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CHAPTER 7

Impediments of coronavirus in healthcare wastewater treatment and ways to ameliorate them

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7.1 Introduction

An increase in global population and climate change implications will further create a bottleneck in the health management and sanitation system in the near future. This demands a clear-cut vision, strategies, policies, and regulations to be implemented by the countries to reduce the damage. The recent outbreak of the COVID-19 pandemic has further aggravated the problem, which is speculated to have originated from Wuhan, China, and has spread as a pandemic infectious agent. The SARS-CoV-1 was first identified in 2003 that affected 26 countries and is considered an animal virus passed from animals, such as the civet cat, to humans. There is direct human-to-human transmission of the virus, which majorly takes place in the absence of adequate infection control and lack of hygiene and precautions. Based on what was learned from the 2003 outbreak, the World Health Organization (WHO) recommended appropriate infection control and safety measures that can be applied to curb the recent COVID-19 outbreak.¹ There are different segments in society such as health care and public transport that have to be dealt with frontline importance and where the pandemic may remain a hotspot. Recent research published in *Nature Sustainability* by an international collaboration have assessed the recent studies on coronaviruses in wastewater.² Conventional wastewater treatment provides only partial removal of virus particles, which demands meticulous additional treatment strategies for safe disposal or reuse depending on the effectiveness of final disinfection.³ Wastewater

containing coronaviruses may be a potential threat, according to a new review of studies that call for additional filtration steps in sewage treatment plants to remove the viruses successfully.⁴

In this context, this chapter focuses on detailed discussions of health care wastewater that reckons to contain infectious virus, mitigation strategies for efficient removal of pathogens, additional precautionary measures for the protection of sanitary, and wastewater treatment operators.

7.2 Municipal wastewater: Definition, classification, and characterization

Municipal wastewater (MWW) can be defined as the water generated as waste either from households or a combination of wastewater from various households, industries, and precipitates as the origin. The content of domestic waste usually constitutes residue from sanitation systems, kitchens, and household chore materials, which are contaminated with bacteria, viruses, synthetic chemicals, etc. These contaminants can be easily degraded with the aid of primary and biological treatments. Other particulates of medicinal and cosmetic origins form micropollutants, which require secondary treatments before discharge. The various types of MWW can be generalized based on the components present in it. The classification of the components based on a myriad of parameters can ease the process of wastewater treatment before discharge.⁴

The composition will vary based on the source and region, but taking into consideration the major components, MWW mostly contains five classified pollutants such as biological oxygen demand (BOD) load (in the form of solids), inorganic nutrients (nitrate and phosphate), toxic xenobiotics, pathogens and inorganic minerals like heavy metals.⁴ The typical range of values present in MWW has been represented in [Table 7.1](#).

7.2.1 Characterization of wastewater pertaining to epidemiological index

The characterization of MWW is vital to analyze the constituents present in it to decide on the method of treatment and discharge. It is not a voluntary concept, since following governmental norms, predisposal is mandatory to curb pollution and the spread of diseases. The researchers have analyzed the domestic sewage at the Beishiqiao Wastewater Purification Center, Xian, China, for an extended period and put forth the following characteristic parameters.⁶

Table 7.1 Characteristic range of different pollutant parameters in MWW.⁵

	Strong	Medium	Weak
Total solids	1200	700	350
Dissolved solids	850	500	250
Suspended solids	350	200	100
Nitrogen (as N)	85	40	20
Phosphorous (as P)	20	10	6
Chloride	100	50	30
Alkalinity (as CaCO ₃)	200	100	50
Grease	150	100	50
BOD	300	200	100

All units are in mg/L.

7.2.1.1 Suspended solids (SS)

In the samples postfiltration through a 0.45 µm membrane, the filter medium showed a negligible amount of SS; hence, most of the raw sewage contained suspended solids above the 0.45 µm as a parameter.⁶

7.2.1.2 Chemical oxygen demand (COD) and biological oxygen demand (BOD)

The microfilter with a pore size of 0.45 µm could retain significant solids that account for the average COD and BOD of 66% and 62%, respectively, in a given wastewater stream. The size of these retainable solids might be their innate nature or attached to other filterable particles.⁶

7.2.1.3 Total phosphorus (TP)

In the analysis of TP in dissolved and suspended solids, it is noticed that suspended matter contained more phosphorus in comparison to the amount in the dissolved matter, with an average concentration of 50.2% and 49.8%, respectively.⁶

7.2.1.4 Total Nitrogen (TN)

It has been observed that a higher amount of TN was present in dissolved fractions rather than suspended solids. The average concentrations in dissolved and suspended fractions were found to be 79.6% and 20.4% respectively.⁶

7.2.1.5 Pathogens

In countries which have prevailing endemics related to helminths diseases such as *Ascaris* and *Trichuris* sp. have shown usage of untreated wastewater in agriculture to irrigate crops or vegetables which are consumed uncleaned or uncooked.⁷ A study in West Germany also showed a similar pattern of

Table 7.2 Possible levels of pathogens in wastewater.⁸

Type of pathogen		Possible concentration per liter of domestic wastewater
Viruses	<i>Enteroviruses</i>	5000
Bacteria	<i>Pathogenic E. coli</i>	—
	<i>Salmonella</i> spp.	7000
	<i>Shigella</i> spp.	7000
	<i>Vibrio cholera</i>	1000
Protozoa	<i>Entamoeba histolytica</i>	4500
Helminths	<i>Ascaris Lumbricoides</i>	600
	<i>Hookworms</i>	32
	<i>Schistosoma mansoni</i>	1
	<i>Taenia saginata</i>	10
	<i>Trichuris trichina</i>	120

transmission of cholera, leading to an endemic in the region. Pathogenic bacteria, protozoa, viruses, and helminths are found in raw waste and can survive in the water for a significant amount of time. Table 7.2 represents some of the possible common pathogens and their count in raw wastewater. Organisms of pathogenic traits present in wastewater are a significant concern when the wastewater is reused for agricultural irrigation. In epidemiological studies, various adverse health impacts have been attributed to the practice of reuse of wastewater in agricultural fields. The pathogen population could be significantly reduced in the tertiary treatment stage by adoption of ultrafiltration, irradiation with UV, and disinfection by chlorination. Further, the digestion of residual sludge by anaerobic digestion can reduce the pathogenic population due to the heat generated in the digester.⁸

In treatability analysis, it is generally observed that most of the contaminants from the suspended fractions can be easily removed by coagulation or sedimentation procedures. Hence, the effect of primary and enhanced primary methods depends on the fraction of suspended solids present in the wastewater. Biological and advanced treatments are applied for the removal of dissolved contaminants depending on the required parameters of the water quality. BOD and COD parameters change in accordance with the removal of suspended solids, and it can be assumed they are present and coexistent in the wastewater.⁷

7.2.2 Possible disinfection routes of MWW

The SARS pandemic outburst can be linked to the transmission of viruses by water sources and wastewater. With the concept “liter of water, an ocean of information,” multiple researchers have studied the presence of

SARS viruses in wastewater and its prolonged presence.⁹ The SARS epidemic in 2003 had cases of spread of the virus in a high-rise building in Hong Kong where around 300 people were affected due to malware in the sewage system.¹⁰ Viral particles were also obtained from the enteric tissues of human small intestines and found to be in larger counts than the cultures found in the lung tissue, showing the high probability of viral particles to be present in excretory matters.¹¹ In the recent case of SARS-CoV-2, the concept of sewage epidemiology, or water-based epidemiology, holds significance to detect the presence of the virus in untreated sewage through fecal matters. The RIVM National Institute for Public Health and the Environment, Netherlands, in their research studies, showed the presence of the virus in the gastrointestinal tract, thus transmitting to the sewage through excreta.^{12,13} Similar findings have taken place in Australia, France, and Paris.¹⁴ Considering such research results and analysis, one can conclude that it is of grave importance to treat sewage and wastewater to control the transmission and outbreak of COVID-19.¹⁰

A varied number of methodologies are applied to disinfect municipal wastewater, which is majorly carried out in the secondary stage of wastewater treatment plants. Though with the increase in numbers of pandemics and epidemics worldwide, a site-specific and conditional approach is required in municipal wastewater treatments. The prevailing technologies and the advent of newer concepts can be broadly divided into four categories as discussed in subsequent sections.¹⁵

7.2.2.1 UV irradiation

This method applies UV irradiation for the purpose of disinfection. Here, a UV irradiation dense zone is created on a segment of the wastewater by using a UV lamp placed outside the volume of the water. UV radiation has a germicidal wavelength of 253.7 nm, which has the ability to damage and alter the genetic structure or biological macromolecule (DNA/RNA/Protein) of the microbial contaminants thereby rendering them inactive and less virulent.¹⁵

7.2.2.2 Electrochemical (EC) disinfection

EC disinfectant is used for the secondary treatment of wastewater. The method resulted in the highest efficiency of killing 99.9% of coliform bacteria in saline water sources (8% salinity). The efficiency was obtained with a contact time of less than 20 s and less than 0.08 kWh/m³ power consumption. Even with an increase in power and time, the efficiency of

the EC method in freshwater remained minimal. In comparison with direct chlorination methods, it can be concluded that this technique does not use electrochlorination; rather, it produces a powerful germicidal compound.¹⁶

7.2.2.3 Ozone disinfection

Ozone treatments decolorize and deodorize wastewater through disinfection. Ozone microbubbles (less than 50- μm diameter and high solubility and reactivity) can be sparged into the wastewater due to the balance between surface tension and high tension, and local hotspots are created. These spots generate intense heat as the gas in microbubbles are compressed. There is pyrolytic decomposition leading to the formation of shockwaves and OH radicals in the water. This provides improved and efficient disinfection of wastewater by inactivating the microbial contaminants present in it.¹⁷

7.2.2.4 Peracetic acid

Peracetic acid acts as a broad-spectrum antimicrobial which shows action on bacteria, fungus, virus, and spores making it a choice for multiple purposes. This method provides ease of application and has no quenching requirements with minimal dependence on pH, short time span, and effectiveness on both primary and secondary effluents. Even with such broad benefits, the major disadvantage of peracetic acid is the formation of acetic acid, which increases the organic load, thereby the microbial growth in the effluent.¹⁸

7.2.2.5 Ultrasonication

Ultrasound (20 kHz) has been used for the disinfection of domestic wastewater. The primary application of this technology is through the ultrasound probe where the disinfection takes place by the thermal mechanism of heat production (52%), mechanical stress created by the ultrasonic cavitation (36%), and synergistic effects (13%). The disinfection efficiency generally increases with the increase in ultrasound power at a rate of 0.003 log kill/min at 70 W/L to 1.8 log kill/min at 1250 W/L, and this is mainly observed by the increase of thermal inputs.¹⁴

7.2.2.6 Chlorination

Chlorination is the most widely used method currently in the field of wastewater treatment. It acts as a disinfectant by oxidizing the cellular material of the microbes. The chlorine can be applied in various forms, such

as chlorine compounds, gas, hypochlorite solution, etc. The addition of chlorine and chlorine compounds leads to the formation of hypochlorous acid (HOCl) and hypochlorite ions (OCl), which are free available ions that act as the oxidizing agents in water. Though this method has multiple downfalls such as the production of toxic, hazardous materials (THMs) as byproducts, an increase in dissolved solids level, and an increase in organic load reduces the overall effectiveness of this method.¹⁹

For effective disinfection of nonenveloped viruses, strategies such as thermal treatment of sludge, the addition of lime, drying, and composting were found to be suitable and which can be applied for SARS-CoVs inactivation.²⁰ However, SARS-CoV-2 is an enveloped virus and can act as a barrier for inactivation; also, during secondary treatment operation, added chlorine/fluorine may get precipitated along with organic matter and nitrogenous compounds, thereby reducing its effectiveness. To overcome such difficulty, separate tertiary treatments that afford combinatorial (physiochemical) inactivation such as membrane filtration, advanced oxidation process, and chlorination shall be provided before release to the environment. To date, there is no specific SARS-CoV-2 disinfection prescribed.²¹

7.3 Healthcare wastewater (HWW)

Water is contaminated severely due to healthcare services, and its discharge is known as healthcare wastewater (HWW). It is majorly composed of solids discarded during treatment of the patients, disinfectants, sewerage, and food waste from healthcare units.²² Fig. 7.1 represents the sources of healthcare wastewater and the possible contaminants, as indicated in Fig. 7.2. HWW is also contaminated by a photochemical solution like hydroquinone, chemicals from diagnostic labs and pharmacy, absorbable organohalogen compounds in X-ray contrast media, anesthetics, formaldehyde, glutaraldehyde, disinfectants, radioactive wastes, nutrients and nitrates in excess, dental amalgam mercury, and infectious microorganisms from biomedical wastes.²³

7.3.1 HWW management

HWW has to be handled with utmost care as it is highly contagious and a possible place to spread disease during an epidemic, endemic, and pandemic. Strictly HWW must be limited from being discarded into public sewers. Safe storage, waste minimization, and segregation are to be

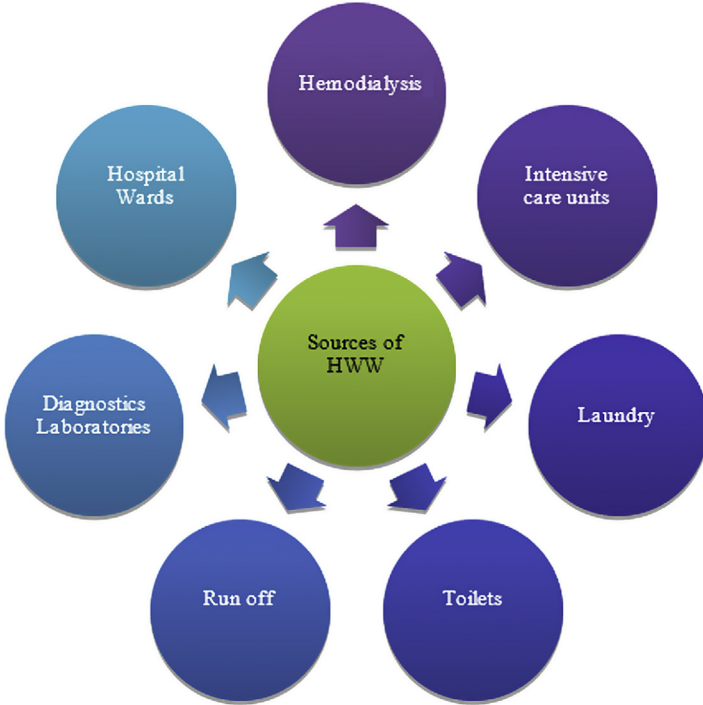


Figure 7.1 Sources of healthcare wastewater (HWW).

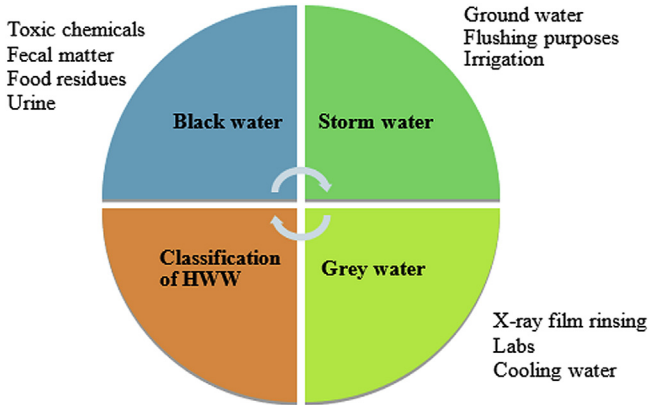


Figure 7.2 Classification of healthcare wastewater (HWW) sources.

performed with equal importance for liquid discards as it is done for solid wastes. Colorants, photographic chemicals, aldehydes, and antibiotics are classified under pharmaceutical and chemical wastes; when directly discarded into sewers, they pose a significant threat.²² Healthcare sewage

systems can be connected to the municipal sewage system and can discharge HWW into it only by meeting demands such as primary, secondary, and tertiary disinfection procedures are met. Approximately 90% of microorganisms are removed with the number of helminth eggs reduced to less than an egg per liter satisfying all regulatory requirements (local). Expired blood bags, including PPE, are disposed of by controlled landfills, high-temperature incinerator treatment, autoclaving with special liquid treatment cycle, prorated pit burying as unopened bags within healthcare establishments, or in a secure location elsewhere.¹

7.3.2 HWW collection methods

7.3.2.1 Central system

A central system collects wastewater from throughout the healthcare establishment to a central underground spot for disposal and treatment.¹

7.3.2.2 Decentralized system

Decentralized wastewater collection channels from medical areas carry wastewater to septic tanks, followed by a standard treatment facility for the reduction of the pollutant load. However, this is not a preferred approach (Fig. 7.3).¹

A sewage system is used for wastewater collection. A stormwater system is installed to collect rainwater on rooftops and pavements of healthcare units, and in turn, use them for flushing, etc. Manholes permit maintenance of 50 or <50 m. Pretreatment is required to reduce contaminants in HWW or manipulate its nature prior to release into the sewer.¹

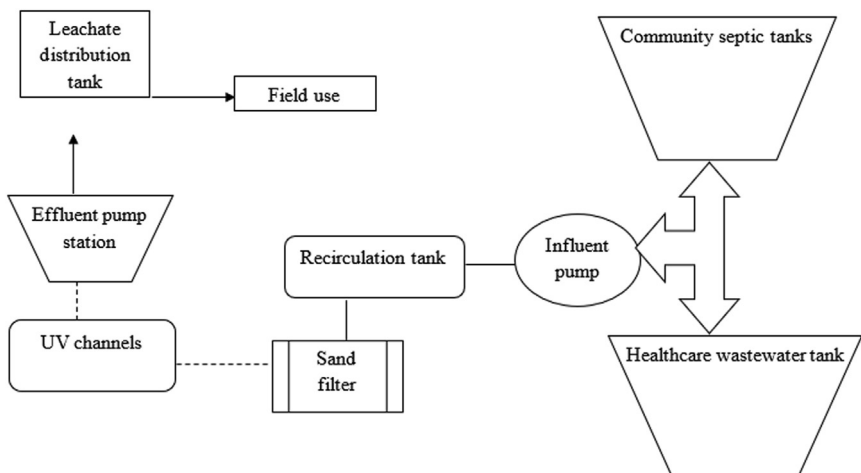


Figure 7.3 Decentralized system of HWW management.

7.3.3 Pretreatment of HWW

Medical labs, feces/vomit during the outbreak, blood, dental departments, and radiotherapy departments require pretreatment, which include acid-base neutralization, filtration, sedimentation, and autoclaving. When there is contamination due to feces in the course of a disease like cholera, the pretreatment can include disinfection with lime milk (calcium hydroxide) administered in a ratio of 1:3. The above mixture is administered for 6 h at least. Then 1:1 urine to lime for at least 2 h is to be incorporated. Blood is pretreated by thermal methods. It is important to note that conventional hypochlorite treatment is not sufficient for blood since blood is a heavy organic load. In the dental department, amalgam separators are used for pretreatment purposes, and safe storage of discarded mercury is done. In the radiotherapy department, collection and storage of radioactive wastewater (e.g., urinary discharge of patients undergoing thyroid treatment) in the die-away basin for decay is done. During this storage time, background concentrations come down, and after meeting the standard storage time, the water is drained into sewers.¹

7.3.4 Medical wastewater treatment in COVID times

Knowing that this deadly virus can be transmitted via human excreta, disinfecting HWW is very important. The China Ministry of Ecology and Environment (MEE) has issued a couple of standards for healthcare facilities to obey. The use of disinfectants demands more research and guidance. On March 3, 2020 National Health Commission and State Administration of Traditional Chinese Medicine announced, “Diagnosis and treatment protocol for Novel coronavirus pneumonia (Trial Version 7).” The probability of fecal-oral transmission has been added in the diagnosis and treatment plans. SARS-CoV-2 are often found in urine or discharged matter; hence, HWW is to be treated appropriately.²⁴

7.3.4.1 Wuhan: A case study

The Water Affairs Bureau of Wuhan’s municipality has implemented complete disinfection for sewage and drainage systems. Between January 29 and February 18, 2020, about 196,358,000 Kg of sanitizers were used for disinfection. At all 26 civic run-off treatment units, sodium hypochlorite was approved for disinfection. Frequent evaluation of fecal coliform was made mandatory in all treatment facilities.²⁵

7.3.5 Mandatory treatment and disinfection plans

Wastewater from general hospitals also shall be treated the same way as HWW. Distinct festering tanks are mounted for affected zones, and specific guidelines must be followed before the wastewater from these areas is mixed. The hygiene index should be studied by means of fecal coliform group (shall be lower than 100). Requirements for hazardous waste disposal will be followed for sludge disposal, and an account in succession is established for all treatment facilities with proper disinfection.²⁶

7.3.5.1 Disinfection procedure

A disinfection procedure removes a majority of or all pathogenic microbes from the HWW. There are many important factors that influence the disinfection process; namely, innate resistance of microorganisms; resistance to chemical germicides, which vary from organism to organism; and the sterilization process, which is also organism-specific. It is important to note that even the population of microorganisms that is most resistant contrast the disinfection time. With prions being an exception, all other bacterial spores are characterized by an inborn resistance toward germicides of chemical origin. The concentration of disinfectants is directly proportional to the efficacy and inversely proportional to the time to kill pathogens. The potency of germicide is essential with respect to the length of disinfection time.²⁷ Some of the physical and chemical factors influencing disinfection are as follows:

- The activity of disinfectant rises with rising in temperature up to a threshold value of temperature beyond which the disinfectant degrades.²⁸
- Disinfectant action is influenced by pH, changing the disinfectant action on all surfaces.²⁸
- Water hardness decreases the rate of the killing action of disinfectants as the divalent cations in water result in insoluble precipitates when interacted with disinfectant.²⁸

7.4 Occurrence and survival of COVID-19 in wastewater, urine, and biosolids

The ongoing global pandemic caused by SARS-CoV-2 has been a health crisis of global concern. Until recently, the only human coronavirus strain was known to infect the respiratory tract, but now they have been found in

the feces of patients too. During the proliferation of an organism like a virus in the host, the infection spread to various organs and bodily fluids. For pathogens transmitted by the fecal-oral route like cholera, the primary site of replication is in the intestinal tract. Infection in other organs leads to the presence of an organism in the blood and then urine after elimination by the kidneys, such as what happens in cases of enteric viruses in urine, and therefore, transported to the community sewage system.²⁹

7.4.1 The survival of SARS-CoV-2 in urine and the urogenital system

Most people infected with SARS-CoV-2 exhibit a mild increase in blood urea nitrogen and urine protein along with renal failure and gradual loss of kidney function. Viral nucleic acids are also isolated from the urine samples. Both SARS-CoV-2 and SARS-CoV share the same receptor Angiotensin Converting Enzyme 2 (ACE2). The researchers analyzed the online database and plotted the expression of ACE2 in various organs, including the renal tubular cells, and surmise that SARS-CoV-2 binds to ACE2 to cause kidney dysfunction.³⁰

7.4.2 Human pathogens can be monitored in sewage

During an active infection, the pathogens are excreted in a range of body fluids. These pathogens may find their way into sewage systems during day-to-day activities like washing, bathing, and flushing, and thereafter in the collection point where biological, physical, and chemical methods are employed to reduce the population. Since the virus can be detected in fecal and urine examination, a monitoring mechanism that includes determination of the virus concentration, type of metabolites, and biomarkers that enable prior detection of outbreaks can thereby curb the spread. Chinese scientists indicated that coronavirus found in a patient's urine is capable of transmission through the blood and can potentially infect multiple organs.³¹

7.4.2.1 A paper-strip urine test kit was developed to detect COVID-19

The paper-strip urine test is similar to a home pregnancy test kit that could be taken anywhere, be it at home, workplace, or healthcare centers, and can detect the presence of coronavirus protein in a given urine or saliva sample. The lead researcher used electrokinetics to concentrate and isolate the charged particles from the samples. "This protein detection is just like a dam, whereas the fluid flows through the paper strip, the electric field backs

up charged molecules including proteins so the test line on the paper is exposed to a higher concentration of them for a longer.” The test uses a small power source such as common 9 V batteries.³²

7.4.3 Novel coronavirus infection and gastrointestinal tract

A recent study affirms the presence of many other members of the virus family (Coronaviridae) in the intestinal tract of other species some of which have been shown to cause gastroenteritis and its related symptoms. The viral nucleic acid fragments can also be found in feces of both symptomatic and asymptomatic carriers.³³ When a patient affected with COVID-19 defecates, a large number of pathogens can persist on the toilet bowl surface. Sequential flushes and sloshing of water can disperse the viruses up to three feet in the air in the form of aerosols and can cause cross-infection among people. Studies of MERS, which shares similarities to SARS-CoV-2, stipulate that this specific virus can persist in the digestive tract of humans, which indicates that the human intestinal tract is susceptible to SARS-CoV-2 and can sustain robust viral replication. One hypothesis suggests that these enveloped viruses can persist in the human gut and protect the germs when the mucus from patients travels down the digestive tract. A Centers for Disease Control and Prevention (CDC) assessment cites one study where they were able to identify the presence of viral nucleic acids in patients’ feces. These genetic snippets stipulate that the virus once persisted in the body but has been degraded and can no longer cause illness.³⁴

7.4.4 Wastewater-based epidemiology

The US Environmental Protection Agency (EPA) suggests that viruses found in wastewater are an emerging cause of disease outbreaks of unknown origin because of their ability to mutate and undergo rapid transport through aquatic environments. Traditional disease detection is based on a diagnostic analysis of clinical samples or rapid antibody tests. Despite that, these techniques have failed to monitor early signs of a disease outbreak. Wastewater-based analysis is an ideal method to understand the proportion of a particular population found to be affected by the virus present in wastewater as it contains virus particles shed from both symptomatic and asymptomatic carriers and helps to monitor the public health of the entire locality: “This test is like a canary-in-a-coal-mine test, so it gives us a snapshot of what’s going on in the entire community.”³⁵

Dissemination of SARS-CoV-2 through wastewater and sewers is being carefully monitored as there is significant evidence of a presence of viral particles in these environmental samples that can potentially transmit to humans.^{36,37} Several reports are available that have detected SARS-CoV-2 RNA in feces, urine, and wastewater; however, the isolation of these strains from these samples seem to be complicated.^{38–40} It has been suggested that possible fecal-oral route is through the active replication within the gastrointestinal tract followed by the release of virions in the wastewater streams and sewers.⁴¹ Because the viral particles from the infected patients are usually mixed with organic matter, such as sputum and feces, and are thereby protected, the disinfection mechanism seems to be ineffective.⁴¹

7.4.5 Gastrointestinal tract may be another site of viral replication

Hubei provincial Renmin Hospital proved that viral nucleic acids are found in fecal samples of infected patients. It was proved in the study that there is a strong convergent evolutionary relationship between the receptor-binding domains of SARS-related coronavirus and COVID-19.⁴² Structural analysis indicates that both the receptor-binding domains share similar side-chain properties that are essential for ACE2 binding. The receptor is expressed densely in the luminal surface of the intestine and colon, thus indicating the possible routes for viral transmission. The receptor has other physiological roles, and it also facilitates amino acid transport to the microbial ecology of the digestive tract, where altered gut microbial compositions are exhibited by the ACE2 mutants. Guidance from China's National Health Commission recommended that modulating the gut microbiota by probiotics could be used to maintain the balance of intestinal microecology and could reduce enteritis and ventilator-associated pneumonia.⁴³

7.4.6 Viruses and the culture methods

Works have suggested the use of electropositive filter media particles for the recovery of the virus from hospital wastewater.⁴³ His work illustrates the use of bacteriophage to estimate the concentration recovery of virus from wastewater. Both bacteriophage f2 and SARS-CoV-2 have a single-stranded RNA genome, and the testing procedure for bacteriophage was straightforward and inexpensive.⁴⁴ There are various concentration methods carried out for the recovery of viruses from wastewater such as the use of a centrifugal filter or the use of polyethylene glycol concentration

methods.^{13,36} None of the works stated have estimated the percent yield of virus recovered from wastewater, due to the problems involved with the handling of clinical specimens and the necessity for a laboratory facility of biosafety-level 3. Only one research study has reported the percent yield of SARS-CoV-2 from wastewaters, which was measured to be approximately 1% by using electropositive filter membrane.⁴³ Since the properties of SARS-CoV-2 are not the same as other waterborne enteric viruses, more study is necessary for the successful recovery of the virus from wastewater. Different test trials may give rise to several contradictory results when the concentration of the virus is low in a given wastewater sample.⁴³

7.4.7 Waterborne viral outbreaks related to virus

The range of human deaths per year lies between 2 and 12 million, with waterborne viruses being the cause. Drinking water from wells has caused the majority of waterborne outbreaks. In natural water bodies, recreational water has been known to cause significant outbreaks. In general, an association of viruses with waterborne diseases is overlooked and it is often difficult to identify the agents. In the United States, the cause for more than half of the outbreaks in recreational and drinking water was associated with noroviruses. Since 1980, the CDC also reported outbreaks due to hepatitis A virus. Adenoviruses caused an outbreak in 1982 and a couple more in 1991. All were linked to recreational water and often led to associated diseases such as pharyngitis.

Three outbreaks occurred in 1982, 1990, and 2006, and these were caused by enteroviruses which were etiological agents. Tap water caused an outbreak in Colorado, and rotaviruses were the causative organisms. Hepatitis E outbreaks also pose a severe threat. Swine is a reservoir of hepatitis E and is transmitted to humans.⁴⁴

7.4.8 Transport of virus in the environment

Surface accumulation of virus enables the transfer of virus into the environment. The transport viruses in the environment depend upon factors such as⁴⁵

- pH
- Ionic strength
- Competitors for binding site
- Isoelectric point (IP)
- Hydrophobicity of sorbent

It is noted that clay possesses higher virus surface accumulation capacity, and cation concentration is directly proportional to virus sorption. Organic matter is known to upgrade the transfer of viruses. The positive charge is exhibited by viruses when pH is lesser than IP, and negative charge when pH is more remarkable than IP. IP has been termed to be the dominant controller of virus absorption during transport. Negatively charged surfaces, less than their IP, tend to absorb viruses. Viruses were resistant to water treatment when IP was low.⁴⁶

7.4.9 Survival of virus in the environment

There are many factors influencing the survival of viruses in the environment.⁴⁷

The key factors are as follows:

- (1) Soil (granule size and dispersion, content in clay)
- (2) Carbon
- (3) Chemistry behind solution
- (4) Oxides of metals
- (5) pH
- (6) Ionic strength
- (7) Air-water interface
- (8) Biological factors

The most important factors are

- (1) Temperature
- (2) UV rays
- (3) Flora of microorganisms

In seawater, polio and adenovirus survive at 15°C for long periods of time. Enteroviruses survive for many weeks in freshwater. Viruses are inactivated by exposure to sunlight or UV.⁴⁷

7.4.10 Microbial tracking tools (viruses)

Microbial source tracking enables us to differentiate between possible sources of contamination due to feces in the environment. Many microorganisms have the potential to be tools for tracking.

Viruses that are potential microbial tracking tools:⁴⁸

- (1) Human polyomavirus (HPvV)
- (2) Human adenovirus (HAdV)
- (3) Human enterovirus (HEV)
- (4) Porcine adenovirus (PAdV)

PAdV is highly human-specific and is a reliable tool. They help to detect contamination in river water samples, slaughterhouse slurries, and urban sewage.⁴⁹ HAdV and HEV are pollution detectors.⁵⁰ To identify sources of water pollution in agriculture, bovine-adenovirus and bovine-enterovirus are useful. Bovine polyomavirus is good when manure is the source of contamination. In freshwater bodies, the contamination of human and animal viruses is relatively low. A concentration procedure is done to filter water in huge amounts while sampling.⁵¹

7.5 Measures to the protection of personnel and wastewater treatment workers from contracting COVID-19

In response to the growing spread of COVID-19, WHO has released a variety of detailed technical guidance documents on specific topics that include infection prevention and control (IPC). The usual method of virus transmission is through respiratory droplets and the immediate environment of an infected individual (i.e., transmission through contact). Even though the risk of being affected by the COVID-19 infection from the feces of diseased individuals has all the earmarks of being negligible. Proof states that COVID-19 infection prompts bowel diseases and its presence is proven in feces. Until today, only one investigation has refined the COVID-19 infection from a single sample of stool. No case of fecal-oral transmission of the COVID-19 infection has been confirmed.¹ The management aspects have been discussed in subsequent sections.

7.5.1 Safe management of fecal waste and wastewater

At present, no case of SARS-CoV-2 transmissions through sewerage systems has been reported in both treated and untreated wastewater. In addition, there is no evidence that sewage treatment workers have developed SARS-CoV-1 (similar to SARS-CoV-2), which was caused by an acute respiratory disease outbreak in 2003. In properly managed and designed wastewater treatment plants, wastewater in sewerage systems should be handled as part of an integrated public health strategy. Hand hygiene should be done frequently, along with other exterior infection routes such as hair, nose, eyes and mouth should be protected from unwashed hands. Workers have to wear suitable personal protective equipment (PPE), which includes gloves, goggles or a face shield, and a mask.¹

7.5.2 Personal Protection Equipment (PPE)

All workers likely to have exposure to sewage and biosolids should be supplied with appropriate PPE. The PPE options include gloves, goggles, respirators, face masks that are splash-proof, and liquid-repellent coveralls (Fig. 7.4). In works associated with exposure to sprays and pressured leakage, face shields should be provided. Management and worker representatives must work together to determine which jobs are likely to result from such disclosure, to have sufficient on-site inspections, and to determine the form of PPE that is appropriate in unification with a qualified health and safety profession. A comprehensive program includes respiratory analysis and training.

The goal of PPE is to decrease workers’ exposure to hazardous substances when engineering and administrative controls are not feasible or successful in decreasing those risks to acceptable levels. PPE is required when hazards are present in the near vicinity or in direct contact. PPE does have the significant disadvantage that it does not eliminate the hazard on the spot and that workers can be exposed to the hazard if the equipment fails.⁵²

PPE acts as a barrier among the wearer/user as well as the work environment. It can impose unnecessary pressures on the user, hinder his capacity to carry out his work, and cause substantial amounts of stress. This would prohibit users from using PPE appropriately, placing them at risk of

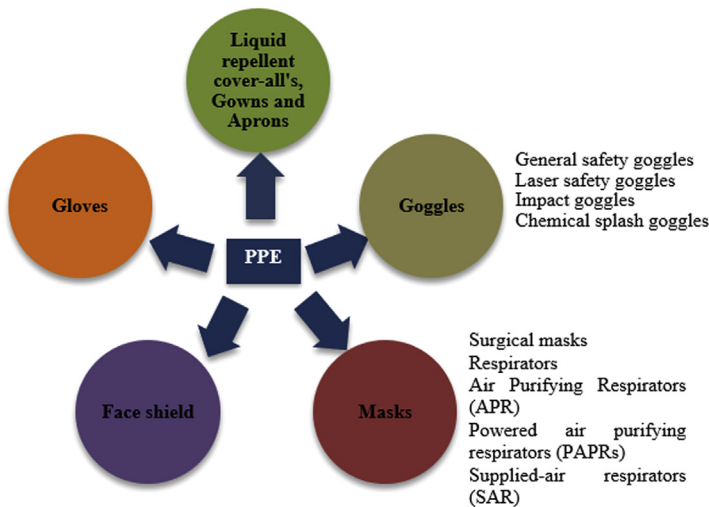


Figure 7.4 Personal protection equipment.⁵⁵

injury, ill-health, or death. Effective ergonomic strategies might support eliminate these obstacles and can also help ensure safe and healthy working environments by using PPE correctly.⁵³

Work-related safety and health practices, which practice exposure controls and involvements to mitigate hazards in the workplace that pose a threat to workers' safety and quality of life.⁵⁴ The hazard management pyramid offers a policy structure that ranks the kinds of hazard controls in terms of absolute risk mitigation. Elimination and substitution are at the top of the hierarchy, which entirely eliminates and replaces the hazards with a safer alternative. If either of the elimination or substitution steps is not suitable to be enforced, engineering controls and administrative controls would be introduced to create secure systems and guide human behavior. PPE ranks last on the control ladder since the sewage workers, with a protective barrier, are frequently exposed to the hazard. The control pyramid/hierarchy is crucial in recognizing that while PPE has considerable utility, it is not the ideal control for workers' health.⁵⁵

PPE can be categorized into four divisions on the basis of the measure of protection being afforded as given in the following sections.⁵⁵

7.5.2.1 Level A protection

This category is preferred for the maximum degree of skin, eye, respiratory, and mucous membrane protection. A standard level A comprises chemical-resistant gloves, boots, and self-contained respiratory equipment.⁵⁵

7.5.2.2 Level B protection

This category is preferred for the maximum degree of respiratory protection, but a lower level of the skin and an eye shield is required. It is also suggested for initial site entries until the hazards have been recognized and established by inspection. It includes chemical-resistant clothing (coveralls), gloves, boots, and a self-contained breathing apparatus.⁵⁵

7.5.2.3 Level C protection

This category is preferred when the exposure of the skin and eyes is unlikely, with the information on the type of airborne material, level of concentration, and basic requirements of an air-purifying respirator. Air must be tracked regularly. A standard level C comprises chemically resistant clothes, gloves, boots, and an air-purifying respirator.⁵⁵

7.5.2.4 Level D protection

This category is preferred as a standard uniform for sewage workers, where respiratory and skin hazards exist. This category comprises coveralls and safety shoes.⁵⁵ The workers who are managing and handling human waste/sewage have to be provided with PPE, instruction on the method of usage of PPE, and facilities for handwashing. Workers must immediately rinse their hands using soap and wash with water as soon as they remove their PPE. For employees treating sewage, the following PPE is recommended.⁵⁶

7.5.2.5 Goggles

Goggles are used to protect eyes from splashes of human waste or sewage. It has transparent glasses, with zero power, well-fitting, and protected on all sides with adjustable holders. Characteristics include:⁵⁶

- Decent seal on the face
- Elastic frame that fits all sizes with little to no pressure
- Mist and abrasion resilient
- Designed with indirect venting so as to prevent or lessen fogging
- Might be reusable (if there are apt arrangements for on-spot) or single-use goggles

There are many types of goggles, such as⁵⁶

- (1) **General safety goggles:** Where it protects the eyes from splashes from fluids, like buffers and salts, which are not likely to affect the eye.
- (2) **Laser safety goggles:** Where it effectively filters all light entering the eyes and its embedded with protective abilities.
- (3) **Impact goggles:** Provide cover from flying debris and have openings on the sides for airflow.
- (4) **Chemical splash goggles:** This is the ideal type of goggles for the sewage workers since it protects the eyes from the spray of chemicals or hazardous substances that may enter the eyes and can protect them from flying debris.

Typically, goggles and safety glasses are made using an injection-molding process, which injects a polymer material into a metal mold manufactured to replicate the desired shape of the lenses and frames. Usually, a composite material known as polycarbonate is used for making goggles or glasses. Polycarbonate is a thermoplastic polymer with good optical consistency and twice the impact strength of other comparable plastic materials, making it an easy alternative for protective eyewear. It is known for its impact strength and optical clarity, which also enables the material to be used to create face shields. Prolonged utilization of goggles might maximize worker's discomfort, exhaustion, and skin tissue damage.⁵⁶

Used goggles can be reprocessed and recycled by washing them with water and detergent accompanying sterilization with either 0.1% sodium hypochlorite (accompanied by water rinsing) or wiping with 70% alcohol. Goggles are cleaned on a presterilized surface. Suitable disinfectant with the right time of contact (e.g., 10 min while utilization of 0.1% sodium hypochlorite) should be adhered to prior to goggle reuse. They have to be stored in a clean area after cleaning and disinfection to avoid recontamination.⁵⁶ There are companies such as CleanRiver Recycling Solutions, Kimberly-Clark Professional, and many other recycling programs that aid in recycling such PPEs. Further, the global standardization of PPE has been provided in EU PPE Regulation 2016/425 Category III, EN 166, ANSI/ISEA Z87.1.⁵⁶

7.5.3 Masks

Masks are used to protect the workers from contracting respiratory disease-causing microorganisms. There are many types of masks, such as⁵⁷

7.5.3.1 Surgical masks

Used to cover around the mouth and nose and can protect from droplets, splashes, and sprays. Studies confirm that using such a mask alone is not always practical, but it is safer because enduring use and reuse can lead to auto-contamination.⁵⁹

7.5.3.2 Respirators

N95 and variants of FFP2/3 come under respirators. The airborne contaminants are filtered through the fibers that are tangled in the mask. The boundaries around the mouth and nose form a barrier. Such masks should not be used by the general public because they are in limited supply. They should be used only by health care workers. Some of the types of respirators include:⁵⁸

7.5.3.3 Air-purifying respirators (APR)

Through cartridges and filters, air-purifying respirators (APR) scrub pollutants from the ambient air. This form is commercially available in either half-mask or full-face versions with a replaceable one-time use of cartridges and filters or as half-mask face filtering pieces typically intended for one-time use. If APRs are determined by the hazard assessment to provide adequate protection, choosing the correct cartridge and/or filter type should be followed. For safety against airborne hazardous substances and particulates, several cartridges and filter options are to be provided.⁵⁸

7.5.3.4 Powered air-purifying respirators (PAPRs)

Operates using a motor that blows filtered air into the face-piece. This is a safety stage between ordinary APRs and airborne respirators.⁵⁸

7.5.3.5 Supplied-air respirators (SAR)

SAR provides workers with safe breathing air and must be used when workers are in oxygen-deficient atmospheres. There are three basic types available, with breathable air supplied from a cylinder bank, personal (worn) bottle, or a combination of both. Typical SAR industrial use is that workers utilize respirators connected to long lengths of air hose.⁵⁸

Masks consist of several sheets of materials, and it is formed using the process called meltdown, and the fabric that has a range of thickness from 100 to 1000 μm is prepared from microfibers of polypropylene. Fibers from such a meltdown process can be crossed one over another to form a porous three-dimensional (3D) assembly with a permeability of approximately 90%. Such fabrics also have a relatively low pressure drop and can accommodate a considerable amount of particulate matter. Consequently, meltdown fibers are typically charged electrostatically to enhance the particle interaction, causing much greater efficiency in filtration.⁵⁸

Face masks are usually suitable for single-purpose use and are not to be utilized when the inner side gets wet or moist. Usually, the masks are rarely sterilized for reuse. There has been an assessment of the possibility of decontaminating and reusing masks, with early tests showing potential for both steam and UV sterilization. These results, however, are not yet peer-reviewed or published and cannot be applied widely. The repeated steam application resulted in deterioration of filtering efficiency, and the fabric was damaged by alcohol and chlorine-based solutions. While reusing the respirators, the used respirators should be dried for three to four days. The hydrophobic nature of polypropylene present in N95 makes the environment of the mask unsuitable for the survival of the virus, which can usually survive even on thoroughly dried respirators (drying time, 3–4 h). Another method is to disinfect the respirator by overhanging it, in an oven, for 30 min at 70°C. Respirators are degraded by UV light so it should be kept away from UV and direct sunlight.⁵⁹

Some of the global standardizations provided for masks and respirators include (1) surgical masks—EU PPE Regulation 2016/425 Category III, FDA Class 2, EN 14683 Type II, IIR, ASTM F2100 minimum level 1; (2) N95—EU PPE Regulation 2016/425 Category III, FDA Class 2, Minimum “N95” respirator under NIOSH 42 CFR 84, minimum “FFP2” according to EN 149, or demonstrate an equivalent set of standards.⁵⁶

7.5.4 Gloves

Gloves help in preventing direct contact of sewage with sanitation workers. An ideal glove for a sewage worker should be chemical and liquid-resistant and should also have high tensile strength and low reactivity. Various types of gloves are depicted in Fig. 7.5.⁶⁰

Chemical-resistant gloves, which are ideal for sewage workers, are produced from variants of different types of rubber such as neoprene, nitrile, butyl, and fluorocarbon; or variants of plastic such as polyvinyl chloride (PVC), polyvinyl alcohol, and polyethylene. Such components are layered to give rise to the best of their nature. The thicker the gloves are made, the more they are resistant to chemicals, but it comes with a drawback of lack of mobility while using the gloves.⁶⁰

Reprocessing of gloves is possible in nitrile gloves, which were experimented upon. Nitrile inspection gloves from a single new box were used. Gloves were worn, and a coin toss was used to determine whether a 15 s hand wash with nonantibacterial soap followed by drying with a paper towel or applying a hand sanitizer based on alcohol. Handwashing and application of hand sanitizers are made as prescribed by the CDC. Gloves were labeled at wrist level using a marker. Per FDA guidelines, a 1 L water test was used to assess glove integrity. Gloves were connected to a two-inch PVC pipe that was suspended and gradually applied 1 L of normal water followed by an observed period of 2 min to check the leaks and are classified at different levels as follows: 1 (water trickle), 2 (small jet), and 3 (rivaling Niagara falls). A control group of 10 gloves was also tested to assess baseline leak rates, taken directly from the box without a hand hygiene method. The same Fisher test was used to compare the levels of leakage

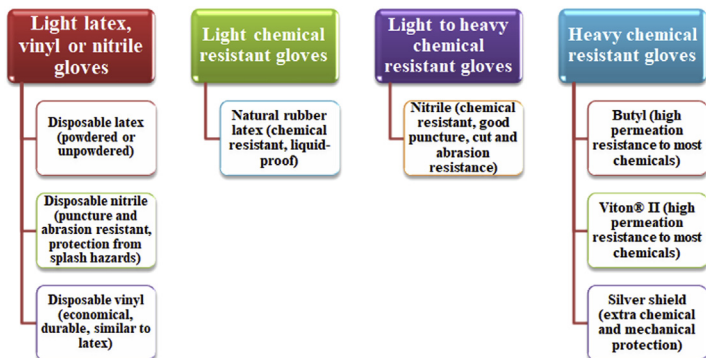


Figure 7.5 Various types of gloves.⁶⁰

between classes. Unfortunately, the recent study found that the procurement of sterile disposable single-use gloves is cheaper than the recycling process.⁶⁰ Some of the global standards for gloves include FDA Class 1, EN 455, ASTM D3577.⁵⁶

7.5.5 Face shields

Face shields are used to protect the nose and mouth from hazardous or infectious fluid splashes and human waste or sewage. Face shields of good quality thermoplastics can be made to withstand heat, impact, chemicals, or other hazards.⁶¹ Polycarbonate and polyester (PET) film are two common plastic materials used in the development of surgical face shields. Both materials are transparent and provide high optical clarity. Polycarbonate and PET are both lightweight and can be quickly processed into almost any shape, so manufacturers can design masks and shields to meet the needs of even the most complex applications. Extended use of face shields may increase discomfort, fatigue, and skin tissue damage may occur to the face. Used face shields can be reprocessed and recycled by soap/detergent and washing with water accompanied by disinfection using either 0.1% sodium hypochlorite or 70% alcohol wipes. Face shields may be cleaned immediately after use or placed in designated closed containers for later cleaning and disinfection of the surface prior to shield cleaning. Appropriate disinfectant contact time (e.g., 10 min when using 0.1% sodium hypochlorite) should be adhered to prior to shield reuse.⁵⁶ Some of the global standardizations provided for face shields include EU PPE Regulation 2016/425, EN 166, ANSI/ISEA Z87.1.⁵⁶

7.5.6 Liquid-repellent coveralls, gowns, and aprons

Coverall's provide overall protection of the user from any infectious agents and reduce the risk of contracting the disease, especially in workplaces like health care centers, sanitary operation, and wastewater treatment facilities. It is made of fluid-resistant material and includes gowns and aprons. Coverall's are made of fabric, i.e., 100% polyester with PVC or other fluid-resistant coated material. It must be waterproof such that sewage or other debris does not stick to the material. Fabrics guard the user against wounds and cuts from sharp, heavy, or rough materials (if present in sewage). It can be reused if apt provisions are provided for sanitization is in place. But most of the time, the coveralls are disposable and can be for single use only. Reprocessing can be done for cotton gowns and machine washed with

warm water of temperature ranges between 60 and 90°C accompanied by laundry detergent. Linen material is stirred with a stick in a huge drum in the presence of soap and hot water. Alternatively, linen is also soaked in 0.05% chlorine for about 30 min. Finally, it is rinsed with water and allowed for drying under sunlight. WHO prefers gowns to aprons for both nonaerosol-generating procedures (non-AGPs) and AGPs during all instances. For AGPs, the guidance suggests clean, long-sleeved, nonfluid resistant gowns and gloves.⁶² Some of the global standardizations provided for coveralls include EN ISO 13688, EN 14126-B and partial protection (EN 13034 or EN 14605), EN 343 for water and breathability or equivalent.⁵⁶

7.6 Recycling of PPE

The commercial recycling process involves the following steps.⁶³

- (1) Sample to be tested from used PPE is directed to recycling plants. Not all PPE can bear the cycle of laundry or dry-cleaning, so care must be taken to ensure the details on the fibers after cleaning. It can lead to shrinkage, but these findings vary from producer to producer.
- (2) Collection bins are located on-site where previously “disposable” PPE are housed.
- (3) Bins are delivered to the recycling plant at assigned intervals.
- (4) Documentation confirms bin receipt and the contents.
- (5) Recycling of PPE.
- (6) Undesirable PPE is parted from a functional batch.
- (7) Before sorting, each PPE is individually scanned for metal traces.
- (8) Sorting of PPE is done based on size.
- (9) For a new life lease, PPE is returned to the property.
- (10) Cleaned PPE is free from contamination or disposed of if it cannot be reprocessed and recovered any more.

7.7 Training for workers

Workers who are handling sewage have to receive drills and training on procedures to prevent contracting diseases due to occupational negligence. The drill will provide knowledge on rudimentary hygienic practices, PPE usage, its disposal, and safe management of sewage. Workers should be qualified to report diseases or symptoms to the appropriate supervisory or health care personnel. This may help in the early diagnosis of health hazards

related to the work. Proper training should be given for the sanitation and sewage workers according to the guidelines provided by WHO or other NGOs responsible for international public health. Some of the basic guidelines to be followed by the sanitation and sewage workers include⁶⁴

- Usual handwashing with soap/detergent with water after handling sewage, especially before eating, drinking, and both before and after using the toilet.
- When handling sewage, avoid touching the nose, mouth, and face.
- Contaminated clothing has to be removed before eating.
- Workers are not allowed to chew gum or tobacco during sanitation works.
- Cuts and wounds (if any) have to be covered using clean and dry bandages.
- Water and chemical-resistant gloves are to be used to prevent contact with the sewage.
- Soiled clothing is to be cleaned daily using 0.05% of chlorine solution.

7.8 Vaccination recommendation for workers

Vaccination guidelines for staff exposed to sewage or human waste should be well established in collaboration with the authorities of local health. Tetanus vaccines must be up-to-date, even taking into account the need for vaccines against measles, typhoid, and hepatitis A and B. The potential hazards to employees are likely to vary from one location to another, and a qualified health and safety specialist has to check to develop on-spot health and safety plans for the workforce.⁶⁴

7.9 Conclusion

Characterization and mitigation of any identified SARS-CoV-2 transmission risks through waterborne pathways necessitates addressing the subsequent knowledge gaps. Currently, exploration of molecular approaches for finding SARS-CoV-2 in wastewater is predominantly focused on quantifying the viral RNA; however, quantification of fully functional infectious virions is yet to be resolved. Thus, the emergence of innovative tools perhaps provides adequate scientific evidence in environmental monitoring for policymakers, whereas mitigation of wastewater-associated SARS-CoV-2 transmission could be achieved via optimized disinfection strategies. Based on the existing evidence, PPE usage decreases the disease transmission rates as well as

protects the workers. It is noteworthy that the workers understand the function and role of PPE as a part of the disease transmission management program and its appropriate usage to ensure its adequate supply during the epidemic surge.

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