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Water science under the global epidemic of COVID-19: Bibliometric tracking on COVID-19 publication and further research needs

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ABSTRACT

There are overwhelming increases of studies and over 200,000 publications related to all the aspects of COVID-19. Among them, 262 papers were published by authors from 67 countries regarding COVID-19 with water science and technology. Although the transmission routes of SARS-CoV-2 in water cycle have not been proved, the water and wastewater play an important role in the control of COVID-19 pandemic. Accordingly, it is scholarly relevant and interesting to look into publications of COVID-19 in water science and technology to track the investigations for moving forward in the years to come. It is believed that, through the literature survey, the question on what we know and what we do not know about COVID-19 so far can be clear, thus providing useful information for helping curbing the epidemic from water sector. This forms the basis of the current study. As such, a bibliometric analysis was conducted. It reveals that wastewater-based epidemiology (WBE) has recently gained global attention with the source and survival characteristics of coronavirus in the aquatic environment; the methodology of virus detection; the water hygiene; and the impact of the COVID-19 pandemic on the water ecosystem being the main topics in 2020. Various studies have shown that drinking water is safety whereas wastewater may be a potential risk during this pandemic. From the perspective of the water cycle, the scopes for further research needs are discussed and proposed, which could enhance the important role and value of water science in warning, monitoring, and predicting COVID-19 during epidemic outbreaks.

1. Introduction

The coronavirus disease 2019 (COVID-19) caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) was epidemically spreading throughout the world in 2020. As the world hopes for swift roll-outs of COVID-19 via vaccines in 2021, researchers' ambitions are likely to still be constrained by the continuing pandemic and its effects for the moment. No doubt, COVID-19 study was the hottest topic throughout 2020. The scientific community has carried out massive research in various fields to respond this global challenge, such as tracking the source of the virus, exploring possible treatments, and addressing the impact of the epidemic on the environment and socio-economy. As a whole, investigation of the COVID-19 became the most urgent priority while over 200,000 studies were published in 2020 [1]. More significantly, some major publishers removed paywalls from papers about COVID-19 last year to maximally speed development and findings into curbing the virus's impact such as strategies, vaccines and treatment approaches.

Water and wastewater play a particularly important role in the spread and control of coronavirus pandemics because clean water is the basic resource for life and any related activities including virus eradicating. Globally, scientists engaged in water research began their work at the beginning of the epidemic. Hundreds of articles were published in 2020 which focused on the investigation and discussion of COVID-19 related with water sector (science and technology). Several webinars to timely update investigation and exchange of ideas about COVID-19 in the water sector were also organized. There has been consensus on the role of water, sanitation and personal hygiene in reducing SARS-CoV-2 transmission and supporting the response to COVID-19 [2–4]. On the other hand, scientific reports indicated that SARS-CoV-2 has been

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widely detected in wastewater [5–18]. The occurrence, fates and potential treatment approaches of this virus in the water cycle should be urgently studied.

General, a series of scientific output confirmed that the water scientific community has offered possible solutions to COVID-19. Yet, considerable uncertainty remains in the information about the fate of SARS-CoV-2 in water and wastewater and the removal efficiency for virus existing treatment infrastructure. It is necessary and interesting to look back at the publications to track the investigations for the purpose of moving forward in the future. As such, we have reviewed the scientific publications related to COVID-19 in water and wastewater. Information extracted from the published literature was summarized regarding what we know about COVID-19 in water based on bibliometric analysis. Furthermore, future efforts and research agenda to help curbing the COVID-19 pandemic in water industry for professionals in the field of the water science and technology were proposed.

2. Overall publications related to weekly count case numbers of the epidemic

Several types of publications, such as peer-reviewed articles, reports, editorial material, letters, and opinions in the Web of Science, Dimensions, PubMed, and Google Scholar database, were searched. The terms of "COVID-19", "SARS CoV-2", "Severe acute respiratory syndrome coronavirus 2", "2019 novel coronavirus", "coronavirus 2019", "coronavirus disease 2019", "2019-novel CoV", "2019 nCoV", "HCoV-2019", and "Water", "Drinking water", "Wastewater", "Sewage", "Sludge", were used to search in the literature and databases. The suitable papers were based on the principles of that: 1) the accepted time of publication was from January 1, 2020 to December 31, 2020; 2) publications must closely describe the relationship between the water/wastewater (science and technology) and COVID-19/SARS CoV-2; 3) each publication must have complete article structure, for those without references will be removed; 4) the preprint articles are not included. The brief literature collection process includes several steps. The initial search yielded over 1329, 1799, 217, and 3150 English papers in Web of Science, Dimensions, Pub Med, and Google Scholar, respectively. After removing duplicate records, 1030 papers remained. Then, by reading the title and abstract, the 762 records were screened. The publications were finally narrowed down to 262 full-text articles based on the above principles, which include 192 articles by context screening and 70 articles from snowball screening. These articles can then be divided into four categories of research article, review, editorial material & letters, and others (e.g. report, short communication, commentary, opinion, and news) (Fig. 1).

In Fig. 1, the publications related to weekly count case numbers of the epidemic are jointly illustrated. Globally, there were 81,484,663 confirmed cases and 701,027 deaths of COVID-19 from January 4, 2020 to December 31, 2020 [19]. During this period, scientific publications also show a sharp increase together with the increase of the confirmed case numbers. The first accepted journal publication was an editorial perspectives in *Environmental Science: Water Research & Technology* on March 18, 2020. In this paper, the authors advocated that the water engineers and professionals need to understand the nature and fate of coronavirus in urban water cycle. The authors also proposed some future research needs, such as upgrading the existing water and wastewater treatment infrastructure; understanding the efficiency of inactivating the coronavirus; monitoring drinking water distribution system; and discussing the potential risks to the ecosystem and human health of the massive use of drugs; as well as the water and sanitation systems in developing countries [20]. Later, opinions and reviews were also accepted in large numbers. The first research article on the detection of the virus in sewage was accepted on April 9, 2020. In the study, the quantitative real-time reverse transcription PCR (qRT-PCR) method was applied to detect SARS-CoV-2 RNA in hospital sewage. The result showed the positive at the entrance of the sewage disinfection pool and the negative after disinfection [21]. From the summer, the number of publications increased dramatically. While 48 documents were accepted before June 1, over 166 had been accepted till September 1, perhaps because the scientists began to return to their posts and then conduct research after the end of the first lockdown period.

Although 70.7% of the publications were peer-reviewed scientific journal papers, the number of review papers (106, 40.5%) was more than research articles (79, 30.2%). The review papers provided broad information and deep analysis about the COVID-19 related to water science and technology in various aspects. Opinion-type articles also accounted for a large proportion, while water engineers and professionals provided key viewpoints and information based on their knowledge and understanding to prevent and control virus transmission in water environment. For example, Lodder and de Roda Husman [22]

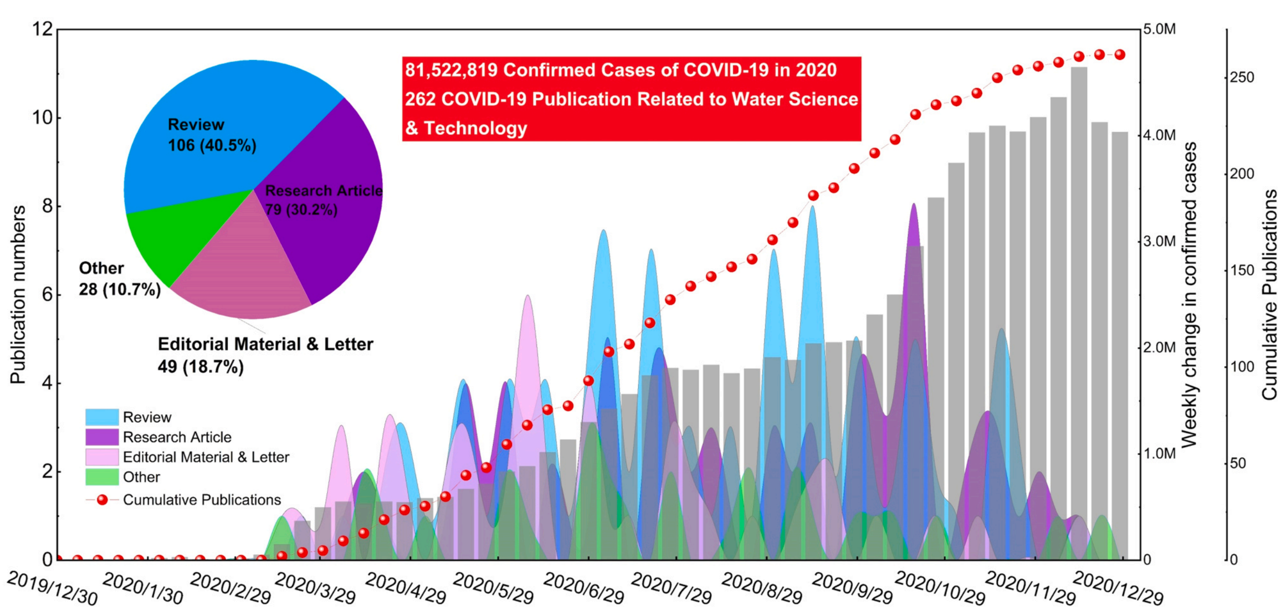

Fig. 1. The COVID-19 publication related to water science and technology with coronavirus cascade during 2020.
Source for COVID-19 cases data: https://covid19.who.int/ (Accessed on 10 January 2021).

provided perspective on “SARS-CoV-2 in wastewater: potential health risk, but also data source”, saying that the wastewater could be a sensitive surveillance system and early warning tool in pandemic. Wastewater-based epidemiology (WBE) has been quickly and widely tested in many countries and regions around the world, such as Spain [11,23], Italy [8,24,25], UK [26], Netherlands [13], USA [27,28], India [14,29], Japan [15], Germany [7], Australia [17,30], and United Arab Emirates [16]. Many countries, such as Ireland and China, were conducting such kind of research to closely monitor wastewater related SARS-CoV-2. These studies aimed to provide a diversified way to gain a deeper understanding of the COVID-19 with the water industry and establish the platform to help curbing the ensuing and future epidemics.

3. Bibliometric tracking of the investigation trends since outbreak

Fig. 2 presents the network visualization map of co-occurrence based on key terms extracted from the titles and the abstracts of the 262 publications. The bibliometric analysis was performed on the VOS-viewer software (version 1.6.15), in which the processes were referred to Ji, et al. [31]. The colors in Fig. 2 represent different clusters. Research on cluster 1 is focused mostly on the source and survival characteristics of coronavirus in aquatic environment. There are some evidences to support the possibility of water transmission of SARS-CoV-2. These include: 1) isolated virus from infected individuals’ excrement [32,33]; 2) detected virus RNA in municipal wastewater [7,10,14,24]; 3) investigating the virus persistence in wastewater and tap water [34,35]. All these show highly stability under certain conditions. No doubt, it is believed that such kind of information triggered people’s concerns. Cluster 2 is in close relation to cluster 1. The methodology of virus detection is a prerequisite to ensure SARS-CoV-2 research in water and wastewater. The achievements of these investigations have been applied to the WBE system. In addition, the torrent of COVID-19 has significantly affected the socio-economy and daily life. Cluster 3 highlights the “Water, Sanitation and Hygiene (WASH)” as a critical control measure in COVID-19 pandemic. The importance of water and virus control is generally accepted and practiced, not only in drink water, but in daily water hygiene as well. The challenges of water availability, accessibility, and quality still remain a matter both in developing and developed countries because of impact of COVID-19 pandemic [36–38]. Meanwhile, water can play an important role in revitalizing the economy after COVID-19 [37]. Finally, cluster 4 concerns on the impact of COVID-19 pandemic on water ecosystem. The government management measures during COVID-19 on the aquatic environment seem to have both positive and negative impacts. The lockdown measures restricted the human activity, with a consequence, and improved the surface water quality [39,40]. However, disinfection threatens the aquatic ecosystem. Excessive use of disinfectants and the cumulative toxicity of disinfection by-products (DBPs) may destroy the fragile aquatic ecosystem [41,42].

Fig. 3 presents the density visualization map of the co-occurrence key terms with the warm red colors representing hot areas in the COVID-19 publication related to water science and technology. Sampling and detecting the SARS-CoV-2 and its RNA in wastewater are undoubtedly the hottest of research in 2020. Although the SARS-CoV-2 RNAs in wastewater have been widely reported, the method of sampling, storage, concentration, isolation, and detection are not the same in each study [43]. Obviously, as a key step in WEB system, the analytical protocols need more evaluation and investigation, which will be discussed in

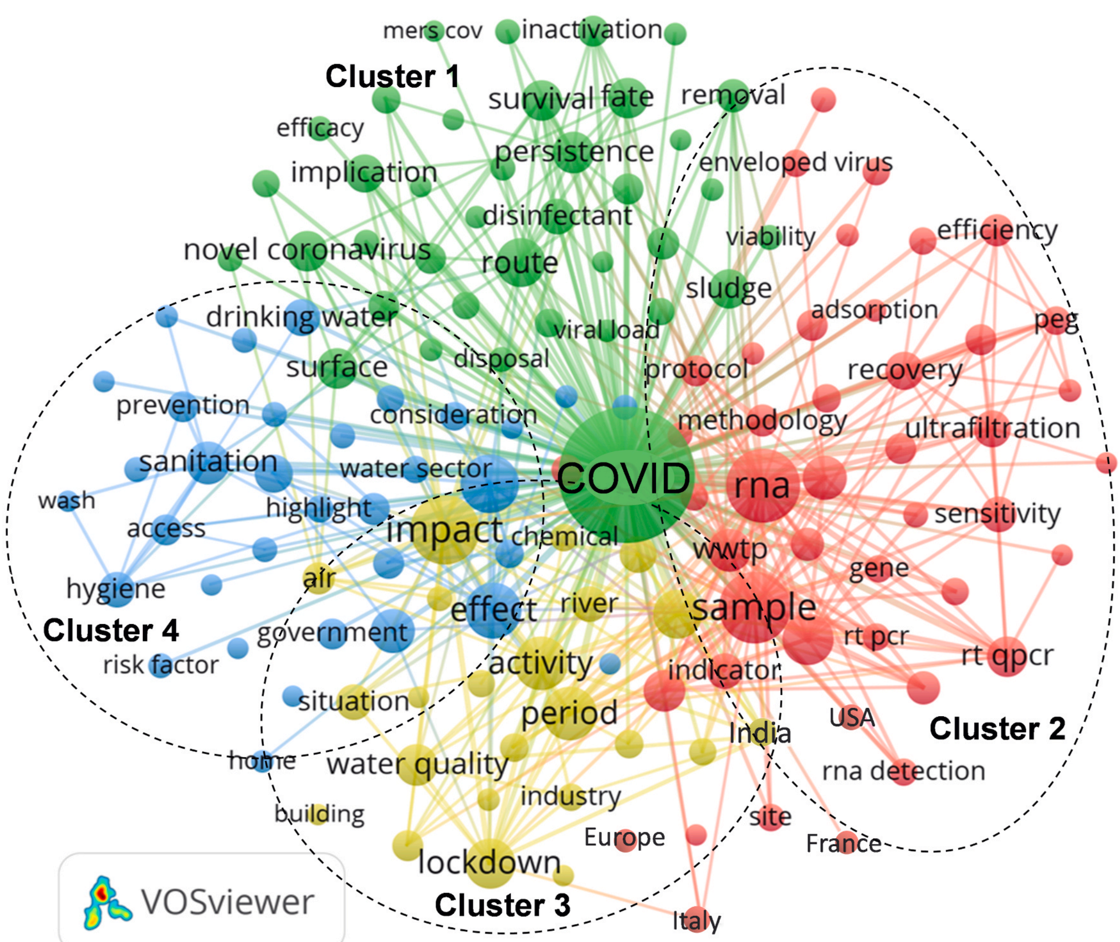

Fig. 2. Key terms occurrences network visualization map in COVID-19 publication related to water science and technology.

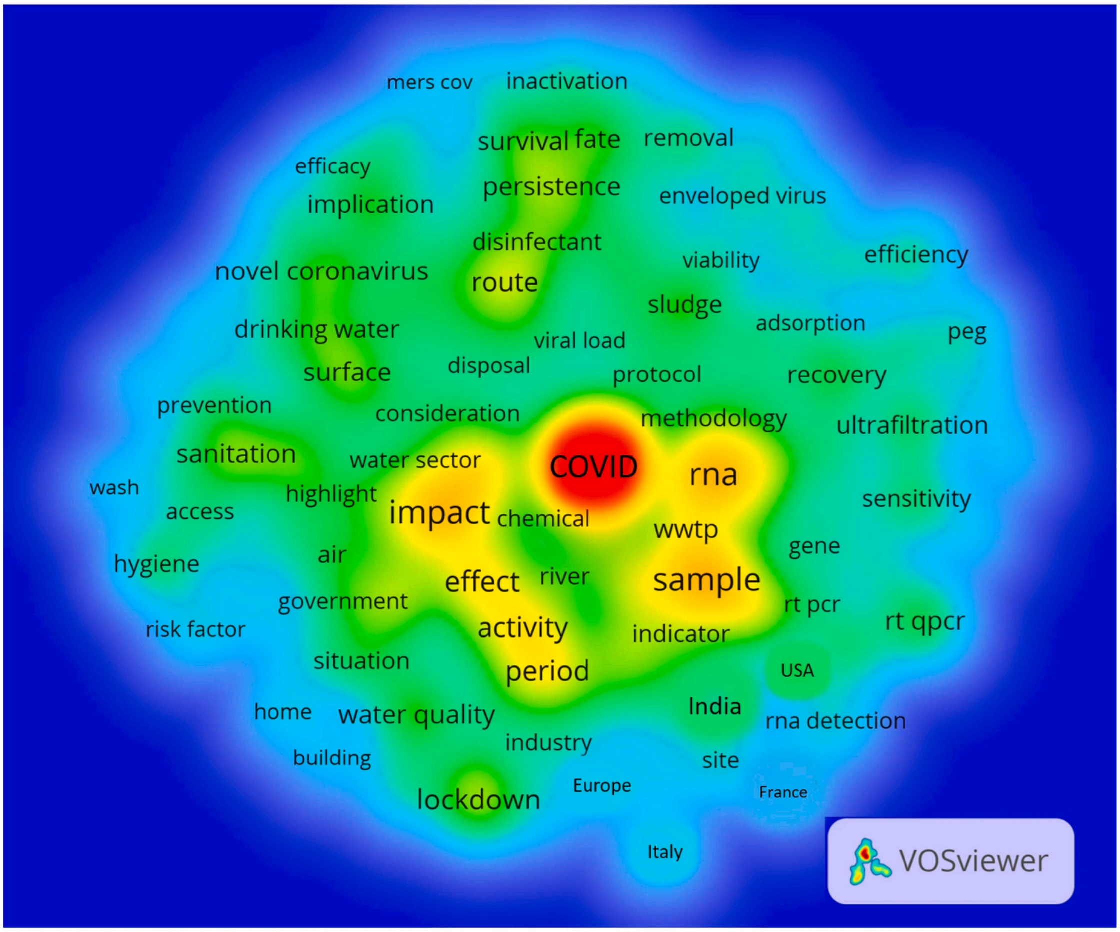

Fig. 3. The density visualization map of co-occurrence keywords COVID-19 publication related to water science and technology

detail in later section of the review. The removal and fate of the virus in wastewater treatment plant (WWTP) have been widely investigated as WWTP is the wastewater collection and treatment site in the urban water cycle [44,45]. Up till now, conventional WWTPs may be sufficient to eliminate the SARS-CoV-2, and there are no reports of transmission via contact with the effluent of WWTPs. Moreover, it is well known that the basic design principle of WWTPs is to avoid the spread of potential pathogens in wastewater. Although the SARS-CoV-2 RNA has been detected in secondary effluent in some cases [11,15], the infectivity of virus still needs to be determined. In addition, the tertiary treatment and disinfection with a higher dosage can enhance the inactivation of SARS-CoV-2 in WWTPs [5]. Accordingly, the survival and persistence of coronaviruses in the environment through water-related routes are a concern and have also been highly investigating. The infectious of SARS-CoV-2 in wastewater can be remained for a few days [34], depending on the environmental conditions. Moreover, the impact of water safety and ecosystem and human health is also highly concerned.

So far, there are 67 countries and regions contributing to the water science and technology with COVID-19 research activity (Fig. 4(a)). The country distribution of publications revealed a strong predominance of articles from the USA, India, UK, China, and Italy. Authors belonged to these countries have contributed 184 publication, while the USA has published more than a quarter of the total. Furthermore, regarding COVID-19 research types related to water science and technology, the USA is undoubtedly the most comprehensive. It is research directions include measurement of SARS-CoV-2 RNA in wastewater and sewage sludge [28,46]; investigation of the persistence of SARS-CoV-2 in water and wastewater [34]; discussion of the potential transmission for SARS-CoV-2 in the water cycle [47,48]; application of WBE for tracking COVID-19 [27,49]; summarization of water policy and law to respond to COVID-19 [50,51]; and spotlight on urban water quality under the pandemic [52] etc. India is the second largest productive country regarding wastewater surveillance [14], water quality [53], and water ecology [54], etc. Some countries only have literature reviews without field research [55,56], which may depend highly on the country's scientific research conditions and socio-economic levels. The technology and resource-poor regions remain under-studied. Generally, North America, Asia, Europe, and Oceania are active for scientific research and publication. However, it is evident that COVID-19 has disrupted science, reflecting the effect of the pandemic.

Travel bans, social distancing, 'lockdown' and closed borders hinder communication across the academic interface, but international cooperation and research have not been interrupted. Fig. 4(b) presents the cooperative publishing of articles among the top 10 countries. The USA, Australia, Japan, and India are active cooperative communities for documents publishing. Webinars and online conferences are important communication ways for academic exchange and dissemination during the pandemic. International Water Association (IWA) [57–59], International Water Resources Association (IWRA) [60], Water Research Foundation (WRF) [61], and United States Environmental Protection Agency (USEPA) [62], etc. have held a series of webinars to share latest research activities/outcomes and to address some issues related to water and COVID-19.

Table 1 presents the top 10 cited research articles. The detection of SARS-CoV-2 in different types of wastewaters is of greatest concern to researchers. Ahmed, et al. [17] published a paper entitled "First confirmed detection of SARS-CoV-2 in untreated wastewater in Australia: A proof of concept for the wastewater surveillance of

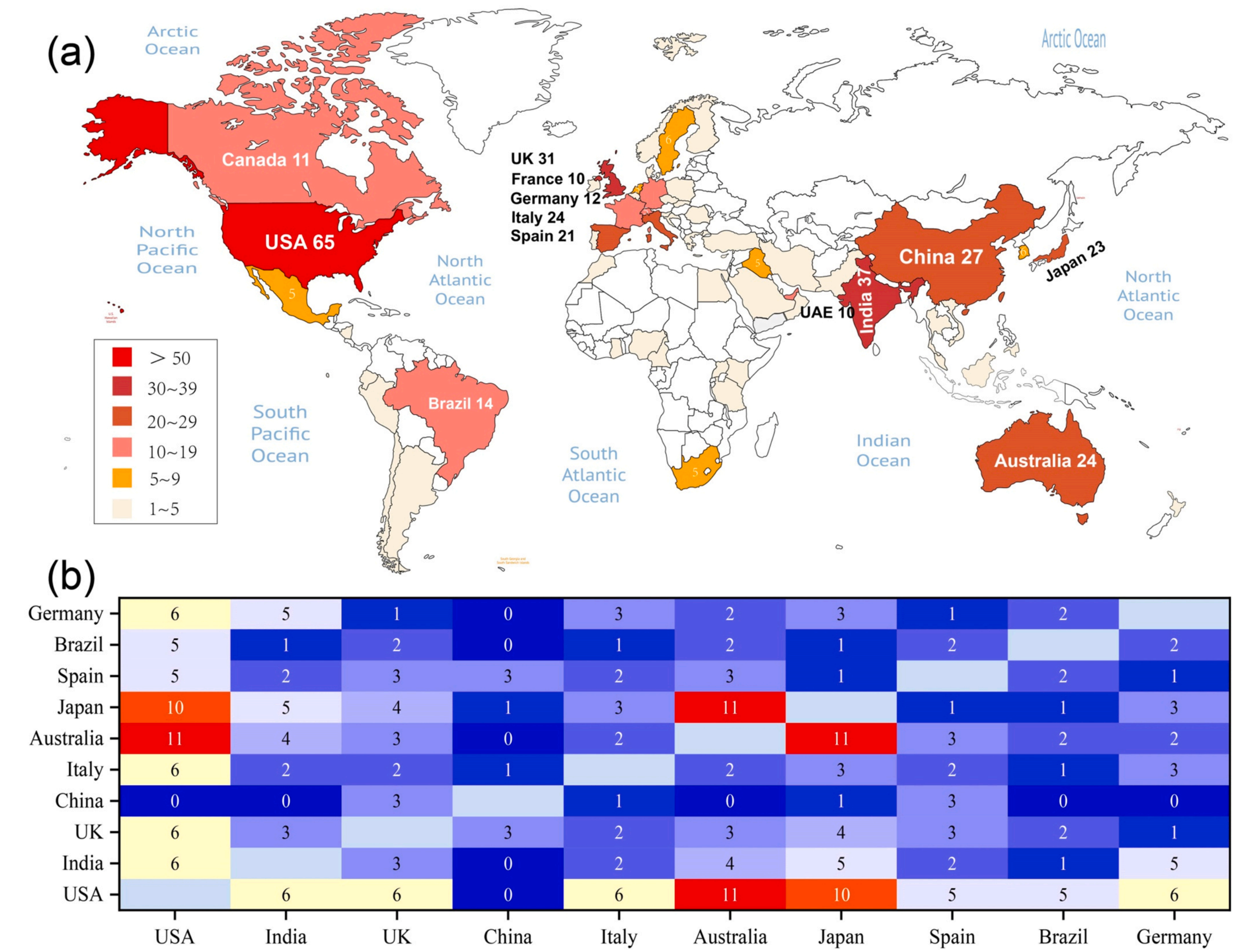

Fig. 4. The countries contributing to COVID-19 publication with water (a) and the cooperative publishing of articles among the top 10 countries (b).

COVID-19 in the community" in *Science of the Total Environment* on 15 April 2020, which was cited over 300 times from Google Scholar database by the end of 2020. They detected the presence of SARS-CoV-2 in the wastewater and then used the Monte Carlo approach to estimate the number of infected individuals in the watershed based on the number of RNA copies observed in the wastewater and proved that the WBE system could provide valuable information on monitoring the prevalence of infections among the population. There is an increased interest in the occurrence of SARS-CoV-2 RNA in wastewater based on other articles with high citation. In addition to the monitoring of SARS-CoV-2 in the wastewater or surface water, the assessment of the impact of COVID-19 pandemic on nature water bodies has also received extensive attention [40]. In term of the source of high cited research article, *Science of the Total Environment* occupied absolutely statues (6 for 10). Coincidentally, all the water related COVID-19 papers have been published in 111 journals. *Science of the Total Environment* published 69 papers, the largest source of publications. As the top professional journal of water science and technology, *Water Research* ranked second, with 9 peer-reviewed articles published.

4. State of the knowledge and research needs

4.1. The facts of COVID-19 with water

Overview of the pass year, the presence of SARS-CoV-2 in aquatic environment is an uncontroversial fact. Over 20 countries and territories have reported relevant evidences (Fig. 5). It was not only presented in raw/untreated wastewater, the SARS-CoV-2 was detected in effluent from secondary treatment and sewage sludge as well, even in rivers [10, 18]. According to Bhowmick et al. [63], the virus has various routes into the water environment, especially in the urban water cycle. The SARS-CoV-2 may hide in faeces, urine, or vomit of the infected person, and then enter the sewage network. But in general, there are limited studies on the persistence of SARS-CoV-2 in water and wastewater. Mean T_{90} of viable infectious SARS-CoV-2 with a high-starting titer (10^5 $TCID_{50}$ mL^{-1}) in wastewater and tap water at 20 ℃ in laboratory is 1.6 and 2.0 days, respectively [34]. In conventional wastewater treatment processes, the primary treatment (screens, grit chamber, primary clarifier) at WWTPs may not be effective because of the size of the coronavirus (60–220 nm), whereas the activated sludge flocs adsorption and membrane filtration could effectively remove coronaviruses from the aqueous phase [29,64]. However, the inactivation process is highly dependent on tertiary treatment with chemical oxidation disinfection and/or UV treatment [6]. Comparing the concentration of SARS-CoV-2 RNA in wastewater before and after treatment suggests that 1–2 log_{10} viral titers can be removed [65], depending on the process and operational conditions. To date, however, the research on the infectivity of SARS-CoV-2 in wastewater is very limited, which requires trained staff and specialized equipment. One study shows that the infectivity of SARS-CoV-2 was null both in raw or treated wastewater, despite the

Table 1
The top 10 cited research articles in COVID-19 publication related to water science and technology.

No	Title	First Author	Corresponding Author	Accepted	Cited Times[a]	Source
1	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	Warish Ahmed	Warish Ahmed	15 April 2020	336	Science of the Total Environment
2	SARS-CoV-2 RNA in wastewater anticipated COVID-19 occurrence in a low prevalence area	Walter Randazzo	Gloria Sanchez	12 May 2020	177	Water Research
3	First detection of SARS-CoV-2 in untreated wastewaters in Italy	Giuseppina La Rosa	Giuseppina La Rosa	21 May 2020	151	Science of the Total Environment
4	Presence of SARS-Coronavirus-2 RNA in sewage and correlation with reported COVID-19 prevalence in the early stage of the epidemic in the Netherlands	Gertjan Medema	Gertjan Medema	20 May 2020	147	Environmental Science & Technology Letters
5	SARS-CoV-2 titers in wastewater are higher than expected from clinically confirmed cases	Fuqing Wu	Eric J. Alm	6 July 2020	127	mSystems
6	Computational analysis of SARS-CoV-2/COVID-19 surveillance by wastewater-based epidemiology locally and globally: Feasibility, economy, opportunities and challenges	Olga E.Hart	Rolf U. Halden	19 April 2020	114	Science of the Total Environment
7	SARS-CoV-2 RNA detection of hospital isolation wards hygiene monitoring during the Coronavirus Disease 2019 outbreak in a Chinese hospital	Jie Wang	Ting ting Qu	9 April 2020	91	International Journal of Infectious Diseases
8	Presence and infectivity of SARS-CoV-2 virus in wastewaters and rivers	Sara GiordanaRimoldi	Fabrizio Stefani	10 July 2020	81	Science of the Total Environment
9	First environmental surveillance for the presence of SARS-CoV-2 RNA in wastewater and river water in Japan	Eiji Haramoto	Eiji Haramoto	19 June 2020	78	Science of the Total Environment
10	COVID-19 and surface water quality: Improved lake water quality during the lockdown	Ali P. Yunus	Ali P. Yunus	24 April 2020	66	Science of the Total Environment

[a] number of citations as of the end of 2020.

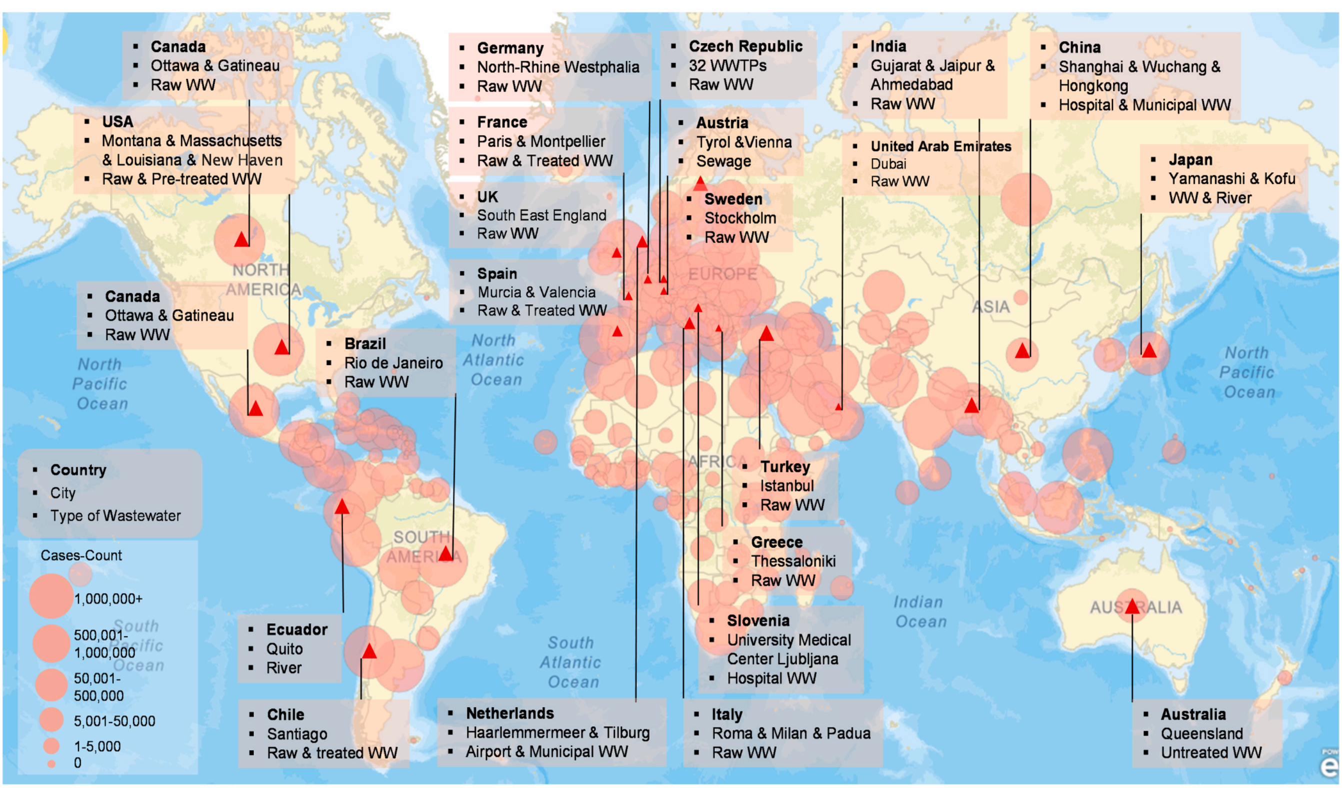

Fig. 5. Confirmed cases of SARS-CoV-2 detection in global aqueous environment.

presence of viral RNA in the samples in field investigation in Italy during the pandemic [10].

Due to the virus transfer from the aqueous phase to the solids phase by adsorption, precipitation, and filtration, the sludge is a potential reservoir of SARS-CoV-2 in water and wastewater treatment [12,66,67]. While limited information about the SARS-CoV-2 in sludge, the risk of virus transmission in sludge disposal should not be ignored as the complex compounds in the sludge can shield viruses from disinfection [68].

The clear water is a fundamental resource to fight the pandemic. So far, there is no evidence to show that the SARS-CoV-2 was detected in drinking water. Moreover, the SARS-CoV-2 is an enveloped virus with a single-stranded RNA, it is less persistent in water than other non-enveloped viruses [69]. Waterworks or drinking water treatment plants are believed to be enough to remove pathogen and non-enveloped viruses, which should also inactivate the SARS-CoV-2. What we are trying to pay the attention is the safety of the water supply network system and the concentration of residual chlorine and/or monochloramine in the terminal water.

WBE provides a new idea for tracing COVID-19 source and monitoring infection dynamic in the community (Fig. 6). SARS-CoV-2 RNA can be detected in sewage before clinically confirmed cases [13,26,70], which supports that WBE could be a sensitive and an early warning tool for COVID-19 epidemiological surveillance. On the other hand, there is a correlation between the concentration of SARS-CoV-2 RNA in the municipal wastewater and the rise and fall of cases in COVID-19 pandemic [12,47,71]. These successful applications of WEB have prompted some countries to plan and implement national wastewater monitoring programs, which can be used as virus tracking tools to supplement existing public health indicators [72].

4.2. The scope for further research needs

Numerous publications in 2020 demonstrated and enhanced the important role and value of water science in warning, monitoring, and predicting COVID-19 during the epidemic outbreaks. No doubt, further studies are needed to explore the details of the relation between COVID-19 and the water environment.

4.2.1. The potential transmission of SARS-CoV-2 in the collection, treatment, and distribution of water cycle

There are several publications exploring the potential SARS-CoV-2 transmission via wastewater plumbing systems in buildings [73,74]. Obviously, this is the important study with high value of COVID-19 early warning and curbing. However, more studies are needed to find nodes that may be overlooked and eradication of this transmission route. In the water/wastewater treatment process, workers dealing with drinking water, wastewater, and sludge may face potential risks. The risks of transmission from direct contact and derived from the sewage-derived aerosol need to be assessed [75]. For the distribution of wastewater systems, the sludge and wastewater discharged from WWTPs are potential infection risks, which may include coronaviruses. There are very limited research reports on the issue of SARS-CoV-2 RNA being detected in receptors water bodies. Rimoldi et al. [10] detected SARS-CoV-2 RNA in rivers in Italy and found no infectivity. Another research report on SARS-CoV-2 RNA being detected in river water is from a low sanitation country of Ecuador, but the infectivity of SARS-CoV-2 has not been discussed [18]. Therefore, the survival characteristics of the virus in the receiving environment (lakes, rivers, soil, etc.) must be further evaluated. On the other hand, for drinking water distribution, network accident and cross-contamination are the most likely source of risk, while the biological safety of booster pumping stations in high-rise buildings also needs further study.

4.2.2. The survival/infection of SARS-CoV-2 in water cycle under field conditions

To date, only a few experiments have studied the survival of SARS-CoV-2 in tap water and wastewater. These experiments are cultured under relatively stable conditions (fixed temperature, constant nutrient substrate), while the survival rates could be different under complexly and variability field conditions. There are some key nodes that need to pay attention in water cycle: 1) wastewater plumbing systems: It is necessary to understand the survival features of virus from source to sink because the wastewater needs a certain time to be transported to a centralized WWTP; 2) wastewater treatment processes: Although some studies have described the fate of coronaviruses in WWTPs with observations of surrogates, the need for confirming the real removal performance of SARS-CoV-2 in treatment process is desirable. Moreover, mastering the removal or inactivating mechanism can further develop wastewater treatment technologies that efficiently remove coronavirus to avoid waste of resources and secondary risks caused by excessive operations.

4.2.3. The methods for the detection and quantification of coronaviruses in aquatic environment

The RT-qPCR and nested RT-PCR are available for detecting SARS-CoV-2 in wastewater, but more research is needed to effectively recover and optimize RNA extraction methods from different water matrices. In addition, the main drawbacks of PCR-based methods for viral nucleic acid detection are time-consumption and high costs. The paper-based devices may provide a "sample-to-answer" tool for near real-time and continuous detection of SARS-CoV-2 in wastewater [76]. It is critical indeed to develop reliable, cheap, easy-to-use protocol/tool for wastewater analysis to help control the pandemic in low- and middle-income countries and remote rural areas.

4.2.4. The standardized protocol for WBE

The research and application about WBE in COVID-19 has recently gained global attention, but there is an obvious need to establish a standardized protocol to strengthen the science of methodology and promote information sharing. Both WRF and IWA have held international webinars with the themes of "Environmental surveillance of COVID-19 indicators in sewersheds" [61] and "COVID-19: Wastewater-based epidemiology" [59], respectively. These Webinars share the cases and results of the WBE monitoring in COVID-19 and presented some new recommendations in several areas for WBE practices. The optimized protocols for SARS-CoV-2 detection and quantification from sampling to reporting the results in WBE have been

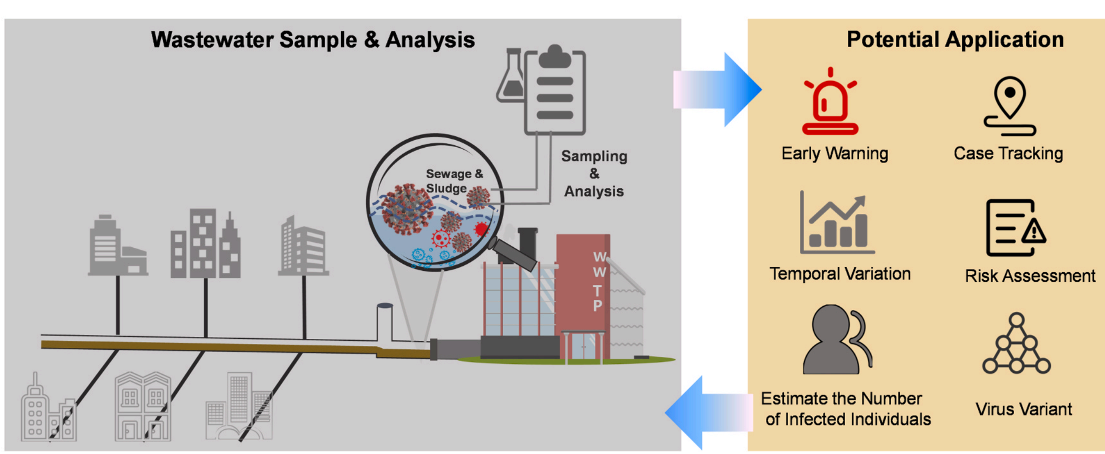

Fig. 6. Schematic diagram of Water-Based Epidemiology (WBE) and potential application (Modified from Farkas, et al. [65]).

discussed in great details in Michael-Kordatou et al. [67] and Daughton [77]. Of course, improving the detection sensitivity of SARS-CoV-2 RNA in sewage is the basis for reflecting the role of WBE early warning and monitoring. In addition, measuring wastewater solids may be more sensitive than measuring SARS-CoV-2 in wastewater [9,28]. Meanwhile, research on the viral load per an infected person or population and sewage network transportation efficiency, as well as the decay rate of viruses can provide more reliable data for WBE prediction models [78, 79]. All of these approaches and proposals need further study and standardized protocol should be established.

4.2.5. The secondary risk in water related with COVID-19

In order to control the spread of SARS-CoV-2 in the environment, the intensified disinfection has been undertaken in indoor and outdoor and water treatment process. The high concentrations of disinfectants and harmful disinfection by-products (DBPs) will pose potential risks to water quality and safety of water environment [41,42]. There is the need to assess water quality and aquatic ecological integrity in before, during, and after the COVID-19 pandemic, and to develop novel disinfection technologies to minimize the environmental hazard load of disinfectants in water treatment. Similarly, the medical service is increasing the use of antiviral drugs to treat patients, which will have potential adverse effects on ecosystems when its residues or metabolites were discharging into wastewater and then entering water environment.

Another potential secondary risk comes from the stagnant water in reopening buildings after extended stagnation during the pandemic. Stagnant water can have chemical and microbiological contaminants that pose potential health risks to occupants [80]. In particular, water stagnation in buildings may lead to *Legionella* growth, but study on the relationship between Legionnaires' disease cases and COVID-19 lockdowns is still limited [81]. This should be considered to ensure the safety building water system and devices when reopening buildings.

As an effective and inexpensive way to prevent the coronavirus outbreak, personal protective equipment (PPE) has significantly increased in the demand and consumption during the COVID-19 [82, 83]. However, after a large amount of PPE is used, the challenge is how to dispose of such plastic products. It has been estimated that 1.56 billion masks could enter ocean in 2020, which pose an existential threat to marine wildlife and ecosystems [84]. In particular, it is noted that plastics will be further broken down into microplastics (MPs) which are regarded as an emerging pollutant [85]. Actually, limited information was exists in the literature on the source, abundance, and distribution of PPE in aquatic environment. Some scientists have initially studied its behavior in the marine environment [86,87], but in the freshwater environment it remains unclear.

4.2.6. Water and digital revolution in pandemic

The ongoing COVID-19 limits human activities, but provides an opportunity to focus on investigating the virus. What happens when the Covid-19 virus gets into the environment through human digestive waste? We know that faeces from people infected with the SARS-CoV-2 virus can contain genetic material (RNA) from the virus, and that it is possible to detect that viral RNA in sewage. This will provide insight into the prevalence of the virus in the community, and serve as an early warning system for a new wave of infection. In addition, this is also an opportunity to promote the digital revolution of the water industry. Merging accurate biosensor tools in wastewater with big data analytics, machine learning strategies will provide a valuable scenario for making predictions way before symptoms appear in a certain community. Digital technology can optimize the water treatment process and management resource allocation to support the achievement of the Sustainable Development Goals (SDG) in the COVID-19 pandemic [88,89]. This can also help to work out what happens to the SARS-CoV-2 virus in nearby bodies of water such as rivers, streams and sea, including the swimming water in beach.

5. Conclusions

Although researchers' ambitions for swift roll-outs of COVID-19 in 2021 are likely to still be constrained by the continuing pandemic and its effects for the moment, COVID-19 study was the hottest topic throughout 2020. By December 31, 2020, authors from 67 countries have published 262 COVID-19 publications related to water science and technology. These studies have greatly demonstrated and enhanced the important role and value of water science and technology during COVID-19 pandemic. Studies have shown that drinking water is safe whereas wastewater may be a potential risk during this pandemic. Based on the bibliometric analysis, the source and survival characteristics of coronavirus in the aquatic environment, the methodology of virus detection, the water hygiene, and the impact of the COVID-19 pandemic on the water ecosystem are the highlighted topics in the past year. Due to the detection of SARS-CoV-2 in sewage in many places across the world, WBE becomes a highly important water science platform. Water scientists and professionals can provide unique and powerful information and practical guides to discover the blind spots of SARS-CoV-2 in the water cycle and further curb the spread of the virus. For better doing so, we need more research on the relationship between COVID-19 and water. The topics of the potential transmission and survival characteristics of SARS-CoV-2 in the collection, treatment, and distribution of water cycle; the method of detection of virus in different aquatic environment; the standardized protocol for WEB; and the secondary risk for water health; as well as the digital revolution in water industry are highly desirable for investigation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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