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ORIGINAL PAPER

Evaluation of global Arsenic remediation research: adverse effects on human health

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Abstract

Arsenic (As) is one of the human carcinogens with a global peril to human health through direct or indirect exposure to contaminated water, food, air and skin contact. As a result, research on arsenic remediation has surged. However, no report evaluating the trends of studies on the subject has been documented. Therefore, the present study was conducted to examine global research trends on arsenic removal and remediation. Web of Science and Scopus were explored to retrieve published papers on the subject between 1929 and 2020. In all, 2605 articles were published within the survey period, with annual mean and growth rate of 28.63 and 11.11%, respectively. Research productivity raised consistently and peaked in 2019 (9.9%) and 2020 (9.2%). China ($n = 574$, 22%) ranked first followed by India ($n = 361$, 10%) and the United States ($n = 239$, 9.2%). The top 20 productive authors published articles between 19 and 49 with total citations of 442 to 511. The highest recurrent Keywords were arsenic ($n = 992$, 38.08%), adsorption ($n = 519$, 19.2%) and arsenic removal ($n = 435$, 16.72%). This study revealed an improved global research on Arsenic removal with greater research outputs from both developed and developing countries; however, the global collaboration appears to be low (collaboration index of 2.5), hence, the policymakers, governments and researchers should encourage international collaborations and establish research programs that can monitor arsenic contamination globally.

Keywords Arsenic · Remediation · Bibliometric · Research collaboration · Arsenic toxicity · Human health risk

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Introduction

Arsenic is one of the most popular and natural metallic chemical element in the earth's crust (Alka et al. 2021) with atomic number of 33, atomic weight of 5.73 g·cm^{-3} and specific gravity of 74.9 g·mol^{-1}. It boils at 614 °C and melts at 817 °C. It exists in diverse chemical forms and can transform from one form to another via geochemical processes (Choong et al. 2007). The inorganic form such as As(III) that is rare except in groundwater, is reported to be 60 times noxious compared to the organic form such as As(V) that are mostly found in toxic water (Chakraborty et al. 2014; Bertolero et al. 1987). Arsenic concentration in an uncontaminated environment is normally between 1 and 2 µg/l, but can increase to 5000 µg/l in a polluted milieu (Al-Makishah et al. 2020).

The global popularity of this stiff and fragile crystal-like solid with a silver–grey colour may be linked to its harmful effect on man, plant and animal (Alka et al. 2021; Zakhar et al 2018). Globally, environmental pollution from arsenic has led millions of people from India, China, Pakistan, Bangladesh, USA, Chile, Canada, Mexico, Brazil, Indonesia, Vietnam and Hungary (Al-Makishah et al. 2020) to experience serious health complications via ingestion of polluted water and food grown on arsenic-polluted soils or food that originates from farms irrigated with arsenic-contaminated water (Rehman et al. 2021). The authorities and researchers have termed Arsenic contamination a twentieth-to-twenty-first-century catastrophe (Hare et al. 2019). In fact, arsenic contamination needs to be tackled to attain some of the sustainable development goals especially Goal 6 (to achieve clean water and sanitation) and Goal 11(to make cities inclusive, safe, resilient and sustainable).

Generally, global urbanization and industrialization, volcanic outburst and breakdown of arsenic-containing rock sediments, have been hinted at as the main risk factors that contribute to the release of arsenic into the environment (Irshad et al. 2020). Industrial processes such as production, smelting and exploration of minerals and other commercial activities of developed and industrialized nations have immensely increased the release of harmful heavy metals including arsenic into the entire ecosystem (Al-Makishah et al. 2020).

To ensure arsenic removal or remediation, several strategies and techniques have been implemented over many decades as extensively reviewed and documented in the literature (Alka et al. 2021; Al-Makishah et al. 2020; Mohammed and Dagang 2019; Asere et al. 2019; Criscuoli and Figoli 2019; Choong et al. 2007). Most of the arsenic removal techniques considered many guidelines and necessities such as explicit considerations, distinguished pollution sources, proficient remediation frameworks and cost of remediation among others (de Souza et al. 2019). In addition, a good removal procedure that does not produce secondary contamination of the target area or another is taught to hold future potential on pollutant remediation in general (Nidheesh and Singh 2017).

The bibliometric study is a statistical technique for evaluation of quantifiable and qualitative scope as well as the competency of research efforts accomplished in a defined area of choice (Ekundayo and Okoh 2018). Such study can help to regulate national and international research direction through research output and propose future research strategies, research financing, and interdisciplinary collaborations. Bibliometric analysis can also offer policy-makers information needed for the implementation of essential preventive measures most especially if the analysis discloses an upsurge in articles about a known health challenge in a given location. Global research appraisals can help international health and environmental agencies with the information they need to identify emergencies (e.g. a certain global health or environmental issue or national emergencies) that requires disbursement of aids and research grants (Swelleh 2017; Zyoud 2017; Ekundayo and Okoh 2018). Bibliometric studies have been conducted and reported for *Plesiomonas* related research (Ekundayo and Okoh 2018), global research on use of bioflocculant for wastewater treatment (Okaiyeto et al. 2020), human recognition of challenges of microplastic pollution (Wu et al., 2021), analysis of industrial wastewater treatments, organochlorine pesticides research (Olisah et al. 2019) and cancer research (Cabra 2018).

Many researchers have reported detailed reviews on arsenic contamination and its removal as mentioned above; however, there has not been any bibliometric analysis of published articles on this globally important topic. Therefore, in the present report, we conducted a global bibliometric scrutiny of articles related to arsenic removal published between 1929 and 2020. The publications were evaluated with respect to the annual and country research outputs, authors and their mean citations, single and co-authorship, thematic and keywords evolutions, collaborations and networking. This review will no doubt help to easily identify research gaps in arsenic removal strategies and technology and as well offers resources that can recognize present and future research priorities on arsenic remediation.

Materials and methods

Published studies on arsenic remediation studies were mined from Scopus and Web of Science databases by applying the principles of the "Preferred Reporting Items for Systematic Reviews and Meta-Analyses: PRISMA" (Moher et al. 2010) (Fig. 1). The search algorithm was 'Arsenic* AND (removal OR remediat* OR bioremediat* OR biodegrad*) (Title)', 'Refined By: Document Types: Articles'' in the WoS and 'TITLE (arsenic* AND (removal OR remediat* OR bioremediat* OR biodegrad*)) AND (LIMIT-TO (DOCTYPE, "ar"))' in the Scopus. All records were downloaded in Bibtex format for analysis on 21 August 2021. The pooled dataset was pre-processed, duplicated and associated variables including authors' variables (names, institutional and national associations) and document variables (keywords and source) normalized by using bibliometrix package (Aria and Cuccurullo 2017) in an R programming environment to avoid double inputs in the subsequent investigation. The explanatory, leaning and output assessments of the normalized data were performed in R Version 4.1.1. While the explanatory analyses included the yearly production and associated mean citations per article and (co)-author indices (i.e. authors count, authors' appearances, articles per author, (co-)authors per article, single-/multi-authored articles, and collaboration index), productivity mapping was limited to the top twenty authors/entities (nations, organizations, and journals) with accompanying citation rate and H-index (Ekundayo and Okoh 2018). Finally, the dataset was analysed for thematic areas using author-keywords co-word

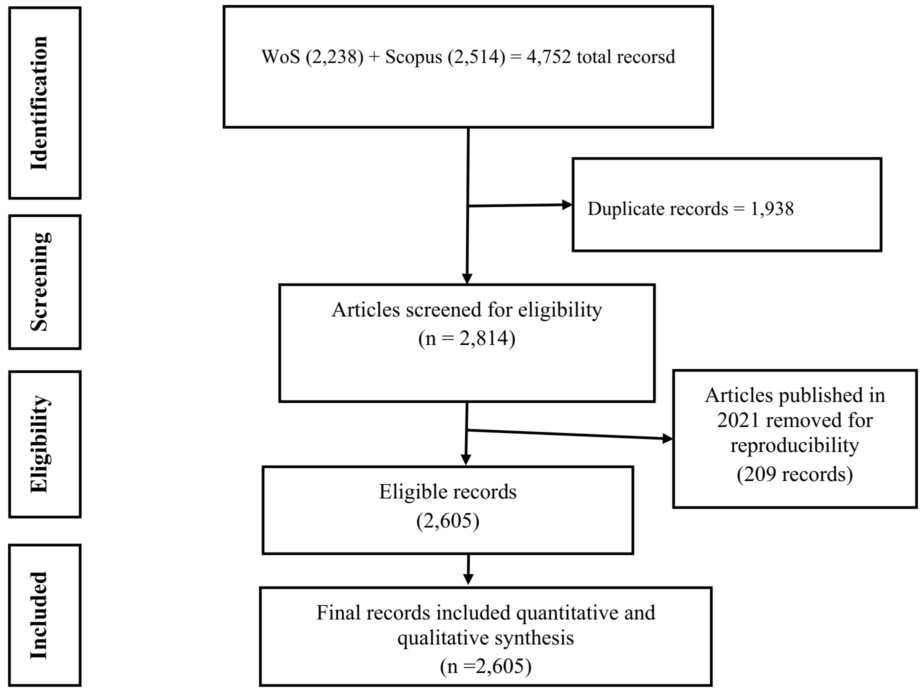

Fig. 1 Schematic diagram for mining and screening arsenic remediation research records

analysis, unsupervised k-means clustering and metric multidimensional scaling (MDS) coupled with Porter's stemming according to Aria and Cuccurullo (2017) and Ekundayo and Okoh (2018) and thematic evolution based on techniques previously described somewhere using simple centres co-word algorithm (Chen et al. 2019; Jacobs 2002).

Results and discussion

Research output trend on arsenic removal related research

The summary of information on arsenic remediation articles published in Scopus and Web of Science is as shown in Table 1. Research articles published within the period under review totals up to 2605. The articles were published by 6372 authors altogether, with 0.41 article/author and 2.45 authors/documents, 4.31 co-authors/document, and a research collaboration index of 2.5. Out of 6372 authors involved, 83 authors published as single authors while all other 6289 authors were involved in co-authored articles. The mean citation per article at the time of information retrieval was found to be 31.8, while the average citation per year per document was 3.45**.** Research output increased from 1 in 1929 to 2605 articles on 21 August 2021 when the data for this analysis were retrieved. The number of articles reported on a research topic indicates a research output based on a bibliometric survey (Olisah et al. 2019; sun et al. 2018). For instance, a seeming variation in the quantity of articles published on a topic over the years may signify a change in that research field. A positive trend was observed in the annual growth rate of 11.11% indicating that scientific research on arsenic removal has attracted broad attention from 1929 to date. A collaboration index of 2.5 signifies great participation of co-authorship per article with a mean citation per article of 31.8. This may be due to continuous

Table 1 Summary of information retrieved on Arsenic removal articles, 1929–2020

Description	Counts and rates
References	15,124
Article; Journal	2473
article; book chapter	45
article; data paper	1
article; proceedings paper	86
Keywords Plus (ID)	5345
Author's Keywords (DE)	4386
Authors	6372
Author Appearances	11,222
Authors of single-authored documents	83
Authors of multi-authored documents	6289
Single-authored documents	91
Documents per Author	0.409
Authors per Document	2.45
Co-Authors per Documents	4.31
Average citations per documents	31.8
Collaboration Index	2.5

global challenges of arsenic contamination and the stanch interest of the various governments to overcome environmental pollution by arsenic (Roswall et al. 2020). The global nature of arsenic contamination has also contributed to the emergency of new researchers and authors from developed and developing countries (Ekundayo and Okoh 2018).

Research trends over the years

The published research on arsenic removal from 1929 to 2020 and the mean total citations of the articles per year are depicted in Fig. 2. The annual growth rate was 11.11% indicating that research on arsenic removal has been on the rise over time. The research output was consistently low between 1929 and 1998 (range of 1 to 10 articles per year); however, a steady increase in output was observed from the year 2000 (21 articles) and peaking in 2019 (259 articles which account for 9.94%). Correspondingly, the mean total citations of the articles fluctuated throughout the period under review and peaked in 2005 (mean total citation of 5.76).

The trend of the research output on arsenic removal over the years suggests that the number of published articles will increase in the future likely due to enhanced laboratory conditions and improved funding support (Cabral et al. 2018). The citation values indicate that the spread of citations of single-authored and multiple-authored documents are certainly skewed (Olisah et al. 2019; Bott and Hargens 1991), though citations are not a faultless index of evaluating an author's influence in a selected field (Baek et al. 2018).

The top productive authors

The 20 most productive authors are listed in Table 2. Wang Y. who started his publication in 2010 occupies the first position, he co-authored 49 articles representing (1.9%) and has an H-index of 5 and a total citation of 511. Li Y. started his publication in 2007 and came second co-authoring 47 (1.8%) articles and has an H-index of 20 and was cited 1058 times. Wang J. and Zhang J. co-share the third position with each having 35 articles. Chen J. despite starting his publication in 2010 recorded the highest total citation of 1512 and came 4th in terms of the number of articles (30) he authored and co-authored. Interestingly, most of the leading authors and most top-cited articles on arsenic removal originate from industrialized countries such as China, the United States, Korea and Japan with few articles from low-income nations, a comparable trend of low research output from such low-income countries even in other fields. The elevated research

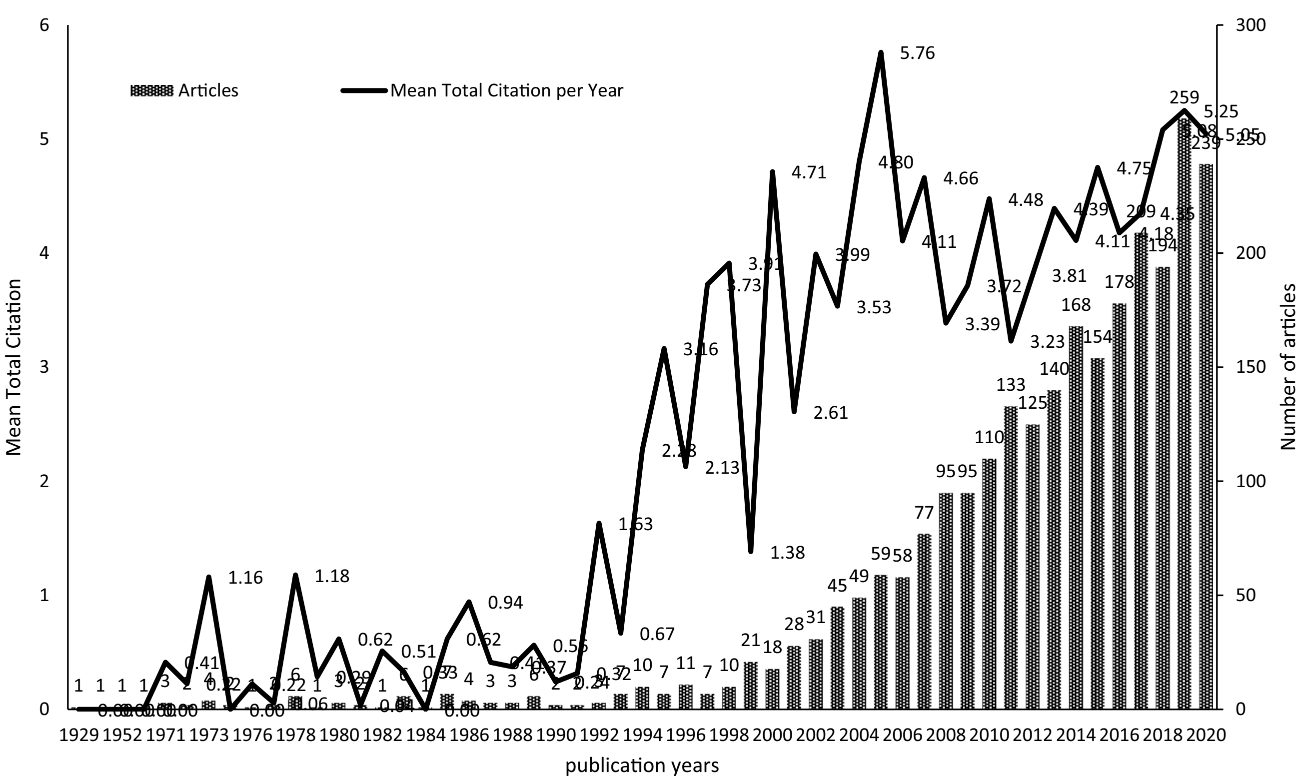

Fig. 2 Annual production number of articles on Arsenic removal from 1929 to 2020. MTC, mean total citations of articles published per year. Research outputs continue to rise over the period under review and peaked in 2019 (259 articles) and 2020 (239 articles)

Table 2 Top 20 productive authors on arsenic removal related studies from 1929 to 2020

Rank	Authors	Articles	% of 2605	H-index	TC	Year publications start
1	WANG Y	49	1.9	12	511	2010
2	LI Y	47	1.8	20	1058	2007
3	WANG J	35	1.3	15	1179	2003
3	ZHANG J	35	1.3	12	418	2010
4	CHEN J	30	1.2	20	1512	2010
5	LI J	29	1.1	12	400	2012
6	LI X	25	1.0	10	362	2003
6	LIU H	25	1.0	11	592	2011
6	RAHMAN M	25	1.0	9	811	2004
6	WANG H	25	1.0	12	1225	1994
7	WANG X	24	0.9	10	305	2009
7	ZHANG Y	24	0.9	13	726	2003
8	YANG J	22	0.8	15	794	2007
8	ZHANG X	22	0.8	10	447	2008
9	GUPTA A	21	0.8	14	991	2005
9	WANG L	21	0.8	11	465	2013
9	ZHAO Y	21	0.8	10	264	2003
10	LEE S	20	0.8	12	635	2004
10	LIU Y	20	0.8	10	454	2014
11	QU J	19	0.7	12	442	2007

output on arsenic removal from the industrialized nations could be traced to the presence of arsenic-related industries in those countries and serious government regulations on the management of wastes generated by the industries (Mohammed and Dagang 2019).

Most globally cited documents

The most globally cited articles on Arsenic removal research are recorded in Table 3. These articles covered the fields of Environmental pollution, Environmental Microbiology, and Chemistry. The number of citations recorded by the top 25 most cited articles ranged from 308 to 1507. The articles were published in Environmental Science and Technology (9), Water resources (5), Journal of Hazardous Matter (3), Bioresource Technology (2) and other 6 journals (1 article each). The most cited documents were published before 2010. Those articles have more tendency to be cited than the recently published articles. In order words, the total citation of a research document accumulates over time, and thus, recent articles need more time to accumulate many citations (Jaward 2004). The spread of research publications associated with arsenic removal in environmental and biological matrices is an indication of improvement of analytical instruments used for pollution detections (including arsenic) and the competence advancement of scientists all over the world (Kanwar et al. 2020).

Most productive countries and most productive academic institutions

Research productivity related to arsenic removal and remediation for the top 20 most productive countries are listed in Table 4. China occupies the first position in terms of the total number of publications ($n = 574$, 22%) followed by India and the United States of America with 369 (21.8%) and 293 (11.2%) articles, respectively. China also ranked first in terms of single country publication ($n = 480$) followed by India and the USA. The frequency of publication among the top 20 most productive countries ranged from 0.01 to 0.23%. This ranking changed entirely when the research output was estimated in terms of citations per country, with the United States of America ranking first ($n = 15{,}063$) followed by China ($n = 14{,}476$) and India which was cited 10,320 times. Other countries that made it to the top 20 most productive nations based on citations per country were Korea (6826), Japan (3242), Canada (2923), Mexico (2188), Australia (2147) and Greece (1962). Turkey, Switzerland, Malaysia, Germany, Iran, Pakistan, Singapore, France, Spain, Italy and the United Kingdom occupied positions 10 to 20 with citations ranging from 826 to 1843. Asian countries found in

Table 3 Most global cited documents on arsenic removal studies from 1929 to 2020

ARTICLES	DOI	TC	TC/Year
CHANDRA V, 2010, A CS NANO	10.1021/nn1008897	1507	125.6
KANEL SR, 2005, ENVIRON SCI TECHNOL	10.1021/es048991u	815	47.9
CHOONG TSY, 2007, DESALINATION	10.1016/j.desal.2007.01.015	606	40.4
KANEL SR, 2006, ENVIRON SCI TECHNOL	10.1021/es0520924	549	34.3
KIM YH, 2004, ENVIRON SCI TECHNOL	10.1021/es0346431	517	28.7
KANEL SR, 2006, ENVIRON SCI TECHNOL	10.1021/es0520924	483	30.2
MENG XG, 2000, WATER RES	10.1016/S0043-1354(99)00,272–9	448	20.4
BISSEN M, 2003, ACTA HYDROCHIM HYDROBIOL	10.1002/aheh.200300485	437	23.0
ZHU H, 2009, J HAZARD MATER	10.1016/j.jhazmat.2009.08.031	431	33.2
KUMAR PR, 2004, CHEMOSPHERE	10.1016/j.chemosphere.2003.12.025	424	23.6
CUMBAL L, 2005, ENVIRON SCI TECHNOL	10.1021/es050175e	405	23.8
BODDU VM, 2008, WATER RES	10.1016/j.watres.2007.08.014	402	28.7
ROBERTS LC, 2004, ENVIRON SCI TECHNOL	10.1021/es0343205	400	22.2
BODDU VM, 2008, WATER RES	10.1016/j.watres.2007.08.014	377	26.9
ZHANG M, 2013, BIORESOUR TECHNOL	10.1016/j.biortech.2012.11.132	371	41.2
MONDAL P, 2006, J HAZARD MATER	10.1016/j.jhazmat.2006.02.023	362	22.6
ROBERTS LC, 2004, ENVIRON SCI TECHNOL	10.1021/es0343205	360	20.0
GIASUDDIN ABM, 2007, ENVIRON SCI TECHNOL	10.1021/es0616534	359	23.9
MAYO JT, 2007, SCI TECHNOL ADV MATER	10.1016/j.stam.2006.10.005	347	23.1
KATSOYIANNIS IA, 2002, WATER RES	10.1016/S0043-1354(02)00,236–1	346	17.3
GU ZM, 2005, ENVIRON SCI TECHNOL	10.1021/es048179r	335	19.7
CHOWDHURY SR, 2010, J ENVIRON MANAGE	10.1016/j.jenvman.2010.06.003	327	27.3
FENG L, 2012, J HAZARD MATER	10.1016/j.jhazmat.2012.03.073	321	32.1
DEMARCO MJ, 2003, WATER RES	10.1016/S0043-1354(02)00,238–5	317	16.7
WANG S, 2015, BIORESOUR TECHNOL	10.1016/j.biortech.2014.10.104	308	44.0

the list included Japan, China, Bangladesh, Malaysia, Singapore, Pakistan and India while no African country made it to the list. The financial and economic growth rate of a country has been indicated to impact its research productivity as the academic and research institutions frequently rely on grants from government and industries to finance their research (Peng et al. 2015; Zhang et al. 2010). A scrutiny of Table 5 shows that most of the top productive countries have more functional research funding bodies involved in funding of the arsenic removal studies. For example, China and India have the National Natural Science Foundation of China NSFC and Department of Science Technology India that have funded 33 and 48 studies on arsenic remediation, respectively. Similarly, Mexico has Consejo Nacional De Ciencia Y Tecnologia Conacyt that have funded up to 40 research on arsenic remediation. The trend is similar for other most productive countries.

The high level of arsenic accumulation in industrialized countries coupled with the availability of research grants from the government and the relevant industries could have motivated researchers in such countries to conduct more investigations on how to remedy this pollutant (Ekundayo and Okoh 2018; Okaiyeto and Oguntibeju 2021; Okaiyeto et al. 2020).

However, some of the most recurrently cited documents on this subject contributed novel strategies for arsenic removal from groundwater or drinking water, for example, the overall most cited article used water-dispersible magnetite-reduced graphene oxide composites to remove arsenic from drinking water (Chandra et al. 2010). Similarly, the document published by Kanel et al. (2005) which was the second most cited article used nanoscale zero-valent iron to remove arsenic from groundwater. The third most cited article (Choong et al. 2007) was a review paper on arsenic toxicity, its health hazard and removal from water. Other most cited articles such as Kanel et al. (2006), Kim et al. (2004) and Meng et al. (2000) used nanoscale zero-valent iron as a colloidal reactive barrier material, mesoporous alumina prepared via a templating method and ferric chloride to achieved arsenic removal. It is convenient to conclude that these most cited articles redirected research on arsenic removal from the conventional strategies to modification of certain known strategies to the introduction of new arsenic removal techniques most especially from water.

Table 4 Top 20 productive countries in terms of Arsenic removal research from 1929 to 2020

Production base on number of articles						Country Production based on no. of citations			
Country	Articles	Freq	SCP	MCP	MCP Ratio	Rank	Country	TC	ACC
CHINA	574	0.23	480	94	0.16	1	USA	15,063	63.03
INDIA	361	0.15	332	29	0.08	2	CHINA	14,476	25.22
USA	239	0.10	190	49	0.21	3	INDIA	10,320	28.59
KOREA	107	0.04	80	27	0.25	4	KOREA	6826	63.79
JAPAN	100	0.04	71	29	0.29	5	JAPAN	3242	32.42
IRAN	87	0.04	82	5	0.06	6	CANADA	2923	45.67
MEXICO	70	0.03	57	13	0.19	7	MEXICO	2188	31.26
TURKEY	67	0.03	56	11	0.16	8	AUSTRALIA	2147	34.08
CANADA	64	0.03	60	4	0.06	9	GREECE	1962	81.75
AUSTRALIA	63	0.03	39	24	0.38	10	TURKEY	1843	27.51
PAKISTAN	46	0.02	35	11	0.24	11	SWITZERLAND	1762	146.83
ITALY	45	0.02	33	12	0.27	12	MALAYSIA	1431	34.07
MALAYSIA	42	0.02	23	19	0.45	13	GERMANY	1341	49.67
ARGENTINA	30	0.01	26	4	0.13	14	IRAN	1335	15.34
SERBIA	30	0.01	25	5	0.17	15	PAKISTAN	1198	26.04
SPAIN	30	0.01	18	12	0.40	16	SINGAPORE	1174	65.22
POLAND	28	0.01	27	1	0.04	17	FRANCE	1056	48.00
CHILE	27	0.01	20	7	0.26	18	SPAIN	1039	34.63
GERMANY	27	0.01	16	11	0.41	19	ITALY	901	20.02
GREECE	24	0.01	19	5	0.21	20	U/KINGDOM	827	34.46

SCP Single country publications, *MCP* Multiple country publications, *TC*, Total Citations, *AAC* Average article citations

Notably, China, India and the United States topped the list of countries that are actively involved in arsenic removal research considering the research output and citations. In addition to the viable economy, financial strength, access to state of art facilities and adequate research funding, their research output can be attributed to a high-level collaboration with other institutions within and across national boundaries (Peng et al. 2015; Zhang et al. 2010). Such intra-national and international collaborations are capable of impacting research prominence, visibility and citation (Ekundayo and Okoh 2018; Zhang et al. 2010).

The domination of China and the United States have been reported in many bibliometric reviews especially on topics that dealt with challenges that are perceived to be global (Ekundayo and Okoh 2018; Geaney et al. 2015; Fricke et al. 2013). The authors' multi-affiliations could impact the country's collaborative network. Conversely, the low research output from low-income countries especially African countries could be linked to a low number of researchers and research institutes, little or no research grants and lack of access to state-of-art literature (Vanni et al. 2014). There was a change in ranking among the top 20 most productive countries in arsenic removal related publications when the research output was estimated based on citations recorded from each country. However, citations cannot be adopted as an accurate estimation of the research output of an author or a country (Fricke et al. 2013). This is because apart from self- and wrong citation that could produce the wrong metric, the little number of research publications used could have a positive influence on regularly cited articles. Authors from universities and research institutes especially from underdeveloped and developing countries may not have access to articles published in closed-access journals if their universities and institutes are not subscribed to relevant journal databases.

The top 20 relevant academic institutions affiliated with arsenic removal research and the number of articles that originate from the institutions are as displayed in Fig. 3. Indian Institute of Technology Delhi came first with 121 articles followed by the Chinese Academy of Science (103 articles), China University of Geosciences (69) and Central South University China (61). Other academic institutions including Universiti Teknologi Malaysia, National University of Singapore, University of Chinese Academy of Sciences had articles ranging from 46 to 28. Interestingly, more institutions from Asian countries especially China is affiliated with arsenic removal publications.

Table 5 Funding agencies/organization on studies related to arsenic removal (> 12 funded studies)

Funding agency	Number of studies funded
National Natural Science Foundation of China NSFC	33
Department of Science Technology India	48
Consejo Nacional De Ciencia Y Tecnologia Conacyt	40
Fundamental Research Funds for the Central Universities	39
National Science Foundation NSF	37
European Commission	32
University Grants Commission India	32
Ministry of Education Culture Sports Science and Technology Japan Mext	27
Council of Scientific Industrial Research CSIR India	26
Comision Nacional De Investigation Cientifica Y Tectological Conicyt	25
National Basic Research Program of China	25
National Key R D Program of China	22
National Key Research and Development Program of China	22
China Postdoctoral Science Foundation	21
Chinese Academy of Sciences	20
Conicyt Fondecyt	20
Japan Society for the Promotion of Science	19
Australian Research Council	18
National High Technology Research and Development Program of China	18
Spanish Government	18
Ministry of Science and Technology Taiwan	17
National Institutes of Health NIH USA	17
Natural Sciences and Engineering Research Council of Canada NSERC	17
The United States Department of Health Human Services	17
Conselho Nacional De Desenvolvimento Cientifico E Tecnologico Cnpq	15
Higher Education Commission of Pakistan	15
Turkiye Bilimsel Ve Teknolojik Arastirma Kurumu Tubitak	14
National Research Foundation of Korea	13
Nih National Institute of Environmental Health Sciences NIEHS	13

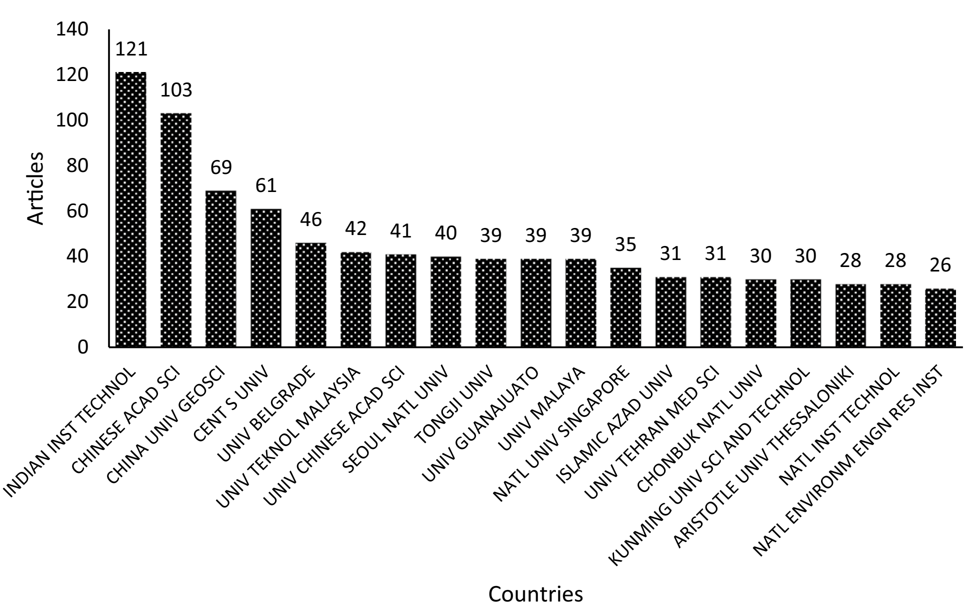

Fig. 3 Top 20 relevant academic institutions affiliated to arsenic removal research from 1929 to 2020

Most relevant keywords and thematic evolutions

To simplify the search for articles online and recognize definite editors and manuscript reviewers, the majority of the journals necessitated manuscript authors to list 5 to 8 keywords in manuscript submission pages and immediately after the abstract of their drafted manuscript. This practice by most of the reputable journals foretells the research progression of a specific field or topic from the Web of Science or Scopus (Ho 2007; Cañas-Guerrero et al. 2013). Table 6 shows the list of most relevant keywords linked to arsenic removal research, the most frequent words were arsenic, adsorption, arsenic removal, groundwater, drinking water and removal occurring 992, 519, 435, 131, 118, 109 times, respectively. Others including arsenate, arsenite, water, treatment, iron, bioremediation, remediation, electrocoagulation and water occurred at the frequency of 60 to 89.

In this survey, we adopted the rate of recurrence of author keywords to understand the publication trend on arsenic removal. Thus, the most relevant keywords linked to arsenic removal studies reflect the research flashpoint during the period under review. These words include arsenic, adsorption, arsenic removal, groundwater, drinking water, removal, arsenate, arsenite, water treatment, etc. The words showed that the most persistent challenge of arsenic contamination has to do with groundwater and wastewater. The groundwater appears to be the central route of human contact with all types of pollutants including arsenic (Zhang et al. 2019). The aftermath effect of arsenic contamination and co-contamination with other heavy metals and research struggles to attain effective removal strategies are well reflected in these most frequently used keywords. This was reinforced by the conceptual framework co-words such as water pollution, groundwater pollution, drinking water, water supply, potable water, water purification, water management and many other related words depicted in Fig. 5. Generally, the global extent of arsenic contamination became established with the gradual ecological assessment and investigations executed over many decades. Upon the development of classy investigative instruments and tools, many pollutants and their mode of contamination were detected, thus permitting the discovery of most contaminants in the environment at major, slight, trace and extreme amounts.

Table 6 Most frequent keywords on arsenic removal research from 1929 to 2020

Rank	Key Words	Occurrences	% of 2605
1	arsenic	992	38.08
2	adsorption	519	19.92
3	arsenic removal	435	16.70
4	groundwater	131	5.03
5	drinking water	118	4.53
6	removal	109	4.18
7	arsenate	89	3.42
8	arsenite	82	3.15
9	water treatment	81	3.11
10	iron	67	2.57
11	bioremediation	64	2.46
12	remediation	62	2.38
13	electrocoagulation	60	2.30
13	water	60	2.30
14	sorption	58	2.23
15	kinetics	56	2.15
16	oxidation	48	1.84
17	coagulation	44	1.69
18	nanoparticles	43	1.65
19	isotherm	41	1.57
20	adsorbent	36	1.38
21	zero-valent iron	35	1.34
22	activated carbon	34	1.31
23	treatment	32	1.23
23	wastewater	32	1.23

Thematic evolution

The thematic evolution of arsenic removal research from 1929 to 2020 is as depicted in Fig. 4. From 1929 to 2008, themes such as arsenic, arsenic removal, adsorption, arsenite and phosphate were majorly used. Other themes used within the same time range were coagulation, reverse osmosis, sorption, and ultrafiltration. Themes such as arsenic, arsenic removal and adsorptive removal received wide usage alongside remediation, arsenate, nanoparticles and sorption. From 2013 to 2016, the themes were mostly arsenic, extraction, arsenic removal and bioremediation. Arsenate, arsenite, adsorption, groundwater, arsenic removal, bioremediation and heavy metals remain frequently used from 2017 to 2020.

However, the latest research themes related to arsenic removal technology such as bioaugmentation (Chen et al. 2017), phytobial remediation (Alka et al. 2021), phytoremediation (Irshad et al. 2021), Nano phytoremediation, biostimulation as well as molecular and genomic modifications of microorganisms and plants as additional or complementary strategies for removing arsenic were not apparent in this review due to low appearance of this themes. The common conceptual frames in retrieved articles determined by *K*-means clustering with clusters showed research responses focused on water pollutants, water purifications, water management, arsenic removal, water supply, filtration and other concepts commonly associated with arsenic remediation (Fig. 5).

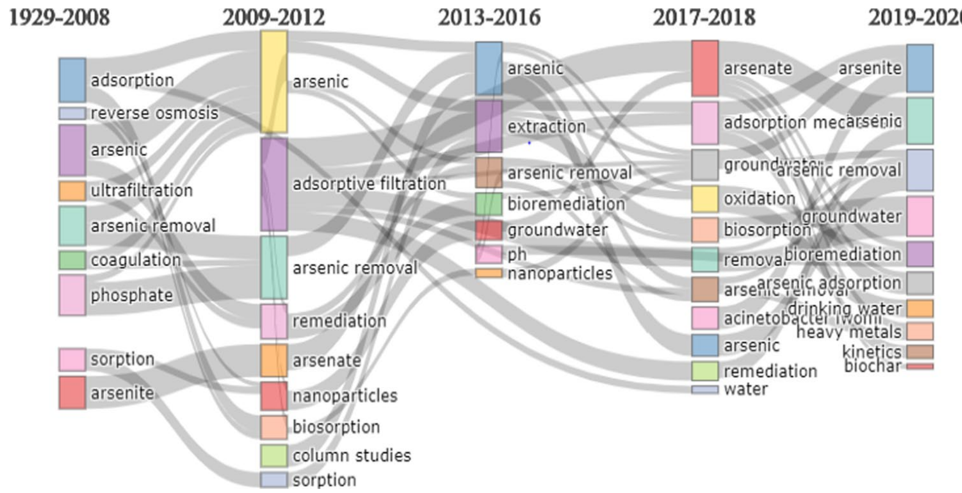

Fig. 4 Thematic evolution on arsenic removal research from 1929 to 2020

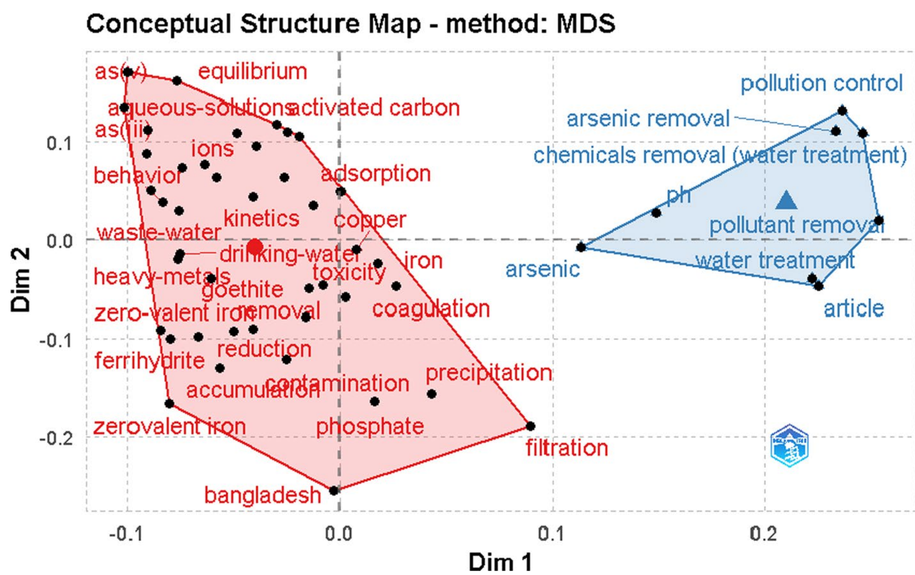

Fig. 5 Common conceptual frames associated with Arsenic removal articles. The 2605 recovered articles displayed K-means with two clusters reflecting concepts frequently linked to Arsenic removal

Authors and country collaboration network

For a thoughtful understanding of the research development on arsenic remediation a co-author collaboration network was conducted. The inclusion criteria for evaluating the authors and countries' global collaboration were mainly based on authorship and corresponding authors' countries, respectively. The collaboration and linkages among authors are depicted in Fig. 6. Each circle-coloured node represents an author. These authors include Wang Y, Li Y, Wang J and Zhang J, Zhang I, Chen J, Wang S, Liu H, Wang W and many others. The size of each node (author) estimates the frequency of their partaking in articles, the edges signify co-author relationships, and the colours of each node differentiate the collaboration clusters. The thickness of the line between any two authors indicates the degree of collaboration. The authors' network encompasses 43 nodes (authors) with one to about ten links. A careful consideration of the size of the nodes indicates that Wang Y, Li Y, Wang J and Zhang J partake in more articles compared to all other authors. This is reinforced by the data in Table 2 which show these authors to be the most top productive researchers in terms of the number of articles and citations. As reported for other fields of research, these authors involved in arsenic removal research collaboration were mostly from developed nations such as China, Japan and USA.

The collaboration and linkages among countries are shown in Fig. 7. Each circle-coloured node represents a country. These countries include China, Switzerland, India, Pakistan, USA, Australia, France, South Africa, Denmark, Belgium and others. The size of each node (country) determines the extent of the countries'

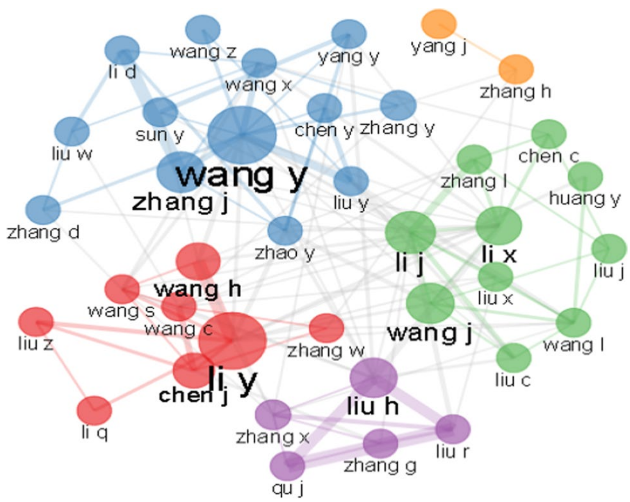

Fig. 6 The authors' collaboration on arsenic removal research. Each node is a representation of a dissimilar author's collaboration. The linking lines are representation of collaboration pathways among authors. The number of lines from a node represents the number of co-authorships

involvement in collaboration, the edges signify countries' relationships, and the colour of the nodes signifies countries' collaboration clusters. The thickness of the line between any two countries shows the degree of collaboration. The country collaboration network encompasses 43 nodes (countries) made up of about 5 different clusters, a careful consideration of the size of the nodes indicates to partake in more collaboration compared to all other countries.

The collaborative network among scientists and researchers from emerging and advanced countries have been reported to be low in most research fields (Vanni 2014). The international collaborative pathways among scientists and researchers from high-income countries such as the United States and China have consistently remained high as indicated by their high publication outputs. The intra- and international collaborative networks have the advantage of fostering division of labour and deployment of adequate resources and ideas to address pressing research questions (Dohse et al. 2018).

Adverse effects of arsenic on humans and Aquatic animals

Arsenic is among the five most toxic substances mentioned in the United States Comprehensive Environment Response, Compensation, and Liability Act (Pfeifer et al. 2002; Rosen and Liu 2009). It could be found either in its organic or inorganic forms; the latter is more toxic than the former. Of the inorganic forms, arsenite (As^{3+}) is even known to be ten folds more hazardous than arsenate (As^{5+}). These two are commonly found in soils and natural water (Wang and Mulligan 2006; Srivastava et al. 2011). They are widely distributed in the environment and are highly resistant to degradation. Human exposure to arsenic is often via the oral route,

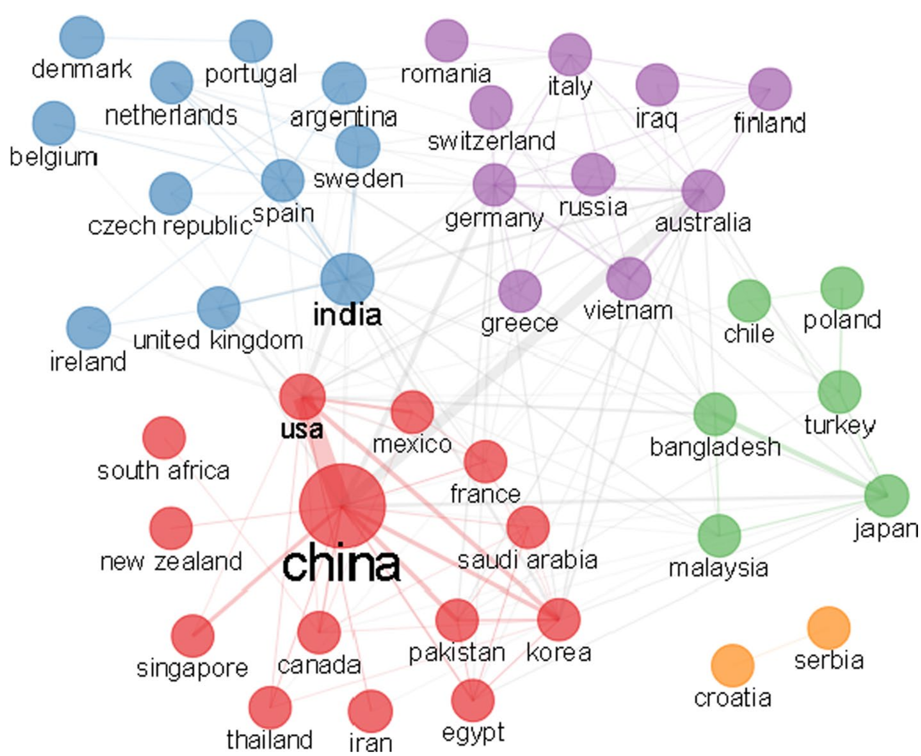

Fig. 7 Countries' collaboration network on arsenic removal research. The nodes represent different countries while the diameter of the nodes is representations of the strength of a country's collaboration with other countries. Lines stand for collaboration path among the countries

skin contact or by inhalation, even though exposure by dermal contact is less common. This metalloid has proven to be carcinogenic to humans even at levels as low as 0.002 mg/l (Liu et al. 2009). Oral exposure could be by ingesting food, water, or soil containing the pollutant; while inhalation is mostly through contaminated dust, gas or metallic particles during the industrial process of metal refining or smelting; prolonged inhalation could be carcinogenic (Rahman et al. 2009). Since organic arsenic is not as toxic as the inorganic forms, oral ingestion of arsenic-contaminated food is not often as harmful to humans as drinking water containing an equal level of inorganic arsenic (Jang et al. 2016).

Inorganic arsenic has been well reported as a possible carcinogen in the kidney, liver, lungs, skin, and/or urinary bladder of humans (IARC 2004; Vahter 2008). Possible non-cancerous effects of this contaminant include weight loss, abdominal pain accompanied with vomiting and diarrhoea, leucopenia, weakness, dementia, keratosis, nausea, loss of appetite, anaemia, hyperpigmentation, peripheral and central nervous disorders, high blood pressure, hypopigmentation, cardiovascular diseases, kidney, liver and respiratory disorders, and diabetes mellitus (Gomez-Caminero et al. 2001; Mandal and Suzuki 2002; WHO & IARC 2004; Bhattacharya et al. 2007; Rahman et al. 2009; Rosen and Liu 2009; Jang et al. 2016). Inorganic arsenic and its methylated metabolites, which are methylarsonic acid (MMA) and dimethylarsinic acid (DMA), are considered as general toxicants, which pass the placenta so easily in both humans and other mammals, and thus affects the development of foetus adversely (Concha et al. 1998). This in some cases can result in loss of the foetus, and retarded growth sometimes. In fact, such damages incurred by the foetus or infant at the early or development stage could result in more deleterious effects much later in life (either at childhood or adult stage of life) (Vahter 2008).

Moreover, the methylation of As^{5+} and As^{3+} in the liver helps to remove arsenic from the body; but the same way increases the amount of the main toxicants. As^{5+} is converted by enzymes into As^{3+}, and subsequently into both DMA and MMA (Clewell et al. 1999). Although these metabolites react less with the internal tissue, but can cause great damage to the body when built up to a higher concentration. Kidneys help rid the bloodstream of As^{5+}; however, As^{3+} (with longer half-lives in the body tissues) has the tendency to bi-accumulate in the organs responsible for the methylation as MMAIII. Ingested arsenic often comes out as an excretion product through the urine, with about 95% of the total already converted to DMA and MMA (Aposhian et al. 2000; Bhattacharya et al. 2007; Vahter 2008; Jang et al. 2016). The health effects of MMAIII's build up in the body tissues include atherosclerosis and cancer (Chen et al. 2003a, b; Tseng et al. 2005; Pu et al. 2007; Steinmaus et al. 2006; Wu et al. 2006; Tseng 2007). Arsenic methylation in women is usually induced during the gestation period (Hopenhayn et al. 2003; Vahter 2008). Cell DNA is damaged via arsenic or any of its metabolites when the iron-bound in the cell is released. This in turn stimulates oxidative stress within the cell, then results in the creation of cancer cells and/or chromosomal alteration (Ahmad et al. 2000; Jang et al. 2016).

Arsenic can be found in natural water bodies being it seawater, warm spring, ground water, river, or lake. It occurs in these natural water bodies mostly as a mixture of arsenate and slightly as arsenite. Uncontrolled application of As containing pesticides, pollution from industries and mining sites remained leading source of global soluble arsenic in water bodies above permissible levels (0.010 mg/L) (Kumari et al. 2017). Incessant exposure of aquatic organisms including fish to even low concentrations of As can lead to bioaccumulation thereby subjecting the liver and kidney to accumulation of As. In most of the cases, altered physiological and biochemical activities such as hyperglycaemia and weak enzymatic activities accompany such bioaccumulation. Other effects of As on fish and other aquatic organisms include severe and lingering toxicity, as well as genetic and immune system disfunction. Exposure with sodium arsenate have been reported to initiate abnormal behaviours in fishes and other aquatic organisms including inconsistent movement, speedy movement of the opercula, jumping out of the test media and lateral swimming (Ventura-Lima et al. 2011). Because of their continuous contact with the external environment, Fish gills are the first targets of water borne poisons. Thus, a high rate of absorption of As through gills also makes fish a susceptible target of As toxicity and leads to respiratory agony (Palaniappan and Vijayasundaram 2009).

Molecular targets of arsenic toxicity

As reported by Mizumura et al. (2010), the trivalent form of arsenic is more toxic than the pentavalent form. Several pathways of arsenic cytotoxicity in cells have been elucidated by some researchers in the literature (McKenzie et al. 2002; Selvaraj et al. 2013). Arsenic induces cytotoxicity by generating ROS (Sies and de Groot 1992). The reactive oxygen species (ROS) levels inside the cell increase dramatically when a cell is exposed to an elevated level of As. For example, the reports of Miller et al. (2002) and Paul et al. (2008) established that As suppressed the replication of DNA with the altered repair of enzymes. Furthermore, since ROS are highly destructive, they can interact with biological macromolecules and consequently causes oxidative stress, affect proteins normal functions, causes lipid peroxidation and DNA damage as well as the activation of signalling caseaded associated with tumour promotion and/or progression occurs (Apel and Hirt 2004; Lai et al. 2008; Suzuki et al. 1997; Kim et al. 2002; Ramana et al. 1998). In addition, it has been reported that As inhibited mitochondrial enzymes by uncoupling of oxidative phosphorylation and impaired tissue respiration (Peraza et al. 2006). Arsenic triggers ROS production and in turn induces Nicotinamide adenine dinucleotide phosphate (NADPH) oxidase (Chou et al. 2004). Interestingly, As can affect the integrity of the mitochondrial membrane potential and negatively affect ATP formation during glycolysis and induction of apoptosis in various cells (Obinaju 2009). There are plethora of reports on As oxidative-DNA damaged based on iron release from ferritin accompanied with ROS production (Colognato et al. 2007; Flora et al. 2008; Lai et al. 2008; Obinaju 2009). For example, Shen et al. (2001) documented that ROS-induced oxidative stress is caused by a mitochondria-dependent apoptotic pathway. Also, damage of genetic information inside the cell results in genotoxicity which ultimately leads to mutation. As a result of proven mechanism of actions of As, to date, numerous studies addressing the genotoxicity of As have been documented (Lu et al. 1995; Valdiglesias et al. 2010). Both cytotoxicity and genotoxicity of As result in the generating of ROS (Hei et al. 2004).

Study limitations

This bibliometric survey is not free of limitations such as the use of only two databases (Web of Science and Scopus), low sensitivity and strict search terms and the omissions of some text categories such as meeting abstract, notes and articles published in other languages except English. Furthermore, the content and findings of the articles surveyed were not revealed in this analysis. Similarly, the recently published articles are at a disadvantage regardless of their eminence and content, because they fall outside the time range of this survey. A bibliometric study combined with a descriptive review of the most recent removal strategies could give a more elaborate analysis of arsenic removal related studies. Comparative and analytical studies can answer questions such as which of newer strategies can remove more arsenic from the environment, which strategies do not produce secondary pollutants and which of the strategies can be combined with one another to yield more arsenic removal. Nevertheless, to our knowledge, this is the first bibliometric report on arsenic removal related research. It will help new and existing researchers in this field to recognize the journey so far and help in directing their future research.

Conclusion

The present study revealed that there is a global increase in arsenic removal related research, high research productivity from developed and few developing countries and restricted collaboration among authors from developed nations and emerging countries. The low research output from developing and underdeveloped countries represents the general research trend in other research fields. Although evolving research themes and current research emphasis on arsenic removal is rarely predictable in bibliometric analysis because of the low appearance in keywords, this study revealed serious global participation in the analysis of arsenic pollutant and its remediation both at environmental and biological matrices. The findings of this survey will provide the basic information needed by the government to formulate policies that can help to prevent and remediate arsenic pollution particularly in countries that have experienced exposure to arsenic in the past and thus reducing public exposure to this health-threatening pollutant. The findings of this survey can also help the governments globally to plan towards achieving the sustainable development goals especially goals 6 and 11. It will also assist scientists working in this field to identify the state of art knowledge needed to streamline their research focus as well as identify which journal to read and where to publish their new findings. Considering the prime importance of arsenic detection for successful removal, Arsenic remediation strategies that incorporate arsenic biosensing techniques such as Aptamer-based arsenic biosensors detailed in the recent work of Mao et al. 2020 and engineered enzyme-conjugated biosensing modalities and devices detailed in comprehensive work of Gul et al. 2021 will open a new dawn in Arsenic remediation.

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Declaration

Conflict of Interests The authors have no relevant financial or non-financial interests to disclose.

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