Global Scientific Research on Electrochemical Detection of Heavy Metal ion by Bibliometric Analysis from 2005 to 2023

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Abstract. The scholarly publications focusing on electrochemical sensors for heavy metal ions have experienced a significant increase in recent years, driven by the efforts of researchers and scientists. This study aims to investigate the current research, identify key areas of interest, and pinpoint future research directions in the field of electrochemical sensing for heavy metal ions. Utilizing bibliometric methods, this paper offers an in-depth analysis of global research trends by examining publications from specific journals, keywords, authors, and countries. The data for this analysis was sourced from the Scopus database and visualized using VOSviewer, encompassing a total of 660 articles published between 2005 and 2023. The most prominent contributors in terms of journal publications, keywords, authors, and countries were found to be Sensors and Actuators B: Chemical, heavy metals, Huang, X-J (Huang, Xing-Jiu), and China, respectively. Looking ahead, future research in this area is likely to address issues related to water quality, water pollution, environmental contaminants, and public health. This research focuses on the study of electrochemical detection systems, specifically designed for heavy metal ions, as discussed in scientific publications.

Keywords: Bibliometric, VOSviewer, Scopus database, Electrochemical sensor, Heavy metal ions.

1 Introduction

Heavy metal ions are a major source of water pollution in the environment. The heavy metal contaminants are not only occurred due to accidentally leaching from the existing water infrastructure but also resulted from domestic effluents, agricultural,

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mining, and industrial activities. Mercury, lead, chromium, arsenic, cadmium, nickel, and copper are the most common heavy metal ions that frequently contaminating water environments [1,2]. Even some ions are considered as essential minerals for human beings, they are toxic at high concentrations and may have negative effects on the human health including damage to multiple organs and nervous system. These may be due to their ability to bind with protein sites, displacing the original essential metals, and bio-accumulating on the human body [2].

Standard analytical methods for detection of trace metals at lower concentrations include atomic absorption spectroscopy [3], capillary electrophoresis (CE) [4], inductively coupled plasma-atomic emission spectroscopy (ICP-AES) [5], ion chromatography ultraviolet-visible spectroscopy (IC-UV-Vis) [6], inductively coupled plasma-mass spectroscopy (ICP-MS), microprobes (MP) [7], and X-ray fluorescence spectroscopy (XPS) [8]. These conventional analytical methods are high sensitivity and selectivity, but in other side these approaches suffer from several limitations including high cost of instruments, complicated sample preparation, restriction of single composition detection and preconcentration procedures which make them unsuitable for real time, online and continuous monitoring application. These techniques also cannot be used for on-site detection due to the large size of equipment [1,9].

Detection method based on electrochemical sensor offers powerful sensing tool for heavy metal ions detection due to its advantages, such as simplicity, low cost, sensitive, selective, effectiveness in multiplexed detection and also its ability for on-site detection [10-14]. Chemical modification of bare electrode with nanomaterials is one of the strategies to increase the sensitivity and selectivity of the electrochemical sensing platform. The wide variety of nanomaterials has some properties that make them as good electron modifier, such as large surface area, extraordinary quantum mechanical properties and active sites enable binding any biorecognition elements.

Nowadays, the review on the evaluation of the heavy metal ions detection based on electrochemical sensor has been growing rapidly, mostly was focused on the particular type of methodology or sensors for specific materials. Bibliometric analysis is a quantitative analysis integrating mathematics and statistics that focuses on the bibliometric characteristics of research in a specific field. It also assists investigators in understanding the field's development priorities and trends and guides their follow up work [15]. Bibliometric methods have expanded the focus on topics, publications, countries, authors, institutions, and journals in many research fields [16,17]. It summarizes the content of a topic, discusses the trend of various directions under the topic according to its development process and also predicts the future direction [18,19].

This article provides a brief overview of the electrochemical sensing for heavy metal ions employing bibliometric analysis. There are no bibliometric studies on current scientific output and future trends of electrochemical sensing heavy ion metals have been reported. In this study, the bibliometric analysis was conducted to see if electrochemistry biosensing may replace existing analytical approaches in heavy metal ion detection based on electrochemical sensing. Furthermore, the future prediction of keyword from this research area is also highlighted.

2 Methods

2.1 Data source and collection

The global literatures about electrochemical sensing for heavy metal ions published between 2005 to 2023 were scanned in the Scopus database. We evaluated and concentrated on research publications that contained the term “electrochemical sensing heavy metal ions” in the title or abstract, in accordance with the Scopus database. The information for the documents that meet the requirements contained year of publication, journal, title, author, affiliation, keywords, document type, abstract, and counts of citation which were exported into comma-separated values (CSV) format. To prevent biases due to frequent database changes, all literature searches and the data downloads were conducted in one day.

A bibliographic information from 660 articles were download as comma-separated values (CSV) files, which are used by several mapping analysis and scientific productivity software programs [20]. The actual data that must be downloaded with this file consists of bibliographic data that includes the author, title, year of publication, source title, author affiliation, keywords, and a number of citations [21].

The CSV format was transferred to Microsoft Office Excel for editing, where it was confirmed that the bibliographic data matched the number of scientific articles and there was no information missing such as authors, publication year, and other data indicated in the Scopus extraction [22]. During the study, no skewed or missing data were observed. Finally, the study employed the same number of scientific articles that were downloaded during data collection: 660.

This should be presented as a clear and detailed description of experimental procedures and analytical conditions to enable readers to carry out similar work. Supply sample preparation procedures, name, model and configuration details of equipment used, and data handing methods.

2.2 Data analysis and visualization

We acquired the bibliometric analysis using VOSviewer version 1.6.18 (Centre for Science and Technology Studies, Leiden University, The Netherlands) and observed a map based on a co-occurrence and identified clusters from the keyword network [22-24]. The standardizations were carried out manually by the authors [25]. The interpretation of the resulting map is based on three characteristics, namely size, distance, and colors [26-28]. A node means a specific element, such as author, country, or keyword. Meanwhile, the size of the node indicates the number of publications or frequency [25, 27,28]. A bigger threshold suggests more occurrence, whereas a smaller threshold represents fewer occurrences. The connection between the nodes is demonstrated between two words reflects the affinities and sparseness of the association. In other words, the tighter the line, the narrower the line is, and vice versa.

3 RESULTS AND DISCUSSION

3.1 Distribution of the number documents by year of publication

The number of articles written about electrochemical sensing for heavy metal ions during the years of 2005 and 2023 has been investigated. The distribution of data from this investigation is depicted in Figure 1. According to reports, researchers and academics from all over the world are becoming increasingly interested in electrochemical detection of heavy ion metal ions. Although there were fewer publications in 2005 and 2006 (2 articles and 1 article, respectively), the trend from 2006 to 2023 showed a rise. Nevertheless, in 2008 and 2009, there was a decrease in the amount of research publications in comparison to the previous year (3 publications and 5 publications, respectively). This bar graph demonstrates that in 2005 the research on electrochemical sensor for heavy metal ions was started to get attention from the researchers and scientist and then increased exponentially until 2023.

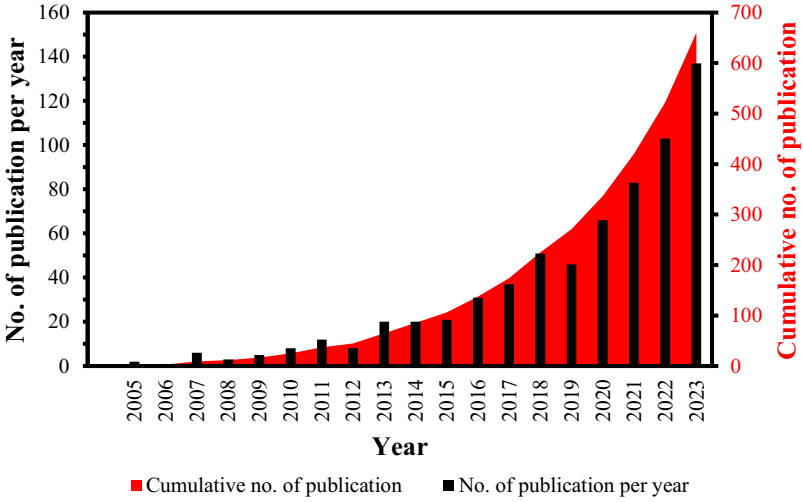

Fig. 1. The annual and cumulative numbers of research articles on electrochemical sensing heavy metal ions indexed in Scopus from 2005 until 2023

3.2 Bibliometric analysis of publication output

A total of 660 publications on the subject of electrochemical sensing for heavy metal ions were identified in the Scopus database which regarded 507 (76.82%) original research articles, 90 (13.64%) review articles, 20 (3.03%) conference papers, 33 (5.00%) book chapters, 10 (1.51%) other types of publications, such as conference reviews, short survey, erratum, letters and so on. In addition, there are 605 (91.67%), 19 (2.88%), and 25 (3.79%) for journal, conference proceedings, book, and other types publications, respectively. The majority of publications were written in English with 646 articles

(97.88%), followed by 13 (1.97%) in Chinese publications, and 1 (0.15%) in Czech publication.

3.3 Bibliometric analysis of the keywords

Journals have generally been quite helpful in indexing and organizing significant research findings. Additionally, using keywords make it easier for researchers to define the focus of their field of expertise. Keywords highlight the main points of each topic as well as the idea of narrative research in the specific topic. The keyword of terms indicates their interdependent connection. The total number of index keywords were 4143 only used only once, 1378 twice, 822 three times, and 582 four times. The final analysis made use of the data keywords that were provided by the manuscript authors and used five times in the Scopus database, as shown in Table 1 and Figure 2. The top fifteen keywords used in the research area of the electrochemical sensing for heavy metal ions research (Table 1). The linkage relationship between keywords, occurrence, and total link strength is demonstrated in this table. Heavy metals (390 occurrences and 5962 total link strength), metal ions (383 occurrences and 5944 total link strength), electrochemical sensor (215 occurrences and 3283 total link strength), and chemical detection with (175 occurrences and 2930 total link strength) are the top five keywords on the subject of the electrochemical sensing for heavy metal ions.

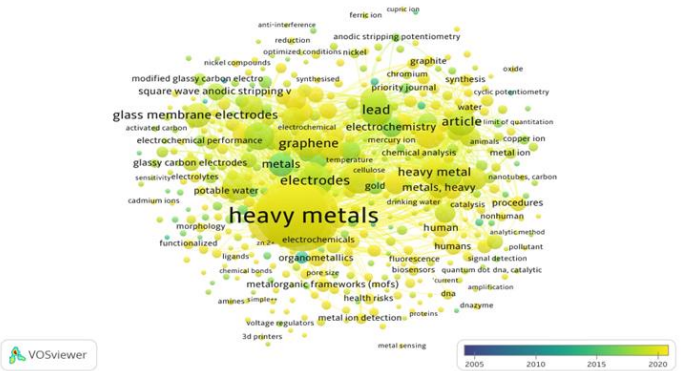

Fig. 2. Bibliometric analysis of the keywords co-occurrences on the electrochemical sensing heavy ion metals in overlay visualization

Figure 2 shows an overlay of the bibliometric analysis of the keywords co-occurrence on the terms on electrochemical sensing for heavy metal ions from 2005 to 2023. The indicator employs dark blue to yellow colors to represent publications from 2005 to 2023. The larger circles around the keywords, the more frequently they are used as keywords. The distance between the two circles represents their relationship. This is relevant and will help researchers figure out their potential research plan and areas of focus.

In addition, it is important to look into the yearly trends in general discussion used in relation to the researchers' emphasis on the electrochemical detection of heavy metal ions. Numerous terms are frequently used in the articles published between 2005 and

2013, including stripping (dyes), electrochemical studies, potentiometry, positive ions, aqueous solutions, concentration (parameters), surface defects, and sensors. These keywords are represented by nodes ranging from dark blue to dark green. The chemical properties of the concentration parameter, which also apply to aqueous solutions and their application to sensors, are terms that closely related to the electrochemical sensing of heavy metal ions.

Table 1. Top fifteen used keywords in the subject research of the electrochemical sensing for heavy metal ions

Keyword	Occurrences	Total Link Strength
Heavy metals	390	5962
Metal ions	383	5944
Electrochemical sensors	215	3283
Chemical detection	175	2930
Electrochemical sensing	135	2175
Electrodes	110	2077
Electrochemical detection	105	2102
Lead	101	2393
Heavy metal ion	101	1669
Graphene	94	1794
Voltammetry	87	1535
Electrochemical electrodes	87	1420
Article	85	2251
Heavy metal	81	1952
Electrochemical analysis	78	1724

The green color nodes indicate, the most frequent search terms from 2014 to 2016, which are nanoparticles, nanowires, micro electrodes, mercury (metal), copper, metals, and synthesis (chemical), as shown in Figure 2. The specific target on the heavy metal ions was more interest during this period as the main term of researcher or scientists. Moreover, since 2017 to 2018, several keywords such as chemical detection, metal ion, graphene, glassy carbon electrode, carbon, carbon nanotube, electrochemical electrodes, metal nanoparticles, modified electrodes, electrochemical techniques, electrochemical sensing, different pulse voltammetry, cyclic voltammetry, voltammetry, chemical analysis, are described with light green node in Figure 2. Some of the carbon material that commonly employed as working electrodes in electrochemistry are carbon and graphene. Glassy carbon electrodes, carbon nanotube, and modified electrodes were the types of electrodes that frequently mentioned in the keywords around this period. They were all used in various forms of different pulse voltammetry and cyclic voltammetry linked to chemical analysis, electrochemical techniques, and electrochemical sensing.

In addition, from 2019 to 2023, the nodes are illustrated in yellow (Figure 2), including such water quality, water pollution, pollution, sensitive detection, pollution detection, environmental pollutants, environmental applications, chemical detection,

chemical composition, heavy metals pollution, heavy metals, metal ions, arsenic, environmental applications, humans, and human health. This suggests that electrochemical sensing of heavy ion metals is a developing trend in the fields of environmental and human health. This demonstrates that electrochemical sensing of heavy ion metals is leading the way and putting a future priority on environmental and human health fields.

Table 2. The top ten journals with most published articles on the field of electrochemical sensing heavy ion metals from 2005 to 2023

Journal Name	Number of Articles	Citations	Citation Per Acticle	JIF (Journal Impact Factor)	Total Link Strength	Publisher
Sensors and Actuators, b: Chemical	32	1534	48	8.4	369	Elsevier
Analytica Chimica Acta	23	987	43	6.2	396	Elsevier
Electrochimica Acta	15	580	39	6.6	225	Elsevier
Analytical Chemistry	15	1100	73	7.4	139	ACS Publication
Journal of Electroanalytical Chemistry	14	320	23	4.5	287	Elsevier
RSC Advances	12	268	22	3.9	81	Royal Society of Chemistry
Microchimica Acta	12	609	51	5.7	41	Springer
Journal of the Electrochemical Society	12	160	13	3.9	10	Electrochemical Society
Microchemical Journal	11	117	11	4.8	208	Elsevier
Talanta	11	654	59	6.1	201	Elsevier

3.4 Bibliometric analysis of the citation and publications

The number of articles in numerous journals on the area of the electrochemical sensing for heavy metal ions from 2005 until 2023 has been reviewed. The top ten journals are listed in the Table 2 along with the number of articles they have published, number of citations, citation per article, the Journal Impact Factor (JIF), and the overall link

strength. Elsevier is the journal publisher dominating half (50%) of the journal publisher of the most published articles in the journal of this field. There is one journal from each of the following publishers such as ACS Publication, Electrochemical Society, RSC (Royal Society of Chemistry), and Springer.

Furthermore, Sensors and Actuators, b: Chemical is the most productive journal in this particular area with 32 articles (accounting for 4.84%) of the total articles. Analytica Chimica Acta, Electrochimica Acta, Analytical Chemistry, Journal of Electroanalytical Chemistry, and RSC Advances produce each 23 articles (3.48%), 15 articles (2.27%), 15 articles (2.27%), 14 articles (2.12%), and 12 articles (1.82%), respectively. The result of this reviewed data confirms that Elsevier is a great reputation publisher, thus it has more readers, choice to open access, and garner the attention of researchers, especially in the area of electrochemical sensing heavy metal ions. In Table 2, it can also be seen that Sensors and Actuators, b: Chemical is the most cited journal, with 1534 citations from 32 articles. It is followed by Analytica Chimica Acta with 987 citations from 23 articles, Electrochimica Acta 580 citations from 15 articles, Analytical Chemistry 1100 citations from 15 articles, and Journal of Electroanalytical Chemistry (320 citations from 14 articles). On the other hand, the highest of total link strength is analyzed from Sensors and Actuators, b: Chemical with the value of 369, followed by Analytica Chimica Acta (396), Electrochimica Acta (225), Analytical Chemistry (139), and Journal of Electroanalytical Chemistry (287). These results demonstrate that Sensors and Actuators, b: Chemical is totally dominant for three categories of number of articles, citation, and total link strength. It confirms that the topic of the electrochemical sensor for heavy metal ions is related to the scope and relationship of these publications.

The number of articles published by each research source is represented by different sized and shaped circles. Further, the colour also indicates the publishing year for each article. Sensors and Actuators, b: Chemical and Analytical Chimica Acta have a dominant form and attract a lot of attention, as seen in Figure 3 From 2014 to 2018, these two journals were firmly related with Analytical Chemistry, Electrochimica Acta, Journal of Electroanalytical Chemistry. This suggests that their contribution to the field of the electrochemical sensing for heavy metal ions is highly valued. On the other hand, the articles related to this particular topic were published between 2005 to 2013 in several journal such as Journal of Chemistry, Journal of the Brazilian Chemical Society, Journal of Materials Chemistry, Electrochemistry Communication, Scientific Reports, and Journal of Physical Chemistry C. Moreover, from 2014 until the end of 2018, this topic was extensively published in a number of prestigious journals, including ACS Applied Materials and Interfaces, Journal of Alloys and Compounds, Talanta, Sensors and Actuators, b: Chemical, Analytical Chemistry, Analyst, Electroanalysis, International Journal of Electrochemical Science, and Biosensors and Bioelectronics. Furthermore, Journal of the Electrochemical Society, Applied Surface Science, Chemical Communications, New Journal of Chemistry, and Trac-Trends in Analytical Chemistry began to attract researchers and academics to write and publish articles in both journals since 2019. Additionally, in 2021 the journals Chemosphere, Critical Review in Analytical Chemistry and ACS Applied Nano Materials started to draw researchers and academics to submit and publish papers in both journals. Microchemical Journal, Angewandte Chemie, ACS Applied Nano Materials, Sensors and Actuators A: Physical,

Biosensors, Journal of Materials Science, ACS Omega, Bulletin of Materials Science, Nano Express, Journal of Hazardous Materials, and Trends in Food Science and Technology had significant growth and may be influenced by upcoming trends.

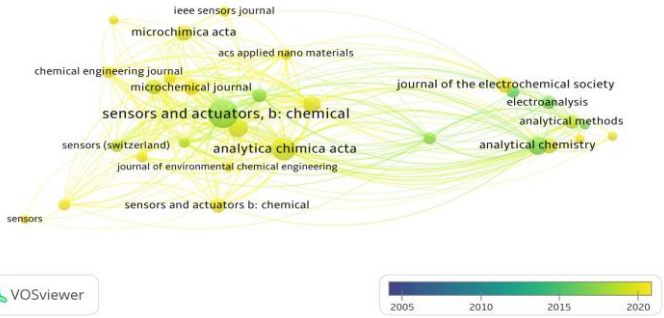

Fig. 3. Network map of the trend topics according to overlay visualization of the source journals

3.5 Bibliometric analysis of the co-authorship

Totally, there were 1945 authors participated in the publication topic of electrochemical sensing for heavy metal ions. These number was recorded from 2005 to the 2023. A network map illustrating collaborative co-authorship on this subject is shown in Figure 4. While using VOSviewer, the minimum number of citations for an author and the minimum number of documents for an author are both set to 0 and 5, respectively. 51 authors who meet the requirements are chosen out of 1945 total authors. Different colours represent distinct clusters made up of different writers who commonly collaborate, and the size of the circle represents the number of articles. Based on the findings, the co-authorships with the closest connections are also provided. They were all sorted into six groups. Group 1 is made up 150 documents with a total link strength of 196 (red colours). Group 2 is made up of 113 documents with a total link strength of 35 (green colours). Group 3 is made up of 64 articles with a total link strength of 181 (blue colours). Group 4 is made up of 35 articles with a total link strength of 35 with a total link strength 28 (yellow colours). Group 5 is made up of 14 articles with a total link strength (purple colours). The top two authors are Huang X-J and Liu J-H with 19 articles and 17 articles, respectively, shown in the Group 3. Following him on the list are Li Y, Zhang Y, Wang X, and Chen X.

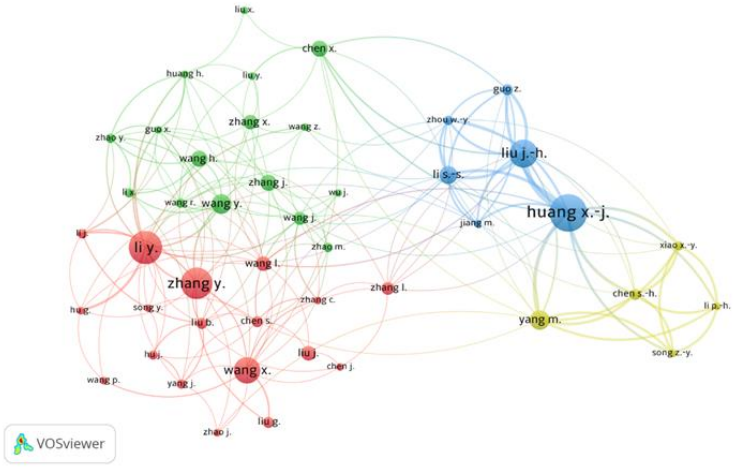

Fig. 4. Bibliometric analysis of the citations of the authors. Five clusters were shown in different colours

3.6 Document distribution by nations

The contributions of several nations to this topic have been evaluated. Table 3 summarizes the conclusion of the investigations based on the document distribution per nation. Figure 5 shows the contribution of several countries in the topic of electrochemical sensing for heavy ion metal ions. The minimum amount of citation and documents required for nation are set to 0 and 5, respectively. It was confirmed that 31 of the 72 nations fulfil the requirements. China is the top country with the total article of 288. India is ranked on the second place on the list with 117 articles, followed by the United States with 50 articles, South Korea with 40 articles, Saudi Arabia with 27 articles, and Malaysia with 25 articles.

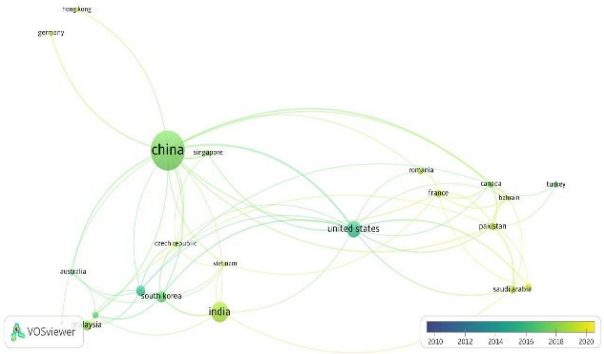

Fig. 5. Bibliometric analysis based on co-authorship of countries in overlay visualization

Moreover, Figure 5 illustrates the contribution of various nations throughout the period 2005 to 2023. As seen by dark blue and dark green, the article has already been

published in 2014 by four nations such as Indonesia, Kyrgyzstan, Iraq, and Spain. From 2015 to 2018, Iraq, India, United States, Pakistan, France, South Korea, and Saudi Arabia were illustrated as light blue and light green. In addition, Germany, Hongkong, Egypt, Belgium, Portugal, and Chile are among the most recent contributors to the published journal, as shown by the yellow colour.

Diverse research partners, mostly overseas graduate students and/or visiting researchers, and strong research funding are all factors that might contribute to the dynamism of international collaboration. It is also important to develop adaptable and stable research strategies to ensure the sustainability of international cooperation.

Table 3. Document distribution by nation

Country	Documents	Citations	Total Link Strength
China	288	9986	8119
India	117	2787	3590
United States	50	2355	3413
South Korea	40	752	4606
Saudi Arabia	27	368	3587
Malaysia	25	524	1329
Iran	23	1083	3163
Pakistan	19	276	3257
Turkey	19	244	2093
France	19	217	1324
Egypt	18	222	1820
Japan	14	238	1518
Canada	12	1115	1549
Taiwan	12	169	1490
Romania	12	43	293

3.7 Future research topics in heavy ion metals sensing

In the future research keyword will be focused on the utilization of graphene as a carbon electrode material such as glassy carbon electrode. Recently, this type of electrodes is familiar for researcher and academicians in the field of electrochemical sensor. Furthermore, anodic stripping, different pulse voltammetry and traditional measurement like amperometry and cyclic voltammetry still important for this science of the electrochemical sensors. On the other hand, when it comes to deciding keywords, there are several subject names that are worth considering and will be frequently used in the future such as water quality, sensitive detection, pollution detection, environmental pollutants, arsenic, water pollution, water quality, and health risks. This indicates that future trends regarding the electrochemical sensing of heavy metal ions will gain traction

in the fields of environment and human health. This shows that the electrochemical sensing of heavy metal ions takes the lead and focuses on the field of environment and human health as future keywords.

4 CONCLUSION

The analytical bibliography concluded with a review of research trends in electrochemical sensing heavy ion metals based on 660 articles evaluated from the Scopus database. The last two decades have seen a fast growth of publications, and this trend is expected to continue. According to publication published between 2005 and 2023, researchers are spending more on this field of research. Furthermore, China is the top leading contributor with the most productive articles than any other nations like India and United States. These nations have many strong international partnerships. Then, numerous articles like Sensors and Actuators B: Chemical. Analytica Chimica Acta, Electrochimica Acta, and Analytical Chemistry are the most productive. On the other hand, Sensors and Actuators B: Chemical, Analytical Chemistry, and Analytica Chimica Acta are the most citation for electrochemical sensing heavy ion metals. Future research in this area might focus on water quality, water pollution, environmental pollutants, and health risks. Lastly, the research should be updated in the near future.

Disclosure of Interests. The authors declare no conflict of interest in this reported work.

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