Review Paper

Investigating SARS-CoV-2 Virus in Environmental Surface, Water, Wastewater and Air: A Systematic Review

Parisa Javanbakht[1], Mehdi Vosoughi[2,3], Zahra Noorimotlagh[4*], Abdollah Dargahi[3,5], Chiman Karami[6*]

1. Students Research Committee, School of Medicine, Ardabil University of Medical Sciences, Ardabil, Iran.
2. Department of Environmental Health Engineering, School of Health, Ardabil University of Medical Sciences, Ardabil, Iran.
3. Social Determinants of Health Research Center, Ardabil University of Medical Sciences, Ardabil, Iran.
4. Health Environment Research Center, Ilam University of Medical Sciences, Ilam, Iran.
5. Department of Environmental Health Engineering, Khalkhal University of Medical Sciences, Khalkhal, Iran.
6. Department of Microbiology, Parasitology and Immunology, School of Medicine, Ardabil University of Medical Sciences, Ardabil, Iran.

Use your device to scan and read the article online

Citation Vosoughi M, Noorimotlagh Z, Dargahi A, Karami Ch. Investigating SARS-CoV-2 Virus in Environmental Surface, Water, Wastewater and Air: A Systematic Review. Health in Emergencies and Disasters Quarterly. 2024; 9(2):69-86. http://dx.doi.org/10.32598/hdq.9.2.551.1

doi: http://dx.doi.org/10.32598/hdq.9.2.551.1

Article info:
Received: 14 May 2023
Accepted: 09 Oct 2023
Available Online: 01 Jan 2024

ABSTRACT

Background: The occurrence of COVID-19 as a public health emergency of international alarm was declared by the World Health Organization (WHO) on January 30, 2020. The identified transmission path is due to direct close contact or via respirational droplets. There is uncertainty about other ways, such as transmission of surfaces, air, and other sources. This study follows the preferred reporting items for systematic reviews and meta-analysis guidelines to investigate severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) virus in environmental surfaces, water, wastewater, and air.

Materials and Methods: In this study, we performed a systematic literature search in PubMed (MEDLINE), Scopus, and Web of Science (ISI) databases in August 2022. The investigation on electronic databases resulted in a total of 2049 articles. A total of 249 potentially relevant were identified for full-text evaluation. Meanwhile, 30 articles were included in the synthesis.

Results: According to four included studies, negative detection of SARS-CoV-2 transmission in water is established. A laboratory study has shown that viable SARS-CoV-2 could be found in aerosols for about 3 h. Also, the virus can be found on dry surfaces, depending on the material of the surface, for 8 to 72 h. Our results showed it is possible to exciting SARS-CoVs in air, environmental surface, and wastewater.

Conclusion: These results can help healthy policymakers make suitable assessments of main prevention measures.

Keywords:
SARS CoV-2, Air, Water, Surface, Wastewater

*** Corresponding Authors:**
Chiman Karami, Assistance Professor.
***Address:** Department of Microbiology, Parasitology and Immunology, School of Medicine, Ardabil University of Medical Sciences, Ardabil, Iran.*
***E-mail:** chkarami.chiman@gmail.com*

Zahra Noorimotlagh, Assistance Professor.
***Address:** Health Environment Research Center, Ilam University of Medical Sciences, Ilam, Iran.*
***E-mail:** noorimotlagh.zahra@gmail.com*

Introduction

In early 2020, the pandemic of the coronavirus disease 2019 (COVID-19) surprised health professionals as it was a newly emerged variant of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). This new variant revealed high mortality and severity due to having a higher infectious rate, making viral infection more contagious, transmissibility, and severity. SARS-CoV-2 mutated to an additional variant called omicron (B.1.1.529) [1-4], which was considerably more infectious and transmissible than the previous deadly delta variant [5]. The World Health Organization (WHO) technical advisory group stated omicron is a concerning variant [6]. SARS-CoV-2 transmits via direct or indirect impact, and person-to-person spread is the early mode of virus transmission, mainly via respiratory droplets. The main pathways are respiratory aerosol and close contact, virus-contaminated substances, droplet transmission in locked environments, urine aerosol, feces, or touching the base in toilets [7].

However, the essential route of spreading COVID-19 is directly contacting an infected person or via respiratory droplets. Droplets cannot transfer more than six feet, remain intact in the air, and are contagious for a limited time. The virus transmits via envelopes in the internal or stick to the surface of respiratory aerosols and droplets. Aerosols are generated when the surface tension of fluid lining the respiratory tract is overcome by force. The required forces can be created by rapid shearing air flows, vocal cord movement, and the opening and closing of terminal airways, all of which are influenced by the type and force of respiratory activity. Heavy breathing, coughing, talking, and singing generate aerosols, causing an exhalation plume of respiratory particles of varying sizes containing potentially infective viral material. The high viral loads in the pharynx early in COVID-19 make these aerosols a plausible cause of both pre-symptomatic and asymptomatic transmission, which is effective in fueling outbreaks and challenging to control. The fluid droplets can cover and absorb greater aerosol elements in the open air. The spread of aerosols and surface viruses is also potential since they can endure viable and transmissible for hours or several days. In poor ventilation locations, viral infection particles <0.1 μm in size can persist in the atmosphere as secondary particles [8]. Studies have indicated that environmental aspects intensely influence the SARS-CoV-2 transmission. SARS-CoV-2 has been demonstrated in the environment, including water, air, surfaces, and soil. SARS-COV-2 is also found in the sink and toilet bowl; however, indoor and outdoor air was free from COVID-19 after daily room cleaning. Depending on the surface properties, the subsistence time of COVID-19 differs less absorbent, such as steel and plastic. In addition, various environmental issues may influence the quantity of air and the humidity in the rooms [9]. It is possible to become infected by touching surfaces or objects with the virus and then bringing the hands toward the mouth, nose, or eyes. The virus can persist on different surfaces for hours or days in ideal conditions. The surfaces most exposed to this transmission type include door handles, lift or light buttons, mobile phones, and public transport handholds [10]. Recently, the SARS-CoV-2 virus has been released in wastewater sources and indicated that the virus can persist in sewage for a long time. This outcome could be a thoughtful tool for following and monitoring the lifecycle of COVID families inside populations. The persistence of COVID in water sources depends upon various environmental aspects, such as sunlight, temperature, and organic combinations where the virus can certainly adsorb and protect itself against antagonistic circumstances, such as pathogenic microorganisms [11]. As informed by WHO, no confirmation of COVID family spread over contaminated drinking water exists. Normally, enveloped viruses are less biologically satisfactory and are more sensitive to oxidizing mediators. For example, SARS-CoV-2 is probably more quickly deactivated in interaction with chlorine than human intestinal non-enveloped viruses [12]. According to the studies conducted on the presence of coronavirus in the air, water, wastewater, and environmental surfaces, this review article investigates the existence of SARS-CoV-2 in the air, wastewater, and environmental surfaces.

Materials and Methods

This study followed the preferred reporting items for systematic reviews (PRISMA) guidelines. This study investigated SARS-CoV-2 in different surfaces, water, wastewater, and air from 2021 to 2023. Today, in addition to PRISMA, the Sinatex strategy is also used. Plain syntax instructions used by the search engine. These syntax rules are conducted whether they are a) Entering words in the main search box under “easy search” on the main page or in the field boxes under the “structured search” option, or b) Combining words with exact field codes in the “expert search” option. For example, we performed a systematic literature search from 2022 to 2023 in the following databases: PubMed (MEDLINE), Scopus, and Web of Science (ISI). We used the following terms to conduct the search: “Environmental surface AND SARS coronavirus,” “Air AND SARS coronavirus," "water AND SARS coronavirus," "wastewater AND SARS coronavirus," "surface AND SARS coronavirus," "environmental surface AND SARS-COV-2," "air AND SARS-COV-2," "water AND SARS-COV-2," "wastewater AND SARS-COV-2," "environmental surface AND COVID-19," "air AND COVID-19," "water AND COVID -19," "wastewater AND COVID-19." We imposed the English language restriction on the search. Additional related articles were retrieved manually from Google Scholar and were critically evaluated. All articles were imported to Endnote software, version 20 (Thompson and Reuters, Philadelphia, USA), and duplicates were removed.

Inclusion and exclusion criteria

In collecting the data, attention was paid to the following items: a) Original articles; b) Studies published in English; c) Articles with the keywords mentioned above, such as articles focusing on environmental surface sustainability, air sustainability, water sustainability, and on wastewater sustainability.

Meanwhile, excluded items are as follows: Full-text review articles (n=73), book reviews (n=9), guidelines (n=56), book chapters (n=5), short communications (n=17), conference papers (n=24), oral presentations (n=16), commentaries (n=12). Some included studies investigated the presence of SARS-CoV-2 in several media (such as air, surfaces, etc.); Therefore, the sum is more than 30 articles.

Data extraction

After screening published articles for eligibility, relevant data and information from each eligible study were entered. Co-authors independently collated data from all eligible studies and independently evaluated the data. Then, information, such as first author's name, publication year, country, sustainability in air, sustainability in environmental surface, disinfectant/concentration, sustainability in wastewater, sustainability in water, sampling method, humidity, temperature, media, sample volume processed, ventilation system type, gen target for reverse transcription-quantitative polymerase chain reaction (RT-qPCR), sampling conditions, rate of positivity, number of positive samples, and number of the test was extracted.

Results

Study characteristics

The search on electronic databases identified a total of 2049 articles. Following the removal of duplicate articles and a critical appraisal of article titles and abstracts, 249 potentially relevant articles were identified for full-text evaluation (Figure 1).

After applying the eligibility criteria, 30 articles were included in the synthesis (Table 1). Then, the included articles were investigated in detail and considered independently according to the environmental stability of coronaviruses to survive in different environmental conditions.

Among the evaluated articles, 12 articles are related to the presence of the coronavirus in the air or considering the conditions mentioned in the tables. Meanwhile, 15 articles are associated with the presence of the coronavirus at the surface and 4 articles are related to the presence of the coronavirus in the water. Finally, 13 articles are associated with the presence of this virus in wastewater.

Discussion

COVID-19 was detected on December 31, 2019, in the Wuhan City, Hubei Province, China. The world faced an emergency condition. This study confirmed the presence of SARS-CoV-2 in indoor air, open air, environmental surfaces, water, and wastewater. Such studies provide valuable evidence about contamination and the risk of virus transmission between healthy individuals and patients. There are unalike thoughts about the transmission and presence of SARS-CoV-2 in environmental studies. A direct assessment between results from studies that evaluated the SARS-CoV-2 transmissibility and existence is not possible due to differences in sampling technique, investigational approaches, the number of samples, features of hospital architecture and cleaning staff service. At the beginning of the pandemic, the WHO and many studies mainly highlighted that the main transmission routes are person-to-person, and people should observe their physical distance. Over the past years, COVID-19 has had profound detrimental effects on everyone worldwide. Such effects have been compounded by the lockdown that has affected all activities and caused global economic disruption. Airborne transmission is the main route for infectious agents, such as viruses. Accordingly, airborne transmission of SARS-CoV-2 has been proven, and caution is taken to prevent and control the airway. To this end, evaluating the pos-

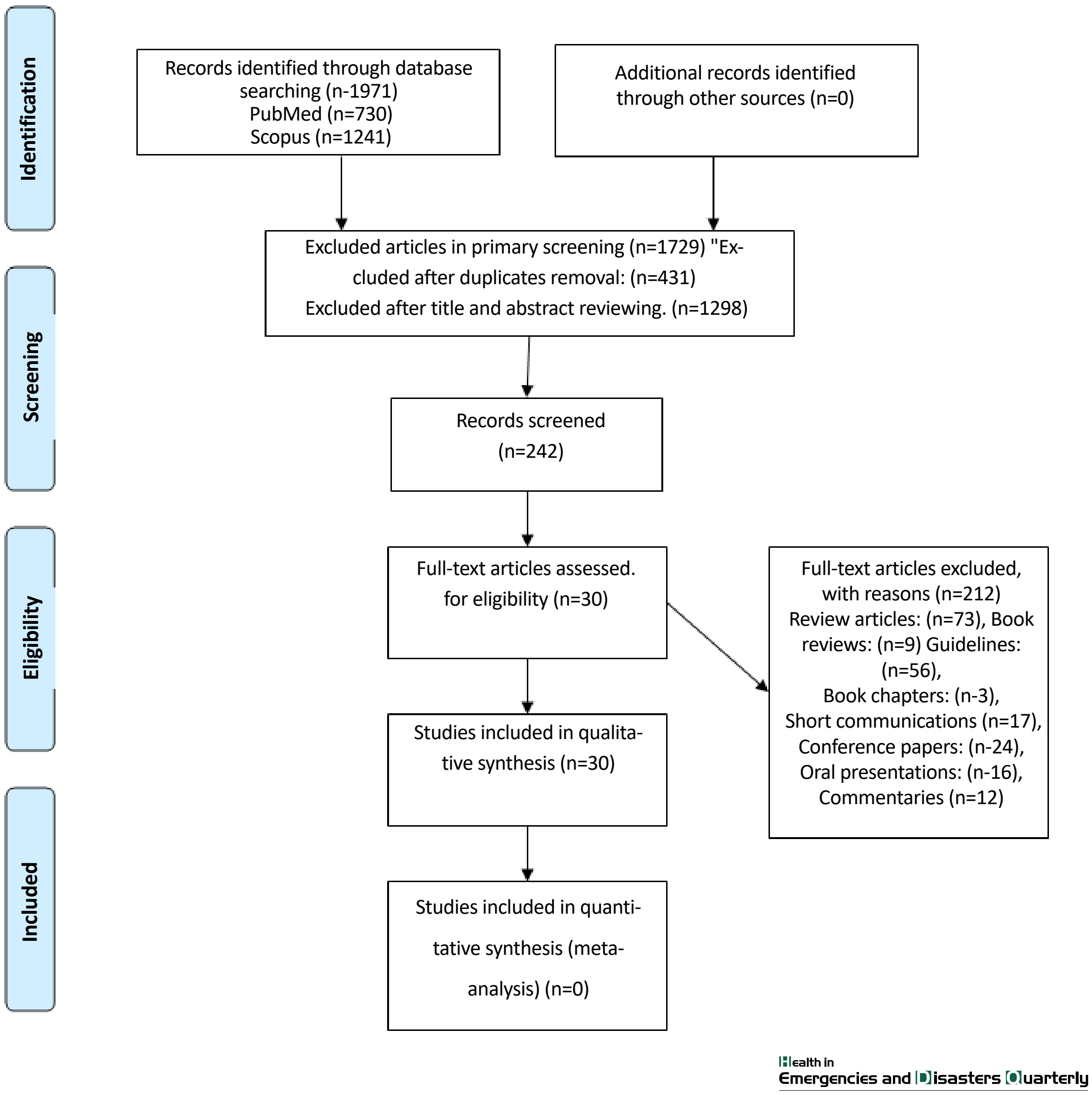

Figure 1. Search strategy and study selection process, indicating numbers of studies (and associated datasets) excluded or Included

sible airborne transmission of SARS-CoV-2 is essential. In this study, we conducted a general literature search for original studies on airborne transmission of SARS-CoV-2.

In the indoor air environment, after examining the collected literature and conducting an in-depth analysis, we included 12 eligible studies (Table 2). Among the 12 included studies, seven eligible studies were experimental and reported different findings on positive or negative detection of SARS-CoV-2 airborne transmission in indoor air. Among them, five studies (Dohla et al. 2022 [21]; Vosoughi et al. 2021 [23]; Razzini et al. 2020 [24]; Cheng et al. 2020 [25]) indicated that all indoor air samples in the hospital were negative, thus confirming that SARS-CoV-2 is transmitted by air. Unlike the results of these studies, other included experimental studies reported positive results that confirmed transmission of the virus through the air. In this context, in 2020, Kenarkoohi et al. and Razzini et al. [41, 24] indicated that air samples were PCR positive for viral RNA in the hospital's indoor air environment of the intensive care unit (Table 2). Furthermore, Chia et al. [38] confirmed that, despite 12 air change rate isolation rooms for airborne infections in the hospital, SARS-CoV-2 PCR-positive were 2 out of 3 airborne infection isolation rooms. The outcomes of the studies in the experimental section disclose a high possibility of airborne transmission of SARS-CoV-2 in indoor air in hospital environments, even with a ventilation rate of 12 air changes per hour. Therefore, it is necessary that the air exchange rate is more effective and takes into

Table 1. Summary of study characteristics of included original studies

Ref.	Country	State/City	Sampling Date	Sample Type	Sampling Method	Sample Volume Processed	Key Findings
[13]	Turkey	Istanbul	2020	Wastewater	Bottles	N/A	All samples were tested positive.
[14]	Iran	Tehran	2020	Wastewater	Plastic bottles	140 µL	The virus was present in all influent and effluent samples of treatment plants.
[15]	Iran	Gorgan	2022	Air surfaces wastewater	Air: Air pump; surface: Swabs	5 µL	The presence of the SARS-CoV-2 genome was confirmed in the indoor air and environments of different hospital sections.
[4]	Iran	Ardabil	2022	Wastewater	Special closed glass bottles	100–200 mL	Out of 76 samples, a total of 15 (19.73%) collected from wastewater in Ardabil Province (Iran) were positive regarding SARS-CoV-2. Wastewater epidemiology can facilitate the detection of the incidence of pathogens through metropolises, measurement of population prevalence without direct testing, and provision of information to the public health system about the efficiency of intervening efforts.
[16]	India	Ahmedabad	2020	Wastewater	Sterile bottles	50 mL	All three (ORF1ab, N, and S genes of SARS-CoV-2) were found in the influent, with no genes detected in effluent collected on 8.
[17]	Australia	-	2020	Wastewater	N/A	100–200 mL	This is a proof-of-concept study, and we have shown that SARS-CoV-2 RNA can be detected in untreated wastewater in Australia. Information on the composition of wastewater and environmental factors, such as storm flow and its impact on wastewater, may also be useful. These requirements are expected to be achievable and should provide accurate information on the disease burden in the community.
[18]	Czech	-	2020	Wastewater	N/A	500 mL	A positive signal was observed for only 11.6% of samples of untreated wastewater. The percentage is lower than expected. The mild course of the epidemic in the Czech Republic and the decline in the number of infected inhabitants during the study may be why such numbers were observed.
[19]	Iran	Maragheh	2021	Wastewater	Sterile bottles	N/A	SARS-CoV-2 RNA was detected in all untreated wastewater samples; however, it was not found in the liquid and solid effluent of the WWTPs.

Ref.	Country	State/City	Sampling Date	Sample Type	Sampling Method	Sample Volume Processed	Key Findings
[20]	Spain	Murcia	2020	Wastewater	Sterile HDPE plastic	200 mL	The detection of SARS-CoV-2 in wastewater in the early stages of the spread of COVID-19 highlights the relevance of this strategy as an early indicator of the infection within a specific population.
[21]	German	Heinsberg	2020	Wastewater, air, surfaces	Wastewater: Sterile syringes and catheters; air: Coriolis micro—air sampler; surfaces: Swab with a synthetic tip and a plastic shaft	Wastewater: 50 mL Air: 15 mL Surfaces: N/A	No statistically significant correlation between reverse transcription-quantitative polymerase chain reaction positive environmental samples and the extent of the spread of infection between household members was observed.
[22]	Iran	Ardabil	2022	Water	Special glass containers	200 µL	Positive samples were taken from rivers and tabs in different cities.
[23]	Iran	Ardabil	2021	Air	Pump with a flow	N/A	Air samples 2 to 5 m away from the patients' beds were negative for the presence of the virus.
[24]	Italy	Milan	2020	Air surface	Air: Airport portable air sampler with gelatin membrane filters; surface: Swab	Air: 5 µL; surface: 5 µL	All the air samples were positive, while viral RNA was not detected in semi-contaminated or clean areas.
[25]	German	Singapore	2020	Air surfaces	Air: Sartorius MD8 air scan sampling device; surfaces: Swab	Air: 5 mL; Surfaces: 1 mL	The presence of SARS-CoV-2 in air samples collected 10 cm from a patient's chin with or without a surgical mask in a single airborne infection isolation room setting was not shown.
[26]	Iran	Kerman	2022	Air surfaces	Air: Pumps at flow; surfaces: Sterile swab	Air: N/A; surfaces: 2 mL	The SARS-CoV-2 can be found in the high-touch surfaces and indoor air of the COVID-19 patient reception centers.
[27]	London	-	2021	Air surfaces	Air: Conical vial; surfaces: Swab	140 µL	SARS-CoV-2 RNA was detected frequently from surface and air samples but was not cultured.
[28]	Greece	-	2020	Air surfaces	Air: Sartorius Airport MD8; surfaces: Swab	50 mL	This study was unable to quantify or check virus viability.
[29]	Iran	Ardabil	2021	Surfaces	Swab	5 µL	This study provides critical insight into the persistence of human coronaviruses at different hospital surfaces and is consistent with the results of recent similar research. It revealed that several samples taken from hospital surfaces, such as handles, cupboards, light switches, and door handles, were positive. However, the likelihood of infection from various characters in hospital wards remains threatening.

Ref.	Country	State/City	Sampling Date	Sample Type	Sampling Method	Sample Volume Processed	Key Findings
[30]	Iran	Ardabil	2021	Surfaces	Swab	10 μM	The results showed that the inside parts of all samples were positive for the presence of SARS-CoV-2. Wearing masks is a part of physical preventive measures that may help decrease the spread of coronavirus from respiratory excretions.
[31]	Singapore	Slovenian	2020	Surfaces	Pre-soaked swab	600 μL	The frequency of environmental contamination was lower in the intensive care unit than in general ward rooms. Eight samples from the common area were positive, though all were negative on cell culture.
[32]	USA	Utah	2021	Surfaces	Swab	4 mL	SARS-CoV-2 RNA was most frequently detected on nightstands and pillows by persons who recently tested positive for SARS-CoV-2. Also, it was detected viral RNA on high-touch surfaces, including light switches, doorknobs, and kitchen appliances.
[33]	Italy	Campania	2022	Surfaces	Swab	20 mL	The risk of contamination increases in environments with more people and where decontamination strategies are not always feasible.
[34]	Wuhan	Guanggu	2020	Wastewater	N/A	200 μL	Positive samples were detected in municipal and hospital wastewater systems during the middle-risk period.
[35]	Ecuador	Quito's	2020	Water	Plastic bottles	2 L	SARS-CoV-2 was detected for both target regions in all samples analyzed.
[36]	Japan	Yamanashi	2020	Wastewater water	Sterilized 1 L plastic bottles	Wastewater: 500 mL; water: 50 mL	None of the river water samples tested positive for SARS-CoV-2 RNA.
[37]	Italy	Milano Metropolitan	2020	Wastewater water	Stainless steel buckets	200 μL	The presence of the SARS-CoV-2 genome in rivers indicated the partial efficiency of the current sewerage system.
[38]	Singapore	-	2019	Air surface	Air: Pumps set at a flow rate; surface: Swab	5 μL	The polymerase-chain-reaction-positivity high-touch surfaces were associated with nasopharyngeal viral loads and peaked at approximately days 4–5 of symptoms. Air sampling of the airborne infection isolation room environments detected the presence of SARS-CoV-2 particles sized 1–4 μm and >4 μm.
[39]	China	Wuhan	2020	Air surface	Air: N/A; surface: Swabs	N/A	Air and surface contamination with viral RNA was relatively low in these healthcare settings after infection prevention and control were enhanced.

Ref.	Country	State/City	Sampling Date	Sample Type	Sampling Method	Sample Volume Processed	Key Findings
[40]	China	Wuhan	2020	Air surface	Air: Natural precipitation; surface: Swab	N/A	SARS-CoV-2 RNA was not detected in the air in a designated hospital for COVID-19. Environmental surface in medical areas was frequently contaminated.
[41]	Iran	Ilam	2020	Air	Liquid-phase sampler, SKC bio sampler	20 µL	Due to the potential of airborne (aerosol) virus transmission in the indoor air of hospitals and based on national and international evidence, it is essential to take the highest levels of PPE precautions.

Health in Emergencies and Disasters Quarterly

reason what was reported in the included study. In 2020, Faridi et al. [42] showed that all air samples collected in the selected large hospital indoor air were PCR negative; however, we recommend more in vivo investigations focused on using definite patient coughing, sneezing, and breathing (Table 2). Aerosols in instruction to show the possibility of generation and the viable portion of the surrounded virus in those carrier aerosols. Transmission through respiratory droplets and contacts is considered the primary transmission route in SARS-CoV-2.

Airborne infection with COVID-19 has remained controversial since the beginning. Several researchers have appealed to the different motivations and relevant national/international cooperation to recognize airborne transmission as another probable dominant route for spreading SARS-CoV-2 [43]. Airborne viruses' Transmission and infectivity depend on the size and quantity of aerosols generated, which regulate the amount (dose) and pattern for deposited particle dose rate [44]. Vosoughi et al. [23] maintained that a comprehensive understanding of the risk of the transmission pathways of SARS-CoVs could allow for a better preventative program.

Such pathways include the airborne transmission path, which triggers the discussion that the virus goes far outside 1 m reported by WHO [45]. This should be observed as a distance protection, especially in general medical settings. International case studies have established that the behavior change of the SARS-CoVs virus has been unprecedented in an environment with most likely persistence and probability viable rates in the air. Atzrodt et al. [46] tested a mix of environmental factors on Cho persistence, especially two temperatures typical of the two extreme indoor atmospheric conditions in temperate countries (6˚C and 20˚C) and three relative humidity demonstrating low (30%), medium (50%), and high (80%) conditions in both indoor and outdoor environments. Based on the obtained results, the presence of the coronavirus in the air and its transmission through aerosols is possible; however, the existence of the coronavirus has not been proven in some hospital air, which is in agreement with the study of Revilla Pacheco et al. in 2021. SARS-CoV-2 can be presented in wastewater by various pathways, such as hand washing, sputum aerosolized particles resulting in vomiting [47], and mainly via viral RNA shedding with gastrointestinal symptoms [48] ( ). Thus, the viruses may enter the water systems through several paths, including fecal contamination from hospitals and home isolation and quarantine for COVID-19 [49]. Also, from houses and habitats of buildings frequented by an infected person, whether patients were more likely to be non-symptomatic [50]. Conventional wastewater treatment processes commonly accept that this method, depending on the process and operational conditions, usually at a secondary or tertiary level, may be sufficient to eliminate. Meanwhile, studies [4] have indicated that all the different parts of Ardabil City and Khalkhal City, Iran, wastewater treatment plants the white (lower risk of COVID-19) and red (high risk of COVID-19) conditions were positive, which shows that following coronavirus through sewage as a tool for the COVID-19 pandemic detection.

Sewage surveillance is an early warning system because people with COVID-19 and common symptoms can be identified with people without symptoms in different areas [51].

Table 2. Detection of SARS-CoV-2 RNA genome in the air

Ref.	Sampling Point	No.		Rate of Positivity (%)	Gene Target for RT-qPCR	Sampling Conditions			Ventilation System Type
		Test	Positive Sample						
[15]	Intensive care unit; emergency ward: Triage, admission, and doctor's room	26	5	29	RdRp N	25	N/A	N/A	N/A
[21]	Living room; household kitchen	15	0	0	N/A	N/A	N/A	N/A	N/A
[23]	Hospital wards: Respiratory section-1 (COVID-19), laboratory section, computed tomography section, respiratory section-2 (COVID-19), respiratory section-1 (COVID-19) checkup room, respiratory section-2 (COVID-19) station section, emergency section intensive care unit	33	0	0	N/A	28	37	438	Mechanical/ natural
[24]	Contaminated area: Corridor for patients, intensive care unit clean area: Lockers passage for the medical staff dressing room clean area: Undressing room	5	0	0	N/A	20-22	18	N/A	N/A
[25]	Intensive care unit	12	0	0	N/A	N/A	N/A	N/A	N/A
[26]	COVID-19 intensive care unit, general Intensive care unit, emergency ward, infectious disease ward	23	2	N/A	N/A	24-26	25-35	N/A	N/A
[27]	Emergency department, admissions ward, COVID-19 cohort wards, theatres during tracheostomy procedures, an intensive care unit	31	14	38.7	N/A	N/A	N/A	N/A	N/A
[28]	Cabins toilets of symptomatic asymptomatic patients	21	1	N/A	N/A	N/A	N/A	N/A	N/A
[38]	General ward in the hospital	6	2	66.7	N/A	23	53–59	N/A	N/A
[39]	General isolation wards Intensive care unit	12	1	N/A	N/A	N/A	N/A	N/A	N/A
[40]	General isolation wards, intensive care unit, fever clinic, clinical laboratory, office areas, restrooms	44	0	0	N E	N/A	N/A	N/A	N/A
[41]	Intensive care unit, Intensive care unit entrance hall, hospital entrance hall, laboratory ward, computed tomography scan, radiology, men's internal ward, women's internal ward, and emergency ward	14	2	-	OR-F1ab N	25	50	377	Mechanical

Table 3. Detection of SARS-CoV-2 RNA genome in wastewater

Ref.	Sapling Point	No.		Rate of Positivity (%)	Gene Target for RT-qPCR	Tem (C⁰)
		Test	Positive Sample			
[13]	Primary and waste activated; sludge samples; municipal wastewater	9	N/A	N/A	N/A	19
[14]	Influent refinery; final effluent refinery	11	9	80	ORF1ab N	N/A
[15]	Treated and untreated sewage; the hospital refinery; hospital wastewater	8	2	37.5	RdRp N	25
[4]	Wastewater collection network, wastewater treatment plant, hospital wastewater; influent and effluent of municipal; hospital wastewater treatment plants, samples of municipal wastewater manholes,	76	15	19.73	ORF1ab N	N/A
[16]	Hospital treating COVID-19 patient; WWTP receives the sewage waste of a government civil Influents; final effluents after UASB aeration pond	8	8	100	ORF1ab N S	N/A
[17]	Untreated wastewater (sewage); suburban pumping station (PS); WWTPs representing urban	3	2	22.2	N	N/A
[18]	untreated wastewater inflow wastewater treatment plants	112	13	11.6	N/A	N/A
[19]	A wastewater collection system in urban: Influent wastewater untreated hospital wastewater	44	N/A	N/A	N/A	N/A
[20]	Influent secondary and tertiary treated effluent water treated effluent water	72	37	N/A	N1 N2 N3	N/A
[21]	Households wastewater: siphons, showers, toilets	66	10	15.15	N/A	N/A
[34]	Wastewater treatment plants: samples of municipal wastewater system; hospitals for COVID-19: of hospital wastewater environment wastewater: lakes and rivers influent, primary treatment effluent, secondary effluent, final effluent, surplus sludge, concentrated sludge, de-watered sludge, surface water, lake sediment, soil samples	216	2	N/A	ORF1ab RBD2	N/A
[36]	Influent secondary treated wastewater	500 mL	200 mL	%30	ORF1a S	N/A
[37]	WWTPs globally sewage wastewater treatment in urban	3	0	%0	ORF1ab N E	N/A

Health in Emergencies and Disasters Quarterly

Table 4. Detection of SARS-CoV-2 RNA genome in the water

Ref.	Sampling Point	No.		Rate of Positivity (%)	Gene Target for RT-qPCR	Sampling Conditions		
		Test	Positive Sample					
[22]	Rivers, dams, lakes	267	2	N/A	N ORF1a/b	7.5	221	7.7
[35]	River	2L	N/A	N/A	N	N/A	N/A	3.5
[36]	River	3	0	0	ORF1a S	N/A	N/A	N/A
[37]	River	3	0	0	ORF1ab N E	N/A	N/A	N/A

Health in Emergencies and Disasters Quarterly

Due to the water resources in various types and different conditions, the persistence of viruses is not always in a similar condition. Rivers usually provide an unstable condition for viruses due to the difference between stable and unstable substrates and physical disturbance. Still, the formation of viral aerosols is more likely than in lakes [52] (Table 3).

Physical, chemical, and biological conditions associated with the lake may help to inactivate the viruses [4]. SARS-CoV-2 can persist in a surrounding matrix to an infected discharge of untreated wastewater. Among the 4 included water studies, all studies were negative detection of SARS-CoV-2 transmission in water, thus concluding that there is low evidence that SARS-CoV-2 is transmitted by water (Table 4). The viability of SARS-CoV-2 on dry surfaces seems identical to that of SARS-CoV-2 and MERS [54]. However, the main difference between SARS-CoV-2 and other viruses is the higher transmission rate, which is currently attributed to individuals carrying the virus asymptomatically. Despite laboratory studies showing the presence of the virus on various surfaces, they had some practical limitations [55]. According to the study of Seif et al. in year 2021 [56], due to the high transmissibility of SARS-CoV-2, investigation of fomites and environmental surfaces to determine the fomite transmission risk of COVID-19 infection is essential. We included 15 eligible studies. Among the 15 included studies, 14 eligible studies were experimental and reported different findings on positive or negative detection of SARS-CoV-2 transmission in environmental surfaces. Among them, one study indicated were negative [57]. To guarantee data uniformity and allow comparison of virus survival studies, we recommend the definition of a reference study protocol for all laboratories investigating this topic. For example, it is essential to assess viral viability until it is completely inactivated. Further, more homogeneous studies assessing coronavirus survival on fomites are needed to fill data gaps. Although prolonged survival of SARS-CoV-2 on surfaces has been proved, evidence of transmission from contaminated dry surfaces is still needed, while direct person-to-person transmission remains the main confirmed route (Table 5). The positive point of our article is the presence of SARS on different surfaces depends on various factors, for example, in the air, on specific humidity and temperature conditions, in water and waste, on the flow rate, biofilm formed, the formation of vesicular structures in the virus, and on surfaces, it depends on the type of surfaces and temperature and humidity conditions which causes contradictions in different articles.

Conclusion

SARS-CoV-2 detection in air, environmental surface, and wastewater samples in a building with clinically confirmed COVID-19 cases suggests that the RNA genomic of the virus, speared by an infected patient, can be traced in the environment. This study provides essential awareness of the persistence of SARS coronaviruses at different environmental surfaces, air, water, and wastewater, consistent with the results of current related research. It showed that several samples taken from hospital surfaces, such as cupboards, light switches, and door handles, were positive. However, the possibility of infection from numerous surfaces in hospital wards remains threatening. This study has elevated significant demands about virus persistence and its relationship with the various conditions of the environment. Appropriate protective strategies such as physical distancing, hand hygiene, and wearing masks are essential to control the COVID-19 pandemic. Despite this, more studies should be done to get more information about the persistence of COVID-19 on different surfaces, water, sewage, and air.

Table 5. Detection of SARS-CoV-2 RNA genome in surface

Ref.	Sampling Point	No.		Rate of Positivity (%)	Gene Target for RT-qPCR	Disinfec-tion Type
		Test	Positive Sample			
[15]	Bed handles, mobile, floor	14	8	16	RdRp N	N/A
	Remote control, cell phone, and knobs handle furniture, fixtures, and clothing	119	4	3.36	N/A	N/A
	Bedrails, benches, computer keyboards, door handles, glove boxes, hand sanitizer dispensers, medical equipment, medical equipment touch screens, shelves for medical equipment, staff lockers, walls, waste containers, water taps, and windows	37	5	24.3	N/A	Chlorine
[25]	Bed rail, locker, bed table, toilet door handle, mobile phone	377	19	5	N/A	N/A
[26]	Intensive care units, emergency ward, infectious disease ward, nursing station	60	8	13.32	N/A	N/A
[21]	Bed rails, clinical monitoring devices (blood pressure monitors), ward telephones, computer keyboards, clinical equipment (syringe pumps, urinary catheters), hand-cleaning facilities	218	114	52.3	N/A	N/A
[24]	Toilet outside doorknob toilet inside doorknob toilet bowl patient food table living room table floor outside the patient's room	65	13	N/A	N/A	N/A
[29]	Ambulances, handles, faucets, nursing station platforms, files, computers, keyboards, soaps and alcohol tanks, blood pressure equipment, pulse oximetry, and thermometers.	50	9	N/A	N/A	N/A
[30]	Internal and external surfaces of various masks	30	6	N/A	N/A	N/A
[31]	Intensive care unit patient	200	28	10	N/A	N/A
[32]	Kitchen surfaces appliances, sink handle, countertop table, refrigerator handle, microwave, trash can lid, phone, computer, TV remote control	150	23	15	N/A	N/A
[33]	Animal farms public transport buses, supermarket, hotel	93	20	N/A	RdRp, E N	N/A
[38]	Cardiac table, the entire length of the bed rails including bed control panel, call bell, bedside locker, electrical switches on top of the beds, chair in general ward rooms	245	N/A	56.7	N/A	N/A
[39]	Touch surfaces near patients, hands, masks of patients	355	9	5.7	N/A	Sodium hypochlorite 1000 mg/L
[40]	Beepers, water machine buttons, elevator buttons, computer mouse, telephones,	200	38	24.83	N E	N/A

Health in Emergencies and Disasters Quarterly

Ethical Considerations

Compliance with ethical guidelines

This study was approved by the Ethics Committee of the Ardabil University of Medical Sciences (Code: IR.ARUMS.REC.1401.018).

Funding

This research did not receive any grant from funding agencies in the public, commercial, or non-profit sectors.

Authors' contributions

Conceptualization and supervision: Parisa Javanbakht, Abdullah Dargahi and Chiman Karami; Data collection: Parisa Javanbakht; Study design and data analysis: Parisa Javanbakht, Zahra Noorimotlagh and Chiman Karami; Drafting the manuscript: All authors; Final approval: Mehdi Vosoghi and Zahra Noorimotlagh.

Conflict of interest

The authors declared no conflict of interest

Acknowledgments

The authors would like to thank Ardabil University of Medical Sciences.

References

[1] Lui GC, Yip TC, Wong VW, Chow VC, Ho TH, Li TC, et al. Significantly lower case-fatality ratio of Coronavirus Disease 2019 (COVID-19) than Severe Acute Respiratory Syndrome (SARS) in Hong Kong-A territory-wide cohort study. Clinical Infectious Diseases. 2021; 72(10):e466-e75. [DOI:10.1093/cid/ciaa1187] [PMID]

[2] Carducci A, Federigi I, Liu D, Thompson JR, Verani M. Making waves: Coronavirus detection, presence and persistence in the water environment: State of the art and knowledge needs for public health. Water Research. 2020; 179:115907. [DOI:10.1016/j.watres.2020.115907] [PMID]

[3] Bedford J, Enria D, Giesecke J, Heymann DL, Ihekweazu C, Kobinger G, et al. COVID-19: Towards controlling of a pandemic. Lancet (London, England). 2020; 395(10229):1015-8. [DOI:10.1016/S0140-6736(20)30673-5] [PMID]

[4] Karami C, Dargahi A, Vosoughi M, Normohammadi A, Jeddi F, Asghariazar V, et al. SARS-CoV-2 in municipal wastewater treatment plant, collection network, and hospital wastewater. Environmental Science and Pollution Research International. 2022; 29(57):85577-85. [DOI:10.1007/s11356-021-15374-4] [PMID]

[5] Noorimotlagh Z, Mirzaee SA, Jaafarzadeh N, Maleki M, Kalvandi G, Karami C. A systematic review of emerging human coronavirus (SARS-CoV-2) outbreak: Focus on disinfection methods, environmental survival, and control and prevention strategies. Environmental Science and Pollution Research International. 2021; 28(1):1-15. [DOI:10.1007/s11356-020-11060-z] [PMID]

[6] Lai CC, Shih TP, Ko WC, Tang HJ, Hsueh PR. Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and coronavirus disease-2019 (COVID-19): The epidemic and the challenges. International Journal of Antimicrobial Agents. 2020; 55(3):105924. [DOI:10.1016/j.ijantimicag.2020.105924] [PMID]

[7] Jayaweera M, Perera H, Gunawardana B, Manatunge J. Transmission of COVID-19 virus by droplets and aerosols: A critical review on the unresolved dichotomy. Environmental Research. 2020; 188:109819. [DOI:10.1016/j.envres.2020.109819] [PMID]

[8] La Rosa G, Bonadonna L, Lucentini L, Kenmoe S, Suffredini E. Coronavirus in water environments: Occurrence, persistence and concentration methods - A scoping review. Water Research. 2020; 179:115899. [DOI:10.1016/j.watres.2020.115899] [PMID]

[9] Azuma K, Yanagi U, Kagi N, Kim H, Ogata M, Hayashi M. Environmental factors involved in SARS-CoV-2 transmission: Effect and role of indoor environmental quality in the strategy for COVID-19 infection control. Environmental Health and Preventive Medicine. 2020; 25(1):66. [DOI:10.1186/s12199-020-00904-2] [PMID]

[10] Fiorillo L, Cervino G, Matarese M, D'Amico C, Surace G, Paduano V, et al. COVID-19 Surface persistence: A recent data summary and its importance for medical and dental settings. International Journal of Environmental Research and Public Health. 2020; 17(9):3132. [DOI:10.3390/ijerph17093132] [PMID]

[11] Yang S, Dong Q, Li S, Cheng Z, Kang X, Ren D, et al. Persistence of SARS-CoV-2 RNA in wastewater after the end of the COVID-19 epidemics. Journal of Hazardous Materials. 2022; 429:128358. [DOI:10.1016/j.jhazmat.2022.128358] [PMID]

[12] Tran HN, Le GT, Nguyen DT, Juang RS, Rinklebe J, Bhatnagar A, et al. SARS-CoV-2 coronavirus in water and wastewater: A critical review about presence and concern. Environmental Research. 2021; 193:110265. [DOI:10.1016/j.envres.2020.110265] [PMID]

[13] Kocamemi BA, Kurt H, Sait A, Sarac F, Saatci AM, Pakdemirli B. SARS-CoV-2 Detection in Istanbul Wastewater Treatment Plant Sludges. medRxiv. Preprint. 2020:1-11. [DOI:10.1101/2020.05.12.20099358]

[14] Tanhaei M, Mohebbi SR, Hosseini SM, Rafieepoor M, Kazemian S, Ghaemi A, et al. The first detection of SARS-CoV-2 RNA in the wastewater of Tehran, Iran. Environmental Science and Pollution Research International. 2021; 28(29):38629-36. [DOI:10.1007/s11356-021-13393-9] [PMID]

[15] Ziarani FR, Tahamtan A, Safari H, Tabarraei A, Shahamat YD. Detection of SARS-CoV-2 genome in the air, surfaces, and wastewater of the referral hospitals, Gorgan, north of Iran. Iranian Journal of Microbiology. 2022; 14(5):617-23. [DOI:10.18502/ijm.v14i5.10954] [PMID]

[16] Kumar M, Patel AK, Shah AV, Raval J, Rajpara N, Joshi M, et al. First proof of the capability of wastewater surveillance for COVID-19 in India through detection of genetic material of SARS-CoV-2. The Science of the Total Environment. 2020; 746:141326. [DOI:10.1016/j.scitotenv.2020.141326] [PMID]

[17] Ahmed W, Angel N, Edson J, Bibby K, Bivins A, O'Brien JW, et al. First confirmed detection of SARS-CoV-2 in untreated wastewater in Australia: A proof of concept for the wastewater surveillance of COVID-19 in the community. The Science of the Total Environment. 2020; 728:138764. [DOI:10.1016/j.scitotenv.2020.138764] [PMID]

[18] Mlejnkova H, Sovova K, Vasickova P, Ocenaskova V, Jasikova L, Juranova E. Preliminary study of Sars-Cov-2 occurrence in wastewater in the Czech Republic. International Journal of Environmental Research and Public Health. 2020; 17(15):5508. [DOI:10.3390/ijerph17155508] [PMID]

[19] Pourakbar M, Abdolahnejad A, Raeghi S, Ghayourdoost F, Yousefi R, Behnami A. Comprehensive investigation of SARS-CoV-2 fate in wastewater and finding the virus transfer and destruction route through conventional activated sludge and sequencing batch reactor. The Science of the Total Environment. 2022; 806(Pt 4):151391. [DOI:10.1016/j.scitotenv.2021.151391] [PMID]

[20] Randazzo W, Truchado P, Cuevas-Ferrando E, Simón P, Allende A, Sánchez G. SARS-CoV-2 RNA in wastewater anticipated COVID-19 occurrence in a low prevalence area. Water Research. 2020; 181:115942. [DOI:10.1016/j.watres.2020.115942] [PMID]

[21] Döhla M, Schulte B, Wilbring G, Kümmerer BM, Döhla C, Sib E, et al. SARS-CoV-2 in environmental samples of quarantined households. Viruses. 2022; 14(5):1075. [DOI:10.3390/v14051075] [PMID]

[22] Jeddi F, Karami C, Pourfarzi F, Dargahi A, Vosoughi M, Normohammadi A, et al. Identification coronavirus (SARS-CoV-2) and physicochemical qualities in various water sources and the efficiency of water treatment plants in their removal- case study: Northwest region of Iran. Applied Water Science. 2022; 12(5):89. [DOI:10.1007/s13201-022-01615-5] [PMID]

[23] Vosoughi M, Karami C, Dargahi A, Jeddi F, Jalali KM, Hadisi A, et al. Investigation of SARS-CoV-2 in hospital indoor air of COVID-19 patients' ward with impinger method. Environmental Science and Pollution Research International. 2021; 28(36):50480-8. [DOI:10.1007/s11356-021-14260-3] [PMID]

[24] Razzini K, Castrica M, Menchetti L, Maggi L, Negroni L, Orfeo NV, et al. SARS-CoV-2 RNA detection in the air and on surfaces in the COVID-19 ward of a hospital in Milan, Italy. The Science of the Total Environment. 2020; 742:140540. [DOI:10.1016/j.scitotenv.2020.140540] [PMID]

[25] Cheng VCC, Wong SC, Chen JHK, Yip CCY, Chuang VWM, et al. Escalating infection control response to the rapidly evolving epidemiology of the coronavirus disease 2019 (COVID-19) due to SARS-CoV-2 in Hong Kong. Infect Control Hosp Epidemiol. 2020; 41(5):493-8. [DOI:10.1017/ice.2020.58] [PMID]

[26] Hadavi I, Hashemi M, Asadikaram G, Kalantar-Neyestanaki D, Hosseininasab A, Darijani T, et al. Investigation of SARS-CoV-2 genome in the indoor air and high-touch surfaces. International Journal of Environmental Research. 2022; 16(6):103. [DOI:10.1007/s41742-022-00462-1] [PMID]

[27] Zhou J, Otter JA, Price JR, Cimpeanu C, Meno Garcia D, Kinross J, et al. Investigating Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) surface and air contamination in an acute healthcare setting during the peak of the Coronavirus disease 2019 (COVID-19) pandemic in London. Clinical Infectious Diseases: An Official Publication of the Infectious Diseases Society of America. 2021; 73(7):e1870-7. [DOI:10.1093/cid/ciaa905] [PMID]

[28] Mouchtouri VA, Koureas M, Kyritsi M, Vontas A, Kourentis L, Sapounas S, et al. Environmental contamination of SARS-CoV-2 on surfaces, air-conditioner and ventilation systems. International Journal of Hygiene and Environmental Health. 2020; 230:113599. [DOI:10.1016/j.ijheh.2020.113599] [PMID]

[29] Dargahi A, Jeddi F, Vosoughi M, Karami C, Hadisi A, Ahamad Mokhtari S, et al. Investigation of SARS CoV-2 virus in environmental surface. Environmental Research. 2021; 195:110765. [DOI:10.1016/j.envres.2021.110765] [PMID]

[30] Dargahi A, Jeddi F, Ghobadi H, Vosoughi M, Karami C, Sarailoo M, et al. Evaluation of masks' internal and external surfaces used by health care workers and patients in coronavirus-2 (SARS-CoV-2) wards. Environmental Research. 2021; 196:110948. [DOI:10.1016/j.envres.2021.110948] [PMID]

[31] Rozman U, Knez L, Novak G, Golob J, Pulko A, Cimerman M, et al. Environmental contamination with SARS-CoV-2 in hospital COVID department: Antigen Test, Real-Time RT-PCR and Virus Isolation. COVID. 2022; 2(8):1050-6. [DOI:10.3390/covid2080077]

[32] Marcenac P, Park GW, Duca LM, Lewis NM, Dietrich EA, Barclay L, et al. Detection of SARS-CoV-2 on surfaces in households of persons with COVID-19. International Journal of Environmental Research and Public Health. 2021; 18(15):8184. [DOI:10.3390/ijerph18158184] [PMID]

[33] Cardinale D, Tafuro M, Mancusi A, Girardi S, Capuano F, Proroga YTR, et al. Sponge Whirl-Pak Sampling Method and Droplet Digital RT-PCR Assay for monitoring of SARS-CoV-2 on surfaces in public and working environments. International Journal of Environmental Research and Public Health. 2022; 19(10):5861. [DOI:10.3390/ijerph19105861] [PMID]

[34] Zhao L, Atoni E, Nyaruaba R, Du Y, Zhang H, Donde O, et al. Environmental surveillance of SARS-CoV-2 RNA in wastewater systems and related environments in Wuhan: April to May of 2020. Journal of Environmental Sciences (China). 2022; 112:115-20. [DOI:10.1016/j.jes.2021.05.005] [PMID]

[35] Guerrero-Latorre L, Ballesteros I, Villacrés-Granda I, Granda MG, Freire-Paspuel B, Ríos-Touma B. SARS-CoV-2 in river water: Implications in low sanitation countries. The Science of the Total Environment. 2020; 743:140832. [DOI:10.1016/j.scitotenv.2020.140832] [PMID]

[36] Haramoto E, Malla B, Thakali O, Kitajima M. First environmental surveillance for the presence of SARS-CoV-2 RNA in wastewater and river water in Japan. The Science of the total environment. 2020; 737:140405. [DOI:10.1016/j.scitotenv.2020.140405] [PMID]

[37] Rimoldi SG, Stefani F, Gigantiello A, Polesello S, Comandatore F, Mileto D, et al. Presence and infectivity of SARS-CoV-2 virus in wastewaters and rivers. The Science of the Total Environment. 2020; 744:140911. [DOI:10.1016/j.scitotenv.2020.140911] [PMID]

[38] Chia PY, Coleman KK, Tan YK, Ong SWX, Gum M, Lau SK, et al. Detection of air and surface contamination by SARS-CoV-2 in hospital rooms of infected patients. Nature Communications. 2020; 11(1):2800. [DOI:10.1038/s41467-020-16670-2] [PMID]

[39] Tan L, Ma B, Lai X, Han L, Cao P, Zhang J, et al. Air and surface contamination by SARS-CoV-2 virus in a tertiary hospital in Wuhan, China. International Journal of Infectious Diseases: IJID : Official Publication of the International Society for Infectious Diseases. 2020; 99:3-7. [DOI:10.1016/j.ijid.2020.07.027] [PMID]

[40] Wu S, Wang Y, Jin X, Tian J, Liu J, Mao Y. Environmental contamination by SARS-CoV-2 in a designated hospital for coronavirus disease 2019. American Journal of Infection Control. 2020; 48(8):910-4. [DOI:10.1016/j.ajic.2020.05.003] [PMID]

[41] Kenarkoohi A, Noorimotlagh Z, Falahi S, Amarloei A, Mirzaee SA, Pakzad I, et al. Hospital indoor air quality monitoring for the detection of SARS-CoV-2 (COVID-19) virus. The Science of the Total Environment. 2020; 748:141324. [DOI:10.1016/j.scitotenv.2020.141324] [PMID]

[42] Faridi S, Niazi S, Sadeghi K, Naddafi K, Yavarian J, Shamsipour M, et al. A field indoor air measurement of SARS-CoV-2 in the patient rooms of the largest hospital in Iran. The Science of the Total Environment. 2020; 725:138401. [DOI:10.1016/j.scitotenv.2020.138401] [PMID]

[43] Kwon KS, Park JI, Park YJ, Jung DM, Ryu KW, Lee JH. Evidence of long-distance droplet transmission of SARS-CoV-2 by direct air flow in a restaurant in Korea. Journal of Korean Medical Science. 2020; 35(46):e415. [DOI:10.3346/jkms.2020.35.e415] [PMID]

[44] Sze To GN, Chao CY. Review and comparison between the Wells-Riley and dose-response approaches to risk assessment of infectious respiratory diseases. Indoor Air. 2010; 20(1):2-16. [DOI:10.1111/j.1600-0668.2009.00621.x] [PMID]

[45] Klompas M, Baker MA, Rhee C. Airborne transmission of SARS-CoV-2: Theoretical considerations and available evidence. JAMA. 2020; 324(5):441-2. [DOI:10.1001/jama.2020.12458] [PMID]

[46] Atzrodt CL, Maknojia I, McCarthy RDP, Oldfield TM, Po J, Ta KTL, et al. A Guide to COVID-19: A global pandemic caused by the novel coronavirus SARS-CoV-2. The FEBS Journal. 2020; 287(17):3633-50. [DOI:10.1111/febs.15375] [PMID]

[47] Revilla Pacheco C, Terán Hilares R, Colina Andrade G, Mogrovejo-Valdivia A, Pacheco Tanaka DA. Emerging contaminants, SARS-COV-2 and wastewater treatment plants, new challenges to confront: A short review. Bioresource Technology Reports. 2021; 15:100731. [DOI:10.1016/j.biteb.2021.100731] [PMID]

[48] Wang X, Zheng J, Guo L, Yao H, Wang L, Xia X, et al. Fecal viral shedding in COVID-19 patients: Clinical significance, viral load dynamics and survival analysis. Virus Research. 2020; 289:198147. [DOI:10.1016/j.virusres.2020.198147] [PMID]

[49] Mupatsi, N. Observed and potential environmental impacts of COVID -19 in Africa. Preprints; 2020. [DOI:10.20944/preprints202008.0442.v1]

[50] Mahari S, Roberts A, Shahdeo D, Gandhi S. eCovSens-ultrasensitive novel in-house built printed circuit board based electrochemical device for rapid detection of nCOVID-19. bioRxiv. Preprint; 2020. [DOI:10.1101/2020.04.24.059204]

[51] Michael-Kordatou I, Karaolia P, Fatta-Kassinos D. Sewage analysis as a tool for the COVID-19 pandemic response and management: The urgent need for optimised protocols for SARS-CoV-2 detection and quantification. Journal of Environmental Chemical Engineering. 2020; 8(5):104306. [DOI:10.1016/j.jece.2020.104306] [PMID]

[52] Graham KE, Loeb SK, Wolfe MK, Catoe D, Sinnott-Armstrong N, Kim S, et al. SARS-CoV-2 RNA in wastewater settled solids is associated with COVID-19 cases in a large urban sewershed. Environmental Science & Technology. 2020; 55(1):488-98. [DOI:10.1021/acs.est.0c06191] [PMID]

[53] Sauter O, La Haye RJ, Chang Z, Gates DA, Kamada Y, Zohm H, et al. Beta limits in long-pulse tokamak discharges. Physics of Plasmas. 1997; 4(5):1654-64. [DOI:10.1063/1.872270]

[54] Fernández-Raga M, Díaz-Marugán L, García Escolano M, Bort C, Fanjul V. SARS-CoV-2 viability under different meteorological conditions, surfaces, fluids and transmission between animals. Environmental Research. 2021; 192:110293. [DOI:10.1016/j.envres.2020.110293] [PMID]

[55] Zhou H, Yang J, Zhou C, Chen B, Fang H, Chen S, et al. A review of SARS-CoV2: Compared with SARS-CoV and MERS-CoV. Frontiers in Medicine. 2021; 8:628370. [DOI:10.3389/fmed.2021.628370] [PMID]

[56] Faezeh Seif, Noorimotlagh Z, Mirzaee SA, Kalantar M, Barati B, Fard ME, et al. The SARS-CoV-2 (COVID-19) pandemic in hospital: An insight into environmental surfaces contamination, disinfectants' efficiency, and estimation of plastic waste production. Environmental Research. 2021; 202:111809. [DOI:10.1016/j.envres.2021.111809] [PMID]

[57] Paul D, Kolar P, Hall SG. A review of the impact of environmental factors on the fate and transport of coronaviruses in aqueous environments. npj Clean Water. 2021; 4:1-13. [DOI:10.1038/s41545-020-00096-w]

Appendix 1.

Section/Topic	#	Checklist Item	Reported on Page #
		Title	
Title	1	Identify the report as a systematic review, meta-analysis, or both.	1
		Abstract	
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	2
		Introduction	
Rationale	3	Describe the rationale for the review in the context of what is already known.	1
Objectives	4	Provide an explicit statement of questions being addressed concerning participants, interventions, comparisons, outcomes, and study design (PICOS).	2
		Methods	
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g. web address), and, if available, provide registration information including registration number.	3
Eligibility criteria	6	Specify study characteristics (e.g. PICOS, length of follow-up) and report characteristics (e.g. years considered, language, publication status) used as criteria for eligibility, giving rationale.	4
Information sources	7	Describe all information sources (e.g. databases with coverage dates, contact with study authors to identify additional studies) in the search and the date last searched.	3
Search	8	Present a complete electronic search strategy for at least one database, including any limits used so that it could be repeated.	4
Study selection	9	State the process for selecting studies (i.e. screening, eligibility, included in a systematic review, and, if applicable, included in the meta-analysis).	4
Data collection process	10	Describe the data extraction method from reports (e.g. piloted forms, independently, in duplicate) and any processes for obtaining and confirming investigator data.	3-4
Data items	11	List and define all variables for which data were sought (e.g. PICOS, funding sources) and any assumptions and simplifications made.	-----
Risk of bias in individual studies	12	Describe methods used for assessing the risk of bias in individual studies (including specification of whether this was done at the study or outcome level) and how this information will be used in any data synthesis.	-----
Summary measures	13	State the principal summary measures (e.g. risk ratio, difference in means).	-----
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g. I^2) for each meta-analysis.	-----
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g. publication bias, selective reporting within studies).	-----
Additional analyses	16	Describe methods of additional analyses (e.g. sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	-----
		Results	
Study selection	17	Give the number of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	4
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g. study size, PICOS, follow-up period) and provide the citations.	4-6
Risk of bias within studies	19	Present data on the risk of bias of each study and, if available, any outcome level assessment (see item 12).	-----

Section/Topic	#	Checklist Item	Reported on Page #
Results of individual studies	20	For all outcomes considered (benefits or harms), present for each study: (a) simple summary data for each intervention group, (b) effect estimates and confidence intervals, ideally with a forest plot.	-----
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	-----
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	-----
Additional analysis	23	Give results of additional analyses, if done (e.g. sensitivity or subgroup analyses, meta-regression [see Item 16]).	-----
		Discussion	
Summary of evidence	24	Summarize the main findings, including the strength of evidence for each primary outcome; consider their relevance to critical groups (e.g. health-care providers, users, and policymakers).	6-7
Limitations	25	Discuss limitations at the study and outcome level (e.g. risk of bias) and review level (e.g. incomplete retrieval of identified research, reporting bias).	-----
Conclusions	26	Provide a general interpretation of the results in the context of other evidence and implications for future research.	7
		Funding	
Funding	27	Describe funding sources for the systematic review and other support (e.g. supply of data) and; role of funders for the systematic review.	---

Abbreviations: PICO: Population, intervention, control, outcomes.

This Page Intentionally Left Blank