Review Article

Global Trends in Caffeine-based Lifestyles: A CiteSpace Exploration of Potential Environmental Sustainability Impacts

Siti Mardhiyah Razali[1], Mohammad Asyraf Adhwa Masimen[2], Noreen Husain[1,3], Izwandy Idris[4], Wan Iryani Wan Ismail[2,5], Hisyam Abdul Hamid[1,3]*

[1]Department of Pharmacology and Life Sciences, Faculty of Pharmacy, Universiti Teknologi MARA, Puncak Alam, 43200 Puncak Alam, Selangor, Malaysia.
[2]Cell Signalling and Biotechnology Research Group (CeSBTech), Faculty of Science and Marine Environment, Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia.
[3]Ecopharmacovigilance Research Initiative Group, Universiti Teknologi MARA.
[4]South China Sea Repository and Reference Centre, Institute of Oceanography and Environment (INOS), Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia.
[5]Biological Security and Sustainability Research Group (BIOSES), Faculty of Science and Marine Environment, Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia.

ABSTRACT

Caffeine-based lifestyles have become increasingly common, reflecting its widespread consumption as a psychoactive stimulant found naturally in coffee, tea and cocoa yet synthetically in personal care products (PCPs) and pharmaceuticals. This trend has raised concerns about its potential environmental consequences as it can bioaccumulate in various species, including aquatic organisms and terrestrial insects, prompting continuous research in this field since decades ago. However, a comprehensive bibliometric and scientometric analysis in this research field appears lacking. Thus, the primary goal of this study is to analyse the scientific literature concerning the impact of caffeine-based lifestyles on the environment. A CiteSpace analysis was applied in this study to determine various aspects of research literature, including the identification of productive authors, institutions, journals, regional distribution and emerging issues in the field. The study yielded 869 relevant publications from the Web of Science Core Collection (WOSCC) database. The results revealed that the United States, China, Canada, Brazil, and Spain were the top five countries out of 3345 writers from 108 countries active in this research area on the top of keywords such as PCPs, pharmaceutical and wastewater. The present study provides the existing body of knowledge on this topic by sharing a visual knowledge map, which highlights the trend, offering a valuable perspective, and opportunity for researchers.

Keywords: Bibliometric, caffeine, CiteSpace, environment, impact, scientometric

***Corresponding author**
Hisyam Abdul Hamid
Department of Pharmacology and Life Sciences,Faculty of Pharmacy,
Universiti Teknologi MARA, Puncak Alam, 43200 Puncak Alam, Selangor, Malaysia
Email: hisyamhamid@uitm.edu.my

Received: 30 Sept 2024; accepted: 08 May 2025
Available online: 30 May 2025
http://doi.org/10.24191/IJPNaCS.v8i1.08

1.0 Introduction

Caffeine-based lifestyles are increasingly popular in today's fast-paced world, considering its beneficial effects. Caffeine, a naturally occurring stimulant found in various plants, plays a significant role on our daily lives. While it is most commonly associated with coffee, tea and cocoa where it naturally occurs, however, its influence expands just being a food and beverage ingredient. Despite its classification as a potentially addictive stimulant, caffeine also has been listed on the World Health Organization (WHO) Model List of Essential Medicines, emphasizing its crucial role in medical practice (1). The widespread of caffeine use in foods and beverages (natural caffeine) and also in pharmaceuticals (synthetic caffeine) has been linked to environmental contamination, as the disposal of caffeinated products and the emergence of caffeine residue in water systems have raised some concerns.

The concentration of caffeine in various products exhibits significant variation. In 2020, the global consumption of coffee exceeded 9 million metric tons (2). Meanwhile, the global caffeine market had a total value of USD 715.2 million in 2021, with synthetic caffeine that is particularly used in pharmaceuticals and personal care products (PCPs) accounting for more than 59% of the market share (3). These data points emphasize the significant extent of caffeine intake whether in natural or synthetic form. Based on the wastewater measurements of caffeine's metabolite, 1-7-dimethyluric acid, the typical intake of caffeine among individuals falls within the range of 87-236 mg per day (4), indicating that caffeine is derived from various sources and consumed by people from different backgrounds and habits. The liver in humans rapidly metabolizes caffeine; with the majority of caffeine, consumed being transformed into one or more secondary metabolites leaving 0.5% to 10% eliminated by urine and faeces. In addition to that, the disposal of unfinished coffee, tea, or soft drinks down household drains, as well as the rinsing of coffee pots and cups, is likely to be a significant source of caffeine in residential wastewater (5). It is estimated that around 80% (over 95% in some developing countries) of the total wastewater volume from various sources such as households, industry and hospitals is released into the environment without first being treated.

The increased consumption of caffeine-containing products has emerged as a concerning global trend towards a caffeine-based lifestyle. Its fate in the environment, has been detected in various regions including Europe, West Indies and South East Asia (4,6). The concentrations of caffeine found in many freshwater environments ranged in the nanograms per litre with average levels detected at 4850 ng/L in Asia, 3290 ng/L in South America and 1500 ng/L in North America, where this level of concentration approached the threshold toxicity values for aquatic organisms (7). Caffeine's presence in the environment has become a serious concern because its environmental risk on non-target organism is significant. Its negative impact on the environment has been studied since 1993, with growing literature continuing to spark attention and understanding. Studies have shown that caffeine residue can harm various aquatic species in diverse water environments, such as lakes, rivers, and oceans, after being consistently exposed to contamination. Table 1 summarizes the observed effects of caffeine contamination on various aquatic species, highlighting the significant ecological impacts as reported in previous studies.

Table 1. Effects of Caffeine Contamination on Various Aquatic Organisms

Organism	Effect Observed	References
Freshwater nematode (*Caenorhabditis elegans*)	- Longer body lengths - Increased bends - Elevated pharyngeal pumping rates compared to untreated	(8)
Coastal and marine life	- Alteration in oxidative stress, lipid peroxidation and neurotoxicity - Changes in energy storage and metabolic activity	(9)
Microalgae	- Alteration in growth rates - Changes in photosynthesis efficiency - Disruption in nutrient cycling	
Marine worm (*Diopatra neapolitana*)	- Impaired physiological and biochemical performance	(8)

The growing interest in this topic suggest the need for a comprehensive bibliometric and scientometric analysis to assess the extent of this trend and its implication to the environment. Such an analysis could provide valuable insight into the patterns and key contributions within this field that is currently limited in scope. Therefore, this review paper's main objective is to analyse the scientific literature on the global trend of caffeine-based lifestyle and to evaluate the environmental impact. Scientometrics has become increasingly essential in recent years for reviewing and analysing manuscripts in related research as establishing specific themes (11). To determine various subject areas of ongoing research and development, technology such as CiteSpace is useful (12). Bibliometric and scientometric techniques were utilized to evaluate and analyse research literature on caffeine demand and its impact on aquatic health and the environment. This method facilitates the identification of the field's primary study areas, the geographical distribution of research, and citation patterns. The result will highlight more specific subjects of more interest, the connection among co-authors, co-journal, and co-document analysis.

2.0 Methods

The bibliometric analysis encompasses a comprehensive portrayal of the metadata search and a meticulous evaluation based on scientometric. Scientometric analysis was conducted following the protocol outlined by the previous study (13). Figure 1 illustrates the research framework utilized in this study.

2.1 Data Sources

A bibliometric and scientometric analysis was conducted utilizing the WOSCC database to examine the global literature about caffeine consumption and its effects on the environment. as illustrated in Figure 1. Our focus was directed towards the navigation of the complete citation network within the WOSCC database, which is widely regarded as a leading database for scholarly literature, books, and proceedings spanning various disciplines.

2.2 Article Search

The WOS article search was conducted based on the "subject" (TS), which encompassed the article title, keyword, and abstract. In our study, two tags within the

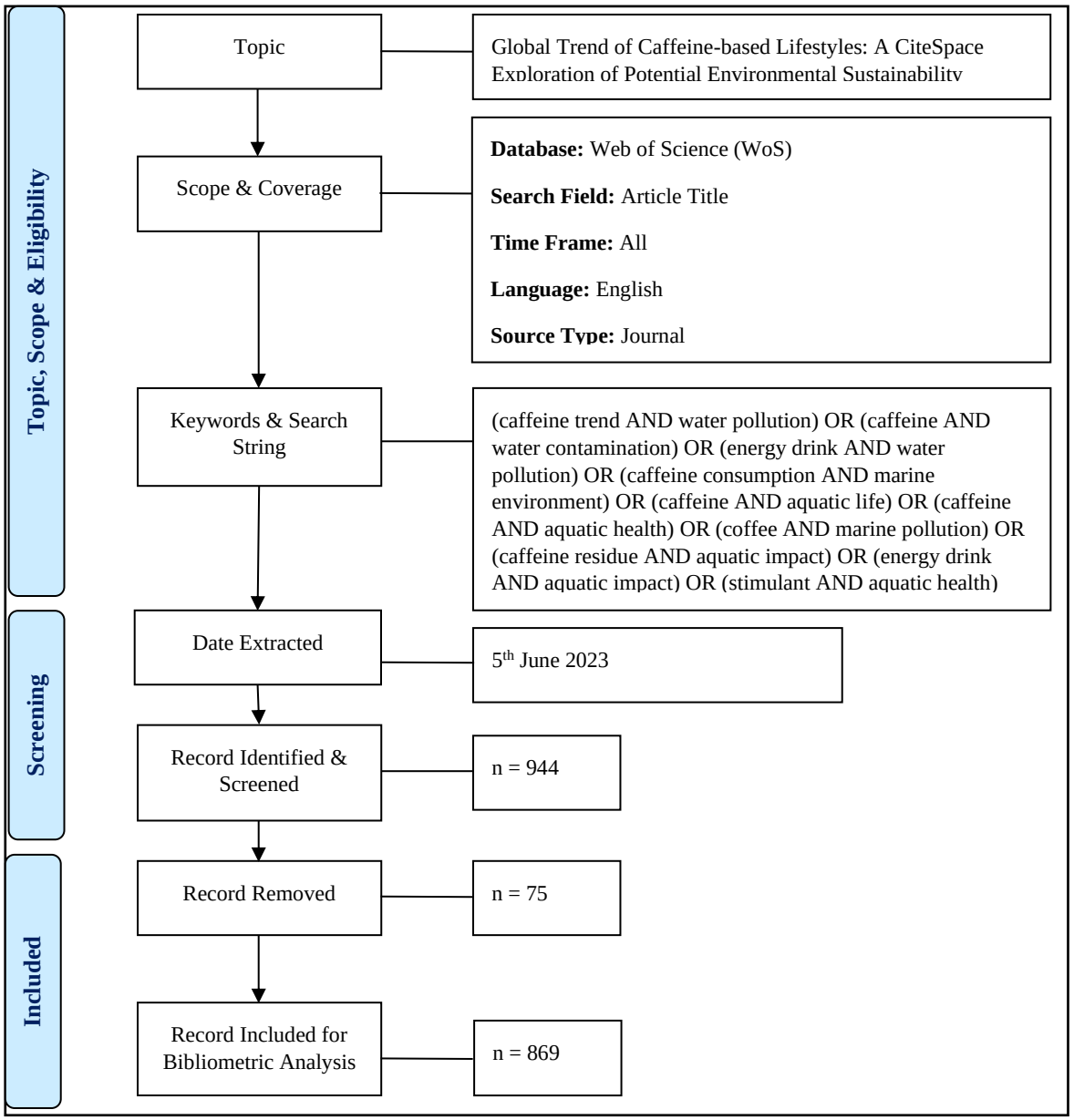

Figure 1. Research framework for caffeine and its environmental impact research based on the WOSCC database.

WOSCC database, specifically Boolean operators (AND, OR), which were employed. These tags functioned as conjunctions to merge or exclude keywords during the search process, thereby yielding more targeted and efficacious outcomes. To narrow down the articles on the impact of caffeine on the environment, the following key terms were utilized:

Caffeine trends and aquatic impact: (caffeine trend AND water pollution) OR (caffeine AND water contamination) OR (energy drink AND water pollution) OR (caffeine consumption AND marine environment) OR (caffeine AND aquatic life) OR (caffeine AND aquatic health) OR (coffee AND marine pollution) OR (caffeine residue AND aquatic impact) OR (energy drink AND aquatic impact) OR (stimulant AND aquatic health)

2.3 Eligibility Criteria

The execution of a scientometric review, particularly during the process of

scientific literature search, requires strict adherence to specific eligibility criteria. Initially, the scholarly articles are primary research manuscripts composed in the English language. Furthermore, it is important to note that our analysis does not encompass research presented in the format of conference papers, book chapters, review articles, letters, editorials, or abstracts. Articles published in 2023 were also excluded from analysis due to the incomplete deposition of records in the database for that year. Their exclusion aimed to prevent complication in the analytical process, as they may not contribute any significant value to the analysed results. Notwithstanding, it is worth noting that our findings encompass literary works and book chapters, as the co-citation analysis inherently incorporates them when referenced by primary research articles.

2.4 Data and Scientometric Analysis

The metadata for the current study was generated from WOSCC and analysed using CiteSpace 6.1.R1 advanced for 64-bit Windows and VOS viewer. This analysis facilitated the data mining process from WOSCC by utilizing the visual summarization tools to depict caffeine trends and their impact on the environment. Meanwhile, co-citation analysis created a science map with connections, nodes and density that provide insight into research trends and influential work within this field (13,14). The quality of nodes or variables is evaluated by several important parameters namely its degree, centrality and sigma values which play an important role in understanding the importance of individual nodes. Nodes with the higher degree value represent that the variables received more citations by other researchers indicating their relevance and influence in the field. Centrality refers to the importance of a node in a particular research network (14). It assesses a node's influence, with a higher centrality value indicating that many influential papers or authors have cited the node. Sigma values describe the structural significance of a node that has had an unexpected surge in citation (15). The findings of the co-citation analysis are presented below for authors, journals, countries/regions, institutions and article documents.

In cluster analysis, Log-likelihood ratio (LLR), Latent Semantic Indexing (LSI), and Mutual Information (MI) were employed. In simple terms, LLR is responsible for finding important words in scientific documents, LSI reveals the hidden meanings and relationships between words in scientific documents, and MI explores different kinds of information and relationships between variables in scientific documents. These three parameters can identify trends and uncover new areas of research. In the cluster analysis, cluster size pertains to the number of documents grouped within a cluster. A larger cluster size indicates a greater number of related documents within that particular group. While silhouette values serve as a metric for assessing the similarity of documents within a cluster in comparison to documents in other clusters. A higher silhouette score indicates that the documents within a cluster exhibit greater similarity to each other (16).

3.0 Results

3.1 Publication Trends

Our analysis focused on scientific articles published between January 1991 and December 2022. During this period, a total of 869 screened articles were generated, with the number of publications rising from 1 in 1991 to 109 documents by 2022 as illustrated in Figure 2. In the past four years, there has been a huge growth in this research field with approximately 460 manuscripts being published. Over 31 years of caffeine-related research focusing on its environmental impact, a total of 35 867

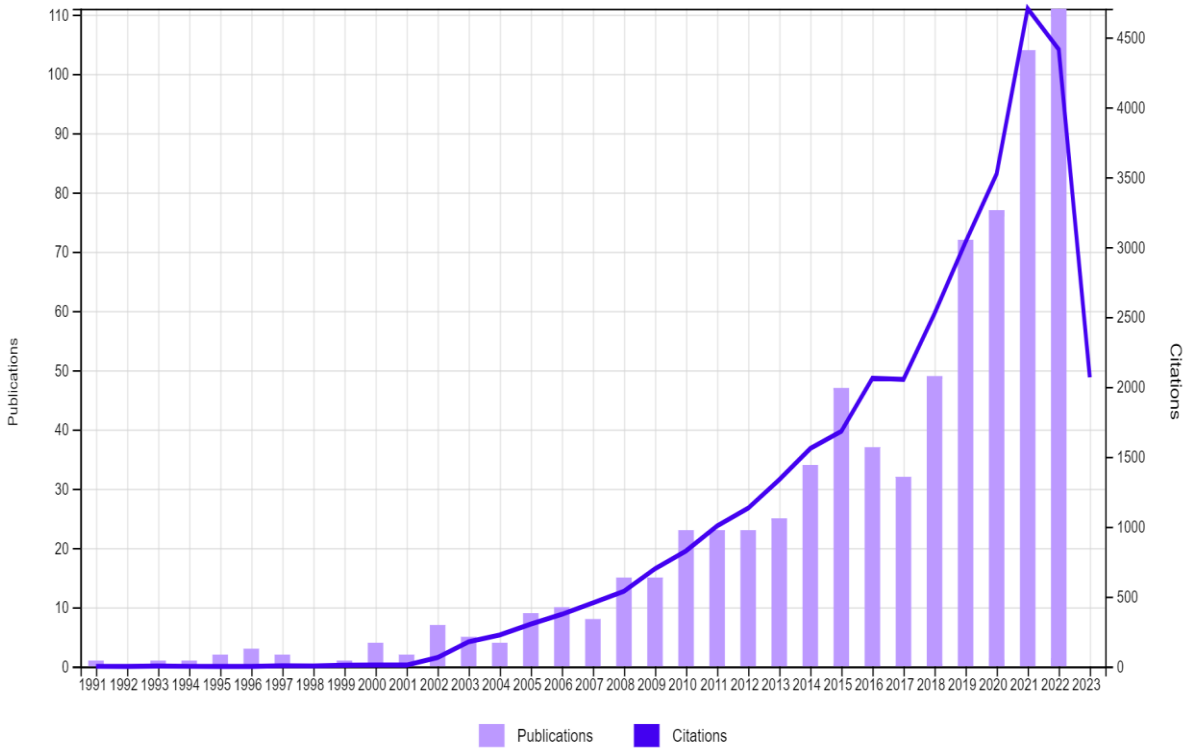

Figure 2. Annual trend in the publication of research article since 1991.

citations were garnered. The number of citations per year also witnessed a dramatic increase, rising from one citation in 1991 to 4394 citations in 2022. This increase shows a shift in scholarly attention, with caffeine not merely as a common stimulant but also as an emerging pollutant with significant implication for aquatic ecosystems.

3.2 Top Ten Authors, Institutions and Productive Journals

The research on caffeine-based consumption and its impact on the environment involved a substantial number of authors, specifically 3345 individuals, over 31 years. On an annual basis, the mean quantity of authors is 104. According to the WOSCC database, Professor Dr Sebastian Sauvé, has holds the highest number of publications, with 13 works focusing on the impact of caffeine consumption on environment research. His research focused on the environment, sustainable development and circular economy. Following closely behind is Professor Dr Prevost Michele, along with her colleague Professor Dr Dorner Sarah, who ranks third in terms of publication frequency in this field. Both of them are professors of the Department of Civil, Geological and Mining Engineering from Polytechnique Montréal. These findings are presented in Table 2.

Among the 1269 institutions involved in research related to caffeine usage and its impact on the environment, the Chinese Academy of Science in China was the most prolific with 23 publications (Table 2). According to WOSCC data, in 2021 alone, this institution ranked 21st globally, and 15th in Asia based on the number of scientific publications between 2017 and 2020. The French National Centre for Scientific Research, which is the largest agency for fundamental science in Europe, ranks as the second most prominent institution globally in publishing research articles in this field. We identified permitted publications - authorized manuscript available for public sharing across a total of 284 journals. As shown in Table 2, Science of the Total Environment

Table 2. Top ten most productive authors, institutions, and journals from 1991 to 2022 in caffeine consumption and its impact on environment-related research in the world, based on the WOSCC database.

Top published author		**Most published institutions**		**Most publication titles**	
Author	**Count**	**Institution**	**Count**	**Journal**	**Count**
Sebastien Sauvé (University of Montréal)	13	Chinese Academy of Science	23	Science of the Total Environment	82
Michele Prevost (Polytechnique Montréal)	9	Centre National De La Recherché Scientifique (CNRS)	18	Environmental Science and Pollution Research	50
Sarah Dorner (Polytechnique Montréal)	8	United States Department of The Interior	17	Chemosphere	36
Khadija Aboulfadl (University of Montréal)	6	United States Geological Survey	17	Water Research	27
Ahmad Zaharin Aris (Universiti Putra Malaysia)	6	University of Montreal	15	Environmental Science Technology	24
Alberto Teodorico Correia (University Fernando Pessoa)	6	Udice France Research Universities	14	Environmental Monitoring and Assessment	16
Edward T. Furlong (National Water Quality Laboratory)	6	University of Chinese Academy of Sciences (CAS)	12	Environmental Pollution	15
Lucianan Lopes Guimaraes (University of Santa Cecilia)	6	Consejo Superior de Investigaciones Cientificas (CSIC)	11	Water Air and Soil Pollution	12
Dana W. Kolpin (United States Geological Survey)	6	Consiglio Nazionale Delle Ricerche (CNR)	11	Marine Pollution Bulletin	11
Li Yan (University of Chinese Academy of Sciences)	6	Polytechnique Montreal	11	Journal of Hazardous Materials	10

Table 3. Top ten published authors, articles, and citation counts for published articles related to caffeine consumption and environmental impact from 1991 to 2022.

Main author	Article Title	Year	Total Citations	Cites per year	Reference
Dana W. Kolpin	Pharmaceuticals, hormones, and other organic wastewater contaminants in US streams, 1999-2000: A national reconnaissance	2002	6169	514.08	(17)
Robert Loos	EU-wide survey of polar organic persistent pollutants in European river waters	2009	737	61.42	(18)
Michael J. Focazio	A national reconnaissance for pharmaceuticals and other organic wastewater contaminants in the United States - II) Untreated drinking water sources	2008	585	48.75	(19)
Ignaz J. Buerge	Caffeine, an anthropogenic marker for wastewater contamination of surface waters	2003	568	47.33	(20)
Jan Willem Erisman	Consequences of human modification of the global nitrogen cycle	2013	512	42.67	(21)
Ignaz J. Buerge	Ubiquitous Occurrence of the Artificial Sweetener Acesulfame in the Aquatic Environment: An Ideal Chemical Marker of Domestic Wastewater in Groundwater	2009	360	30.00	(22)
Marcelo Munoz	Measurement of reactive oxygen intermediate production in haemocytes of the penaeid shrimp, Penaeus vannamei	2000	329	27.42	(23)
Wonjin Sim	Occurrence and distribution of pharmaceuticals in wastewater from households, livestock farms, hospitals and pharmaceutical manufactures	2011	340	28.33	(24)
Angela Yu-Chen Lin	Pharmaceutical contamination in residential, industrial, and agricultural waste streams: Risk to aqueous environments in Taiwan	2008	312	26.00	(25)
Angela L. Batt	Evaluating the vulnerability of surface waters to antibiotic contamination from varying wastewater treatment plant discharges	2006	305	25.42	(26)

featured the highest number of (82 publications), nearly double that of Environmental Science and Pollution Research (50 publications), followed by Chemosphere (36 publications). The rise in academic interest and publication volume not emphasize the critical need for regulatory frameworks to regulate caffeine pollution, but also calls for collaboration among researchers.

3.3 Most Cited Article

This section contains the most referred publications on caffeine consumption and environmental impact particularly in water contamination investigations worldwide,

based on the WOSCC database (Table 3). According to the statistics, the peer-reviewed publication Environmental Science and Technology's article, "Pharmaceuticals, hormones, and other organic wastewater contaminants in US streams, 1999-2000: A national reconnaissance" (17) obtained the most total citations. Since 2022, this article has been cited 6169 times, with an average of 514 citations per year. The study identified caffeine was among the organic waste contaminants frequently detected highlighting its status as an emerging pollutant in aquatic environments indicating widespread contamination linked to urbanization and modern human lifestyle. Following that, an article titled "EU-wide survey of polar organic persistent pollutants in European river waters" (18) received 737 citations, averaging of 61 citations per year since 2009. Both studies have garnered significant citations indicating the growing interest of researchers in understanding the impacts of caffeine on ecosystem. This interest is strongly related to an increasing awareness of how caffeine lifestyle choices and consumption patterns contribute to environmental contamination

3.4 Important Publications Categories

The 869 publications were classified into 91 categories using the WOS classification. However, due to the large number of publications, this study presents only the five most important categories as shown in Figure 3. Research on caffeine usage and its impact on the environment has been expanding, owing mostly to the increased number of articles published in various journals. The Environmental Sciences category stands out above the others since it has the most publications (318 publications) during the previous two decades, with an average of 15 papers released each year. The Engineering Environmental category included 107 published papers (during the last 20 years) with an average of five articles per year, all of which investigated caffeine intake and its impact on the aquatic environment. The other three categories are connected to Water Resources and produced between 90 papers about caffeine and its environmental impact over the previous 20 years. This growing body of research reflects a growing understanding of the potential environmental consequences of caffeine and its widespread use.

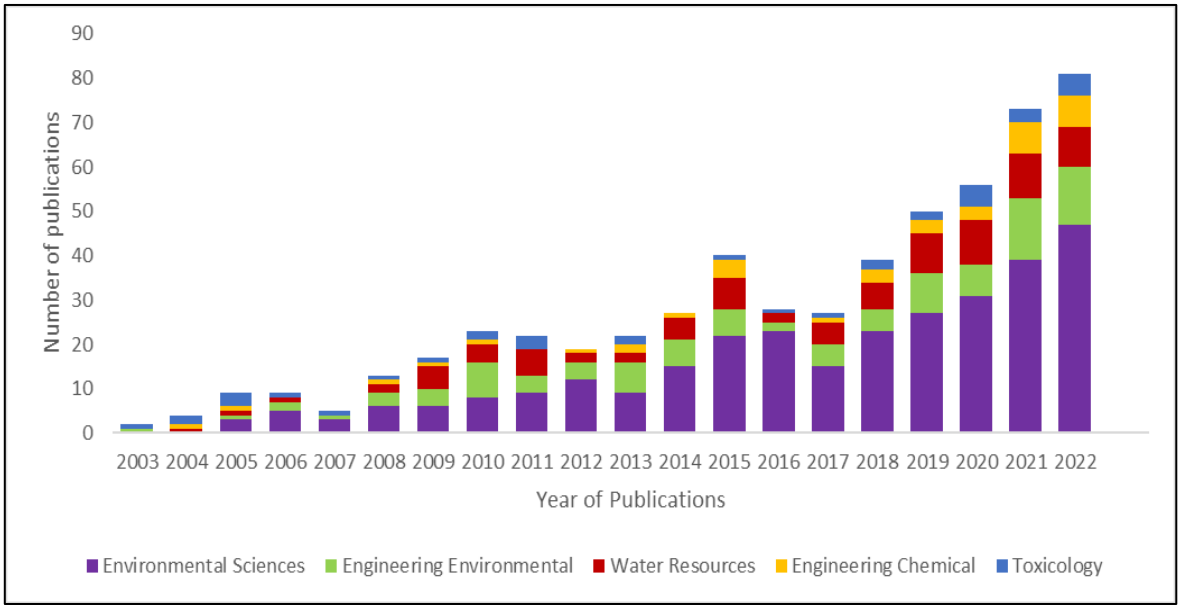

Figure 3. Number of publications across WOS categories related to caffeine consumption and environmental impact

3.5 Regional Distribution

The research findings indicate that a total of 108 countries are involved in this research area with at least one publication. However, only 28 countries have published more than 10 articles. The United States of America (149 countries), the Republic of China (130 countries), Canada (55 countries), Brazil (54 countries), and Spain (54 countries) were the primary contributors of published articles, with over 50 publications each as illustrated in Figure 4. The top 10 countries identified in the study accounted for 81.6% of the total publications. The results of our study indicate that 50% of the total number of countries in the world (108 out of 195) are currently engaged in research activities on caffeine consumption and its environmental impact.

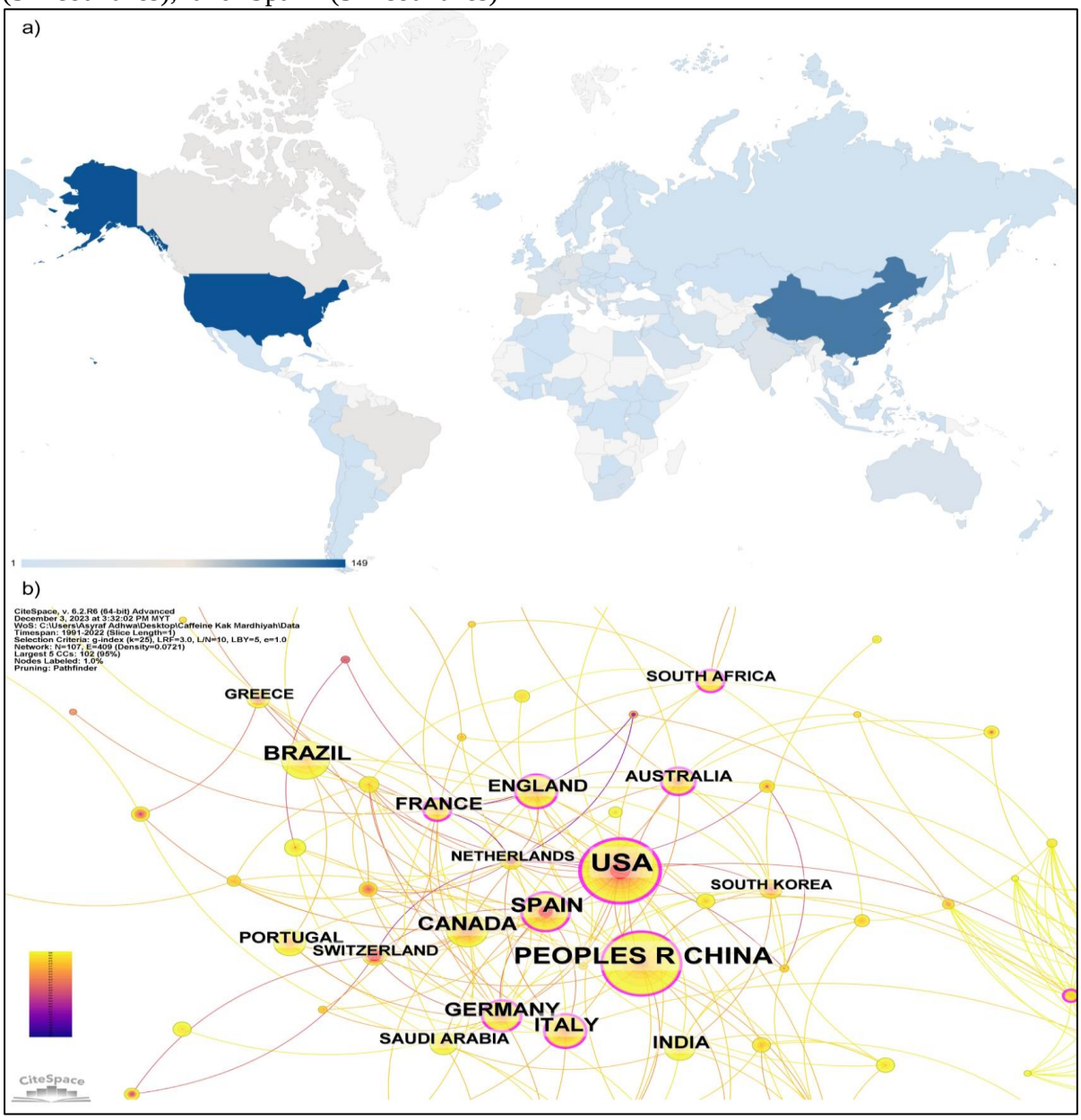

Figure 4. a) The distribution of caffeine consumption and its impact on environment-related manuscripts worldwide. The darkest blue indicates the greater number of total publications while the brighter blue indicates a relatively moderate to fewer total articles have been published. b) Network of collaborating countries based on the CiteSpace analysis; the size of the nodes corresponds to the number of documents produced while font size corresponds to the centrality score.

Based on Figure 4, b) the USA emerged as the most prominent country in collaborating with other countries, with a centrality score of 0.32. A high centrality score indicates that the country plays a pivotal role in enhancing scientific collaboration. Germany, Australia, and Costa Rica have centrality scores of 0.17, followed by France and South Africa with centrality scores of 0.14 and 0.13, respectively.

3.6 Author Co-Citation Analysis

An author from the Geological Survey United States, Dr Larry B. Barber, is the most influential author in the field, with the highest 0.15 centrality score compared to the next most influential author, Dr Chirstian G. Daughton, who is currently affiliated with US Environmental Protection Agency, United States with 1.0 centrality value. The third most influential author based on the sigma score is Professor Dr Andreas Musolff, from Helmholtz Centre for Environmental Research, Germany. These findings are summarized in Table 4 and graphically represented in Figure 5.

3.7 Co-Citation Analysis

The results presented in the knowledge map in Figure 6 only included articles with a centrality score greater or equal to 0.1. Dr Mark J. Benotti (27) article was the most influential in this field, with a centrality score of 0.2. Susan T. Glassmeyer (28) was the author of the article with the second highest centrality value (1.96), followed by the study entitled “Caffeine, an Anthropogenic Marker for Wastewater Contamination of Surface Waters” by (20) with the centrality value 0.13 as per reported in Table 5.

Table 4. Top 10 most influential authors in caffeine consumption and its impact on aquatic environment-related research based on centrality score, analysed from the WOSCC database.

Author	Year	Affiliation	Degree	Centrality	Sigma
Larry B. Barber	1999	Geological Survey, United States	55	0.15	2.63
Christian G. Daughton	2002	US Environmental Protection Agency, United States	57	0.1	1
Andreas Musolff,	2009	Helmholtz Centre for Environmental Research, Germany	39	0.1	1.53
Michael H. Barrett	2007	University of Surrey, England	18	0.09	1
Michael A. Bender	1993	Brookhaven National Laboratory, United States	42	0.08	1
Thomas Heberer, Thomas	2002	Technical University of Berlin, Germany	48	0.07	1.72
Thomas A. Ternes,	2002	Federal Institute of Hydrology, Germany	42	0.07	1.79
Susan T. Glassmeyer, Susan T.	2006	United States Environmental Protection Agency, United States	28	0.07	1.86
Abolfazl Daneshvar,	2013	Gonbad Kavous University, Iran	23	0.07	1

Robert Loos	2011	European Commission Joint Research Centre, Belgium	27	0.06	1.4

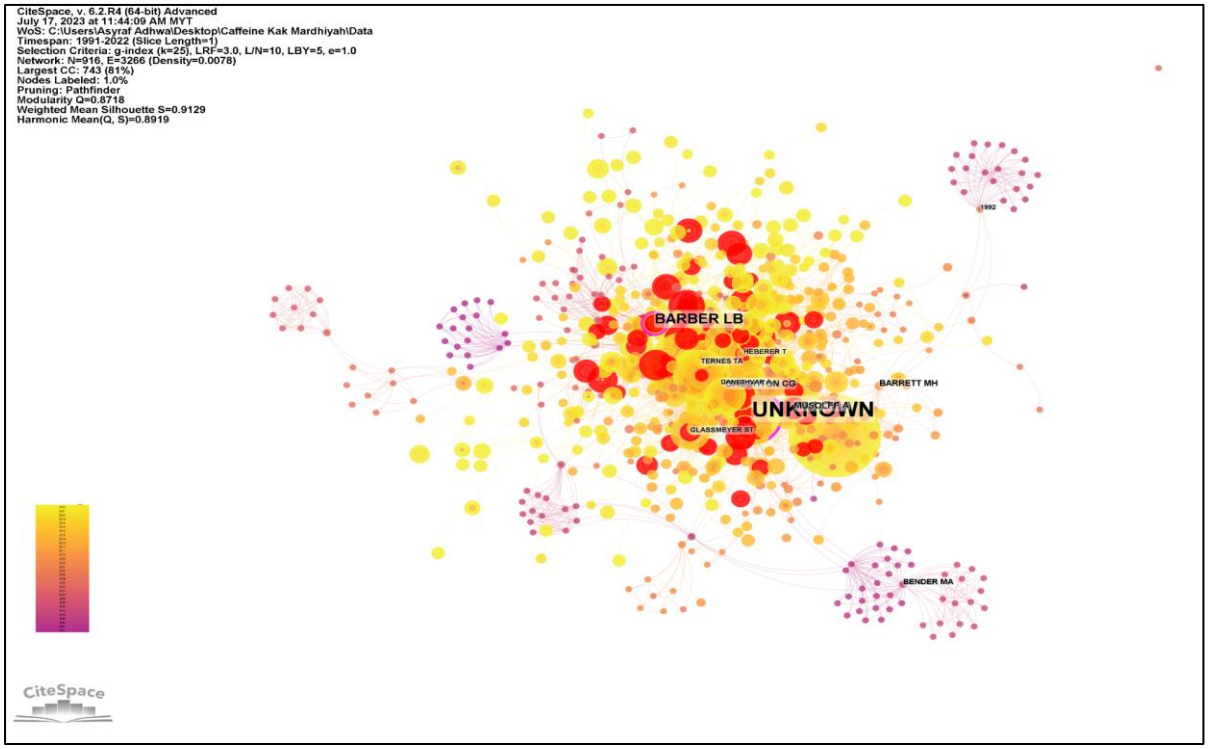

Figure 5. Network of authors' co-citations, with a bigger writing format of an author's name indicating a more cited author (more frequently referred to) in the research; the large node indicates a high number of citations (red ring), based on the WOSCC database.

Table 5. Top ten document co-citation analysis related to the caffeine-related field

Title	Year	Degree	Centrality	Sigma	References
Pharmaceuticals and Endocrine Disrupting Compounds in U.S. Drinking Water	2009	22	0.3	3.78	(27)
Transport of Chemical and Microbial Compounds from Known Wastewater Discharges: Potential for Use as Indicators of Human Faecal Contamination	2005	20	0.24	6.11	(28)
Caffeine, an Anthropogenic Marker for Wastewater Contamination of Surface Waters	2003	18	0.13	2.72	(20)
Temporal variability of combined sewer overflow contaminants: Evaluation of wastewater Micropollutants as tracers of faecal contamination	2013	12	0.13	1.00	(29)
Occurrence and spatial distribution of 158 pharmaceuticals, drugs of abuse, and related metabolites in offshore seawater	2016	25	0.11	1.67	(30)
Investigating the environmental transport of human pharmaceuticals to streams in the United Kingdom	2004	25	0.09	1.00	(31)

Potential for biodegradation and sorption of acetaminophen, caffeine, propranolol, and acebutolol in lab-scale aqueous environments	2010	19	0.09	1.5	(32)
Occurrence and Environmental Behaviour of the Chiral Pharmaceutical Drug Ibuprofen in Surface Waters and Wastewater	1999	18	0.09	1	(33)
Pharmaceuticals and personal care products (PPCPs) in the freshwater aquatic environment		14	0.08	1.65	(34)
Seasonal Variations in Concentrations of Pharmaceuticals and Personal Care Products in Drinking Water and Reclaimed Wastewater in Southern California	2006	5	0.08	1.00	(35)

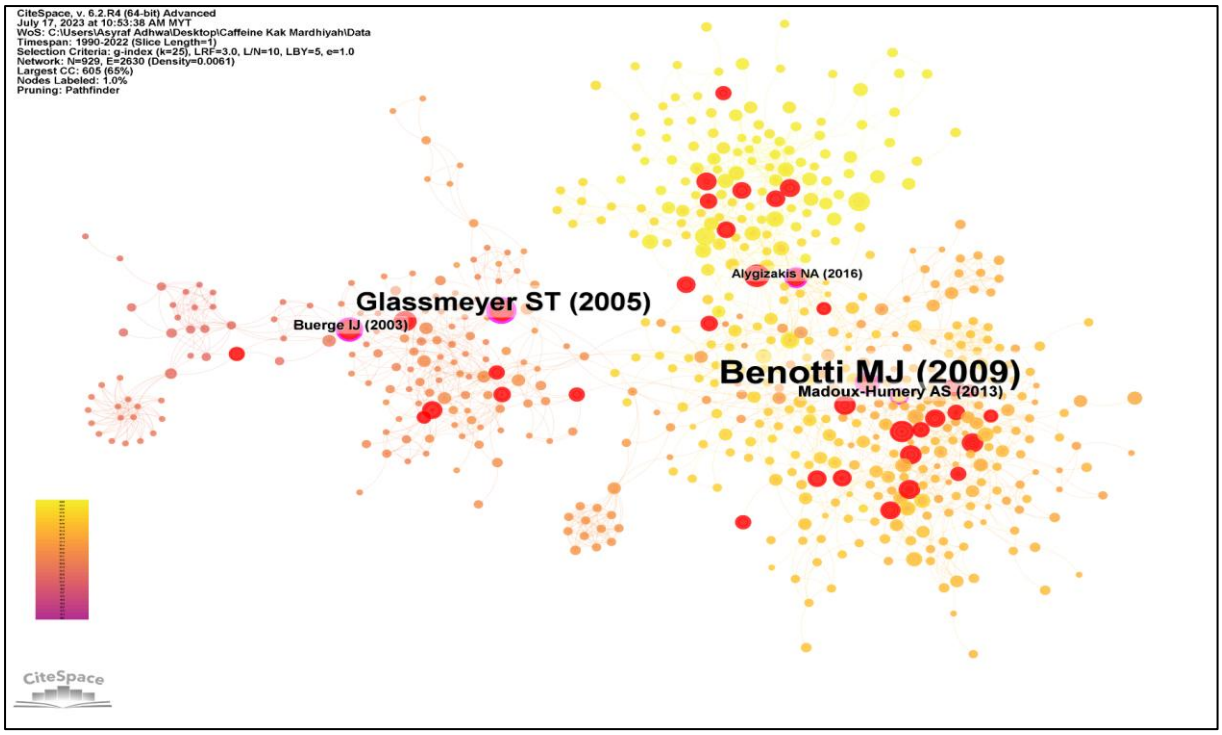

Figure 6. The network of document co-citation analysis with centrality scores greater than 0.1.

3.8 Cluster Analysis

Fifteen significant group clusters were discovered through a document cluster analysis in the CiteSpace software. The clusters were numbered and ranked in order of size, with #0 being the largest. Table 6 shows top 15 significant group clusters based on LSI, LLR, and MI analysis.

These clusters were also fifteen different clusters were summarized on a horizontal line, with the cluster label on the right side of the figure (Figure 7). The figure shows the timeline co-citation cluster analysis in which each node denotes a document and the line reflects the connection between the nodes. The size of the nodes denotes citation frequency and documents with the red nodes represent documents with a high citation burst. The largest cluster (#0) based on Table 6 and Figure 7 has 94 members and with silhouette value of 0.901. It is labelled as a micro-organic contaminant by both LLR and LSI and as photocatalytic degradation (0.85) by MI.

Table 6. Top 15 significant group clusters in caffeine-related research based on the LSI, LLR, and MI.

Cluster-ID	Size	Silhouette	Label (LSI)	Label (LLR)	Label (MI)	Average Year
0	94	0.901	micro-organic contaminant	micro-organic contaminant	photocatalytic degradation	2011
1	94	0.854	ecological risk assessment	urban drainage channel	liquid chromatography-mass spectrometry	2017
2	73	0.908	pharmaceutical product	pharmaceutical product	varying wastewater treatment plant discharge	2004
3	65	0.902	chemical source tracking marker	raw wastewater contamination	polar micropollutant	2010
4	63	0.897	personal care product	personal care product	polymeric resin	2016
5	39	0.959	using an integral pumping test	using an integral pumping test	agricultural pesticide concentration	2007
6	37	0.951	supplying New York City drinking water	supplying New York City drinking water	wastewater contamination	2002
7	36	0.876	global exposure distribution	probabilistic risk assessment	non-conventional water resource	2014
8	22	0.953	*ruditapes philippinarum*	caffeine ibuprofen carbamazepine	personal care product	2008
9	20	0.986	regenerative capacity	regenerative capacity	personal care product	2012
10	18	0.996	ranking and prioritization of environmental risks of pharmaceuticals in surface waters	prioritization	personal care product	2002
11	18	0.961	pharmaceuticals, hormones, and other organic wastewater contaminants in US streams, 1999-2000: a national reconnaissance	other organic wastewater contaminant	personal care product	1999
16	11	0.995	other source	sewer overflow	personal care	2006
26	8	0.994	emerging concern	occurrence removals mass	personal care product	2020
29	7	1	mitigation of diclofenac pollution in aqueous media by adsorption	mitigation	personal care product	2016

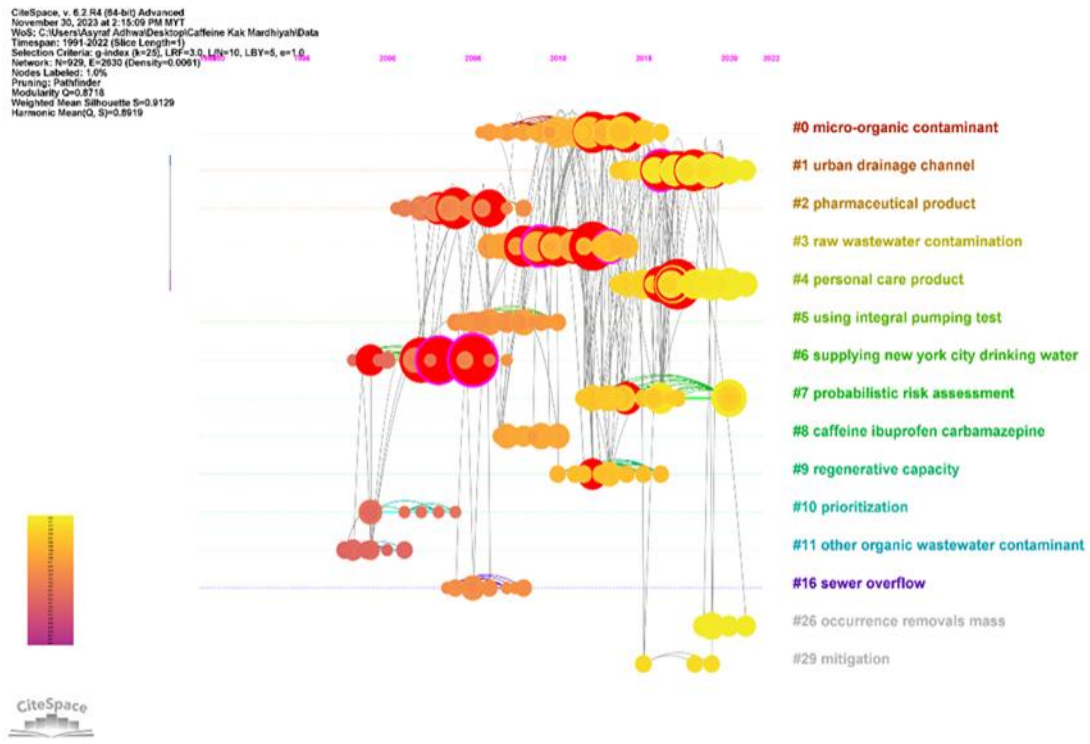

Figure 7. Timeline co-citation cluster analysis. The cluster label was generated from CiteSpace. Fifteen clusters were summarized along a horizontal line, with the cluster's labels positioned on the right side.

In this cluster, the most influential article is A national-scale assessment of micro-organic contaminants in groundwater of England and Wales (36). In this article, the study analysed a large set of monitoring data to determine the relative occurrence and detected concentrations of different groups of compounds and to determine relationships with land use, aquifer types, and groundwater vulnerability. The study found that trace concentrations of a large range of compounds are still detected in groundwater, including newly 'emerging contaminants' like pharmaceuticals including caffeine and lifestyle compounds, particularly those with potential endocrine disrupting properties. Caffeine is among the most frequently detected emerging contaminants in groundwater samples with concentrations reaching up to 0.23 µg/L. The presence of caffeine in groundwater is likely due to contamination from leaking sewer sources, and aquifers in chalk and limestone are especially vulnerable to this contamination.

The second-largest cluster (#1) consists of 94 members and boasts a silhouette value of 0.854. It's labelled as an urban drainage channel by LLR, ecological risk assessment by LSI, and liquid chromatography-mass spectrometry by MI. The standout article in this cluster is "Occurrence of Pharmaceuticals and Cocaine in the Urban Drainage Channels Located on the Outskirts of Sao Vicente Island (Sao Paulo, Brazil) and Related Ecological Risk Assessment." (37). This article marks the first record of various pharmaceuticals and illicit drugs in urban drainage channels flowing to São Vicente Island. The ecological risk assessment revealed significant environmental concerns for the island, ranging from low to moderate risks for different substances, including caffeine. This study emphasizes the potential ecological risks associated with pharmaceuticals in urban drainage channels, highlighting the need for more comprehensive research to monitor and assess the impact of these contaminants of the environment.

The third-largest cluster (#2), is labelled as a pharmaceutical product by both LLR and LSI and as varying wastewater treatment plant discharge by MI. This cluster includes 73 members and has a silhouette value of 0.908. The pivotal article in this cluster is "An Overview of Pharmaceuticals and Personal Care Products Contamination Along the River Somes Watershed, Romania" (38). This study examines the occurrence of pharmaceuticals and personal care products (PPCPs) in the River Somes watershed. It assesses PPCPs in wastewater treatment effluents and the receiving river water, noting caffeine concentrations of up to 42,560 ng L-1. The most prevalent PPCPs in the Somes include caffeine, galactoside, carbamazepine, and triclosan, with concentrations ranging from 10 to 400 ng L-1 across all 15 sampling sites. The study underscores the significance of reducing contaminant effluent into the river Somes.

Apart from the cluster (#1), cluster (#4) is also gaining interest recently based on the location of the node in Figure 7. This cluster is identified as a personal care product by both LLR and LSI and as polymeric resin by MI with 63 members and a silhouette value of 0.897. The prominent article in this cluster is "Contamination, Source, and Potential Risks of Pharmaceuticals and Personal Products (PPCPs) in Baiyangdian Basin, an Intensive Human Intervention Area, China." (39). The study explores the presence of PPCPs in the heavily impacted area by human activities in the Baiyangdian Basin. Focusing on 30 PPCPs, the research identifies sulfamethoxazole, ofloxacin, anhydro-erythromycin, carbamazepine, and caffeine as the predominant PPCPs. The study emphasizes rivers as a crucial source of PPCPs, with domestic sewage being the primary contributor. Risk assessment indicates elevated ecological risks for carbamazepine, caffeine, ofloxacin, and anhydro-erythromycin, posing potential threats to diverse species.

Another emerging cluster (#7) comprises 36 members and boasts a silhouette value of 0.876. It is categorized as probabilistic risk assessment by LLR, global exposure distribution by LSI, and non-conventional water resource by MI. The primary referenced article in this cluster is "Caffeine and Paraxanthine in Aquatic Systems: Global Exposure Distributions and Probabilistic Risk Assessment." (40). The study provides an extensive examination of the worldwide prevalence of caffeine and its principal metabolite, paraxanthine in aquatic systems, coupled with a probabilistic risk assessment for aquatic organisms. The findings suggest that the presence of caffeine and paraxanthine in aquatic systems poses an environmental risk to certain species, while the anticipated human health risk from caffeine exposure through drinking or groundwater is deemed negligible. The study highlights the potential of caffeine as an environmental tracer for anthropogenic wastewater contamination and emphasizes the imperative for additional research on the ecological ramifications of caffeine contamination in aquatic systems.

Lastly, the 14th largest cluster (#26) encompasses 8 members and exhibits a silhouette value of 0.994 also gaining interest in the recent years. It is labelled as an occurrence of removals mass by LLR, emerging concern by LSI, and personal care product by MI. The central article in this cluster is "Assessment of a Wide Array of Organic Micropollutants of Emerging Concern in Wastewater Treatment Plants in Greece: Occurrence, Removals, Mass Loading, and Potential Risks." (41). The study evaluates the occurrence, removal, mass loading, and potential risks associated with various emerging organic micropollutants in two wastewater treatment plants in Greece. Using solid-phase extraction and ultra-high-performance liquid chromatography Orbitrap high-resolution mass spectrometry, the study reveals higher influent concentrations compared to effluent concentrations. Notably, caffeine,

acetaminophen, irbesartan, and valsartan emerge as ubiquitous compounds. The research emphasizes the need for intensified surveillance programs for receiving water bodies and the investigation of toxicity to non-target organisms.

3.9 Keywords' Cluster and Burstiness Analysis

The keywords "personal care products", "pharmaceutical", and "waste water" were the top three highly cited keywords in this research area, and the most popular keywords used are shown in Table 7.

Table 7. Top 10 popular keywords in titles, abstracts, and keywords for caffeine and water contamination-related research based on WOSCC

Keyword	Times
Personal care products	138
Pharmaceuticals	111
Waste water	108
Removal	104
Surface waters	90
Aquatic environments	89
Drinking water	73
Contamination	67
Fate	63
Emerging contaminants	63

As shown in Table 8, the red line demonstrates the burstiness phase, and the blue line represents the timeframe (from 1991 to 2022). The top three keywords with the highest citation burst strength are "anthropogenic marker", "contamination" and "surface water". Notably, "anthropogenic marker" receives the strongest citation strength with 7.91. The "surface" and "risk" are the recently emerged keywords (2020-2022). The keywords "anthropogenic marker", "contamination" and "surface water" describe fundamental characteristics of caffeine's position as a major environmental pollutant particularly in aquatic ecosystem. The expanding interest among researchers' interest in this area reflects academic community's acknowledgement of the urgent need to understand and address the ecological impacts of caffeine.

4.0 Discussion

Our study examines the state of the research area in global trends in caffeine-based lifestyle and its impact on environment-related studies through a bibliometric and scientometric analysis. The data analysis provides valuable insight into the current status and future direction in this research area. In terms of bibliometric analysis, the study highlights information from multiple journals across global geographical location with no restrictions to specific countries. Although a previous bibliometric article that focused on coffee/caffeine relating to sport (42), no specific article has yet addressed the trends of caffeine intake and its impact on the environment, making this study a novel contribution to the field. Studies have shown that caffeine can bioaccumulate in aquatic organism and adversely affect their health, leading to concerns about its ecological impact. However, there is no comprehensive bibliometric analysis that collates and evaluates the existing literature in this topic. Although individual studies have explored the bioaccumulation and environmental risks of caffeine residues in non-target organisms, as highlighted in the previous research (9,43), no overarching bibliometric review synthesizes these findings or identifies trends in research output over time. This review would serve as a valuable resource for researchers, policymakers, and practitioners aiming to address caffeine pollution.

Table 8. Top ten keywords with the strongest citation

Keywords	Year	Strength	Begin	End	1991 – 2022
anthropogenic marker	2007	**7.91**	2007	2016	
contamination	2003	**7.29**	2007	2014	
surface waters	2002	**5.82**	2006	2013	
tandem mass spectrometry	2007	**5.42**	2011	2017	
surface	2014	**5.36**	2020	2022	
sewage treatment plants	2007	**5.06**	2007	2015	
environmental risk	2018	**4.6**	2020	2022	
risk	2017	**4.58**	2017	2019	
waste water treatment	2012	**4.08**	2018	2019	
aquatic environment	2004	**3.9**	2016	2018	

4.1. Evolution of the publication

Research on the global trends in caffeine-based lifestyles and their impact on environment-related studies have been published more frequently in recent years, with the number of publications exceeding 100 articles in 2022. This upward trend can be attributed to several factors. First, the surge in demand for caffeine-based products such as, coffee, the annual production exhibited a consistent growth from roughly 9.9 million metric tons in 2019 to about 10.5 million metric tons in 2020 (2). Additionally, the speciality coffee shops industry, known for its high quality and unique coffee products, is predicted to increase steadily over the five periods from 2022 to 2027 – with an average growth rate of 7.43% (44).. As the consumption of caffeine has become more common in contemporary lifestyles either as beverages or medications, it has prompted a greater awareness of its possible impact on the environment. Over time, the awareness of caffeine-based lifestyle and its negative impact on the environment will gain more attention among researchers and facilitate the number of paper publications. The increasing focus on caffeine consumption and its environmental impacts has gained significant attention among researchers, leading to a notable rise in related publication over time. For instance, caffeine has been identified as an emerging global pollutant that enters waterways primarily through wastewater systems, impacting water quality and marine biodiversity (5,45).

This corresponds with the number of citations also steadily increasing by years as it rises from just one citation in 1991 to an astonishing 4406 citations in 2022. Some studies have discovered the abundant occurrence of caffeine in marine and estuarine environments emphasizing the need for more comprehensive research to gain an understanding of its ecological

impact. Caffeine pollution was reported to occur in Taiwan and Switzerland wastewater, and also Korean sewage treatment plants (STP), that lead to passing caffeine residue to the environmental waters, with concentrations reaching 24 µg/L, 73 µg/L and 23.7 µg/L respectively (22,32,46). These findings raise important questions regarding caffeine's ecological impact and require continuous research into monitoring and mitigating potential effects on aquatic ecosystems. Scarce information can be obtained from previous studies concerning this matter. For example, caffeine has been reported to cause alterations in the biochemical profiles of polychaetes such as *Diopatra neapolitana* and *Arenicola marima* after chronic exposure to caffeine (8). In another study, acute exposure to caffeine in the freshwater fish *Astyanax altiparanae* led to the reduction of antioxidant enzymatic activity including catalase (47). The collective findings suggested the need for a more comprehensive understanding of the caffeine-based lifestyle consequences to ecological health particularly in aquatic animals. This study is particularly relevant as it addresses the increasing scholarly interest in caffeine-based lifestyles and their negative environmental impacts, providing a comprehensive bibliometric review that highlights trends in research output and identifies critical gaps in the literature.

In addition, this field involved 3345 authors, and Professor Dr Sauvé an expert in Environmental Chemistry at the University of Montréal, Canada has the highest number of publications. Following closely are Professor Dr Prevost Michele and Professor Dr Dorner Sarah, both affiliated with Polytechnique Montréal as reported in the descriptive data (Table 2). Professor Dr Sauvé Sebastien is an Associate Dean of Research and Creation at the Faculty of Arts and Sciences. One of his most highly cited articles on caffeine consumption and its environmental impact research area titled “Faecal coliforms, caffeine and carbamazepine in storm water collection systems in a large urban area”, was published in Chemosphere in 2011 (48). Interestingly, this publication is a collaborative effort with the other leading authors in this field, Professor Dr Prevost Michele and Professor Dr Dorner Sarah.

Dr Sauvé‘s most recent publication “Suspect screening of pharmaceuticals, illicit drugs, pesticides, and other emerging contaminants in Argentinean *Piaractus mesopotamicus*, a fish species used for local consumption and export” was also published in *Chemosphere* in 2022 (49). Both articles have a direct connection to caffeinated product disposal and the consequences of water contamination. His research trajectory illustrates his continued commitment to exploring the vital connection between caffeine, environmental concerns and water quality. Another prominent figure is Professor Dr Michele Prevost, an expert from the Department of Civil, Geological and Mining Engineering who specializes in technology development in drinking water. She has collaborated on various publications with Dr Sarah Dorner, whose research focuses on the treatment of surface water in highly urbanized areas. Notably, two of their joint manuscript are titled “Faecal contamination of storm sewers: Evaluating wastewater micropollutants, human-specific Bacteroides 16S rRNA, and mitochondrial DNA genetic markers as alternative indicators of sewer cross connections” (50) was published in Science of the Total Environment in 2019. The other manuscript titled “Temporal variability of combined sewer overflow contaminants: Evaluation of wastewater micropollutants as tracers of faecal contamination” published in Water Research in 2013 (29). Both of the authors focused on the occurrence of potentially toxic substances including caffeine in water systems. They highlighted that the presence of caffeine in the environment poses potential risks to both ecosystem and aquatic health. This indicates that the

research in this area is crucial to minimize the potential adverse effects of a caffeine-based lifestyle and its environmental consequences by developing effective caffeine waste management strategies.

Furthermore, there are also many institutions involved in this research (1269 institutions) although the number of countries does not achieve 30% of the total countries in the world (Figure 6). The total number of papers published on the caffeine-based lifestyle and its impact on the aquatic environment-related study based on the country remains smaller. Hence, we strongly encourage more researchers to exchange and collaborate globally in the future in this research area. The top two journals that published based on environmental, are Science of The Total Environment (Netherlands, publisher: Elsevier) and Environmental Science and Pollution Research (Germany, publisher: Springer) with 82 and 50 articles have been published respectively. Articles with an environmental or pollution context are the basic requirement to be published in both journals. The fact that the fate of caffeine has been devoted to natural water has received much attention in recent years (20) and has been recognized as a contaminant of water bodies (5). This is consistent with the WOSCC result that the Environmental Science category shines out above the other 91 categories that have been identified from a total of 728 papers, as seen in Figure 5. In addition to that, both journals hold a Q1 status, signifying that the research on caffeine-based lifestyle and its environmental impact has a high impact and the significant number of articles of this research field, published in these Q1 journals underscores the growing importance of this issue.

The increasing scholarly attention to caffeine consumption and its environmental impacts is evident in the rising number of publications dedicated to this topic, as more journals recognize the significance of caffeine as an emerging pollutant. Researchers are increasingly focusing on the adverse effects of caffeine on aquatic ecosystems highlighting its role as a pervasive contaminant that enters waterways primarily through wastewater systems. This trend is supported by recent studies that have documented the bioaccumulation of caffeine in various aquatic organisms and its detrimental effects on species such as fish, polychaetes and microalgae, which include impaired in antioxidant mechanism (8) and increased oxidative stress (47). Moreover, the recognition of caffeine as a significant environmental contaminant has prompted many journals to publish studies addressing its ecological risks. Recent studies support this trend and highlight that while caffeine is widely consumed and generally safe in moderate amounts, it can lead to significant toxicological effects such as inducing anxiety-like behaviours in adult zebrafish, with significant alteration in swimming patterns and increased cortisol levels (51). By highlighting trends in publication, this study will contribute valuable insights to the scientific community and inform policymakers about the importance of managing caffeine waste effectively to protect aquatic ecosystems from contamination.

4.2 Co-Citation Trending Topic

Co-citation analysis was used to identify the conceptual structure of a research field based on its citation patterns by a specific bibliometric method. The output of the analysis includes the knowledge map that serves the influential research of the author, journal and documents of a research area. In this review, the co-citation analysis is based on the centrality and sigma value generated from CiteSpace to understand the importance of a node. In co-citation analysis, when two or more articles are cited together by other papers, they are considered to be co-cited. Thus, a central article refers to the article that acquired a large number of co-citations. In this review, the paper entitled “Pharmaceuticals and

Endocrine Disrupting Compounds in U.S. Drinking Water" (27) can be considered as the central paper since the letter labelling in the knowledge mapping (Figure 6) is the biggest in comparison to others. In the document cluster analysis, the top three clusters that emerged in the caffeine and water contamination-related research were micro-organic contaminants, urban drainage channels and pharmaceutical products. This trend is consistent with numerous studies that have documented that caffeine can be considered an emerging contaminant agent in fresh water as a result of human activities, which can cause negative effects on aquatic life and thus contribute to water pollution (7,9). Furthermore, the growing body of evidence underscores the urgent need for effective monitoring and management strategies to mitigate caffeine pollution, as its ecological impacts continue to pose risks to biodiversity and the overall health of ecosystem.

In recent years, there has been growing interest in four main clusters within cluster analysis. These clusters include #1 urban drainage channel, #4 personal care product, #4 probabilistic risk assessments, and #26 occurrence removals mass. These clusters indicate a focus on the release of caffeine into aquatic systems through urban drainage channels and the incorporation of caffeine in personal care products (PCPs), where it subsequently leaches into the aquatic environment. Additionally, clusters #4 probabilistic risk assessments and #26 occurrence removals mass suggest a shift in research focus towards assessing the risks associated with caffeine in aquatic environments and developing methods for its removal from the system.

The top three keywords with the highest count were "personal care product", "pharmaceuticals" and "waste water" suggesting that the use of caffeine has been expended in certain PCPs and pharmaceuticals rather than only in food and beverages. It is interesting that "personal care product" is the top keyword in our analysis, despite the study focus on caffeine-based lifestyle and environmental impact, given that caffeine is mainly derived from coffee and tea. PCPs represent a diverse variety of compounds found in items like toiletries, skin care products and other cosmetic products that are not subjected to metabolic alterations (52). As a result, more PPCPs will be introduced into the estuarine and marine environment prompting researchers to issue more publications in this research area. Consequently, these substances tend to accumulate in the environment. Furthermore, the synergistic effect of caffeine when combined with conventional drugs makes it widely used in various therapeutic fields (53). As one of the pharmaceutical ingredients, designed to be biologically active and stable in the environment for lengthy periods (54), caffeine as a pharmaceutical product disposal may have an impact on the aquatic environment. Interestingly, the most recent keyword in caffeine and water contamination-related studies was "surface" (strength 5.36, 2020-2022) and "risk" (strength 4.58, 2020-2022). The finding indicates that the usage of caffeine has shifted more to its environmental impact and risk to humans and animals. As this study trend gathers popularity, more studies are required to focus on better understanding to address caffeine's role in water contamination and its consequences.

4.3 Promoting Future Generation Sustainable Choices and Future Work

As the caffeine-based lifestyle is becoming more common, whether in beverages, personal care products or pharmaceuticals, researchers are being increasingly engaged in studying its varied environmental implications. The Environment Protection Agency (EPA) has taken a comprehensive strategy to adopt a comprehensive approach to pharmaceutical waste management in response to increasing concern regarding the harmful effects of caffeine, along with other pharmaceutical compounds (55). The EPA aims to protect the health and

sustainability of aquatic habitats for future generations by addressing the proper disposal and management of pharmaceutical waste including caffeine-containing products. This approach is consistent with Education for Sustainable Development (ESD), a fundamental component of the 2023 Agenda for Sustainable Development Goal (SDG) on Education supported by the United Nations Educational, Scientific and Cultural Organization (UNESCO). ESD aims to provide individuals with the information and principles required to make eco-friendly conscious decisions about the aquatic environment, thereby promoting a sustainable future for younger generations (56). This is accomplished by raising knowledge of proper disposal practices of caffeinated products along with other potentially hazardous compounds, educating people about the environmental impact of caffeine residue particularly and conveying a sense of responsibility for protecting our aquatic environment.

The future study of this caffeine-based lifestyle has the potential to expand more into emerging trends in sustainable aquatic environmental management. As this lifestyle continues to grow and its various environmental impacts become more noticeable, researchers are likely to concentrate more on innovative technologies to remove caffeine from caffeinated products before they are introduced into sewage water. Conventional wastewater treatment plants have demonstrated varying levels of caffeine removal however despite these removal efficiencies, many of these systems often partially biodegrade caffeine, leading to its persistence not only in the treated effluents but also in residual sludge (57). Advanced treatment technologies are required to achieve more comprehensive degradation and assure that treated water is safe to discharge into natural water bodies. Further research may also look into the larger effects of caffeine as an ingredient in beverages, PCPs or pharmaceutical residue on water quality and aquatic life health. International collaborations between institutions, authors and governments will be crucial in resolving the concerns posed by this caffeine-based lifestyle.

Conclusion and Limitations

This bibliometric review uncovers a broad network of scientific literature on caffeine's impact on the environment. The bibliometric and scientometric analysis in this study found that the caffeine consumption trends have shifted, extending its use to include personal care products and pharmaceutical drugs beyond its common consumption in food and beverages only. This upward trend parallels with the findings of numerous studies on the occurrence of caffeine residue in ecosystems with potential implications for aquatic organisms and perhaps correlated to human health and well-being as well. We may think that this occurrence is somewhat a hint of an impending silent disaster. This suggests the importance of further research, particularly on the solution and mitigation efforts, and the need for interdisciplinary collaborations and engagements among authors and researchers, industries, governments and communities' countries to address this emerging environmental awareness.

The current study has some limitations, including the fact that it only focused on papers from a WOSCC database. This narrow focus may contribute to publication bias as it may potentially omit relevant manuscripts in this study in other sources not indexed in WOSCC. It is advisable to include more databases and search engines to acquire a more comprehensive collection of related studies. Despite this limitation, the findings of the current study still contribute insight to a better knowledge of caffeine's impact on water pollution and aquatic ecosystems within WOSCC scope.

Authorship contributions statement

SMR and MAAM: Conceptualization literature search, data collection,

methodology, formal analysis, writing–original draft. NH: Editing, draft corrections. II and WIWI: Visualization, draft corrections. HAH; Conceptualization, draft corrections, supervised. All authors contributed to the study's idea and design.

Acknowledgments

The preparation of this manuscript was made possible due to the support of the Malaysian Ministry of Higher Education through the Fundamental Research Grant Scheme (FRGS/1/2022/WAB05/UITM/02/2) and Universiti Teknologi MARA via Community Engagement – Social Innovation Research (CE-SIR) (600-RMC/CE-SIR 5/3 (015/2023)).

Conflict of Interest

The authors have no relevant financial interests that could be considered as influencing the content or interpretation of this word.

References

1. WHO. World Health Organization. 2023 [cited 2024 Jan 28]. Model List of Essential Medicines. Available from: https://www.who.int/groups/expert-committee-on-selection-and-use-of-essential-medicines/essential-medicines-lists

2. ICO. International Coffee Organization. 2023 [cited 2024 Jan 28]. Coffee Market Report. Available from: https://icocoffee.org/coffee-prices-close-2022-on-stable-note/

3. AMR. Allied Market Research. 2022 [cited 2024 Jan 28]. Caffeine Market Research. Available from: https://www.alliedmarketresearch.com/caffeine-market

4. Gracia-Lor E, Rousis NI, Zuccato E, Bade R, Baz-Lomba JA, Castrignanò E, *et al*. Estimation of caffeine intake from analysis of caffeine metabolites in wastewater. Sci of Total Environ. 2017;609:1582–8.

5. Edwards QA, Kulikov SM, Garner-O'Neale LD. Caffeine in surface and wastewaters in Barbados, West Indies. SpringerPlus. 2015;4(1):1–12.

6. Pires A, Almeida Â, Calisto V, Schneider RJ, Esteves VI, Wrona FJ, *et al*. Long-term exposure of polychaetes to caffeine: Biochemical alterations induced in *Diopatra neapolitana* and *Arenicola marina*. Environ Pollut. 2016;214:456–63.

7. Mohd W, Wan A, Khalik M, Loh SH, Albani H, Aisyah S, *et al*. Caffeine Residue in Terengganu River Basins in Malaysia: Distribution and Risk Assessment. Nat. Environ. Pollut. Technol. 2020;19(2):711–9.

8. Li S, Wen J, He B, Wang J, Hu X, Liu J. Occurrence of caffeine in the freshwater environment: Implications for ecopharmacovigilance. Environ Pollut. 2020;263:114371.

9. Kuo-Esser L, Chen R, Lawson K, Kuchinski K, Simmons N, Dominguez M, *et al*. Early-life caffeine exposure induces morphological changes and altered physiology in *Caenorhabditis elegans*. Biochem Biophys Res Commun. 2024;690:149240.

10. Vieira LR, Soares AMVM, Freitas R. Caffeine as a contaminant of concern: A review on concentrations and impacts in marine coastal systems. Chemosphere. 2022 Jan 1;286: 131675.

11. Kim MC, Nam S, Wang F, Zhu Y. Mapping scientific landscapes in UMLS research: a scientometric review. J Am Med Inform Assoc. 2020;27(10):1612-24.

12. Chatterjee J, Dethlefs N. Scientometric review of artificial intelligence for operations & maintenance of wind turbines: The past, present and future. Renew Sustain Energy Rev. 2021;144:111051.

13. Azra MN, Noor MI, Burlakovs J, Abdullah MF, Abd Latif Z, Yik Sung Y. Trends and new developments in Artemia research. Animals. 2022;12(18):2321.

14. Chen C. CiteSpace II: Detecting and visualizing emerging trends and transient patterns in scientific literature. J. Am. Soc. Inf. Sci. Technol. 2006;57(3):359–77.

15. Chen C. Science Mapping: A Systematic Review of the Literature. J Data Inf Sci. 2017;2(2):1-40.

16. Chen XX, Ji ZG, Wang Y, Xu J, Wang LY, Wang HB. Bibliometric analysis of the effects of mental fatigue on athletic performance from 2001 to 2021. Front Psychol. 2023;13:1019417.

17. Kolpin DW, Furlong ET, Meyer MT, Thurman EM, Zaugg SD, Barber LB, *et al*. Pharmaceuticals, hormones, and other organic wastewater contaminants in U.S. streams, 1999-2000: A national reconnaissance. Environ Sci Technol. 2002;36(6):1202–11.

18. Loos R, Gawlik BM, Locoro G, Rimaviciute E, Contini S, Bidoglio G. EU-wide survey of polar organic persistent pollutants in European river waters. Environ Pollut. 2009;157(2):561–8.

19. Focazio MJ, Kolpin DW, Barnes KK, Furlong ET, Meyer MT, Zaugg SD, *et al*. A national reconnaissance for pharmaceuticals and other organic wastewater contaminants in the United States - II) Untreated drinking water sources. Sci Total Environ. 2008;402(2–3):201–16.

20. Buerge IJ, Poiger T, Müller MD, Buser HR. Caffeine, an anthropogenic marker for wastewater contamination of surface waters. Environ Sci Technol. 2003;37(4):691–700.

21. Erisman JW, Galloway JN, Seitzinger S, Bleeker A, Dise NB, Roxana Petrescu AM, *et al*. Consequences of human modification of the global nitrogen cycle. Philos Trans R Soc Lond B Biol Sci. 2013;368(1621) :20130116.

22. Buerge IJ, Buser HR, Kahle M, Müller MD, Poiger T. Ubiquitous occurrence of the artificial sweetener acesulfame in the aquatic environment: An ideal chemical marker of domestic wastewater in groundwater. Environ Sci Technol. 2009;43(12):4381–5.

23. Munoz M, Cedeño R, Rodríguez J, van der Knaap WP, Mialhe E, Bachère E. Measurement of reactive oxygen intermediate production in haemocytes of the penaeid shrimp, *Penaeus vannamei*. Aquaculture. 2000;191(1-3):89-107.

24. Sim WJ, Lee JW, Lee ES, Shin SK, Hwang SR, Oh JE. Occurrence and distribution of pharmaceuticals in wastewater from households, livestock farms, hospitals and pharmaceutical manufactures. Chemosphere. 2011;82(2):179–86.

25. Lin AYC, Yu TH, Lin CF. Pharmaceutical contamination in residential, industrial, and agricultural waste streams: Risk to aqueous environments in Taiwan. Chemosphere. 2008;74(1):131–41.

26. Batt AL, Bruce IB, Aga DS. Evaluating the vulnerability of surface waters to antibiotic contamination from varying wastewater treatment plant discharges. Environ Pollut. 2006;142(2):295–302.

27. Benotti MJ, Trenholm RA, Vanderford BJ, Holady JC, Stanford BD, Snyder SA. Pharmaceuticals and endocrine disrupting compounds in U.S. drinking water. Environ Sci Technol. 2009;43(3):597–603.

28. Glassmeyer ST, Furlong ET, Kolpin DW, Cahill JD, Zaugg SD, Werner SL, *et al*. Transport of chemical and microbial compounds from known wastewater discharges: Potential for use as indicators of human fecal contamination. Environ Sci Technol. 2005;39(14):5157–69.

29. Madoux-Humery AS, Dorner S, Sauvé S, Aboulfadl K, Galarneau M, Servais P, *et al*. Temporal variability of combined sewer overflow contaminants: Evaluation of wastewater micropollutants as tracers of fecal contamination. Water Res. 2013;47(13):4370–82.

30. Alygizakis NA, Gago-Ferrero P, Borova VL, Pavlidou A, Hatzianestis I, Thomaidis NS. Occurrence and spatial distribution of 158 pharmaceuticals, drugs of abuse and related metabolites in offshore seawater. Sci Total Environt. 2016;541:1097–105.

31. Ashton D, Hilton M, Thomas K V. Investigating the environmental transport of human pharmaceuticals to streams in the United Kingdom. Sci Total Environ. 2004;333(1–3):167–84.

32. Lin AYC, Lin CA, Tung HH, Chary NS. Potential for biodegradation and sorption of acetaminophen, caffeine, propranolol and acebutolol in lab-scale aqueous environments. J Hazard Mater. 2010;183(1–3):242–50.

33. Buser HR, Poiger T, Muller MD. Occurrence and environmental behavior of the chiral pharmaceutical drug ibuprofen in surface waters and in wastewater. Environ Sci Technol. 1999;33(15):2529–35.

34. Ebele AJ, Abdallah MA, Harrad S. Pharmaceuticals and personal care products (PPCPs) in the freshwater aquatic environment. Emerg Contam. 2017;3(1):1-6.

35. Loraine GA, Pettigrove ME. Seasonal variations in concentrations of pharmaceuticals and personal care products in drinking water and reclaimed wastewater in Southern California. Environ Sci Technol. 2006;40(3):687–95.

36. Manamsa K, Crane E, Stuart M, Talbot J, Lapworth D, Hart A. A national-scale assessment of micro-organic contaminants in groundwater of England and Wales. Sci Total Environ. 2016;568:712–26.

37. Roveri V, Guimarães LL, Toma W, Correia AT. Occurrence of pharmaceuticals and cocaine in the urban drainage channels located on the outskirts of the São Vicente Island (São Paulo, Brazil) and related ecological risk assessment. Environ Science Pollut Res. 2022;29(38):57931-4.

38. Moldovan Z, Schmutzer G, Tusa F, Calin R, Alder AC. An overview of pharmaceuticals and personal care products contamination along the river Somes watershed, Romania. J Environ Monit. 2007;9(9):986-93.

39. Yang L, Wang T, Zhou Y, Shi B, Bi R, Meng J. Contamination, source and potential risks of pharmaceuticals and personal products (PPCPs) in Baiyangdian Basin, an intensive human intervention area, China. Sci Total Environ. 2021;760:144080.

40. Rodríguez-Gil JL, Cáceres N, Dafouz R, Valcárcel Y. Caffeine and paraxanthine in aquatic systems: Global exposure distributions and probabilistic risk assessment. Sci Total Environ. 2018;612:1058–71.

41. Ofrydopoulou A, Nannou C, Evgenidou E, Christodoulou A, Lambropoulou D. Assessment of a wide array of organic micropollutants of emerging concern in wastewater treatment plants in Greece: Occurrence, removals, mass loading and potential risks. Sci Total Environ. 2022 Jan 1;802:149860.

42. Contreras-Barraza N, Madrid-Casaca H, Salazar-Sepúlveda G, Garcia-Gordillo MÁ, Adsuar JC, Vega-Muñoz A. Bibliometric analysis of studies on coffee/caffeine and sport. Nutrients. 2021;13(9):3234.

43. Li S, He B, Wang J, Liu J, Hu X. Risks of caffeine residues in the environment: Necessity for a targeted ecopharmacovigilance program. Chemosphere. 2020;243:125343..

44. Technavio. Technavio. 2012 [cited 2024 Jan 29]. p. 154 Specialty Coffee Shops Market Analysis Forecast 2023-2027. Available from: https://www.technavio.com/report/specialty-coffee-shops-market-size-industry-analysis

45. Rodriguez del Rey Z, Granek EF, Sylvester S. Occurrence and concentration of caffeine in Oregon coastal waters. Mar Pollut Bull. 2012;64(7):1417–24.

46. Choi K, Kim Y, Park J, Park CK, Kim MY, Kim HS, *et al*. Seasonal variations of several pharmaceutical residues in surface water and sewage treatment plants of Han River, Korea. Sci Total Environ. 2008;405(1–3):120–8.

47. Muñoz-Peñuela M, Lo Nostro FL, Dal'Olio Gomes A, Tolussi CE, Branco GS, Pinheiro JPS, *et al*. Diclofenac and caffeine inhibit hepatic antioxidant enzymes in the freshwater fish *Astyanax altiparanae* (Teleostei: Characiformes). Comp.

Biochem. Physiol. C.: Toxicol Pharmacol. 2021;240:108910.

48. Sauvé S, Aboulfadl K, Dorner S, Payment P, Deschamps G, Prévost M. Fecal coliforms, caffeine and carbamazepine in stormwater collection systems in a large urban area. Chemosphere. 2012;86(2):118–23.

49. Carrizo JC, Vo Duy S, Munoz G, Marconi G, Amé MV, Sauvé S. Suspect screening of pharmaceuticals, illicit drugs, pesticides, and other emerging contaminants in Argentinean *Piaractus mesopotamicus*, a fish species used for local consumption and export. Chemosphere. 2022;309:136769.

50. Hajj-Mohamad M, Hachad M, Deschamps G, Sauvé S, Villemur R, Blais MA, *et al*. Fecal contamination of storm sewers: Evaluating wastewater micropollutants, human-specific Bacteroides 16S rRNA, and mitochondrial DNA genetic markers as alternative indicators of sewer cross connections. Sci Total Environ. 2019;659:548–60.

51. Santos N, Picolo V, Domingues I, Perillo V, Villacis RAR, Grisolia CK, *et al*. Effects of environmental concentrations of caffeine on adult zebrafish behaviour: a short-term exposure scenario. Environ Sci Pollut Res. 2023;30(23):63776–87.

52. Brausch JM, Rand GM. A review of personal care products in the aquatic environment: environmental concentrations and toxicity. Chemosphere. 2011;82(11):1518-32.

53. Ialongo D, Tudino V, Arpacioglu M, Messore A, Patacchini E, Costi R, *et al*. Synergistic effects of caffeine in combination with conventional drugs: Perspectives of a drug that never ages. Pharmaceuticals 2023;16(5):730.

54. Mahamad Dom SH, Abdul Hamid H, Jamal JA, Dali AF, Md Saman K, Ibrahim N. Environmental sustainability impacts of improper disposal of domestic pharmaceutical waste in the global south. E-Bangi J Soc Sci Hum. 2023;20(4):414-31.

55. EPA. United States Environmental Protection Agency. 2022 [cited 2024 Jan 29]. Resources for Managing Hazardous Waste Pharmaceuticals. Available from: https://www.epa.gov/hwgenerators/management-hazardous-waste-pharmaceuticals#standards

56. UNESCO. United Nations Educational, Scientific and Cultural Organization. 2016 [cited 2024 Jan 29]. Sustainable Development Goals - Resources for educators. Available from: https://en.unesco.org/themes/education/sdgs/material

57. Gadi N, Boelee NC, Dewil R. The Electro-Fenton Process for Caffeine Removal from Water and Granular Activated Carbon Regeneration. Sustainability (Switzerland). 2022;14(21):14313.