

Original Research

Bibliometric Analysis of Research Hotspots Related to Viruses in The Environmental Field Based on the Web of Science

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Abstract

Various viruses inhabit diverse environments, encompassing aqueous, terrestrial, and atmospheric domains. While viruses lack the ability to self-replicate in the absence of living cells, they endure in the environment and instigate infections in new hosts. The presence of viruses in the environment poses a significant risk to human health, and there has been a notable increase in research focused on viruses in the environmental field. Scholars have investigated the identification, eradication, and surveillance of viruses in the environment. To comprehend current research advancements, focal areas, and emerging patterns in virus research, a bibliometric analysis was conducted on publications from 1990 to 2022 using the Web of Science Core Collection (WOSCC) database, alongside analytical tools such as R package Bibliometrix, VOSviewer, and Citespace. A comprehensive analysis was conducted on 3,805 articles related to virus research in the environmental field published over 33 years. The primary focus of this analysis was on the top 10 countries/regions in terms of publication frequency, prolific authors, source journals, significant research institutions, and main research topics. These findings provide an objective evaluation of the scientific contributions and impacts of pertinent countries, institutions, and individuals in this field.

Keywords: environmental field, virus, bibliometric analysis, Web of Science

Introduction

Viruses, as non-cellular organisms, exclusively possess either DNA or RNA. They depend on parasitizing and multiplying within a host cell to execute processes such as replication, transcription,

and translation [1]. Viruses including the Middle East Respiratory Syndrome (MERS) virus, COVID-19 [2, 3], and emerging waterborne enteroviruses, noroviruses, hepatitis A viruses, and adenoviruses, pose a significant threat to human health [4]. Although viruses cannot undergo reproduction in the environment, they can disseminate globally through various environmental pathways, utilizing mutational adaptation, host infection, and environmental adaptation. Human enteropathogenic viruses have the potential to infiltrate

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the aquatic environment via the release of waste from infected individuals. Enteroviruses, in particular, exhibit a high degree of transmissibility in aquatic settings and can be readily assimilated by aquatic organisms through adsorption in the water's sediment [5]. Through fecal-oral transmission, viruses can re-enter the body, leading to disease outbreaks. The transmission of a virus is contingent not solely upon its interaction with the host organism, but also upon its interaction with the host's external environment. The interplay between viruses and environmental media is intricate, as both serve as crucial agents for virus transmission and major receptors of secondary environmental hazards and ecological harm that stem from outbreak management and environmental factors; virus inactivation is achieved through the direct or indirect impact of environmental factors on specific components of the virus structure, such as the genome, capsid, or envelope [6]. Numerous studies have been conducted by researchers regarding the impact of environmental parameters such as temperature, humidity, sunlight/radiation, and environmental pollution on the viability of airborne and waterborne infectious organisms, including viruses, bacteria, and fungi [7-9].

In recent decades, scholars have conducted extensive research on viruses in the environmental field. Noorimotlagh et al. [10] reviewed studies on the airborne transmission of SARS-CoV-2 in the air environment. Corpuz et al. [11] conducted a comprehensive review of methodologies used for detection and quantification of viruses in wastewater treatment systems including transmission electron microscopy (TEM), nucleic acid staining with fluorescent dyes, flow cytometry (FCM), in situ fluorescence, immunofluorescence assay (IFA), enzyme-linked immunosorbent assay (ELISA), pulsed-field gel electrophoresis (PFGE), polymerase chain reaction (PCR), and sequencing. Zhang et al. [12] reviewed the mechanism and research progress of disinfection performance of TiO₂-based, metal-containing (in addition to TiO₂), and metal-free photocatalysts. Verbyla and Mihelcic [13] reviewed the efficiency of different wastewater treatment processes for the removal of viruses from wastewater and the mechanism of virus removal in wastewater treatment tank processes. The increasing body of literature on virus research in the environmental field and the growing public concern for environmental hygiene and health have prompted the use of bibliometric techniques to provide a comprehensive and unbiased overview of the current state and progress of research in this field. Bibliometrics is a multidisciplinary field that draws upon the disciplines of bibliography, information science, mathematics, and statistics [14]. Bibliometrics is a quantitative statistical analysis method employed to determine the geographical distribution of publications, researchers, and research institutions. This method provides researchers with a comprehensive overview of the development of the discipline and potential trends [15]. It is increasingly regarded as a vital tool

for predicting trends in various disciplines and has been widely used in many disciplines or fields such as microplastics [16], biochar [17], and e-waste [18].

This study systematically conducted a systematic bibliometric analysis of the literature pertaining to virus research in the environmental field from January 1990 and December 2022, extracted from the Web of Science Core Collection database (WOSCC). Key metrics, such as the annual number of publications, journals, authors, research institutions, countries, highly cited literature, and keywords were evaluated quantitatively and qualitatively using Bibliometrix. Furthermore, co-occurrence and burst analysis of keywords were performed using VOSviewer and CiteSpace. The primary objective of this investigation is to offer insights into the developmental trajectory and current status of virus research in the environmental field, including its historical progression, current status, and anticipated future trends. Moreover, this study aims to identify research hotspots, thereby providing a scientific foundation for researchers to comprehend the evolving landscape and future directions of virus research in the environmental field.

Data and Methods

Data Collection

The process of collecting and analyzing data is depicted in Fig. 1. In this study, the Web of Science Core Collection database published by Thomson Reuters was used as the data source. The search parameters were set to include documents with the topic of "virus" or "virome" and document type of "Article" within the subject categories of "Engineering, Environmental", "Environmental Sciences", "Environmental Studies", "Water Resources", "Soil Science", and "Meteorology & Atmospheric Sciences". The search was conducted for the period of January 1990 to December 2022, and a total of 12,806 documents were initially retrieved. Duplicate documents were removed, and the remaining search results were screened to exclude irrelevant information such as keywords, authors, countries, and institutions. In the end, 3,805 documents related to virus research in the environmental field were obtained.

Data Analysis

The analysis utilized the Bibliometrix, VOSviewer, and CiteSpace software. Additionally, an econometric evaluation was conducted to assess various factors including the number of publications, countries (regions), institutions, journals, author groups, highly cited papers, and keywords. Bibliometrix is an R toolkit for comprehensive scientific cartographic analysis. It enables bibliometric statistical analysis and prediction of future research directions [19]; VOSviewer visual analytics software is a free visual analysis software

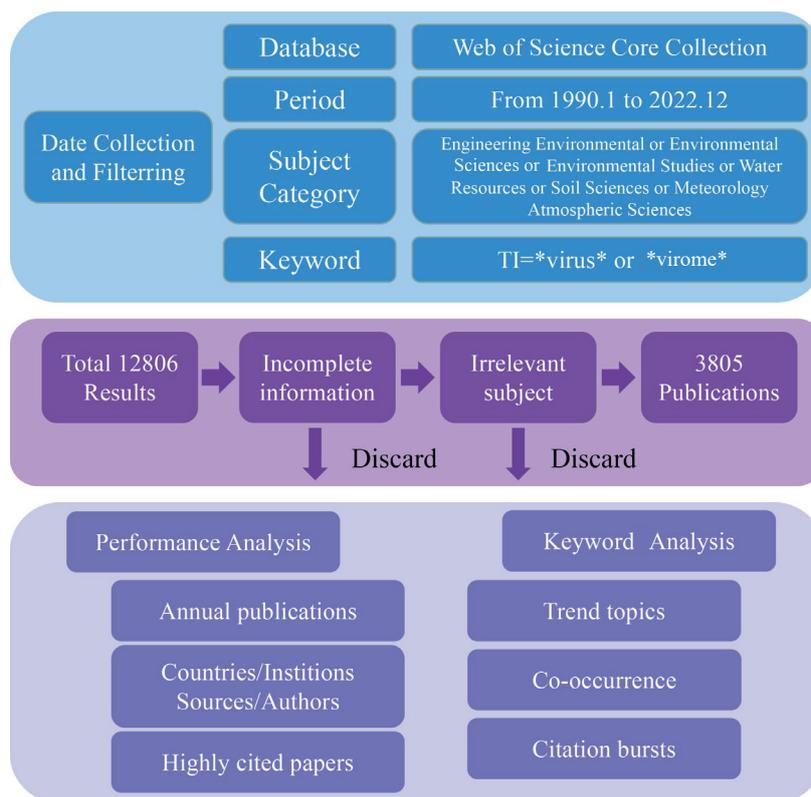


Fig. 1. Flow chart of literature collection and bibliometric analysis.

tool developed by Leiden University in the Netherlands to perform cluster co-occurrence visual analysis of important literature, high-yield authors, keywords, and institutions [20]; CiteSpace is visualization and analysis software that swiftly identifies research hotspots and the evolution of the literature in a subject area [21]. To ensure clarity and concision, keywords or phrases with similar meanings were combined into one keyword,

for example, “virus” for “viruses” and so on, while “waste water” represented variations such as “waste waters”, “waste-water”, “wastewater”, etc. Similarly, “drinking water” included forms like “drinking-water”, etc. Lastly, “norovirus” was used for related terms like “noroviruses”, “norowalk virus”, “norwalk virus”, etc.

Table 1. Top 10 productive countries for virus research in the environmental field during 1990–2022.

Rank	Total publication		Single country publication	International collaboration publication	ICP ratio	Number of citations	Average citation per paper
1	USA	881	716	165	18.73	27592	31.32
2	China	498	384	114	22.89	9209	18.49
3	Japan	185	141	44	23.78	4522	24.44
4	Australia	166	85	81	48.80	6073	36.58
5	Italy	156	124	32	20.51	4606	29.53
6	Brazil	151	113	38	25.17	2461	16.30
7	Spain	135	74	38	33.93	3381	25.04
8	UK	119	64	55	46.22	3521	29.59
9	Korea	113	91	22	19.47	1927	17.05
10	France	107	79	28	26.17	3276	30.62

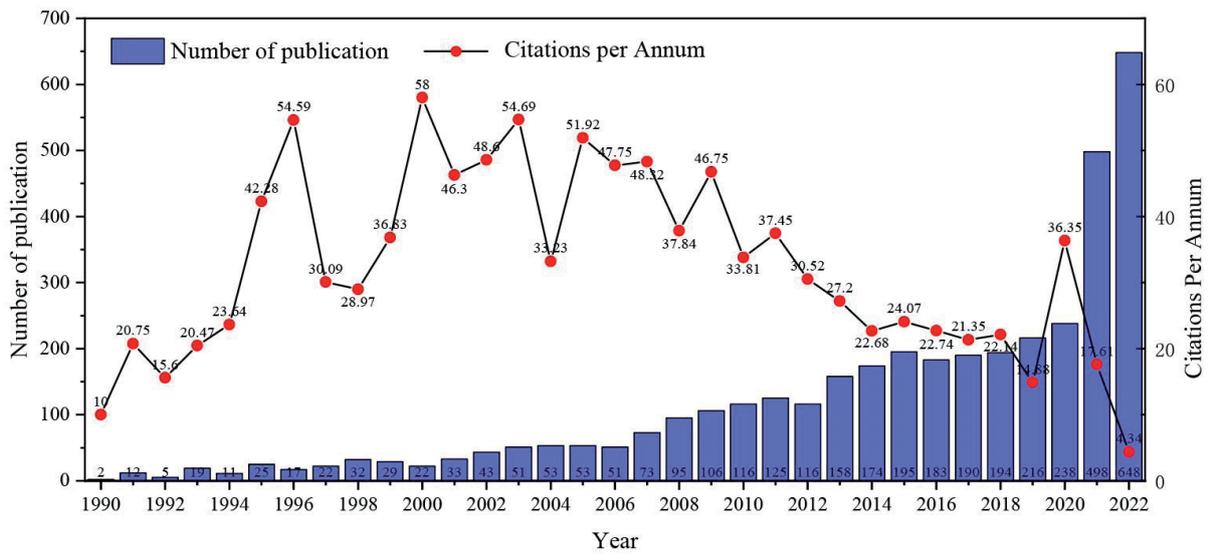


Fig. 2. Annual number of articles published on virus research in the environmental field from 1990 to 2022.

Country Collaboration Map

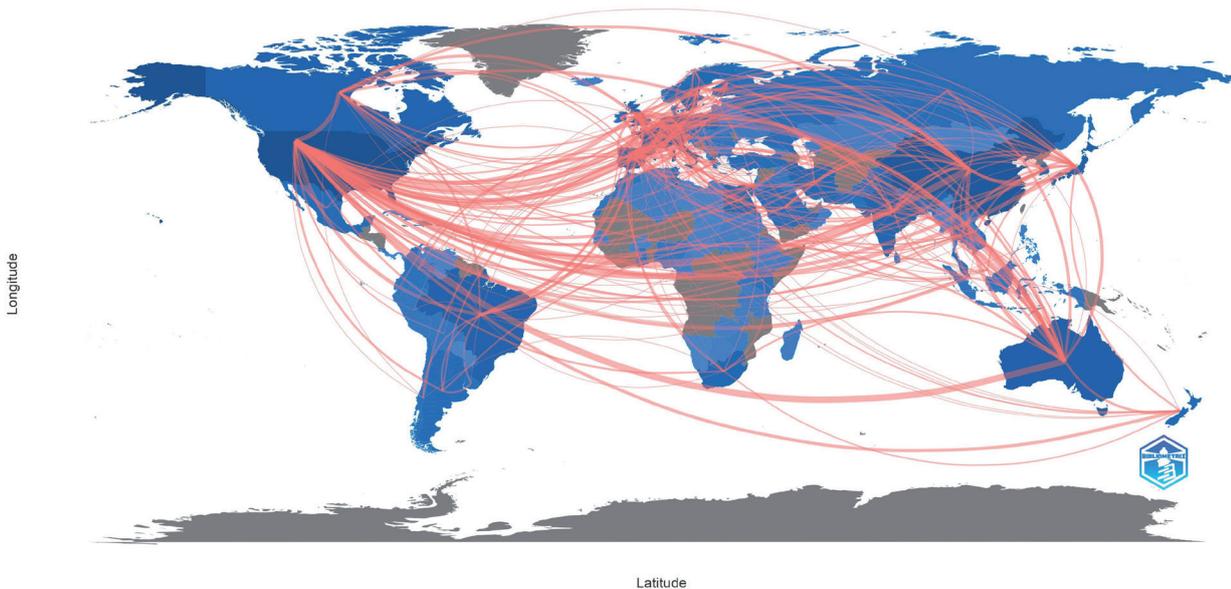


Fig. 3. Cooperation between countries in virus research in the environmental field from 1990 to 2022.

Results and Discussion

Publication Trends

The quantity of published articles serves as a direct metric for gauging engagement in virus research in the environmental field. As shown in Fig. 2, the number of publications in virus-related research journals in the field of the environment has exhibited a consistent upward trend in the past 33 years. There were only 2 in 1990 and 22 in 2000, while the number of publications escalated to 116 in 2010, and 238 in 2020. Over the last 33 years, a conspicuous surge has been evident in recent years, with 498 publications in 2021 and a subsequent

rise to 648 in 2022, reflecting respective increases of 260 and 150 from the previous year. The increase in publication numbers for 2021 and 2022 surpasses the increase observed in 2020, linked to the healthcare response to SARS-CoV-2. The emergence of SARS-CoV-2 occurred in late 2019. The outbreak has stimulated advancements in virus research in the environmental field, prompting scholars to place greater emphasis on the transmissibility of viruses through aerosols, water, and other media, as well as their capacity to endure in the environment. Since the emergence of SARS-CoV-2, scholars have identified the novel coronavirus in various environmental matrices, including but not limited to fecal matter, aerosols, and wastewater.

Table 2. Top 10 productive institutions for virus research in the environmental field during 1990–2022.

Rank	Institution	Country	Total publication		Number of citations	Average citation per paper
			No.	%		
1	Univ Arizona	USA	101	2.65	3362	33.29
2	Chinese Acad Sci	China	88	2.31	1624	18.45
3	Univ Barcelona	Spain	70	1.84	2620	37.43
4	Univ Tokyo	Japan	57	1.50	1895	33.25
5	US EPA	USA	55	1.45	2348	42.69
6	Univ N Carolina	USA	54	1.42	2031	37.61
7	Hokkaido-Univ	Japan	49	1.29	2710	55.31
8	Tsinghua Univ	China	49	1.29	1895	38.67
9	Ist Super Sanita	Italy	48	1.26	1165	24.27
10	CSIRO Land and Water	Australia	44	1.16	2797	63.57

Publication by Countries

During the period spanning 1990 to 2022, research papers pertaining to viruses in the environmental field from the WOSCC database were published in 79 countries/regions. The foremost contributors to scholarly articles during this timeframe were the USA, China, Japan, Australia, Italy, Brazil, Spain, the UK, Korea, and France, with the USA exhibiting the highest volume of publications at 881. The USA has the most international collaboration publications (ICP), despite having the lowest ICP ratio. Conversely, Australia held the highest ICP ratio, succeeded by the UK and Spain. As delineated in Table 1, nearly fifty percent of Australia was from international collaboration. Moreover, the three countries with the highest average citation were Australia, the USA, and France, underscoring their significant impact within the field.

In Fig. 3, the Bibliometrix package (version 3.1.4) is used to visually demonstrate the countries/regional network of virus research in the environmental field. The intensity of color corresponds to the volume of documents originating from each country or region. The pink lines connecting different countries or regions signify the extent of collaboration; a greater number of lines indicate closer cooperation. As Fig. 3 shows, there is close cooperation between various countries/regions working together for virus research in the environmental field. The USA has much cooperation with Europe, China, and Australia.

Publication by Institutions

The analysis of publications by institutions provided valuable and detailed information. There were 1,038 institutions involved in virus research in the environmental field. Table 2 presents the top 10 institutions in terms of publication, including the University of Arizona, Chinese Academy of Sciences,

University of Barcelona, University of Tokyo, US EPA, University of North Carolina, Hokkaido University, Tsinghua University, Istituto Superiore di Sanità, and CSIRO Land and Water. Among these institutions, three (University of Arizona, US EPA, and University of North Carolina) are located in the USA, two (Chinese Academy of Sciences and Tsinghua University) are in China, two (University of Tokyo and Hokkaido University) are in Japan, and one each are in Spain, Italy, and Australia. Seven of these institutions are universities. The University of Arizona from the USA ranks first in the number of citations, followed by CSIRO Land and Water from Australia in second place, and Hokkaido University from Japan in third place. When considering the average citations per paper, CSIRO Land and Water from Australia (63.57) places first, followed by Hokkaido University from Japan (55.31) and the US EPA from the USA (42.69). In addition, the average number of citations for the top 3 productive institutions, namely the University of Arizona from the USA (33.29), the Chinese Academy of Sciences from China (18.45), and the University of Barcelona from Spain (37.43), is relatively low, which may be the result of their relatively high volume of publications.

Publication by Journals

These publications on virus research in the environmental field were published in 284 journals. Table 3 provides a list of the top 10 productive journals during 1990–2022. Water Research was the most productive journal with 502 publications (13.19% of 3,805), followed by Science of the Total Environment with 378 publications (9.93%), and then Food and Environmental Virology with 345 publications (9.07%). The impact factor is a significant indicator that reflects the academic influence of a journal in recent years. The average impact factor of these 10 journals was 8.1 in 2022. The highest impact factor among these

Table 3. Top 10 productive journals for virus research in the environmental field during 1990–2022.

Rank	Journal	Total publication		IF2023	Index			Number of citations	Average citation per paper
		No.	%		h	g	m		
1	Water Research	502	13.19	12.8	86	119	2.529	24471	48.75
2	Science of the Total Environment	378	9.93	9.8	53	93	1.656	12218	32.32
3	Food and Environmental Virology	345	9.07	3.4	35	51	2.333	5816	16.86
4	Water Science and Technology	221	5.81	2.7	38	54	1.152	5052	22.86
5	Journal of Water and Health	163	4.28	2.3	29	44	1.45	3055	18.74
6	Environmental Science and Pollution Research	103	2.71	5.8	19	30	1.583	1283	12.46
7	Environmental Research	71	1.87	8.3	19	33	1.056	1275	17.96
8	Journal of Hazardous Materials	64	1.68	13.6	21	41	1.235	1825	28.52
9	Water	59	1.55	3.4	13	17	0.929	434	7.36
10	Chemical Engineering Journal	58	1.52	15.1	22	35	1.571	1371	23.64

journals was 15.1 for the Chemical Engineering Journal, while the lowest was 2.3 for the Journal of Water and Health. Citation frequency assesses the academic value and professional influence of a publication. According to Table 3, Water Research had the highest average number of citations per paper (48.75), as well as the highest total number of publications. Science of the Total Environment, which had the second-highest total number of publications, had an average number of citations per paper of 32.32.

Publications by Author

In terms of publications by author from 1990 to 2022, we focused on the total number of publications and the

number of citations (Table 4). CP Ger had the highest number of publications, with 74 articles, which was more than twice the number published by the second most productive author, W Ahmed. Throughout this period, W Ahmed published a total of 36 articles, while C Gantzer, who ranked tenth, had only eight articles, a significant difference from W Ahmed. M Kitajima's publications received the highest number of citations. His 28 publications were cited a total of 2,701 times, resulting in an average of 96.46 citations per paper.

Analysis of Highly Cited Papers

The quantification of a publication's citations is a crucial metric in evaluating the scholarly impact

Table 4. Top 10 productive authors for virus research in the environmental field during 1990–2022.

Rank	Author	Total publication	Index			Number of citations	Average citation per paper
			h	g	m		
1	Gerba CP	74	30	53	0.882	2970	40.14
2	Ahmed W	36	20	36	1.333	2657	73.81
3	Katayama H	34	21	34	0.955	1276	37.53
4	La Rosa G	33	18	26	0.621	769	23.30
5	Sobsey MD	32	23	32	0.742	1438	44.94
6	Haramoto O E	32	17	32	0.895	1702	53.19
7	Girones R	31	22	31	0.710	1364	44.00
8	Miagostovich I MP	30	14	27	0.933	770	25.67
9	Kitajima M	28	17	28	1.133	2701	96.46
10	Gantzer C	28	15	28	0.500	1151	41.11

Table 5. Top 10 highly cited review papers.

Rank	Year	Authors	Title	Journal	Institution	Local Citation	Global Citation
1	2020	Ahmed W	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	Science of The Total Environment	CSIRO Land and Water	196	853
2	2020	Haramoto E	First environmental surveillance for the presence of SARS-CoV-2 RNA in wastewater and river water in Japan	Science of The Total Environment	University of Yamaguchi	117	380
3	2008	Katayama H	One-year monthly quantitative survey of noroviruses, enteroviruses, and adenoviruses in wastewater collected from six plants in Japan	Water Research	University of Tokyo	111	262
4	2020	Ahmed W	Comparison of virus concentration methods for the RT-qPCR-based recovery of murine hepatitis virus, a surrogate for SARS-CoV-2 from untreated wastewater	Science of The Total Environment	CSIRO Land and Water	96	253
5	2011	Wyn-Jones AP	Surveillance of adenoviruses and noroviruses in European recreational waters	Water Research	University of Aberystwyth	94	207
6	2014	Kitajima M	Relative abundance and treatment reduction of viruses during wastewater treatment processes — Identification of potential viral indicators	Science of The Total Environment	The University of Arizona	92	213
7	2020	Sherchan SP	First detection of SARS-CoV-2 RNA in wastewater in North America: A study in Louisiana, USA	Science of The Total Environment	Tulane University	90	273
8	2009	Gundy PM	Survival of Coronaviruses in Water and Wastewater	Food and Environmental Virology	University of Arizona	87	291
9	2020	Rimoldi SG	Presence and infectivity of SARS-CoV-2 virus in wastewaters and rivers	Science of The Total Environment	University Hospital "L. Sacco"	79	259
10	2020	Ahmed W	Decay of SARS-CoV-2 and surrogate murine hepatitis virus RNA in untreated wastewater to inform application in wastewater-based epidemiology	Environmental Research	CSIRO Land and Water	66	182

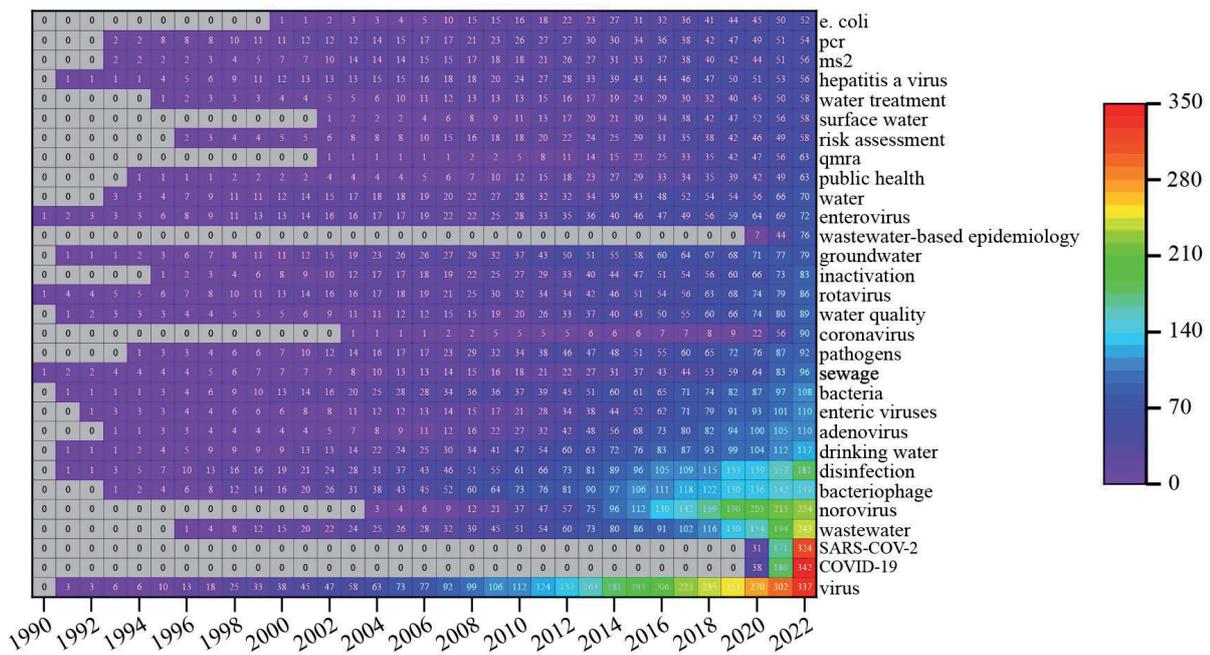


Fig. 4. Top 30 high-frequency keywords of virus research in the environmental field from 1990 to 2022.

of research in a specific field. This study presents a compilation of the most frequently cited papers on virus research in the environmental field between 1990 and 2022, as documented in Table 5. The publications have been ranked based on their citation count, and the top 10 papers have been identified. Six out of the ten articles included in the study explicitly mention SARS-CoV-2 in their titles. These articles were published in 2020, primarily in response to the outbreak of SARS-CoV-2 in 2019. The most highly cited article, authored by Ahmed in 2020, is titled “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”. This article, published in the journal *Science of the Total Environment*, has received a global citation of 853. This study established the initial verification of SARS-CoV-2 identification in raw wastewater in Australia, serving as a demonstration of the feasibility of utilizing wastewater monitoring as a means of detecting COVID-19 within the general population. In 2020, E Haramoto published two highly cited publications with global citations of 380. The present study was the first to document the environmental monitoring of SARS-CoV-2 RNA in wastewater and river water in Japan. Both of the aforementioned works demonstrate the potential of utilizing wastewater-based epidemiology as a means of monitoring infectious diseases. Notably, six out of the ten highly cited articles were published in *Science of the Total Environment*, an interdisciplinary journal renowned for its innovative, hypothesis-driven, and influential research encompassing various aspects of the environment.

Keyword Analysis

Keyword Frequency Analysis

Keywords are crucial for indicating the main research content and fundamental concepts of publications. The frequency of their occurrence can serve as an indicator of the research direction and content within a specific area of study [22]. Fig. 4 demonstrates that virus research in the environmental field has primarily focused on the water environment, including surface water, groundwater, drinking water, and wastewater. The main viruses investigated in this area include COVID-19, noroviruses, enteric viruses, hepatitis viruses, and others. The waterborne transmission of various viruses such as hepatitis viruses, enteroviruses, rotaviruses, enteric viruses, and noroviruses is well-documented. Apart from the aforementioned pathogens, there exist other viral agents such as coronaviruses, SARS-COV-2, and COVID-19, which are disseminated through aerosol transmission. The keyword “coronavirus” first gained prominence in 2003 during the global outbreak of Severe Acute Respiratory Syndrome Coronavirus (SARS-CoV). The emergence of SARS-COV-2 and COVID-19 was first observed in the year 2020, aligning with the nascent development of wastewater-based epidemiology during the same period. The global detection of SARS-CoV-2 RNA in aquatic environments has provided evidence that waste or wastewater containing the coronavirus can enter water systems, posing a risk to public health. The present analysis focuses on the state of virus research in the environmental field, wherein the existence of bacterial strains, such as *E. coli*, has been detected. Additionally, high-frequency keywords included “disinfection”, “water treatment”,

The current research provides evidence that the RNA of SARS-CoV-2 can still be detected even after hospital wastewater undergoes disinfection. Sewage systems have the potential to serve as a source of virus transmission for an extended duration, particularly in environments characterized by low temperatures [27]. The potential presence of the coronavirus in drainage systems and the use of effluent virus nucleic acid fragment detection as a means of early outbreak warning has garnered significant attention in recent years. The mechanisms of virus inactivation employed in disinfection measures and the environmental risks associated with disinfection by-products are currently significant areas of research focus in virus research in the environmental field.

The yellow cluster primarily focuses on risk assessment studies of viruses in the environment with the keywords “indicators”, “quantitative microbial risk assessment (QMRA)”, “risk assessment”, and “health risk”. Researchers have discovered more than 700 waterborne viruses in sewage, with over 150 of them identified as enteric viruses. Waterborne viruses, including adenoviruses, enteroviruses, hepatitis viruses, noroviruses, and rotaviruses, are known to be transmitted through water. These viruses have been frequently detected in various water sources, including surface water, groundwater, and treated drinking water, posing a significant risk to human health. Furthermore, waterborne viruses can lead to various illnesses, including fever, cardiovascular disease, hepatitis, meningitis, paralysis, and respiratory infections [28]. Phage MS2, crAssphage, and pepper mottle virus (PMMoV) have been employed as prevalent viral indicators. Due to their ease of detection, non-pathogenicity to humans, and similarity to human enteroviruses, these viruses exhibit considerable potential for evaluating viral contamination in wastewater, attenuating viruses, and studying virus transmission in wastewater. Treated wastewater is widely used as a fundamental water source for the generation of potable water, as well as for landscaping, irrigation, and aquifer recharge purposes. Furthermore, the sludge obtained in the process of treating wastewater is repurposed for agricultural purposes, serving as a means of enhancing soil quality or providing nutrients as a fertilizer. The current wastewater treatment methods are insufficient in completely deactivating all viruses present in the wastewater. As a result, detectable levels of viruses can still be found in the treated effluent. The aeration process used in wastewater treatment generates bioaerosols that can disseminate chemicals and viruses, posing potential health hazards to humans. QMRA has been utilized to assess the potential hazards associated with viruses found in water and aerosols, including emerging coronaviruses and noroviruses.

This method involves applying dose-response models for specific reference pathogens and employing a range of exposure scenarios.

The green cluster focuses on the analysis of viruses in wastewater, with primary keywords including “sewage”,

“waste water”, “source tracking”, “surveillance”, and related terms. Viruses found in wastewater mainly consist of enteroviruses, adenoviruses, rotaviruses, and noroviruses, among others. These viruses primarily originate from human and animal fecal matter. The distribution of virus content in the influent water ranges from 3.14×10^2 to 1.93×10^5 copies/mL. The viruses are capable of surviving in the water column for a duration exceeding 1 month while retaining a high level of infectivity [29]. The sludge generated during the process of treating wastewater is reused to enrich the soil as a soil conditioner or fertilizer. Additionally, the aeration process in wastewater treatment leads to the release and spread of bioaerosols that may contain chemicals and viruses. Consequently, the removal of viruses from wastewater holds significant importance in the context of wastewater reclamation and subsequent reuse. As a barrier to the spread of viruses in wastewater to the aqueous environment, water treatment plants use different processes such as retention, adsorption, filtration, chemical oxidation, and biological competition to eliminate viruses [30, 31].

The purple cluster mainly focuses on the study of virus migration behaviors in the environment, emphasizing keywords such as “adhesion”, “adsorption”, “transport”, and “movement”. The intricate mechanism of virus adsorption and migration in environmental media is influenced by numerous factors, such as virus particle size, soil type, pH, ionic strength, multivalent cations, and organic matter [32]. Researchers have predominantly studied the impact of soil properties on virus migration and elimination using the soil column steady-state flow method. The studies conducted by Chu et al. (2001), Jin et al. (2000), and Ryan et al. (2002) present the simulation of virus adsorption and inactivation in sand columns under varying conditions. The studies aimed to explore the viability and potential transmission of viruses in natural environments. However, soil is a complex environmental medium. Further studies are needed to investigate the mechanism of virus adsorption and extinction by soil during migration, as well as the impact of physicochemical properties on the natural migration and fate of viruses. The COVID-19 pandemic has garnered significant attention from various sectors, including the government, society, and the scientific and technological community, due to its potential impact on public health. The investigation of viruses’ migration attributes, mechanisms, and disappearance routes in diverse environmental media can furnish crucial information for safeguarding human health and the environment. This can be achieved by revealing the transmission patterns of viruses in various environmental media.

Keyword Burst Detection Analysis

Analysis of keywords with a high burst can accurately identify research hotspots, reflect research frontiers, and highlight current trends [33]. Fig. 6

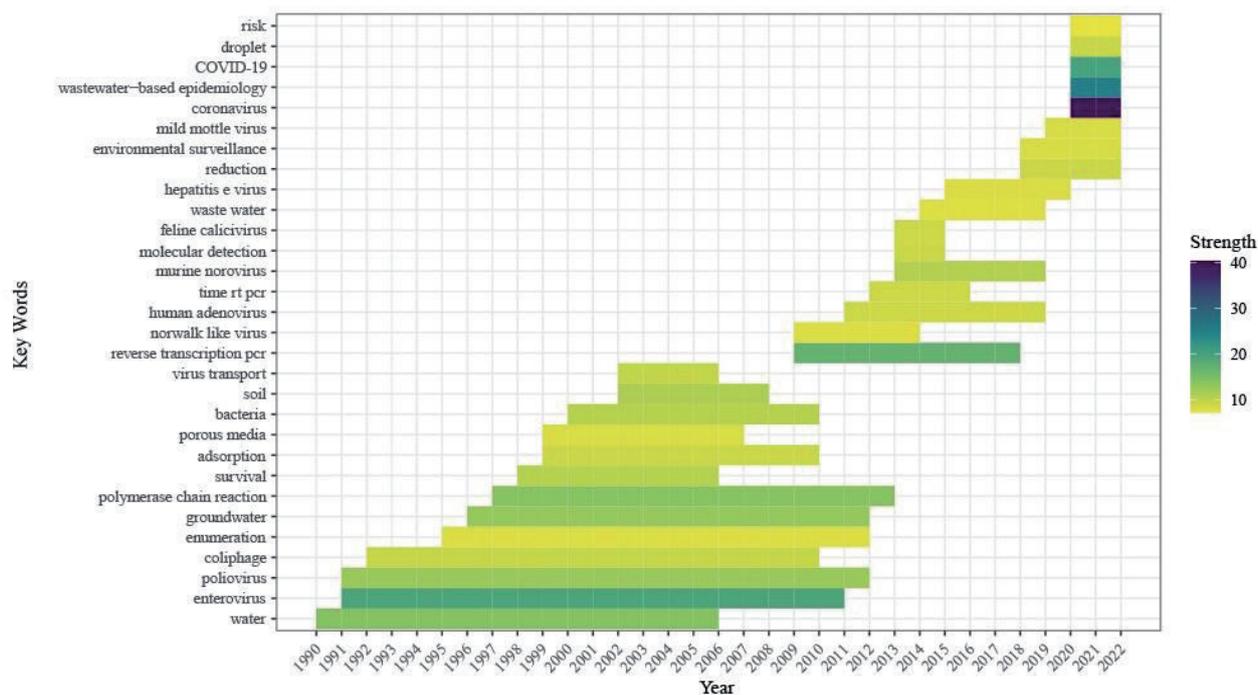


Fig. 6. Top 20 keywords with the strongest citation bursts for virus research in the environmental field from 1990 to 2022.

demonstrates the division of keywords into three time periods (1990-2009, 2010-2019, and 2020-present) for burst detection analysis:

a. During the period from 1990 to 2009, virus research primarily revolved around topics such as enteroviruses, survival, adsorption, groundwater, soil, and porous media. The research conducted during this period primarily delved into the topics of virus adsorption, migration, and survival in porous media, such as soil groundwater. Viruses are frequently used as bioindicators to reflect the movement of colloids in porous media. The migration of viruses in porous media is subject to various influencing factors, including the characteristics of the colloid and the medium, as well as hydrodynamic, hydrochemical, and environmental factors.

b. From 2010 to 2019, the keywords “reverse transcription PCR” and “time RT PCR” were frequently mentioned. The existence of viruses in the environment poses a potential risk of infection to susceptible individuals through respiratory and fecal-oral transmission pathways. Consequently, the detection and monitoring of viruses in the environment, particularly in water environments, have gained paramount importance. The application of high-throughput sequencing has effectively addressed the challenge of limited viral genetic material concentrations in vast environments. This approach has led to a significant increase in the abundance of genomic information and has greatly facilitated the advancement of the molecular ecology of viruses in environmental samples. In 2002, scholars used shotgun sequencing to explore the genomic constitution of viruses present in the coastal waters of

California, USA, thereby initiating the investigation of macrogenomics of environmental viruses in aquatic ecosystems [34]. Nanopore sequencing technologies have emerged in recent years, allowing real-time detection of long DNA/RNA fragments on portable devices [35]. The MinION nanopore sequencing technology is characterized by several advantageous features, including extended read length, rapid sequencing velocity, live tracking of sequencing data, and convenient portability of the device [36], which can rapidly identify pathogens within 6 hours [37], enabling rapid detection of unknown viruses in environmental samples. The search for and development of techniques for enhancing, isolating, and accurately detecting viruses in diverse environmental media, including water, gas, soil, solid waste, and sludge, alongside novel approaches for detecting their viability, is poised to be a focal point on virus research in the environmental field.

c. Since 2020, there has been a notable increase in the occurrence of keywords such as “COVID-19” and “wastewater-based epidemiology (WBE)”, mainly due to the global outbreak of the COVID-19 pandemic. WBE, an effective and cost-efficient technique, is employed for analyzing viral infections in communities. The rapid advancement of WBE has been greatly accelerated by the global emergence of COVID-19 [38]. By utilizing the detection results from WBE, it is possible to delineate the dynamics and trends of virus transmission, gauge the proportion of infected cohorts, deduce the initial infection status in the community via mathematical modeling, and implement efficacious measures such as isolation, observation, and medical examination of community residents to effectively curb

the widespread dissemination of the epidemic [39]. SARS-CoV-2 was detected in sewage samples by Xu et al. [40] through the application of WBE, a mere 2 days before the initial case was identified. Surveillance systems incorporating WBE have shown effectiveness in predicting virus outbreaks and issuing timely alerts, making them an essential component in disease management. The optimization of surveillance methods and processes is crucial for effectively integrating clinical and epidemiological data in the fight against epidemics.

Conclusions

In this study, a bibliometric analysis was performed on virus research in the environmental field from 1990 to 2022. The analysis was conducted using the WOSCC database and the R package Bibliometrix, VOSviewer, and Citespace bibliometric analysis software. The analysis focused on identifying the top 10 countries/regions of publication, important research institutions, source journals, high-producing authors, highly cited articles, and hotspots of research directions. Based on the findings of our analysis, it has been observed that there is a growing global interest in virus research in the environmental field. Over the past 33 years, a comprehensive total of 3,805 articles pertaining to virus research in the environmental field have been published. The majority of these articles originated from the USA, China, and Japan. The University of Arizona, the Chinese Academy of Sciences, and the University of Barcelona are the three most prominent research institutions in this field. CP Gerba, W Ahmed, and H Katayama are the authors with the highest number of publications. The bibliometric analysis conducted in this study provides valuable insights into the present state of virus research in the environmental field, including the prevailing research trends, disciplinary dynamics, areas of active investigation, and scientific frontiers.

The present research in the environmental field focuses on studying viruses in terms of their detection, migration behavior, survivability, decay patterns, removal inactivation, and health risk assessment in environmental media. Currently, extensive research has been conducted on the effects of environmental factors, such as temperature and pH, on the survival, transmission, transfer, and transformation of viruses in various environmental media. Nonetheless, there is limited understanding of the processes and mechanisms through which viruses interact with contaminants in environmental media. Viruses play a crucial role as catalysts in global biogeochemical cycling processes. Although researchers have made progress in understanding the functions of viruses in ecosystem nutrient cycling, food chains, and elemental transformations, there is still a considerable knowledge gap regarding the role of viruses in biogeochemical cycling. Further comprehensive research is necessary.

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Conflict of Interest

The authors declare no conflict of interest.

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