REVIEW ARTICLE
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The One Health concept for the threat of severe acute respiratory syndrome coronavirus-2 to marine ecosystems

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Abstract

Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) is a global health threat. This virus is the causative agent for coronavirus disease 2019 (COVID-19). Pandemic prevention is best addressed through an integrated One Health (OH) approach. Understanding zoonotic pathogen fatality and spillover from wildlife to humans are effective for controlling and preventing zoonotic outbreaks. The OH concept depends on the interface of humans, animals, and their environment. Collaboration among veterinary medicine, public health workers and clinicians, and veterinary public health is necessary for rapid response to emerging zoonotic pathogens. SARS-CoV-2 affects aquatic environments, primarily through untreated sewage. Patients with COVID-19 discharge the virus in urine and feces into residential wastewater. Thus, marine organisms may be infected with SARS-CoV-2 by the subsequent discharge of partially treated or untreated wastewater to marine waters. Viral loads can be monitored in sewage and surface waters. Furthermore, shellfish are vulnerable to SARS-CoV-2 infection. Filter-feeding organisms might be monitored to protect consumers. Finally, the stability of SARS-CoV-2 to various environmental factors aids in viral studies. This article highlights the presence and survival of SARS-CoV-2 in the marine environment and its potential to enter marine ecosystems through wastewater. Furthermore, the OH approach is discussed for improving readiness for successive outbreaks. This review analyzes information from public health and epidemiological monitoring tools to control COVID-19 transmission.

Keywords: coronavirus disease 2019, marine environment, One Health, sewage, shellfish, zoonosis.

Introduction

The One Health (OH) approach, as identified by the World Health Organization (WHO), is not new. However, it has recently become more important [1]. The approach recognizes that the health and well-being of animals, humans, and the environment are intricately linked [2]. All three play an essential role in the emergence of various diseases, and the majority of human infectious diseases have animal origins [3]. The interaction between animal health and public health has been recognized by the "One Medicine" concept, which is an intersection of human health and veterinary science [4].

The quality of marine environments is essential for maintaining public health [3]. Marine pollution poses severe threats to marine animals and human health [5]. Moreover, marine systems are often contaminated by human excreta, agricultural activities, household garbage, and wild animals. Contamination in the marine environment may negatively affect marine ecosystems through pathogenic microbes and chemical substances [1,5,6].

Marine ecosystems are often affected by microbiological pollution when sewage from human and animal origin is discharged into the sea. Pollutants carried by untreated wastewater to the marine ecosystem reach fish food chains [6]. Marine organisms can thus be a source of pathogenic microorganisms for terrestrial and aquatic animals and humans [7]. Further, bacteria and viruses from animals and humans can affect seawater quality and accumulate in shellfish [5,8].

Coronavirus disease 2019 (COVID-19) is caused by sever acute respiratory syndrome coronavirus 2 (SARS-CoV-2) [9,10]. The WHO declared (SARS-CoV-2) as a medical and public health emergency [11]. In December 2019, COVID-19 began in Wuhan, China [12,13]. The surge in this disease in Asia and Europe led the WHO to declare the outbreak as a pandemic in March 2020 [14].

SARS-CoV-2 permeates the environment, especially aquatic and marine habitats and wild animals [15]. An increased concern developed concerning the occurrence of coronaviruses in the aquatic environment during the outbreak of COVID-19. Globally, increased awareness of the risk of coronaviruses from sewage arose following the discovery of SARS-CoV-2 in sewage in several countries [16]. This finding was an early sign of a community outbreak of COVID-19 [17].

The spread of coronaviruses within the environment is an increasing challenge to public health [18].

Filter-feeding organisms accumulate and transmit these microbes to humans [18], thus playing an important role in fecal-oral transmission [19]. Coronaviruses are detected in marine mammals, and the survival of coronaviruses in aquatic environments depends on water temperature, organic matter, and light intensity [7].

The OH concept will help address COVID-19, which is thought to have originated from animals, and then transmitted to humans. Further, waterborne transmission of SARS-CoV-2 is recognized. Many authors report coronaviruses in sewage treatment plants, and wastewater is an important means of virus transmission. Further, filter-feeding shellfish can be used as markers for seawater quality. To date, only limited studies of SARS-COV-2 in wastewater and aquatic waters are available. This review identifies the best OH actions to control the incidence and outbreak of COVID-19. In addition, the review gathers current knowledge of SARS-CoV-2 in marine systems as receiving waters for treated and untreated sewage and its effects on aquatic animals.

SARS-CoV-2

SARS-CoV-2 is the causative agent for the ongoing COVID-19 pandemic first identified in a Wuhan seafood market in China in late 2019. The virus is 50-200 nanometers in diameter and characterized by club-shaped projections on its surface. It is a positive-sense, single-stranded RNA virus with four structural proteins. SARS-CoV-2 is categorized in the genus Betacoronavirus of the viral family, Coronaviridae [20].

No Betacoronaviruses were isolated from marine mammals based on the literature review. In contrast, Alphacoronaviruses and Gammacoronaviruses are reported in these animals [21,22]. SARS-CoV-2 might be shed for lengthy periods in feces of COVID-19 patients, [23-27]. Hence, SARS-CoV-2 is detected in wastewater management facilities [28] and could be introduced to aquatic habitats through sewage outfalls.

Zoonoses and the OH concept

Many authors have embraced the “One Health” concept [3]. In 1984, the international organizations and scholarly bodies adopted this approach [29]. The OH approach integrates direct impacts of environmental epidemiology on animal and human health. Human, animal, and ecological health are thus inextricably interdependent [4,30]. The concept encourages collaboration among physicians, veterinarians, wildlife biologists, ecologists, agriculturists, biomedical engineers, and epidemiologists to comprehensively improve health [3].

Humans, animals, and the environment are significant in the emergence and spread of various diseases. Infectious diseases in humans often emerge in foods of animal origin [3,31]. Zoonoses are diseases caused by many pathogens, such as viruses, bacteria, fungi, and parasites, that are naturally transmissible between non-human vertebrates and humans [32,33]. Zoonoses currently make up approximately 60% of the roughly 1350 infectious diseases known to affect humans [33,34]. Vectors transmit almost 20% of these illnesses [35]. Zoonotic diseases lead to millions of death annually [36]. Further, zoonotic pathogens spread broadly across national and continental boundaries, as is reflected in the global transmission of SARS-CoV-2 [33]. Wild animals are often vectors for the movement of zoonotic pathogens to peridomestic, then livestock animals, and, finally, indirectly to humans (Figure-1). Therefore, OH is vital for controlling zoonotic diseases [29].

Importance of the OH approach for COVID-19

The outbreak of COVID 19 is an ideal case for analyzing how the OH approach can be used for zoonotic diseases [37]. SARS-CoV-2 was reported in cats, lions, and tigers in a zoo. The virus may also be transmitted from humans to domestic cats [30]. Thus, OH can be used to investigate the role of wild animals in the epidemiology of coronaviruses [38]. The OH approach is particularly relevant because it includes the control of zoonoses that spread between humans and animals and incorporates food safety and combating antibiotic resistance [34,37]. OH concepts that use disease surveillance and eradication through collaboration between veterinarians that address wild animal and livestock populations, public health experts, and ecologists may yield a more rapid resolution to outbreaks [29]. Collaboration between human medicine and veterinary medicine might enhance public health outcomes (Figure-2). Further, global zoonotic disease prevention through increased vaccination and increased use of technology may improve animal living conditions [34]. Nevertheless, the OH approach remains challenging for most nations [2].

Marine viral pathogens and human health

Waterborne microbes, such as bacteria, viruses, and parasites, can be transmitted to humans through exposure to marine waters or the consumption of contaminated seafood [39]. Coastal habitats and marine microbes are considered reservoirs for newly emergent pathogens [40]. Viruses are the most abundant microbes in seawater and are found in concentrations of about 10-fold greater than prokaryotic organisms [41]. Viruses are abundant in surface water and sub-surface sediments [41]. Further, viruses in the marine environment are more persistent than *Escherichia coli* [42]. The ability of viruses to survive in the marine environment and their transport from sources to shellfish habitats or marine beaches are reported. Overall, viral pathogens are believed to cause most waterborne marine diseases [43].

Human stools contain various viral pathogens that enter marine ecosystems by discharging wastes from infected individuals [42]. Many viruses are

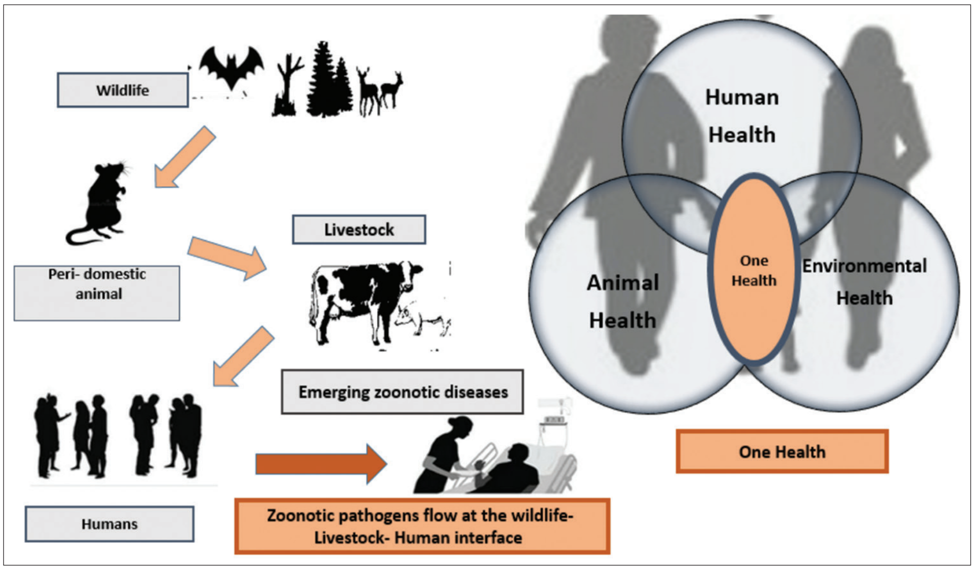

Figure-1: Emerging zoonotic diseases. (The figure was generated using Microsoft PowerPoint and Adobe Illustrators by KKB).

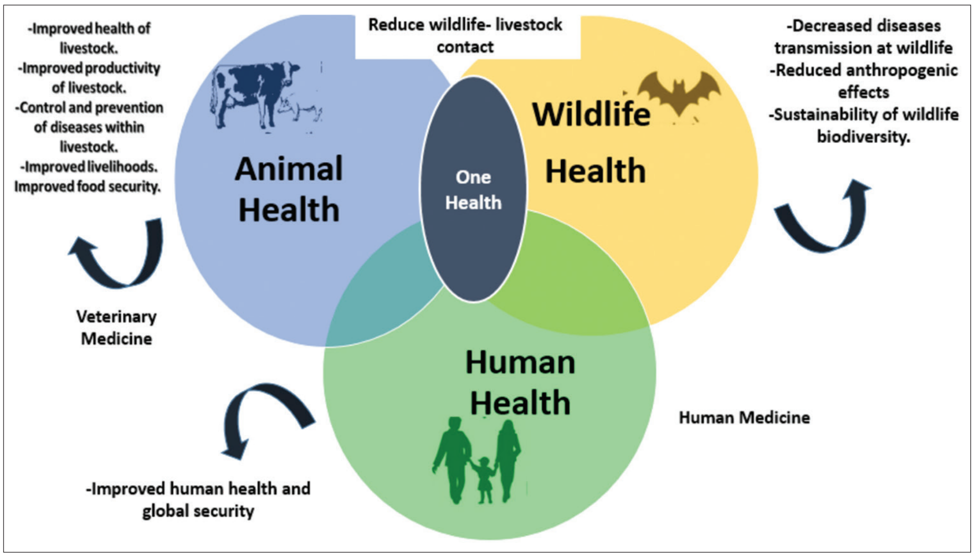

Figure-2: One Health concept to address emerging zoonotic diseases. (The figure was generated using Microsoft PowerPoint and Adobe Illustrators by KKB).

transmitted through the fecal-oral route [44]. Viral pathogens in the marine environment are known threats to public health, including enterovirus, adenovirus, astrovirus, reovirus, rotavirus, calicivirus, and *Norovirus*. Infections by viruses in the latter genus represent 21% of enteric viral illnesses [5] and are responsible for many notifiable diseases in humans due to ingesting contaminated water or seafood [45]. Coronaviruses are enteric viruses and are associated with gastroenteritis in humans [46].

Several viruses in aquatic environments pose significant public health threats. Viruses in sewage may contaminate drinking water, recreational waters, and shellfish that threaten public health [43]. These pathogens cause many illnesses, such as gastroenteritis, hepatitis, fever, meningitis, and conjunctivitis [47]. In addition, respiratory and enteric diseases are associated with consuming contaminated seafood [39]. Accumulation of viruses in shellfish increases during periods of low water temperature, and a higher incidence of human viral gastroenteritis occurs through shellfish consumption during these periods [43].

Decay rates of viable coronaviruses in the aquatic environment

A Sala-Comorera *et al.* [48] first published an analysis of the viability of SARS- CoV-2 in the aquatic environment. Viruses remained viable and infectious in marine water for just 1-2 days depending on water temperature. Infectivity coronavirus decreased rapidly in seawater and rivers, especially at high water temperatures. Marine and river water contaminated with fecal matter from COVID-19 infected patients is unlikely to show high levels of infectious coronaviruses due to rapid inactivation [48]. In natural waters, environmental factors, such as UV light, organic matter, and other microorganisms, would also alter decay rates of viable coronavirus [49]. Still, the behavior of SARS-CoV-2 in the gastrointestinal tract of humans is some evidence for fecal-oral transmission [26,50]. SARS-CoV-1 may also be transmitted in this fashion [51]. Wong *et al.* [52] suggested that coronavirus can actively replicate in the gastrointestinal tract of infected individuals.

Presence of SARS-CoV-2 on the toilet

Coronaviruses are usually spread by respiratory and fecal aerosols [53]. The spread of viruses in sewage is also through solid waste or aerosols from toilets. Such findings confirm fecal-oral transmission [54]. Toilets pose a particular risk for SARS-CoV-2 transmission due to aerosolization of feces and urine of infected individuals [55]. Coronaviruses are detected in feces and urine [56], suggesting a risk of aerosol transmission from flushing toilets [57].

Fever, cough, rhinorrhea, dyspnea, muscle ache, lethargy, neurological manifestation, or diarrhea are recognized symptoms of COVID-19. However, SARS-CoV-2 is detected in the stools of patients who do not suffer gastrointestinal tract upset [56]. Overall, toilets in hospitals are the most contaminated areas and the primary source of infection [11]. A toilet may be shared by patients of hospitals in large isolation rooms. Therefore, personal spaces overlap with toilet area contamination and generate an additive effect [53]. Two hospitals in Wuhan, China, showed high coronavirus concentrations in toilets but low concentrations in isolation wards and aerosols in ventilated patient rooms [58]. Moreover, aerosols in hospital toilets contain the most detected coronavirus [53].

Stools of patients be positive for coronavirus for many weeks, even if the respiratory tract is negative [56]. Thus, surfaces, such as over-bed tables, nurse call buttons, and bed rails should be cleaned at least twice daily [59]. Conversely, stools from toilets are discharged into sewer networks and undergo dilution. Viral pathogens in stools may be transformed within sewerage systems. The coronavirus may survive for several hours in feces and several days in urine [54]. Nevertheless, detecting SARS-CoV-2 in sewage is considered an early signal of outbreak [54].

Fate of SARS-CoV-2 in the urban water cycle (UWC)

Human viruses are excreted in urine, feces, and other body fluids [60]. The persistence of coronaviruses in these wastes in sewage is a health and environmental issue [17]. As mentioned, coronavirus enters water systems through individuals infected with COVID-19. Traces in sewage are associated with the discharge of urine or feces from such individuals [61]. Overall, SARS-CoV-2 is reported in wastewater and effluents [61].

The UWC is spatiotemporal interaction among hydrological processes [61]. The cycle consists of wastewater treatment plants (WWTPs), stormwater runoff management, and a drinking water distribution system [60]. SARS-CoV-2 has been assessed in wastewater samples from many nations, such as France, India, Italy, Australia, Netherlands, Japan, Turkey, Spain, the USA, the UAE, and other countries [62-66]. In Australia, coronavirus was found in 22% of sewage samples with viral concentrations as low as 1.2×10^2 copies/L [61]. The presence of SARS-CoV-2 in sewage suggests the presence of a viable virus [67].

Fate of SARS-CoV-2 coronavirus in wastewater

Coronaviruses in aquatic environments are due to untreated and treated sewage [60]. Release of treated, partially treated, and untreated sewage into aquatic systems is common. Discharges in developing countries to receiving waters are comprised of up to 80% partially treated wastewater [14]. The volume of sewage discharged from urban cities of India was 61.754 million liters per day [14]. Moreover, several Mediterranean countries dump wastewater into coastal waters without treatment, and this practice has a substantial negative impact on the aquatic flora and fauna of the Mediterranean Sea [68]. The highest concentration of viral particles is in raw wastewater, while the lowest concentration is in secondary and tertiary treated wastewater [60].

The concentration of coronavirus in feces is typically 10^2-10^8 copies per gram of stool [13]. SARS-CoV-2 persisted in stool for 3 days and in urine for 17 days [17]. Overall, coronavirus showed maximum presence in the stool of infected individuals for up to 14 days after the onset of the illness [17]. A high concentration of virus was found in the feces of hospitalized individuals with COVID-19. Furthermore, the virus can be isolated from the lungs of patients but not from feces [11]. SARS-CoV-2 in the stool of infected individuals was observed on the 5th day after the onset of symptoms, and traces of virus were still present after 30 days [60]. Virus shedding was seen in the stools of infected individuals from day 1 to 33 after a negative nasopharyngeal swab [66]. In China, the presence of coronavirus in stools was observed before the onset of symptoms [69].

Detection of SARS-CoV-2 is confirmed in municipal sewage of several countries worldwide [9,14,70-72]. In Italy, SARS-CoV-2 was found in river samples, and in Turkey was seen in primary and activated waste sludges from seven WWTPs [17,60]. Coronavirus was not detected in China in raw sewage but was reported in treated sewage of Wuchang Fangcang hospital. These reports highlight low efficacy of disinfection for WWTPs in this hospital [16]. Furthermore, no coronavirus was found in wastewater samples from Spanish WWTPs [60]. In France, high concentrations of SARS-CoV-2 were found in sewage during the spring season, and low concentrations were observed during the summer season [18,73].

Wastewaters typically undergo three treatment stages in WWTPs: Primary, secondary, and tertiary [74]. In the United States, Sherchan *et al.* [66] observed that wastewater samples did not produce positive results for SARS- CoV-2 after secondary and tertiary treatment, indicating that these processes can remove the virus [17]. The current development of new treatments for COVID-19 patients may increase viral incidence in wastewater treatment facilities, which might increase the risk for aquatic organisms. The lack of a standardized protocol for detecting coronavirus in sewage is considered a significant challenge [17].

Fate of SARS-CoV-2 in the marine environment

In some countries, wastewater is discharged into shallow coastal waters [75]. Such discharges represent the threat of viable pathogens to wild marine ecosystems [74]. SARS-CoV-2 may be introduced to the marine environment through contact with infected swimmers or wastewater outfalls [76]. Moreover, marine contamination may enhance the zoonotic transmission of coronavirus to marine mammals [77]. Further, COVID-19 has adverse direct and indirect impacts on marine ecosystems (Figure-3). The virus may be viable and infective for many days and weeks in wastewater and the aquatic environment [13]. Still, after introduction to the environment, coronaviruses are subject to physical dilution and physiochemical stresses, such as salinity, temperature, ultraviolet (UV) radiation, and pH [77-80].

The ocean rapidly dilutes wastewater. Nevertheless, dilution may be insufficient to reduce viral risks [47]. Human pathogens are often unstable in the marine environment, leading to loss of viability over short periods. This phenomenon is more apparent in the marine environment than in rivers [47]. Conversely, sediments can act as viral reservoirs in marine environments [60]. Guo *et al.* [77] suggested that continuous discharge of untreated sewage carrying coronaviruses can pollute tens of thousands of km^2 of marine areas. Therefore, fish movement is considered a major route for the long-distance spread of viral pathogens [12].

Coronaviruses prefer dry and cold environments for survival and spread. Warm and humid conditions are not well-matched with virus viability [77]. The health of marine environments is critical for protecting human health. Contaminants may reach the food chain of fish in the marine environment through wastewater discharge. At present, plans and future programs for joint Oceans and Human Health efforts are being discussed [6]. However, pollution of the marine environment by municipal sewage is considered the main mode of transmission for human enteric viruses [18]. Even so, natural disasters have damaged marine environments and led to a range of negative consequences for human health [81]. Marine animals are vulnerable to pollution by detergents, pharmaceuticals, and nanoparticles from wastewater [74]. Several marine mammal species are susceptible to SARS-CoV-2 since they exhibit the virus-host receptor, ACE2 [74,77].

Shellfish and monitoring of SARS-CoV-2

Filter-feeding animals are ubiquitous in the marine environment [82]. Further, viruses are the leading cause of outbreaks of foodborne diseases [83]. Filter-feeding organisms are a long-standing source of such illnesses [19]. Further, shellfish, such as oysters and other bivalves, are vulnerable to contamination by enteric viruses in surrounding waters [83]. Moreover, shellfish may threaten human health due ability to filter and bioaccumulate pathogens [45]. Viral foodborne outbreaks are associated with raw or undercooked shellfish consumption [83].

Bivalve mollusks, such as mussels, clams, or oysters, are vectors of human viral pathogens. These marine animals are a fundamental part of marine ecosystems [84]. Oysters are highly commercialized seafood and are often consumed undercooked or raw [19]. Oysters can concentrate viral pathogens up to 99 times [83]. Mussels are sessile filter-feeders, used as the best choice bioindicator for monitoring

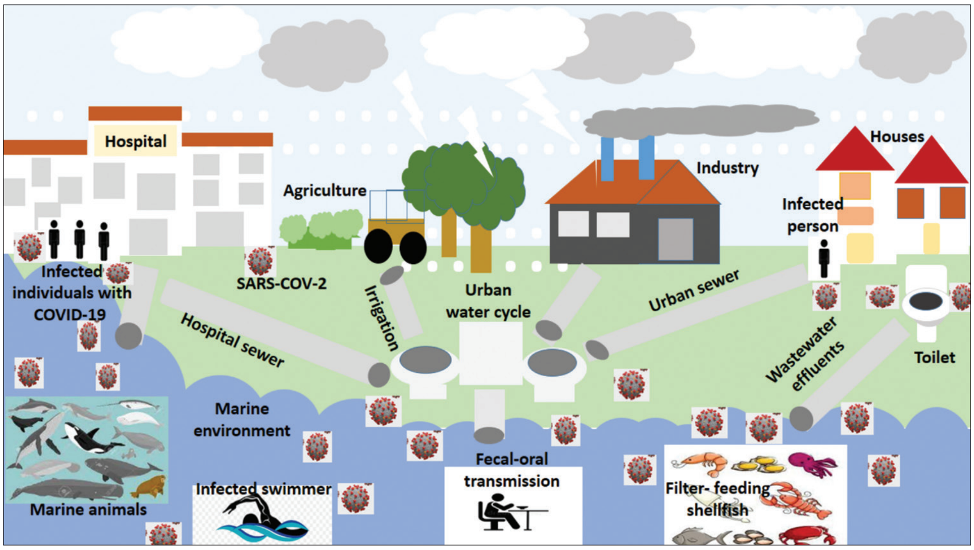

Figure-3: Fate of severe acute respiratory syndrome coronavirus 2 coronavirus in the marine environment. (The figure was generated using Microsoft PowerPoint and Adobe Illustrators by KKB).

pollution [85]. These animals feed by filtering water through their gills [83].

Most outbreaks of shellfish-associated noroviruses are linked to raw and undercooked oyster consumption [86]. Several locations on the French Coast reported the absence of SARS-CoV-2 in shellfish samples [19]. Further, SARS-CoV-2 is not a foodborne virus but can survive in cold-chain food sources. Furthermore, the virus does not replicate in cold-blooded animals. Therefore, it is unlikely that human consumption of aquatic animals can transmit SARS-CoV-2 or other marine coronaviruses [41]. Overall, SARS-CoV-2 is transmitted between humans through airborne aerosols, respiratory droplets, direct contact with fomites, fecal-oral transmission, and consumption of infected seafood (Figure-4).

Effects of environmental factors on SARS-CoV-2

Virus replication requires host intracellular resources [60]; replication is not possible outside host cells. Viability will depend on environmental conditions, such as temperature, salinity, pH, and UV light [87]. Coronaviruses are enveloped viruses with club-shaped surface spikes that give the appearance of a crown. Spikes of this virus range from 9 to 12 nm [88]. Enveloped viruses are less stable than non-enveloped viruses against various environmental stress factors due to the ease of disruption of lipids and proteins of the envelope [16].

Environmental factors are essential to the spread of COVID-19, highlighting the transformation of the disease seasonally. Seasonal outbreaks of this virus may be driven by their response to suitable changes in the weather [89]. In Singapore, factors, including temperature, humidity, and water vapor, were positively correlated with viral transmission [90,91]. Humidity and temperature are assumed to favor the spread of coronaviruses [92]. Furthermore, Basray *et al.* [93] reported a positive correlation of SARS-CoV-2 with different temperature ranges and a negative correlation with humidity. Climate factors affect the incidence of COVID-19 in Pakistan. Temperature and population density played an important role in transmitting coronaviruses [89].

High temperature minimizes viral populations due to the denaturation of proteins and increased activity of exoenzymes [60]. Overall, virus survival decreases in high temperatures; maintaining temperatures >60°C for more than 60 min usually inactivates viruses [94]. At 4°C, viruses may persist for 14 days [95,96]. Coronavirus remains viable on glass surfaces, plastic, and stainless steel for 2 and 4 days at 24°C room temperature, while on paper, it survives for 30 min and 3 h on tissue paper [95-97]. Some researchers suggested that SARS-CoV-2 is still active for 25 days at 5°C in the aquatic environment [80,97,98].

pH and salinity are also significant factors that affect infectivity and survival of coronaviruses in seawater. pH may affect viral survival by directly affecting viral capsid protein conformation [99]. However, viruses can survive in water with pH values ranging from 3 to 10 [96]. In addition, high salt concentrations in seawater may inactivate viruses. The highest viral presence was shown for low salinity coastal waters and surface coastal sediments [41].

Coronaviruses are inactivated in water by exposure to solar or UV radiation [11]. Solar light may inactivate coronavirus rapidly on surfaces, and showing that sunlight is vital for reducing viral transmission risk [95]. Exposure of SARS-CoV-2 infected water to UV radiation disrupts and destroys the integrity of viral DNA [60].

The high concentration of organic matter in many water bodies increases the survival of viruses due to physical protection afforded by particles from detergents, antiviral agents, and UV light [60].

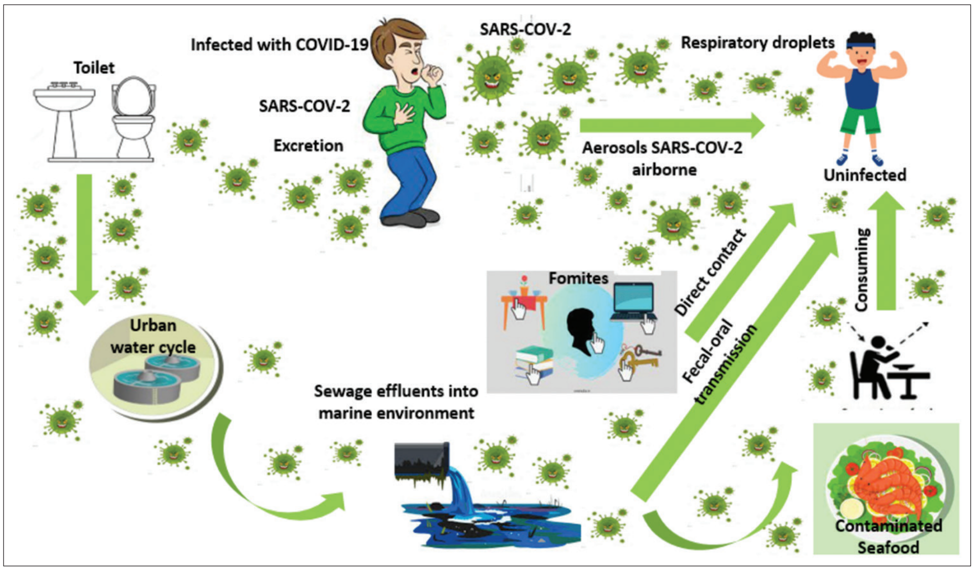

Figure-4: Mechanism of coronavirus disease 2019 transmission. (The figure was generated using Microsoft PowerPoint and Adobe Illustrators by KKB).

Disinfectants inactivate viruses by altering viral proteins. Therefore, disinfection remains the best means for inactivating coronaviruses in water [11].

Conclusion

The increasing global threat from zoonotic disease supported the emergence of OH. OH was subsequently modified by incorporating expertise and data from animal, human, and ecosystem health. OH supports research and development to prevent and control animal diseases to enhance food security. The recent COVID-19 outbreak has spread rapidly and unexpectedly worldwide at the cost of many human lives. Poor wastewater treatment and the resulting possibility of SARS-COV-2 transmission is considered a significant challenge; the discharge of untreated wastewater could expose the public to infection. Lack of basic sanitation and sufficiently treated wastewater in developing countries may exacerbate COVID-19 outbreaks. Viruses that reach the marine environment contribute to reduced marine water quality caused by human sewage and refuse that negatively affect both ecosystems and public health.

Detection of coronaviruses in wastewater raises the possibility of analyzing sewage for future epidemiological monitoring of SARS-CoV-2. Fecal-oral transmission can evade measures for countering COVID-19 outbreaks. The OH concept is an excellent choice to guide coordination among scientific sectors early in an outbreak. The evolution of the OH concept supports the development of more equitable actions at the animal, human, and environmental interfaces. The OH contribution to novel coronavirus control can only be achieved through prevention and therapeutic options. The general operationalization of OH understands disease ecologies within environmental factors, such as weather parameters, pathogen transmission through aerosols, wastewater surveillance, sanitization measures, and environmental hygiene. Further studies are needed to understand the survival of coronavirus in wastewater and the measurement of SARS-CoV-2 in wastewater aerosols, and the assessment of associated risks.

Authors' Contributions

KKB: Collected the literature and wrote the first draft of the review article. EAS and IME: Participated in the drafting and revision of the review article. All authors have read and approved the final manuscript.

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Competing Interests

The authors declare that they have no competing interests.

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