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Bibliometric Analysis of Global Research Trends on Electrochemical Nitrite Sensing using Scopus Database

Satrio Kuntolaksono,[1,*] Joelianingsih,[1] Linda Aliffia Yoshi,[1] and Marcelinus Christwardana[2]

[1]Department of Chemical Engineering, Institut Teknologi Indonesia, Jl. Raya Puspitek Serpong, South Tangerang, 15320, Indonesia
[2]Department of Chemistry, Faculty of Sciences and Mathematics, Diponegoro University, Jl. Prof. Soedarto SH, Tembalang, Semarang, 50275, Indonesia

*Corresponding Author, Tel.: +6281932759587
E-Mail: satrio.k@iti.ac.id

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Abstract- The research and progress in electrochemical nitrite sensing are continuously increasing and have a great choice of interest by researchers and scientists. Therefore, understanding the topics of interest and expanding the network of collaborations are necessary to advance the research development towards integrated and beneficial efforts. This bibliometric study aims to use the VOSviewer to evaluate the global research trends in the fields of electrochemical nitrite sensing area based on the publication of the journal name, keyword co-occurrences, co-authorship, and country. A total of 387 journal articles published between 2000 to 2021 were analyzed using the Scopus database. Since 2000, the data shows that the studies released tend to increase year by year. The most productive countries are China, India, and United States. In conclusion, water pollution, pollution detection, ligands, layered semiconductors, heavy metals, and carbon black have the potential to be a hotspot for future research in this field.

Keywords- Bibliometric analysis; VOSviewer; Scopus database; Electrochemical nitrite sensing; Literature review

1. INTRODUCTION

Nitrite (NO_2^-) is a major symmetric inorganic ion that is frequently utilized in the food industry as an additive, as a corrosion inhibitor in environmental systems [1,2], and as a colorant in meat products [3]. However, excessive nitrite may hasten the irreversible oxidation of haemoglobin to methaemoglobin, resulting in the loss of haemoglobin's oxygen-carrying capacity and hypoxia [4,5]. In addition, nitrite can react with amines and amides to form highly carcinogenic N-nitrosamines, which are extremely hazardous to human health and have been linked to gastric cancer [6,7], oesophageal cancer [8], blue baby syndrome [9], spontaneous abortion [10], and birth defects of the central nervous system [11]. Consequently, the precise detection of nitrite is crucial for evaluating the quality of food, physiological systems, and the environment.

In recent years, numerous analytical methods for nitrite detection have been reported for nitrite including chemiluminescence [12,13], fluorescent spectrophotometry [14,15], colorimetric analysis [16], flow injection kinetic spectrophotometry [17], microfluidic Griess assay [18], a liquid phase microextraction [19], spectrofluorimetric [20,21], capillary electrophoresis [22,23], high performance liquid chromatography [24], gas chromatography [25], ion chromatography [26,27], atomic absorption spectroscopy [28], and electrochemical methods [29,30]. However, the most of these procedures are expensive and time-consuming, requiring complex sample pre-treatment, skilled operators, and substantial interference from the background [31-33]. In addition, these techniques are hampered by extreme environments, restricted application ranges, and low stability. Electrochemical approaches, on the other hand, are advantageous due to their quick reaction, easy manufacturing, high sensitivity, and cheap cost [34-36]. In order to produce a high-performance nitrite sensor, electrochemical techniques have lately gained considerable interest.

Although there is an increasing interest in electrochemical nitrite sensing, there are relatively few studies that measure and analyze scholarly publications from a worldwide viewpoint. Through quantitative and statistical analysis, Bibliometric obtained insight into the evolution of numerous study topics [37]. Despite the fact that duplicates are very significant when indexing journals [38,39], the WoS and Scopus databases also index distinct journals. Web of Science (WoS) and Scopus are the most extensively utilized databases for literature searches [40]. Scopus is the biggest collection of abstracts and citations from peer-reviewed literature on a broad variety of topics [41]. In addition, 94% of the Scopus journals with the highest impact factor were indexed in WoS [40]. Consequently, using Scopus is an effort to cover a larger number of titles that may not be accessible in WoS [42,43].

This article provided a concise overview of the evolution of electrochemical nitrite sensing research from 2000 to 2021. To do this, we conducted a quantitative study using bibliometric techniques [44] to identify, organize, and assess the primary features of scientific output within the specified research area [45-47]. On the contrary, the following were the objectives: (i) to investigate the temporal distribution patterns of electrochemical nitrite sensing; (ii) to identify the contributions of prolific authors, leading countries, and the most productive academic institutions; (iii) to determine the dominance of countries based on major applications; (iv) to highlight common terminology and research topics; and (v) to offer insight into potential collaboration and future directions. This information will be very useful for researchers in understanding their research patterns, potential, and prospects for future study.

2. EXPERIMENTAL SECTION

2.1. Bibliometric Method

Based on the outputs of an academic literature database, bibliometric analysis study is a mechanistic method for comprehending worldwide research trends in a particular field. This method differentiates a bibliometric analysis study from a review paper, which is mainly designed to address the most recent advancements, issues, and future perspectives pertaining to a certain subject. Using the Scopus database, the themes of articles on electrochemical nitrite sensing were gathered. These data sources were gathered on April 4, 2022. This investigation focused on research publications with "electrochemical nitrite sensing" in the title or abstract.

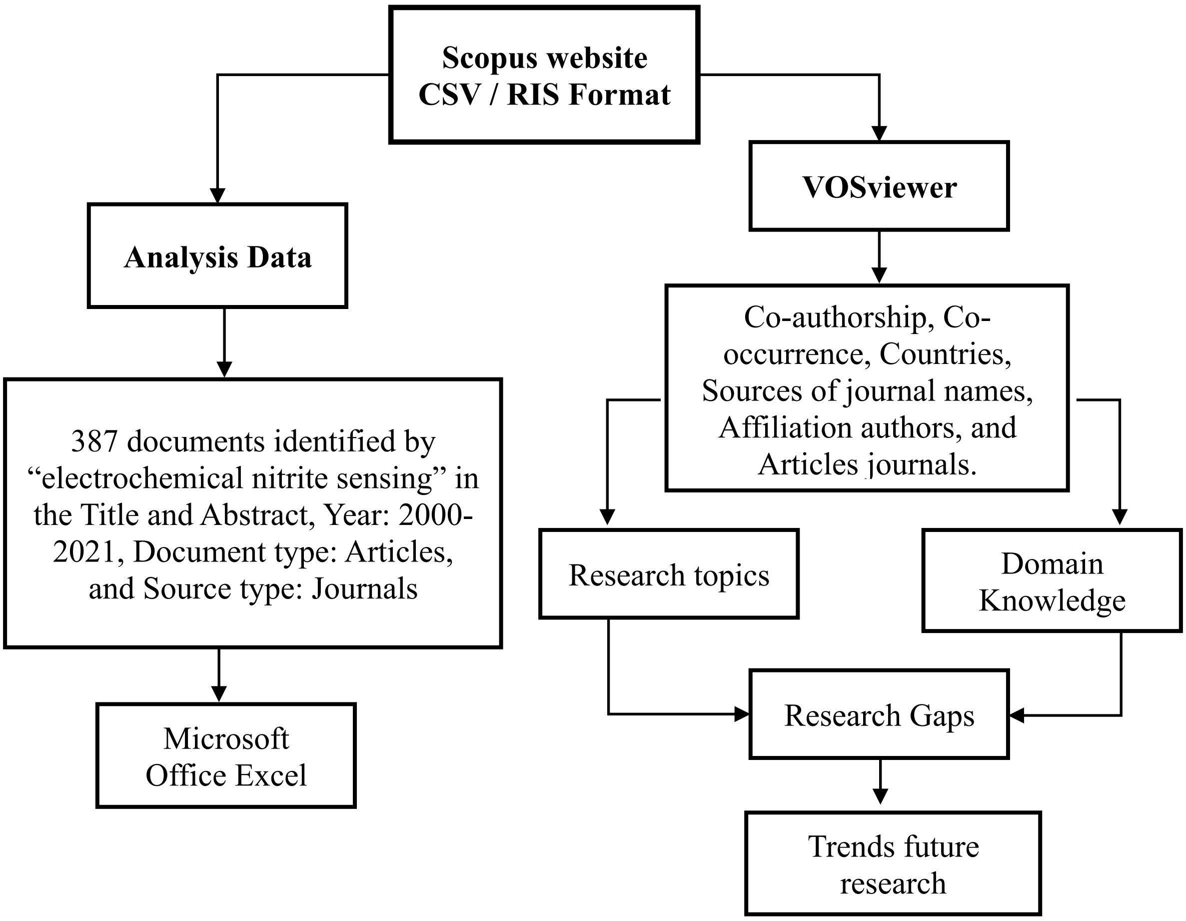

Figure 1. Flowcharts of documents published from the Scopus database collection for data screening and analysis

Figure 1 shows a summary of the data gathering, extraction, and analysis processes. The acquired data is validated and examined depending on its contribution to the study subject or its substance. Therefore, bibliographic information from 387 papers was downloaded as comma-separated values (CSV) files, which are used by several mapping analysis and scientific productivity software programs [48]. The actual material that must be downloaded with this file consists of bibliographic data providing the author, title, year of publication, source title, author affiliation, keywords, and a number of citations [49].

The CSV format was transferred to Microsoft Office Excel for editing, where it was confirmed that the bibliographic data matched the quantity of scientific papers and that there was no missing information, including authors, publication year, and other data indicated in the Scopus extraction. During the study, no skewed or missing data were discovered. In addition, the study was conducted using the same number of scientific papers as were downloaded at the time of data collection: 387.

2.2. Data Processing

VOSviewer (version 1.6.18, Centre for Science and Technology Studies, Leiden University, The Netherlands) is a software application for creating and displaying bibliometric maps [50-52]. The scientific publications discovered via web searches are thoroughly studied and serve as the foundation for a deeper comprehension of the research phenomena. This facilitates the description of existing and future initiatives. In addition, VOSviewer was used for co-authorship, co-occurrence, citation, bibliographic coupling, co-citation, and keyword index analyses [53]. Two standard weight attributes, termed as "links attribute" and "total link strength attribute," were applied [54].

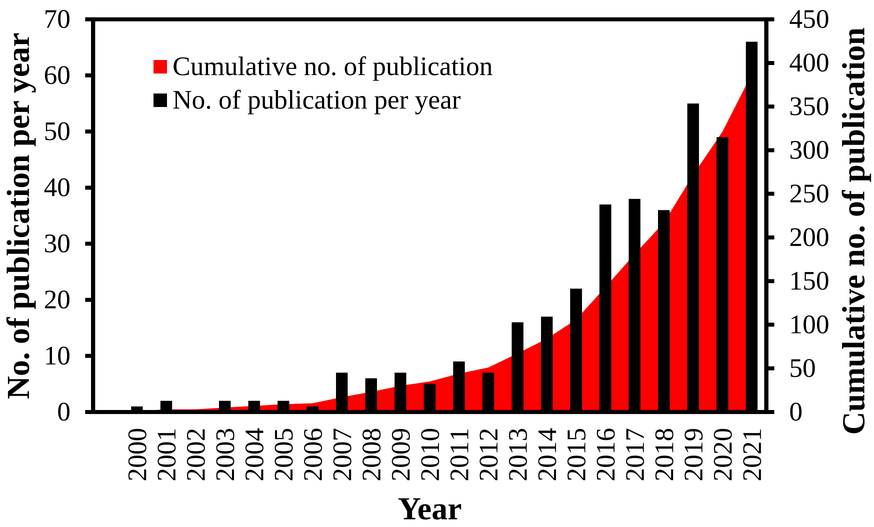

Figure 2. The relationship between number of publications per year and cumulative number of publications by year of publication

3. RESULTS AND DISCUSSION

3.1. Distribution of the number of documents by year of publication

From 2000 to 2021, the number of publications on the topic of electrochemical nitrite sensing has been analyzed. Figure 2 shows the distribution of data from this inquiry. It is stated that electrochemical nitrite detection is gaining the interest of scientists and academics throughout the globe. In 2002, there were no publications created, however, the trend from 2003 through 2021 indicated an increase. Nonetheless, some years, such as 2010 and 2012, saw a decline in the number of research publications compared to the preceding year.

3.2. Distribution of the number of documents by year of publication

The number of publications published in this field of electrochemical nitrite sensing in various journals between 2000 and 2021 has been analyzed. Table 1 displays the outcomes of this experiment. Five publishers have ownership of the top 10 most productive journals. Elsevier was the publisher of five of the top 10 journals. Springer, The Electrochemical Society (ECS), Wiley, and the Royal Society of Chemistry (RSC) published the remaining five journals. With 33 papers, Sensors and Actuators B: Chemical was the most productive journal, accounting for 8.53% of articles gathered. Electrochimica Acta, Microchimica Acta, Journal of Electroanalytical Chemistry, and Journal of the Electrochemistry Society contributed 22 articles representing 5.68%, 18 articles representing 4.65%, 18 articles representing 4.65%, and 14 articles representing 3.62%, respectively. On the basis of these statistics, it can be stated that Elsevier has a strong reputation, is respectable, and has garnered the interest of researchers, particularly in the field of electrochemical nitrite sensors.

Table 1. The top 10 most productive journals based on the number of articles on electrochemical nitrite sensing research from 2000 to 2021

Journal Name	Number of Articles	Publisher
Sensors and Actuators, B: Chemical	33	Elsevier
Electrochimica Acta	22	Elsevier
Microchimica Acta	18	Springer
Journal of Electroanalytical Chemistry	18	Elsevier
Journal of the Electrochemical Society	14	The Electrochemical Society (ECS)
Electroanalysis	13	Wiley
Biosensors and Bioelectronics	11	Elsevier
New Journal of Chemistry	10	Royal Society of Chemistry (RSC)
Talanta	10	Elsevier
RSC Advances	9	Royal Society of Chemistry (RSC)

The network of scientific publications that publish articles on electrochemical nitrite sensing is shown in Figure 3. Different sized and shaped circles represent the number of articles published by each research outlet. In addition, the colour denoted the year of publication for each article. As shown in Fig. 3, Sensors and Actuators, B: Chemical and Electrochimica Acta have a dominating shape and get a great deal of attention; these two journals are firmly related with Microchimica Acta, Journal of Electroanalytical Chemistry from 2012 to 2017. This demonstrates that their contribution to the field of electrochemical nitrite detection is well regarded. In contrast, research on electrochemical nitrite sensing was published between 2000 and 2010 in the journals Synthetic Metals, Analytical Science, and Journal of Physical Chemistry B. In addition, from 2010 until the end of 2017, this subject was extensively published in a number of prestigious journals, including Talanta, Analytical Chemistry, Analytica Chimica Acta, Analyst, Biosensors and Bioelectronics, Electroanalyst, Electrochimica Acta, Microchimica Acta, Journal of Electroanalytical Chemistry, and Journal of the Electrochemical Society. Despite being in the bottom two of the top ten most prolific journals, Microchemical Journal and Inorganic Chemistry Communications started attracting the interest of researchers in 2019 to write articles. Several journals, including Carbon Letters, Electrocatalysis, Sensors and Actuators Reports, ACS Applied Electronic Materials, Chemistryselect, Trac-Trend in Analytical Chemistry, and CrystEngComm, have grown substantially and may be affected by future trends.

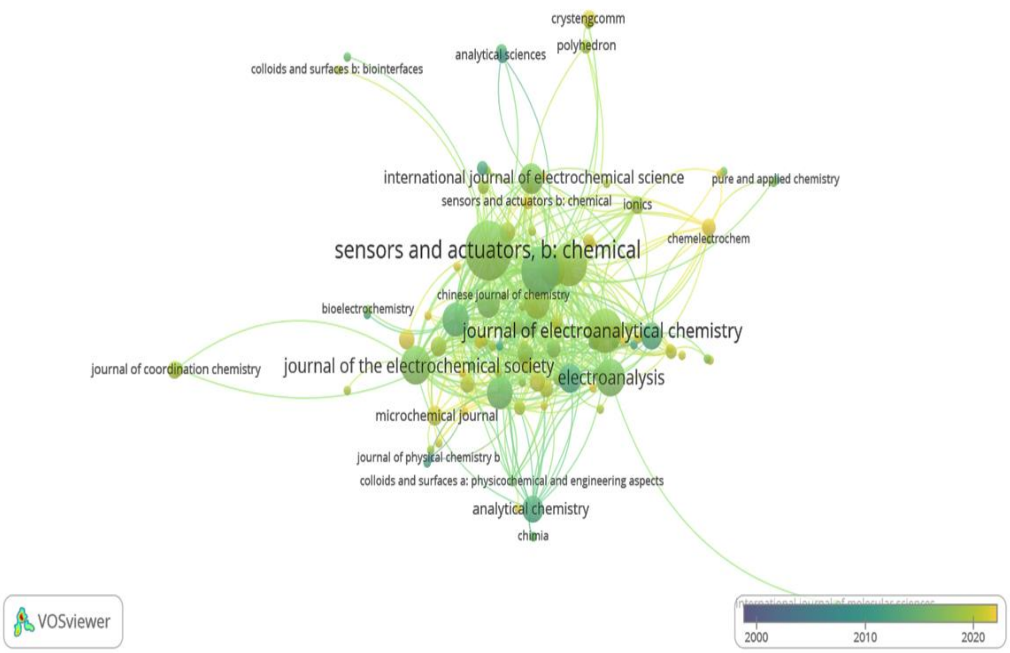

Figure 3. Bibliometric map generated by time range source in overlay visualization mode

Table 2 shows the 10 most productive journals based on the number of citations. This table also illustrated the connection between the number of articles, the number of citations, the Journal Impact Factor (JIF), and the overall link strength for each journal.

Table 2. The top 10 most productive electrochemical nitrite sensing research with their most citation article

Journal Name	Number of Documents	Citation	Citation Per Article	JIF (Journal Impact Factor)	Total Link Strength	Publisher
Biosensors and Bioelectronics	11	1231	112	10.62	101	Elsevier
Sensors and Actuators, B: Chemical	33	1081	33	7.46	212	Elsevier
Electrochimica Acta	22	746	34	6.90	121	Elsevier
Analytical Chimica Acta	7	610	87	6.56	23	Elsevier
Analytical Chemistry	7	427	61	6.66	23	American Chemical Society (ACS)
Microchimica Acta	18	416	23	5.83	100	Springer
Journal of the Electrochemical Society	14	326	23	4.32	77	The Electroche mical Society (ECS)
Account of Chemical Research	2	307	154	22.38	0	American Chemical Society (ACS)
Analyst	8	291	36	4.62	31	Royal Society of Chemistry (RSC)
Journal of Electroanalytical Chemistry	18	249	14	4.46	67	Elsevier

Furthermore, Biosensors and Bioelectronics had the highest number of citations with 1231 citations from 11 documents, followed by Sensors and Actuators, B: Chemical (1081 citations from 33 documents), Electrochimica Acta (746 citations from 22 documents), Analytical Chimica Acta (610 citations from 7 documents), and Analytical Chemistry (427 times, 7 documents). Biosensors and Bioelectronics, a journal published by Elsevier, had the highest number of citations per article with a total of 112, but the publication's overall link strength was only 101 when compared to Sensors and Actuators, B: Chemical, which had the highest total link strength.

Sensors and Actuators, B: Chemical contains 33 papers and Electrochimica Acta has 34 publications for electrochemical nitrite sensing, according to citations per article. Compared to the other five prolific journals, the number of citations per publication in these two journals is the lowest. Nevertheless, the overall connection strength for both publications is quite robust. In addition, several journals, such as Biosensors and Bioelectronics and Microchimica Acta, have a rather robust link strength following Sensors and Actuators, B: Chemical and Electrochimica Acta. It indicates that electrochemical nitrite sensing connects with the relevant scope and relationships of these publications.

3.3. Bibliometric analysis of the co-occurrence

In general, journal keywords have played a significant role in indexing and arranging relevant research findings. Keywords also facilitate researchers' ability to establish the emphasis of their area of practice.

Table 3. Distribution of keywords used in the topic of electrochemical nitrite sensing

Keyword	**Occurrences**	**Total Link Strength**
Electrochemical sensors	119	1559
Nitrite	116	2022
Electrodes	79	1336
Electrochemical Sensing	76	979
Article	57	1274
Carbon	57	1009
Electrochemical Electrodes	57	830
Glass Membrane Electrodes	55	786
Cyclic Voltammetry	54	855
Electrochemical Analysis	53	1063
Chemical Detection	48	636
Limit of Detection	46	1015
Electrochemistry	46	929
Graphene	46	688
Scanning Electron Microscopy	44	766
Oxidation	43	882
Electrocatalysis	42	660
Nanocomposites	41	718
Electrochemical Detection	41	691
Electrocatalytic Activity	40	522

In addition, keywords highlight the primary substance of each study and the concept of narrative research in a certain field. The co-occurrence of terms indicates their interdependent connection. A total of 2979 index keywords were gathered, of which 2979 were used just once, 894 were used twice (30.01%), 521 were used third (17.49%), and 368 were used fourth (12.35%). The minimum number of keyword occurrences is set to five, and as shown in Table 3, 295 keywords match to the issue of nitrite sensing. According to Table 3, electrochemical sensors have 119 occurrences and 1,559 Total Link Strength. Nitrite (116 occurrences and 2022 link strength) is the next most frequent term, followed by electrodes (79 occurrences and 1336 link strength), electrochemical sensing (76 occurrences and 979 link strength), and article (57 occurrences and 1274 link strength). In addition, Figure 4 shows the network map of trend themes based on the keywords researched between 2000 and 2021. An indicator displays the current publications in a progression from dark blue to yellow. The bigger size of the circles around the keywords indicates their frequency as keywords. The distance between the two circles represents their relationship. This is relevant and helps researchers select their future research plan and focus area.

Similarly, it is necessary to investigate the general language used each year as it pertains to the focus on electrochemical nitrite sensing investigations undertaken by researchers. Several terms, including film, sensitivity and specificity, electrophoresis, ammonia, and electrolysis, are used in articles published between 2005 and 2012. These keywords are represented by nodes ranging from dark blue to dark green. The processing of the current through a material by employing a film that focuses on the sensitivity and specificity of the parameter is also linked to those terms. The use of film for electrochemical nitrite sensing is critical for managing processes that are connected to sensitivity and specificity. From 2013 to 2018, green to yellowish-green nodes were described using terms such as sensors, electrochemistry, fabrication, carbon, graphene, glassy membrane electrode, glassy carbon electrode, electrochemical electrodes, the limit of detection, electrocatalysis, cyclic voltammetry, electrochemical sensing, and electrochemical sensors. Graphene as a carbon material for working electrodes such as glassy membrane electrode or glassy carbon electrode with connections of electrochemical measurement on the cyclic voltammetry and limited of detection of a substrate has had a high impact on every researcher in the world during these years. The nodes will be described in yellow beginning in 2019. When it comes to keywords, there are several different subject names to consider, such as water contamination, pollution detection, and heavy metals. This suggests that electrochemical nitrite sensing is starting to lead to environmental sectors such as pollution detection, water pollution, and heavy metal detection. Meanwhile, a new generation of carbon compounds, such as carbon black, is replacing glassy carbon electrodes as functioning electrodes.

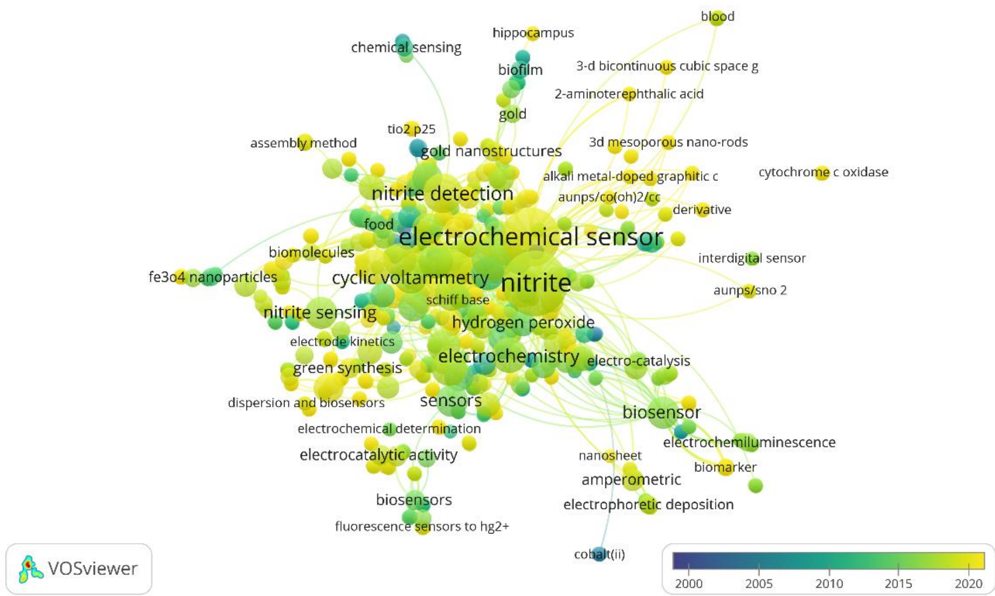

Figure 4. Bibliometric map created based on keyword co-occurrence in overlay visualization mode

3.4. Bibliometric analysis of the co-authorship

Figure 5 shows a network map indicating collaborative co-authorship on electrochemical nitrite sensing from 2000 to 2021. The minimum number of citations and the minimum number of documents are set to 0 and 5, respectively, while using VOSviewer. It selects 43 authors from a total of 1287 who match the criteria. The varied colors signify distinct clusters made up of different writers who generally work with each other, and the size of circles denotes the number of articles. The most interconnected co-authorship is presented based on the findings. They were all organized into six groups. Cluster 1 is made up of 79 documents with a total link strength of 97 (red colours). Cluster 2 is made up of 56 documents with a total link strength of 66 (green colours). Cluster 3 is made up of 44 documents with a total link strength of 102 (blue colours). Cluster 4 is made up of 45 documents with a total link strength of 87 (yellow colours). Cluster 5 is made up of 33 documents with a total link strength of 31 (purple colours). Cluster 6 consists of 14 documents with a total link strength of 5 (light blue colours). Wang X and Zheng J, on the other hand, are at the top of the list, with 14 documents. Following him on the list are Zhang Y, Wang L, and Liu Y.

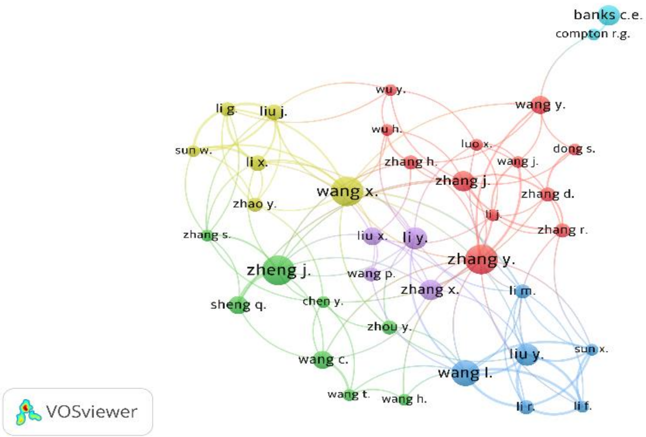

Figure 5. Bibliometric analysis of the co-authorship. The Co-authorship map of authors which indicates the cooperate in the topic of electrochemical nitrite sensing

Table 4. Distribution of documents by countries

Country	Documents	Citation	Total Link Strength
China	179	4252	18
India	73	1363	26
United States	35	1147	19
Taiwan	20	387	11
United Kingdom	19	582	16
Brazil	14	247	8
South Korea	13	393	12
Saudi Arabia	10	183	13
Malaysia	10	220	5
Iran	9	664	5
Germany	8	115	11
Australia	8	176	7
Japan	8	126	7
Egypt	8	112	5
France	6	445	6
Spain	6	78	5
Turkey	6	62	2
Tunisia	5	69	7
Switzerland	5	93	4
Serbia	5	99	3

3.5. Distribution of documents by countries

The contributions of several countries in this subject have been studied. Table 4 summarizes the findings of our investigations. Figure 6 shows the contributions of several countries. The minimum citation and minimum number of documents for countries are set to 0 and 5, respectively, in VOSviewer. It selects 20 of the 48 nations that match the criteria. With a total of 179 published papers, China was rated first on the list. India is rated second on the list with 73 publishing papers, followed by the United States in third place with 35 publication documents. Taiwan (with 20 publication documents), the United Kingdom (with 19 publication documents), Brazil (with 14 publication documents), South Korea (with 13 publication documents), and Saudi Arabia (with 10 publication documents) presented their respective research outputs based on the number of publications. Next, Figure 7 displays the contribution of various nations based on the period 2000 to 2021. Japan and France are two nations that began publishing papers in 2014, as shown by the color blue. In 2015, the United States, Serbia, and the United Kingdom were described as blue-green. Following these years, Switzerland, South Korea, Australia, and Tunisia were denoted by the color light green. Several nations, including Germany, Saudi Arabia, Turkey, and Egypt, are the most recent contributors to the published journal, denoted in yellow.

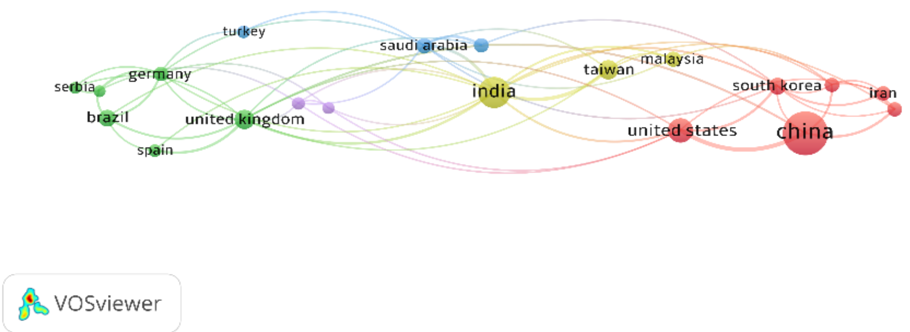

Figure 6. Bibliometric map created based on co-authorship map of countries with network visualization

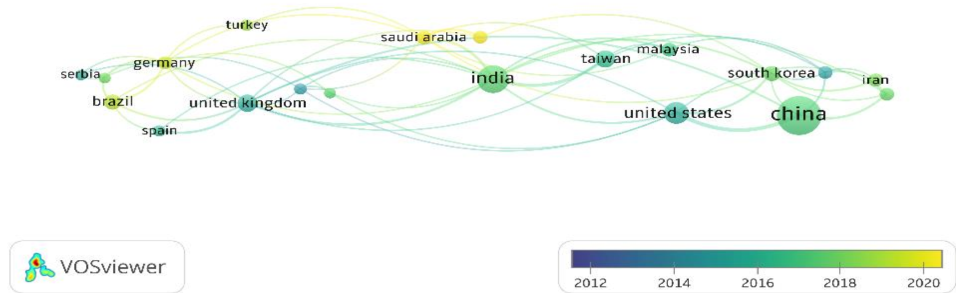

Figure 7. Bibliometric map created based on co-authorship map of countries in overlay visualization mode. Minimum occurrences of a keyword are set to five

Diverse research partners, a large proportion of foreign postgraduates and/or visiting researchers, and robust research funding are all variables that may contribute to the dynamism of international cooperation. It is also essential to establish a flexible and stable research strategy to guarantee the longevity of international cooperation.

3.6. Future research topic about nitrite sensing

For future research theme will focus on amperometry, electrochemical sensors, cyclic voltammetry, the utilization of carbon electrode materials such as glassy carbon and carbon felt electrodes. Those themes are at the heart of the science of the electrochemical sensors. On the other hand, when it comes to deciding keywords, there are various subject names that are worth considering and will be frequently used in the future such as water contamination, pollution detection, and heavy metals. This suggests that electrochemical nitrite sensing is starting to lead to environmental sectors such as pollution detection, water pollution, and heavy metal detection. In addition, a new generation of carbon compounds, such as carbon black are replacing glassy carbon electrodes as functional electrodes.

4. CONCLUSION

This bibliometric analysis concludes with an overview of research trends in electrochemical nitrite sensing based on the 387 articles extracted from the Scopus database. Rapid growth in the number of publications during the last two decades is predicted to continue. The articles published between 2000 and 2021 indicate that scholars are focusing more on this field of research. Moreover, China is the leading contributor, with more publications than any other country, followed by India and the United States. These countries have many and robust international partnerships. The numerous articles Sensors and Actuators, B: Chemical, Electrochimica Acta, and Microchimica Acta are the most productive. Biosensors and Bioelectronics, Sensor and Actuators, B: Chemical, and Electrochimica Acta were, on the other hand, the three most cited publications for electrochemical nitrite sensing. Water contamination, pollution detection, ligands, layered semiconductors, heavy metals, and carbon black might be the focus of future study in this topic. And the research should be updated in the near future.

Declarations of interest

The authors declare that there are no conflicts of interest in this reported work.

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