of solid waste is again a menace for terrestrial and marine life. Recycling of waste should be promoted in all parts of world. The excessive production of solid waste cannot be ignored, however the strategic recycling or reuse of the waste is need of the hour.

**d)** ***Industries towards sustainability:***
During lockdown the industries were shut down and it impacted the environment positively. However industries are required for economic growth of a country and hence world. We cannot decrease the extent of industrialization, however we can work for sustainable industrialization. We can shift towards cleaner technologies, renewable sources of fuels. The waste generated by industries should also be managed for reuse or treatment.

**e)** ***Social responsibilities:***
Again we are building society and we are society. It is our responsibility to keep it clean. We need to change our life style so that we can reduce the production of harmful gases, large amount of waste, decrease the noise level etc.

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CHAPTER 17

# COVID-19 Boon or Bane: A case study of Air pollutant transport in the Yangtze River Delta region and its consequent health effects during the COVID-19 lockdown period

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## 17.1 Introduction

The tragic outbreak of COVID-19 pandemic during 2020 (Tian et al., 2020; Wang et al., 2020a) has caused tremendous impacts on people's livelihoods across the world (Wang et al., 2020a). To date (as of 12th, December 2020), there have been 69,808,588 confirmed cases of COVID-19, including 1,588,854 deaths globally according to World Health Organization (WHO; https://covid19.who.int). From the time when the pandemic started, the government of the People's Republic of China rolled-out rigorous response policies to control the rapid spread of the disease (Tian et al., 2020; Wang et al., 2020b). This included shutting down of education institutions, industrial operations, construction activities and restaurants; restriction of traffic and reduction in the number of vehicle kilometres travelled (VKT); cancellation of mass gatherings and events; and enforcement of social distancing and personal protection. Ultimately, the spread of the disease was brought under control. Besides, the air quality during the lockdown period improved significantly in China as a result of reduced industrial activities. Notably, the concentrations of $PM_{2.5}$, $NO_2$ and other key pollutants were reduced substantially in the designated key regions of China based on evidences from satellite imagery and ground-based measurements (NASA, 2020; Wang et al., 2020a, 2020b).

The Yangtze River Delta (YRD) region is one of the major economic city-clusters in China. Usually, the wintertime pollution episodes in the YRD region raises a lot of attention, attributed mainly to unfavourable meteorological conditions (Huang et al., 2019; Li et al., 2018, 2019). In early 2020 coincidentally, the lowered human activities during the COVID-19 lockdown in YRD occurred during the winter period. This presented

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an opportunity for comprehensive investigation of the level of air quality improvement attributable to different aspects of human activities and the corresponding health impact benefits. Typically, the COVID-19 control in the YRD followed the 'National Emergency Response Plan for Public Emergencies' issued by the Chinese government: Level I (particularly serious), Level II (serious), Level III (heavy) and Level IV (general). Therefore, this work studies the air quality and its transport during pre-lockdown period (before 24th January 2020); Level I response period (24th January to 25th February 2020) and Level II response period (26th February to 31st March 2020).

The pre-lockdown period was characterised by a "status-quo" for all socio-economic activities running normally and smoothly relative to similar periods in the previous years. However, from the 24th January 2020, abrupt halting of large-scale economic and social activities happened as Level I emergency response measures were affected. After about a month, gradual resumption to normalcy through Level II and Level III was instigated and observed. In a nutshell, the lockdown period (Level I and Level II) saw significant reduction or closure of transportation services, industrial enterprises, construction sites and catering enterprises among others.

It must be noted that each province in the YRD region implemented (and adjusted slightly differently) the COVID-19 response measures independently: the adjustments are based on variation of daily new confirmed cases and the number of people being cured and discharged from hospitals for each respective province. For instance, as the pandemic situation improved, Anhui and Jiangsu provinces downgraded its respective emergency response level to a secondary response on 25th February 2020. A week later, Zhejiang province also shifted to Level II on second March, while Shanghai adjusted to Level II three weeks later on 24th March. During the secondary response period, the cities in YRD under the premise of good protective measures, allowed some key industrial enterprises and construction sites to be operational with strict adherence to protective measures. Moreover, Level II response saw the blanket lifting and cancellation of the village closures, mandatory use of the public health QR-code for local travel, mandatory wearing of face mask as well as gradual relaxation and increase in road traffic. Most of the YRD region ultimately entered into Level III response since 31st March, with most activities gradually entering into operation (except schools and a few other sectors) with strict observation of protection measures.

The robust adjustment of socio-economic activities during the COVID-19 prevention and control period prompted a comprehensive assessment of the impact of reduced human activity on air pollution reduction. With this in end, an integrated approach is adopted to study the analysis of multi-pollutant observations, backward trajectory and potential source contribution analyses, estimates of pollutant emission reductions, and photochemical model simulations (Chang et al., 1987). The aim is to conduct a comprehensive assessment of the impact of reduced human activity on air pollution reduction. Along this direction of travel, the correlation between the substantial change of human and industrial activities on the air pollution scenarios in YRD during pre-lockdown, Level I and Level II can be studied in depth. In addition, the changes of the source contributions as well as the sources of residual pollution related to local activity factors during the COVID-19 period can be better investigated.

The value for this study has clear policy implications for future air pollution control, but also provide invaluable information for health-related impact studies. The simulated results are here used to quantify the short-term health impacts by estimating the number of avoided premature death due to lowered $PM_{2.5}$ concentrations during COVID-19 lockdown.

## 17.2 Materials and methods

The hourly ambient concentrations of criteria air pollutants ($SO_2$, $NO_2$, CO, $O_3$, $PM_{2.5}$ and $PM_{10}$) are obtained publicly from the Ministry of Ecology and Environment of the People's Republic of China (http://datacenter.mep.gov.cn). In addition, meteorological data are obtained from the National Oceanic and Atmospheric Administration (NOAA)'s National Climate Data Centre archive (http://www.ncdc.noaa.gov/oa/ncdc.html) and also from the National Data Centre of the Chinese Meteorology Agency (http://data.cma.cn/).

### 17.2.1 Meteorological assessment during COVID-19

The Weather Research Forecasting model (WRF) version 3.4 (https://www.mmm.ucar.edu/wrf-model-general) is used to study the meteorological conditions during the COVID-19 period. Initial and boundary conditions (IC/BCs) for the WRF modelling are based on 1° × 1° grids FNL Operational Global Analysis data that are archived at the Global Data Assimilation System (GDAS). The BCs are updated at 6-hour intervals for the outmost domain. In addition, the Yonsei University (YSU) scheme (Hong et al., 2006) is applied to parameterise the boundary layer processes; the NOAH land surface scheme (Hong et al., 2006) is used to describe the land-atmosphere interactions; the Purdue-Lin microphysics scheme (Lin et al., 1983) is chosen to reproduce the cloud and precipitation processes; and the RRTM long-wave and Goddard Short-wave radiation schemes (Chou et al., 1999; Mlawer et al., 1997) are adopted to reflect the radiation. Parameterisation of the WRF model is listed in Table 17.1.

**Table 17.1** Parameterization of the WRF model.

| Item | Selection | Reference |
|---|---|---|
| Microphysics scheme | Purdue-Lin | Lin et al. (1983) |
| Short wave scheme | Goddard | Chou et al. (1999) |
| Long wave scheme | RRTM | Mlawer et al. (1997) |
| Planet boundary scheme | YSU scheme | Hong et al. (2006) |
| Cumulus scheme | Kain-Fritsch | Kain et al. (1993) |
| Land surface scheme | Noah land-surface | Ek et al. (2003) |

### 17.2.2 Model set up and configuration

The WRF-CAMx model system is used to evaluate the improvement in air quality resulting from the reductions of human activities in the YRD region during COVID-19. WRF model provides the meteorology inputs for the simulations, while gridded hourly pollutant concentrations are generated by CAMx model Version 6.1 (http://www.camx.com/). The CAMx model is configured with CB06 (Yarwood et al., 2010), CF module and an updated mechanism of the Regional Acid Deposition Model (RADM) for the gaseous, aerosol and aqueous-phase processes respectively. The WRF-CAMx modeling domain is based on a Lambert Conformal map projection, run over three nested domains of 36 km - 12 km - 4 km with the innermost domain covering the YRD region (Fig. 17.1). The lateral and vertical boundary of WRF domain is 3 grids larger at each boundary and 13 layers more than the CAMx modelling domain respectively.

The simulation period is from first January to 31st March 2020 to cover the pre-lockdown stage (sixth to 24th January 2020); Level I response (24th January to 25th February 2020) and Level II response (25th February to 31st March 2020) periods. The first five days are model spin-up period. The provincial capital cities of Shanghai, Nanjing, Hangzhou, and Hefei are considered for comprehensive analysis, as shown in Fig. 17.1.

The most recent emission inventory developed by our group is utilised for the YRD region; the MEIC model (Multi-resolution Emission Inventory of China (http://www.meicmodel.org) for areas outside YRD (within China); and the MIX emission inventory (Li et al., 2017) for other Asian regions. In addition, a reduced emission inventory

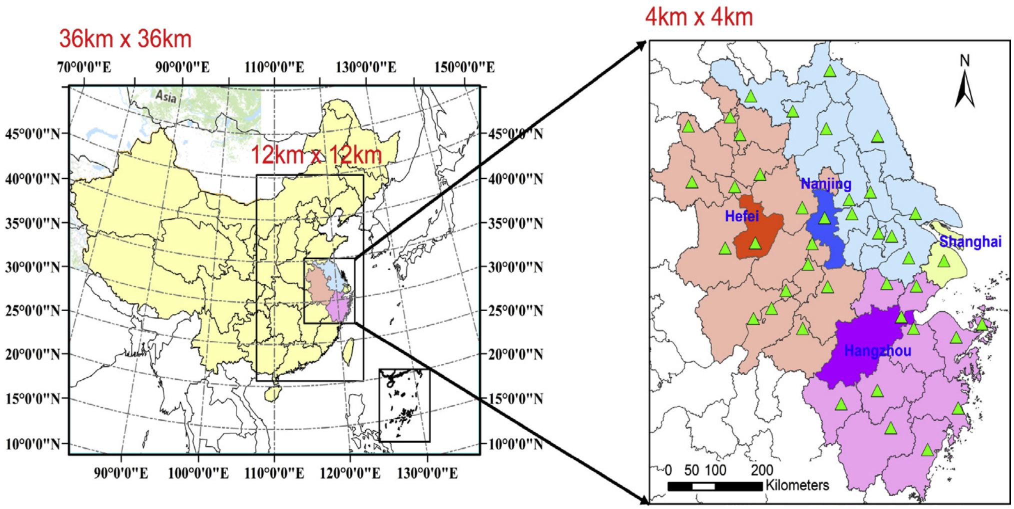


**Fig. 17.1** Modelling domain and locations of the national observational sites (green triangle).

to account for the restricted human activities due to COVID-19 is developed based on reported activity data and best estimates. For emission reductions outside the YRD region during lockdown, we apply the reduction ratio used by Wang et al. (2020b). The Model of Emissions of Gases and Aerosols from Nature (MEGAN, v3.0, http://aqrp.ceer.utexas.edu/projects.cfm), the OCEANIC pre-processor developed by Ramboll (http://www.camx.com/download/support-software.aspx) and the Sparse Matrix Operator Kernel Emissions (SMOKE model, https://www.cmascenter.org/smoke) are used to prepare the gridded and speciated hourly biogenic, sea salt and anthropogenic emissions respectively.

### 17.2.3 Source contribution analysis

Potential source contribution factor (PSCF) analysis is applied to locate pollution sources using air mass trajectories (Duan et al., 2019; Liu et al., 2019). PSCF can be calculated for each 1° × 1° cell by dividing the number of trajectory endpoints corresponding to samples with factor scores or pollutant concentrations greater than specified values by the number of total endpoints in the cell (Hopke and Zeng, 1989). Since the deviation of PSCF results can increase with the raise of distance between cell and receptor, a weight factor, $W_{ij}$, is adopted in this study to lower the uncertainty of PSCF results (i.e. weighted PSCF, WPSCF); (Hopke and Zeng, 1989; Polissar et al., 1999; Zhang et al., 2019). Furthermore, the TrajStat modelling system is combined with the Global Data Assimilation System (GDAS) to analyse potential source contribution areas of $PM_{2.5}$ and show the air mass transport pathway within the YRD during different periods of COVID-19 respectively.

$$\mathrm{PSCF}_{ij} = m_{ij}/n_{ij} \tag{17.1}$$

$$\mathrm{WPSCF}_{ij} = \mathrm{PSCF}_{ij} \times W_{ij} \tag{17.2}$$

$$W_{ij} = \begin{cases} 1 & 2\times Avg < n_{ij} \\ 0.7 & Avg < n_{ij} \le 2\times Avg \\ 0.42 & 0.5\times Avg < n_{ij} \le Avg \\ 0.05 & 0 < n_{ij} \le 0.5\times Avg \end{cases} \tag{17.3}$$

Where $n_{ij}$ and $m_{ij}$ are the total number of back-trajectory segment endpoints that fall into the grid cell (i, j), during all days and in days when receptor concentrations were higher than the criteria value, respectively. A higher ratio of $m_{ij}$ /$n_{ij}$ indicates a higher probability of a particular grid through which a passing air mass would result in a higher receptor concentration. where Avg is the average number of trajectory segment endpoints in all cells.

### 17.2.4 Quantitative analysis of air quality changes during COVID-19

Air quality changes are analysed using the Brute Force Method (BFM) (Burr and Zhang, 2011), by running the model in its base state and then re-running it with adjusted

**Table 17.2** Definition of CAMx PSAT groups.

| No. | Source Category | Abbreviation | Emission source sector |
|---|---|---|---|
| 1 | Agriculture | AGR | Agriculture |
| 2 | Residential | RES | Cooking; Residential combustion |
| 3 | Dust | DST | Construction dust; Road dust |
| 4 | Industry | IND | Power plants; industrial boilers; industrial kilns; industrial processes |
| 5 | Biomass burning | BB | Biomass burning |
| 6 | Mobile | MOB | On-road vehicle exhaust; Non-road; Aircraft |
| 7 | Solvent use + storage | OTHER | Architectural coating; Household solvent usage; Hospital solvent usage; Gas station; Oil storage |
| 8 | Natural | NAT | Biogenic emissions; Sea-salt emissions |

emissions. In this case, a *baseline-scenario* ($C_b$) utilises emissions from normal activities assuming no lockdown, while a *COVID-19 scenario* ($C_s$) is based on a reduced emission inventory. Through comparative analysis, a ratio of simulated concentrations between the two scenarios (i.e. relative improvement factor, *RF*), is combined with ground based observations ($C_o$) to assess air quality changes associated emission reductions due to lowered human activities during the lockdown ($C_d$), such that,

$$\mathrm{RF} = \frac{C_b - C_s}{C_b} \tag{17.4}$$

$$C_d = C_o.\mathrm{RF} \tag{17.5}$$

*RF* is calculated for Level I and Level II periods separately and applied at selected monitoring sites to reflect spatial variability of the changes of air quality associated with COVID-19 emission reductions.

The Particulate Source Apportionment Technology (PSAT) in CAMx is utilised to quantify the sectoral contributions to $PM_{2.5}$ (from eight source categories, Table 17.2). The differences in PSAT results under baseline and COVID-19 scenarios are used to quantify the contributions of $PM_{2.5}$ reductions associated with emissions reduction in each sector due to the lowered human activities.

### 17.2.5 Health impact assessment due to changes in air quality during COVID-19 lockdown

Premature mortality due to ambient $PM_{2.5}$ exposure is carried out based on a widely-used log-linear exposure-response function (Gao et al., 2016),

$$Y = \sum_k P \times (1 - e^{\beta_k (C - C_0)}) \times R_k \tag{17.6}$$

where $Y$ is the number of premature deaths attributed to ambient $PM_{2.5}$ exposure due to five leading causes ($k$= 5) (i.e. cerebrovascular disease (stroke), ischemic heart disease

(IHD), chronic obstructive pulmonary disease (COPD), lung cancer (LC) for adults at least 25 years old, and acute lower respiratory infection (ALRI) for infants under 5 years of age). $\beta$ is the cause-specific exposure-response coefficients and values reported from a meta-analysis study (Lu and Yao, 2015). Such that, a 10 μg $m^{-3}$ increases in ambient $PM_{2.5}$, $\beta$ is 0.63 percent for stoke and IHD (95 percent confidential interval (CI): 0.35 percent - 0.9 percent) and 0.75 percent for COPD, ALRI and LC (95 percent CI: 0.39 percent - 1.11 percent). $R$ is the baseline incidence rate obtained from the Sixth National Population Census (http://www.stats.gov.cn/tjsj/pcsj/rkpc/6rp/indexch.htm), while the Global Burden of Diseases (GBD) estimates that stroke, IHD, COPD, LC, and ALRI contribute 20.2 percent, 16.7 percent, 9.2 percent, 6.4 percent and 1.7 percent of total deaths in China for 2017 respectively (https://vizhub.healthdata.org/gbd-compare/). Furthermore, $P$ is the exposed population to $PM_{2.5}$ concentration ($C$) averaged during each period for each city in the YRD region. 25 μg $m^{-3}$ is used as the threshold $PM_{2.5}$ concentration, $C_0$ , as per World Health Organization (WHO) air quality guidelines (World Health Organization, 2005).

The number of premature mortality is calculated using observed $PM_{2.5}$ concentrations during similar period of 2017–20 to show temporal trends over the past four years. The adjusted $PM_{2.5}$ concentrations calculated based on the $RF$ method are used to calculate the number of premature mortality assuming no lockdown occurred. The differences between results obtained based on observed and adjusted $PM_{2.5}$ concentrations illustrate the health impacts due to changes in air quality during lockdown periods.

## 17.3 Results and discussion

### 17.3.1 Meteorological changes during the COVID-19

Generally during the COVID-19 period, there is no significant or observable change in the meteorological conditions during the period January to March from 2017 to 2020 in YRD region. Comparative analysis reveals that temperature, air pressure, and wind field in Shanghai, Hangzhou, Nanjing and Hefei match well with previous years, only that, the surface temperature and humidity in 2020 is slightly higher than previous years, falling well within normal statistical variations. Table 17.3

**Table 17.3** Changes of meteorological parameters at typical cities in the YRD region (first January to 31st March).

| | Temperature ( °C) | | Pressure (hPa) | | Relative humidity (percent) | | Wind Speed (m•$s^{-1}$) | |
|---|---|---|---|---|---|---|---|---|
| | 2017–19 | 2020 | 2017–19 | 2020 | 2017–19 | 2020 | 2017–19 | 2020 |
| City | Avg±SD | | Avg±SD | | Avg±SD | | Avg±SD | |
| **Shanghai** | 7.9 ± 4.3 | 9.7 ± 4.2 | 1024.7 ± 5.8 | 1023.8 ± 5.6 | 74.8 ± 17.6 | 75.7 ± 16.8 | 4.8 ± 2.1 | 4.9 ± 2.0 |
| **Hangzhou** | 8.6 ± 5.1 | 10.2 ± 5.0 | 1024.2 ± 5.9 | 1023.4 ± 5.7 | 75.6 ± 19.4 | 76.4 ± 18.4 | 2.7 ± 1.4 | 2.5 ± 1.5 |
| **Nanjing** | 6.9 ± 5.7 | 8.5 ± 5.4 | 1024.6 ± 6.2 | 1023.7 ± 6.1 | 74.8 ± 20.6 | 78.3 ± 21.7 | 2.7 ± 1.6 | 2.6 ± 1.6 |
| **Hefei** | 6.8 ± 6.0 | 8.1 ± 5.8 | 1024.2 ± 6.4 | 1022.7 ± 5.8 | 74.1 ± 20.5 | 79.2 ± 21.6 | 3.0 ± 1.6 | 3.1 ± 1.6 |

## 17.3.2 Air quality changes due to COVID-19 lockdown

### *17.3.2.1 Observed air quality changes during the COVID-19 lockdown*

In Fig. 17.2, the concentration of $PM_{2.5}$ before and during the lockdown exhibit blanket reduction across the YRD region. It is evident that substantial decrease in $PM_{2.5}$ is mostly confined in the highly urbanised central areas of YRD where vehicular traffic is usually high. Generally, the level of $PM_{2.5}$ in YRD during the lockdown

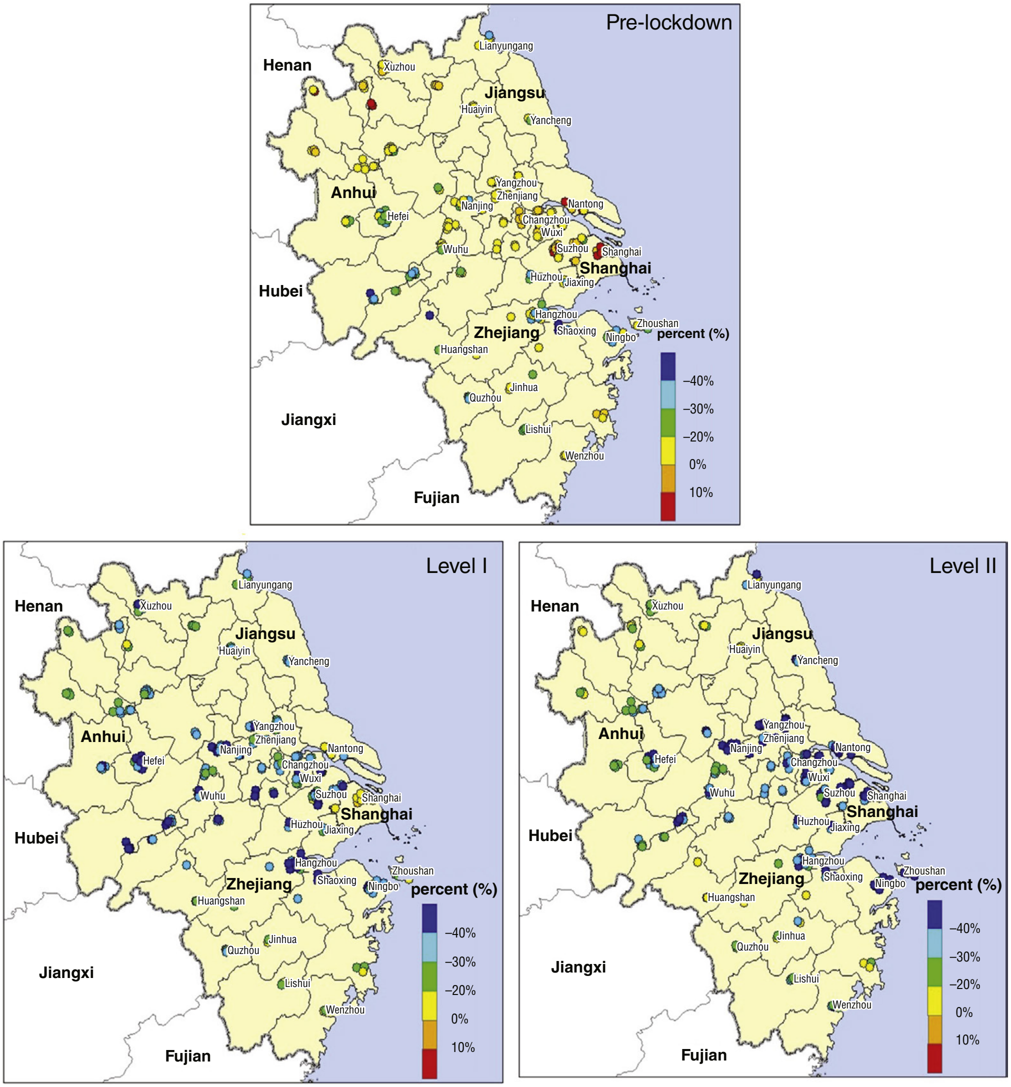


**Fig. 17.2** (Top) relative changes of $PM_{2.5}$ before lockdown and during lockdown; (bottom left) $PM_{2.5}$ concentrations during lockdown period and (bottom right) adjusted $PM_{2.5}$ concentrations in the YRD.

period can be considered to be at good air quality level based on internationally recognised standards.

Furthermore and unsurprisingly, other air pollutants also reveal drastic reduction during the COVID-19 lockdown period in YRD (Fig. 17.3). For instance, the average concentrations of criteria pollutants ($PM_{10}$, CO, $NO_2$ and $SO_2$) in the YRD region decreased substantially in 2020, except the rebounding of $O_3$-8 h compared to similar period in 2017–19. In fact, a double-digits change was realised during Level I and Level II response periods (Table 17.4). From these results, it is clear that the lockdown during COVID-19 period produced the conspicuous air pollution reduction in the YRD region.

#### *17.3.2.2 Simulation of air quality changes during the COVID-19 lockdown*

If no lockdown had occurred (i.e. emissions had been at baseline level), $PM_{2.5}$ concentrations in Shanghai and the entire northern YRD are estimated to be between 50–100 μg $m^{-3}$, which is about 60 percent higher than lockdown values.

Detailed scrutiny (Table 17.5) reveals that, during Level I response period, Zhejiang, Anhui and Jiangsu experienced a more pronounced air quality improvement compared to Shanghai. This signifies the slightly different level of implementation of lockdown from each province.

Subsequently, during Level II, it is also apparent that the extended Level I response in Shanghai, as mentioned earlier, produced a much higher improvement. It is understandable that the prominent drop of $NO_2$ (high *RF*) is directly related to the sharp decrease of VKT as a result of the lockdown. Similarly, the sharp decreases in $SO_2$, particularly in Anhui, Zhejiang and Jiangsu, where industries are concentrated, are linked to the stoppage of industrial activities, as well as small and medium enterprises during the lockdown period. In contrast, significant ozone increase is seen in the areas with higher $NO_2$ and $PM_{2.5}$ decrease. This phenomenon is attributed to a weakened ozone titration due to the sharp drop of $NO_x$ emissions during the lockdown. Recent studies also suggest that a decrease in $PM_{2.5}$ and its chemistry, makes ozone less sensitive to $NO_x$ controls, because ideally $PM_{2.5}$ acts as a sink for $NO_x$ radicals that would otherwise have produced ozone. Therefore, policies focused on reducing the regional atmospheric oxidation capacity are urgently needed to tackle the increasing ozone phenomenon in the YRD region, especially with regarding to its interconnectivity with $PM_{2.5}$ and $NO_x$.

### 17.3.3 Clustering analysis and potential source contributions

To study the air mass trajectories and source characteristics of $PM_{2.5}$ in the YRD, a PSCF threshold of 75 μg $m^{-3}$ is set to make it consistent with the daily average standard.

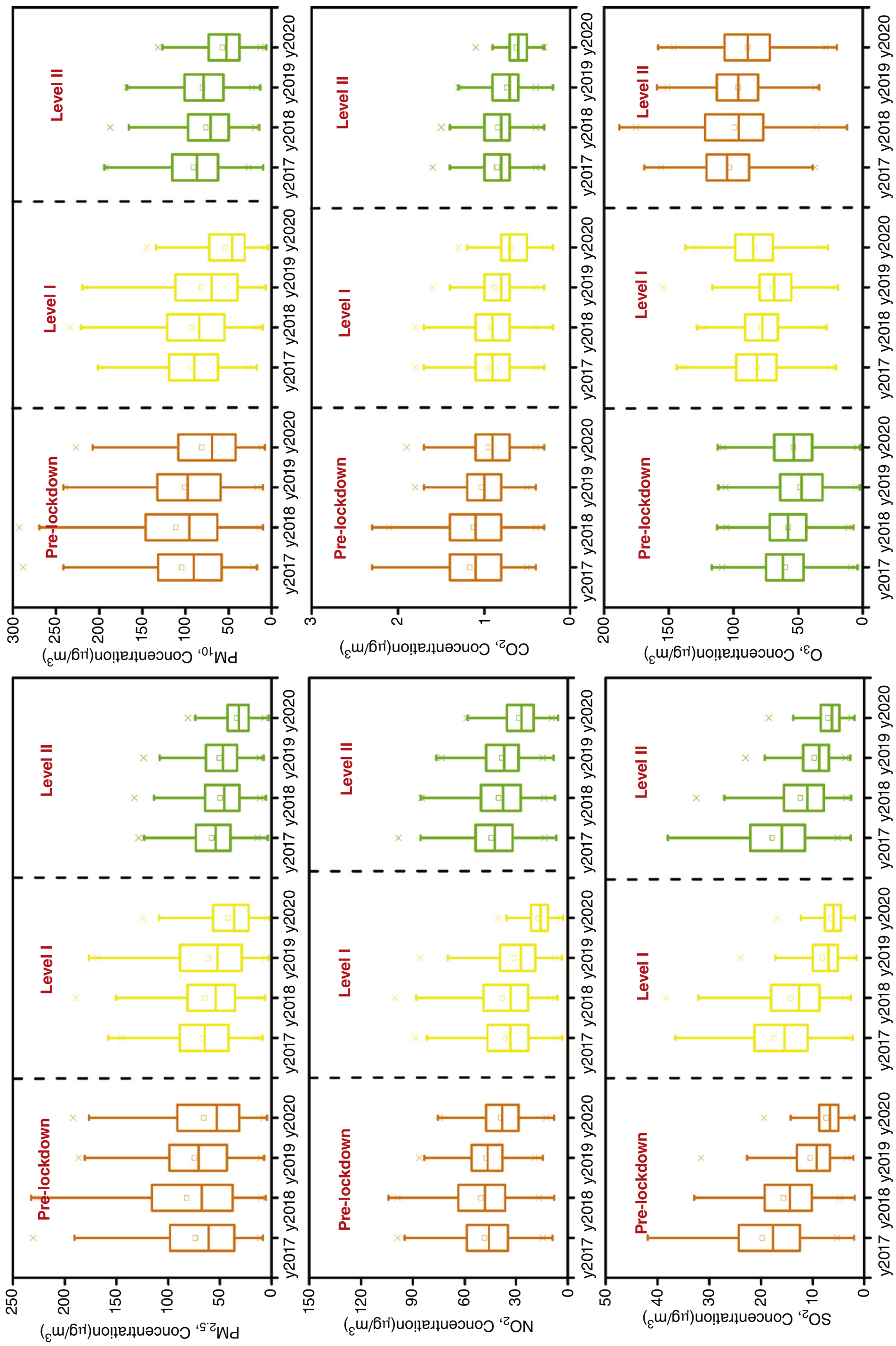


**Fig. 17.3** Yearly changes of PM$_{2.5}$, PM10, CO, NO$_2$, SO$_2$ and O$_3$-8h in 41 cities in the YRD (first January - 31st March).

**Table 17.4** Comparison of various pollutants in 2019 and 2020 in YRD (first January - 31st March).

| | Pre-lockdown | | | Level I Response Period | | | Level II Response Period | | |
|---|---|---|---|---|---|---|---|---|---|
| **Pollutants** | **2019** | **2020** | **Changing rate** | **2019** | **2020** | **Changing rate** | **2019** | **2020** | **Changing rate** |
| $PM_{2.5}$ | 75 | 66 | −12.3 percent | 62 | 42 | −31.8 percent | 51 | 34 | −33.2 percent |
| $PM_{10}$ | 101 | 81 | −19.6 percent | 81 | 54 | −33.7 percent | 81 | 57 | −29.0 percent |
| CO | 1.0 | 1.0 | −7.8 percent | 0.9 | 0.7 | −20.9 percent | 0.7 | 0.6 | −14.7 percent |
| $NO_2$ | 48 | 39 | −18.5 percent | 31 | 17 | −45.1 percent | 38 | 28 | −25.9 percent |
| $SO_2$ | 11 | 7 | −29.3 percent | 8 | 7 | −20.4 percent | 10 | 7 | −27.2 percent |
| $O_3$-8h | 49 | 54 | 10.4 percent | 70 | 84 | 20.5 percent | 96 | 89 | −7.6 percent |

**Table 17.5** Changes of key pollutants' concentrations in key cities of YRD region during 2020 COVID-19 lockdown.

| | | Level I | | | Level II | | |
|---|---|---|---|---|---|---|---|
| **Province** | | **Observed ($\mu g\ m^{-3}$)** | **Relative Improvement Factor (RF)** | **Changes due to lockdown ($\mu g\ m^{-3}$)** | **Observed ($\mu g\ m^{-3}$)** | **Relative Improvement Factor (RF)** | **Changes due to lockdown ($\mu g\ m^{-3}$)** |
| Shanghai | $PM_{2.5}$ | 36.5 | −40.9 percent | −14.9 | 26.9 | −34.9 percent | −9.4 |
| | $NO_2$ | 27.2 | −59.1 percent | −16.1 | 32.2 | −52.8 percent | −17.0 |
| | $SO_2$ | 6.1 | −24.6 percent | −1.5 | 6.3 | −17.6 percent | −1.1 |
| | $O_3$ | 69.1 | 24.2 percent | 16.7 | 75.6 | 16.8 percent | 12.7 |
| Anhui | $PM_{2.5}$ | 50.2 | −35.5 percent | −18.1 | 40.2 | −21.6 percent | −8.7 |
| | $NO_2$ | 18.4 | −55.6 percent | −10.0 | 27.6 | −23.4 percent | −6.3 |
| | $SO_2$ | 7.6 | −27.3 percent | −2.1 | 8.0 | −18.0 percent | −1.4 |
| | $O_3$ | 62.4 | 9.20 percent | 5.9 | 61.9 | 1.0 percent | 0.7 |
| Zhejiang | $PM_{2.5}$ | 26.0 | −38.0 percent | −9.9 | 23.5 | −27.6 percent | −6.5 |
| | $NO_2$ | 13.1 | −51.2 percent | −6.6 | 29.1 | −28.2 percent | −8.0 |
| | $SO_2$ | 5.1 | −32.0 percent | −1.6 | 5.9 | −18.8 percent | −1.1 |
| | $O_3$ | 65.6 | 2.9 percent | 2.1 | 59.3 | 0.8 percent | 0.6 |
| Jiangsu | $PM_{2.5}$ | 46.2 | −40.4 percent | −18.7 | 35.2 | −24.5 percent | −8.7 |
| | $NO_2$ | 18.0 | −51.4 percent | −9.2 | 28.5 | −25.3 percent | −7.0 |
| | $SO_2$ | 6.4 | −28.8 percent | −1.9 | 7.1 | −16.7 percent | −1.2 |
| | $O_3$ | 64.4 | 8.0 percent | 5.1 | 68.1 | 3.2 percent | 2.2 |

From the PSCF results (Fig. 17.4), dark grid colours represent greater contribution of the potential source area to the concentration of $PM_{2.5}$ in Shanghai. From the Figure, it can be seen that $PM_{2.5}$ in Shanghai is contributed by a wide and complex sources of pollution. This includes the neighbouring provinces and also other areas such as

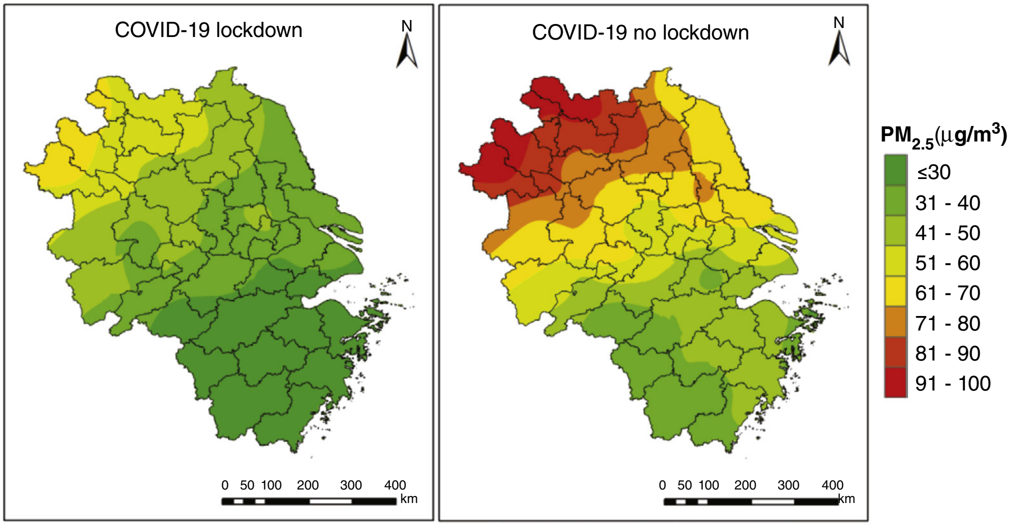


**Fig. 17.4** Concentration of $PM_{2.5}$ during lockdown period and (left) and adjusted $PM_{2.5}$ concentrations in the YRD.

Shandong, Henan, Shanxi, Hebei, Jiangxi, Hunan, Beijing, Tianjin, Hebei, and other regions. Clearly, a major fraction of concentration of $PM_{2.5}$ in Shanghai comes from long-range transport, as in Fig. 17.5.

The air mass trajectories during pre-lockdown period mainly originate from the Northern Mongolia region and as far as Siberia. These air masses carry primary and secondary air pollutants through long distances and reach the YRD region via Beijing, Tianjin and the Yellow Sea region. During Level I response, local sources and adjacent areas in the North and Northwest of Shanghai (i.e. Xuzhou-Suzhou-Wuxi-Changzhou-Nantong area) were the main potential impact sources with WPSCF is above 0.6. Moreover, the regional potential sources (WPSCF > 0.5) and the polluted air mass from the north landed on the eastern coastal area after detouring at the sea (WPSCF of 0.3–0.4), thus impacting the concentration of $PM_{2.5}$ in Shanghai.

During Level II period, $PM_{2.5}$ in Shanghai is mainly affected by the contribution of surrounding cities within YRD, particularly the southwestern city of Huzhou with a WPSCF above 0.6 (Fig. 17.4). In addition, YRD region is greatly affected by the monsoon climate owing to its location. Usually during March Shanghai receives more southerly winds (i.e. southeast and southwesterly winds), which causes polluted air masses. Besides, after Level II response was effected, industries resumed production, and economic activities brought more anthropogenic pollution sources which eventually impacted $PM_{2.5}$ in Shanghai. In conclusion, the PSCF results reveal an intricate and complex wintertime pollution sources of $PM_{2.5}$ in the YRD region, especially in Shanghai that require large-scale regional joint-control strategies.

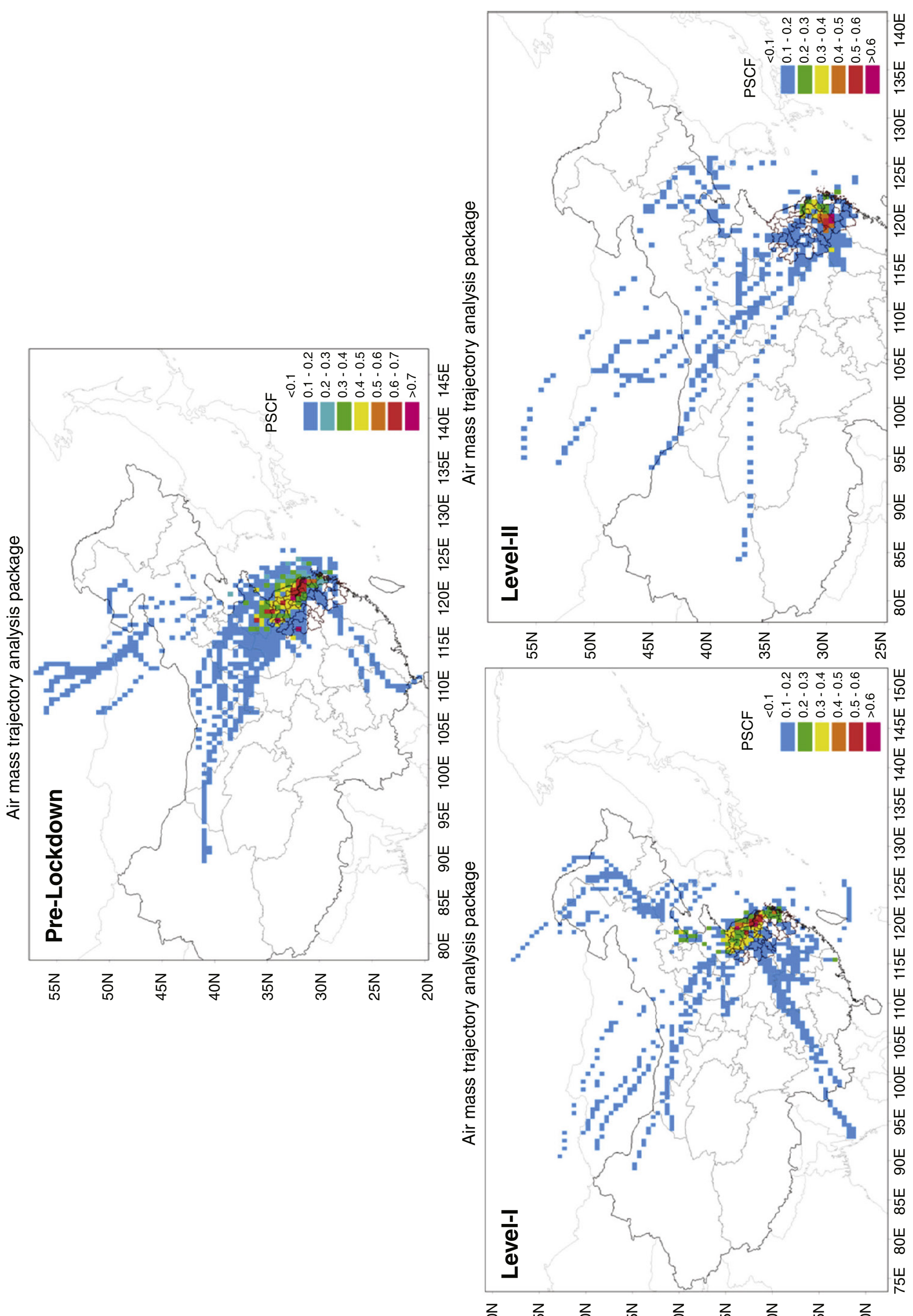


**Fig. 17.5** PM2.5 potential source regions: air mass trajectory analysis during COVID-19 period in Shanghai.

#### *17.3.3.1 Source apportionment of $PM_{2.5}$ during COVID-19 lockdown*

Before and during the COVID-19 period, industrial and residential contributions to $PM_{2.5}$ were significant. This is the case because according to the industrial production data published by the bureau of statistics in the provinces of YRD, the manufacturing sector did not actually show major slowdown. The production of iron and other non-ferrous materials, medical and pharmaceuticals remained roughly constant. However, the report noted the petrochemical industry, construction industry and facility manufacturing were strongly affected and hampered by both the upstream and downstream chain. Fig. 17.6

It is also worth noting that the promulgation of Level I response coincided with the Chinese New Year holidays, starting 25th January 2020. Therefore, the lockdown restrictions confined most people within their homes leading to the increase in residential emissions. In contrast, the contribution of dust (DST) and mobile (MOB) emissions to $PM_{2.5}$ show substantial reduction. This is attributed to the shutdown of the construction sector and the restriction of travel during the lockdown. Data published by the bureaux of statistics of Anhui and Zhejiang provinces show a drop of about 50 percent in passenger traffic in both provinces between January-February 2020 compared to the same period in 2019. Traffic flow monitoring data from Bengbu and Changzhou cities show a 75 percent and 50 percent decline during Level I and Level II respectively, compared to pre-epidemic period. As to the total departures from China's 25 busiest airports (Flightradar 24, https://www.flightradar24.com/), the decline during Level I and Level II is 80 percent and 60 percent, respectively.

### 17.3.4 Impact of air quality changes on health during COVID-19 lockdown

#### *17.3.4.1 Premature mortality attributable to short-term $PM_{2.5}$ exposure*

As mentioned before, ambient $PM_{2.5}$ exposure leads to higher mortality in infants (< 5 years) because of ALRI and in adults (≥ 25 years) due to stroke, IHD, COPD and LC. Therefore, premature mortality over the YRD region is calculated based on the health impact function (Eq. (17.6) during pre-lockdown, Level I, and Level II period of 2017–20.

In 2020 during the pre-lockdown period, the total premature mortality attributed to $PM_{2.5}$ exposure is 36.4 thousand (95 percent CI: 30.4–38.8 thousand) in the YRD region (Fig. 17.7). The previous years (i.e. 2017–19) show relatively consistent results. It is noted that stroke and IHD account for over 70 percent of total $PM_{2.5}$-related premature death during the pre-lockdown period. During Level I and Level II response periods, a clear contrast is visible between 2017–19 when compared with 2020. Although

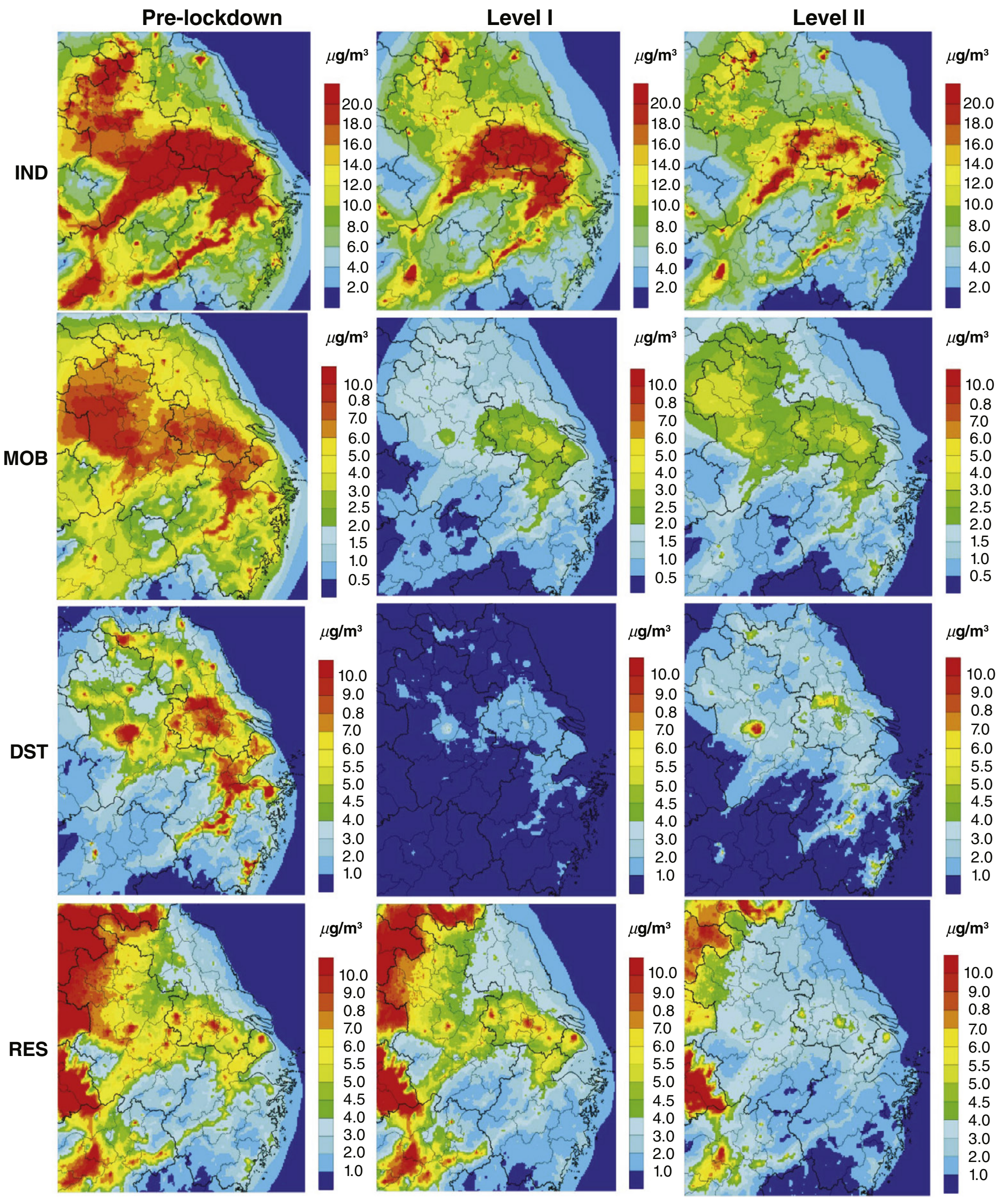


**Fig. 17.6** Sectoral contributions to PM2.5 during pre-lockdown, Level I and Level II response periods in YRD.

the results of 2017–19 exhibit slight fluctuations, a clear contrast is visible in the results of 2020. Therefore, the significant reduction in premature mortality during lockdown periods (Level $I$ + Level II), indicate clearly the substantial health benefits associated with lowered $PM_{2.5}$ concentrations due to the COVID-19 lockdown.

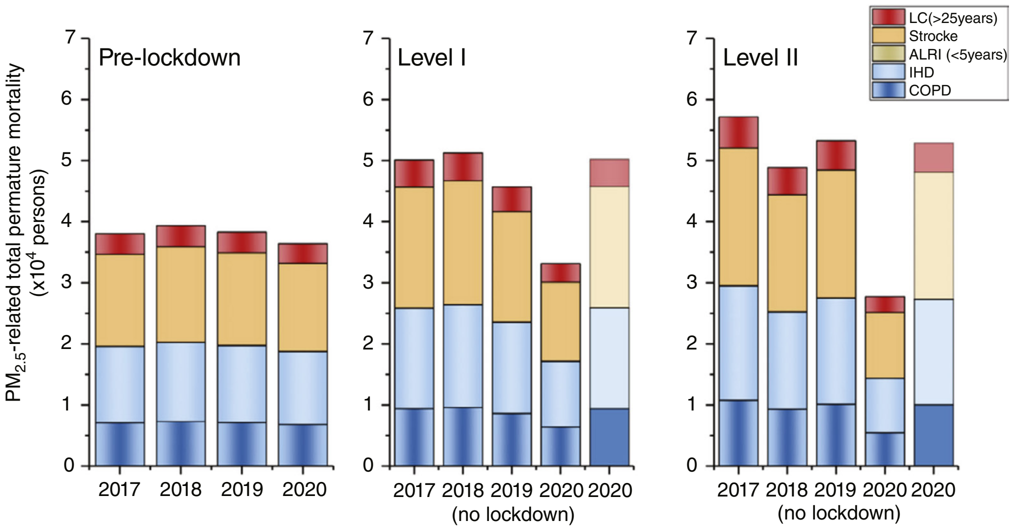


**Fig. 17.7** ***Premature mortality due to LC, stroke, ALRI, IHD, COPD during pre-lockdown, Level I and Level II periods of 2017–20.*** Estimated premature mortality with the assumption of no-lockdown is also shown for Level I and Level II.

### *17.3.4.2 Avoided premature mortality due to relative improvement of $PM_{2.5}$ during COVID-19 lockdown*

The potential health benefits due to lockdown are estimated as the differences of premature mortality calculated with observed $PM_{2.5}$ concentrations and the simulated 'no lockdown' concentrations. The number of avoided premature death for different cities depends on the base population and the changes in $PM_{2.5}$ concentrations due to lockdown. During Level I period, the top five cities with largest avoided premature death are Shanghai (1932), Wenzhou (1124), Suzhou (Jiangsu province; 1118), Ningbo (934), and Hangzhou (934). During Level II period, the top five cities with largest avoided premature death are Shanghai (3502), Wenzhou (1628), Suzhou (Jiangsu province; 1542), Nantong (1270), and Nanjing (1227). This is not to imply that COVID-19 of any positive consequences, but more about to initiate a discussion with evidence that air pollution has tremendous health effects. Fig. 17.8

## 17.4 Conclusions

COVID-19 control period was characterised by major reduction of human activities which led to significant reduction in primary pollutants like $PM_{2.5}$, $NO_x$, $SO_2$ and VOCs. However, it was discovered that during the period $O_3$ rebounded. This indicates the complexity in the co-control of $PM_{2.5}$ and $O_3$, especially with regard to the titration effect with NOx. Therefore, more stringent measures such as adjustment of the energy and industrial structure; more stringent and wider regional joint-control to achieve a better air quality.

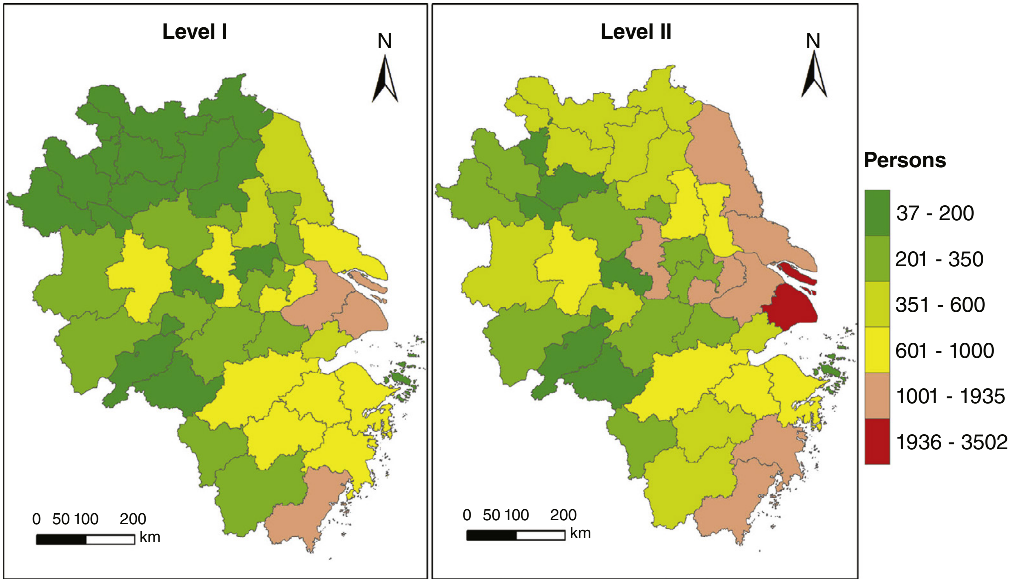


**Fig. 17.8** Spatial distribution of city-level total avoided premature death during COVID-19 lockdown in YRD.

It is also worth to note that, the COVID-19 pandemic continues run havoc globally. For that reason, our results of this study has no intention to indicate that pandemics bring a positive effect on health, rather, the COVID-19 lockdown in YRD provided a good opportunity to reveal the health impacts related to improved air quality. In fact, our results strongly reinforce our knowledge on detrimental health effects that $PM_{2.5}$ has. Moreover, it is now evident that substantial health benefits can be achieved with reduced $PM_{2.5}$ concentrations as a result of emission controls. However, although $PM_{2.5}$ concentration decreased substantially during lockdown period, there is evidence of high concentrations of residual $PM_{2.5}$ that exceed the WHO standards. Therefore, continuous efforts are needed to reduce emissions in the long term and through the most cost-effective ways in order to protect public health.

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# COVID-19
# IN THE ENVIRONMENT

## IMPACT, CONCERNS, AND MANAGEMENT OF CORONAVIRUS

Deepak Rawtani | Chaudhery Mustansar Hussain | Nitasha Khatri

***COVID-19 in the Environment: Impact, Concerns, and Management of Coronavirus*** highlights the research and technology addressing COVID-19 in the environment, including the associated fate, transport, and disposal. It examines the impacts of the virus at local, national, and global levels, including both positive and negative environmental impacts and techniques for assessing and managing them. Utilizing case studies, it also presents examples of various issues around handling these impacts, as well as policies and strategies being developed as a result.

Organized into six parts, *COVID-19 in the Environment* begins by presenting the nature of the virus and its transmission in various environmental media, as well as models for reducing the transmission. Section 2 describes methods for monitoring and detecting the virus, whereas Sections 3, 4, and 5 go on to examine the socio-economic impact, the environmental impact and risk, and the waste management impact, respectively. Finally, Section 6 explores the environmental policies and strategies that have comes as a result of COVID-19, the implications for climate change, and what the long-term effects will be on environmental sustainability.

**Key Features**

- Examines the fate, transport, and management of COVID-19 and COVID-19-related waste in the environment
- Explores a variety of issues related to the environmental handling and impacts of COVID-19, particularly utilizing case studies
- Offers tools and techniques for assessing real-time environmental issues related to COVID-19

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