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A Bibliometric Analysis of Carbon Dots in Sensors Application

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Abstract

The exponential increase in carbonaceous-based research has prompted the scientific community to apply it to numerous value-added applications. This paper aimed to systematically analyze the comprehensive contributions clusters of publications per year, country, institution, authors, and keywords-wise by using a quantitative review technique called bibliometric analysis. The data was retrieved from the Scopus database to identify the overall scientific trend results with the keyword "carbon dots as a sensor" from 2010 to 2020. The VOSviewer, WordItOut, and Datawrapper are selected as tools for bibliometric analysis and data visualization. In this work, the total citations from the Scopus Core Set and the total citations in the most recent year have only been used for the assessment of highly cited papers. The results showed that after 2014, the number of publications increased significantly with the work related to "carbon dots as sensors." Thus, comprehensive journals like the Angewandte Chemie - International Edition were the most popular in publishing articles, contributing to almost 6.39% of the research area. The country-wise analysis revealed that China accounted for more than 67.18% of the articles published, followed by the United States and India, comprising 6.24% and 6.13%, respectively. Lastly, keyword cluster analysis revealed five major research hotspots for future discussion. Thus, this analysis provides an important starting point for further studies on research concerning the direction of "carbon dots as a sensor" for

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positive development in the research area.

Keywords: *bibliometric; carbon dots; Datawrapper; sensor, VOSviewer; WordItOut*

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INTRODUCTION

Over the past decade, carbon dots, an emerging class of luminescent carbon-based nanomaterials, have attracted great attention from multiple disciplines owing to their superior properties and widespread applications [1–6]. These potential applications have been widely studied in various fields ranging from thick/thin films [7–9], optoelectronic devices [10], solar cells [11], photocatalysts [12], bio-imaging [13], drug delivery [14], sensors [15–17], and other works.

The many sensing techniques were susceptible and reliable. It still has several disadvantages, such as high costs, expensive equipment, the need for sample preparation, and long-time consumption; hence, it has led to the demand for fast, simple, reasonable, and cost-effective methods. Because of high sensitivity, low cost, and speed, along with operational simplicity, fluorescence-based sensing techniques have attracted much attention in recent years [18]. There are various reports based on publication results that can be clustered into carbon dots, functionalized-carbon dots, carbon dots-based composite, and carbon dots-based hybrid as sensors based on the photoluminescence mechanism. The reports related to carbon dots-based material sensors that have been published such as for application of detection metal ion (Fe^{3+} [19]; Cr^{4+} [20]; Cr^{6+} [21]; Hg^{2+} [22]; Pb^{2+} [23]; Cu^{2+} [24]; V^{5+} [25]; Mn^{7+} [26]; Al^{3+} [27]; Co^{2+} [28]; Zn^{2+} [29]; Ag^{+} [30]), pH [21], temperature [31], humidity [32], pathogenic bacterial (Escherichia coli [33]; Pseudomonas aeruginosa [34]), gas (MeOH [35]; NO_2 [36]; NH_3 [37]; O_2 [38]), Organophosphate (diazinon [18]; dimethoate [39]), organosulfur (thiophenols [40]), amino acids (tyrosine [41]; cysteine [22]; arginine [42]; histidine [43]), antibiotics (metronidazole [44]; tetracycline [45]; oxytetracycline [46]; cefixime [47]), antioxidant (glutathione [48]), vitamin (vitamin B12 [49]; ascorbic acid [50]; folic acid [51]), drug (sumatriptan [52]; famotidine [53]; paracetamol [54]; retinoic acid [55]; prilocaine [56]), simple monosaccharide sugars (fructose [57]; glucose [58]).

As first introduced in 1969 [59], bibliometrics was an effective method for describing the research trends of specific areas. There are two main aspects to describe bibliometric analysis [60–62]. Firstly, it describes patterns of distribution of publications according to some clusters, such as topics, fields, sources, authors, institutions, and countries. Second, it is widely applied to analyze scientific production and research trends in several fields, such as citations and the number of publications. A bibliometric analysis of the literature relating to "carbon dots as sensors" published in the Scopus database was performed in the present work. In this work, the research questions were developed based on Zupic et al. and Secinaro et al. [63,64] to achieve the aims of the analysis. The research aimed to evaluate its quantitative characteristics and define current and potential patterns that are most important and provide a basis for better mapping of future research areas related to "carbon dots as sensors".

METHOD

Bibliometric analysis data should be obtained from well-known and validated databases such as Scopus and Web of Science, posing as the most suitable literature retrieval and analysis databases that are influential, comprehensive, and trustworthy [65,66]. Scopus is a bibliometric database often used in bibliometric studies. It is useful for this purpose because it has a larger number of indexed journals than the Web of Science [67,68]; thus, the Scopus database was used in this research. The Scopus database trend was searched for as bibliometric data from 2010 to 2020, and the data was extracted on October 13, 2020.

The five-step methods adopted the research procedures for bibliometric analysis [69–71], including determination of search keywords, initial search results, refinement of search results, compilation of preliminary data statistics, and data analysis. First, we used the keywords "carbon dots" AND (sensor OR nanosensor OR nanosensor probe). Second, we checked the information in the initial search process as citation, bibliographical, and abstract & keywords; they are important to be used as the main information for bibliometric analysis. Third, we refined the search results for the Scopus database based on document type, such as Articles, Reviews, Book Chapters, Conference Papers, Conference Reviews, Erratum, Retracted, and Notes. In this work, only the Article type was chosen as the database for bibliometric analysis. The 1023 articles met the threshold after final refinement and were analyzed. Fourth, we compiled preliminary data statistics using important information such as citation information, bibliographical information, and abstract & keywords. Finally, we inputted and performed data analysis using Microsoft Excel, VOSviewer, WordItOut, and Datawrapper.

RESULTS AND DISCUSSION

The number of citations is a major and important factor in evaluating a publication [72]. Specific aspects of the publication details of the papers were used for bibliometric analysis, such as the number of publications per year, publications per country, publication per organization, number of authors, and number of keywords [65]. Also, we compared the number of citations through calculations such as sums '=SUM(_)', averages '=AVERAGE(_)', maximums '=MAX(_)', and minimums '=MIN(_)' in Microsoft Excel software to determine the optimal factors for the most citations of publications with the topic of "carbon dots as a sensor".

Publication Performance Analysis

The most fundamental way to understand the performance of the publication in a specific field is to observe the annual frequency of the publication of scholarly articles. The data collection of 1023 articles was considered the final number of publications for analysis on "carbon dots as sensor" from 2010 until 2020. The annual publication trend of articles can be observed in Figure 1. The lowest number of publications, fewer than 30 articles per year, was recorded from 2010 until late 2014. The data from 2015 showed the first dramatic increase in the number of publications, with a spike from just 24 articles published in 2014 to 77 articles published in 2015. From 2016 to 2019, the peak number of publications has increased further every year. The data peaked in 2019 with 230 publications. However, in 2020, the peak number of publications slightly decreased to 221 articles, but this decrease may not be satisfactorily reliable [73]. This is due to the process of searching and collecting the Scopus database was carried out in mid-October 2020, so publications from the end of October to December 2020 have not been accumulated.

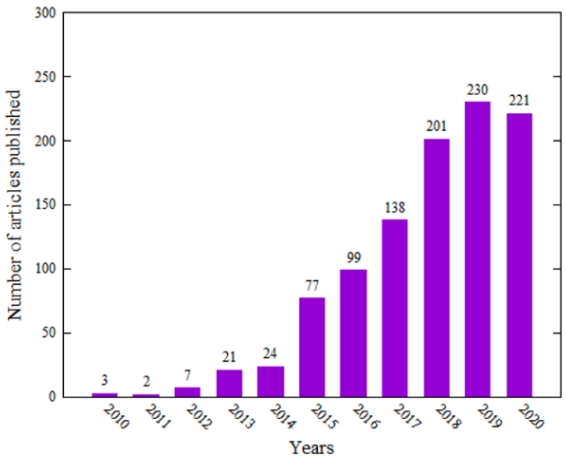

Figure 1. Distribution of Articles Published per Year

While Figure 1 demonstrates the number of articles published per year, not all of these publications have been cited. Out of the 1023 total articles published, only 888 of those articles have been cited, which was equivalent to 86.80% of the total number of published articles. Meanwhile, 135 articles published (13.20% of the total number of published articles) in 2017, 2018, 2019, and 2020, consisting of 1, 3, 13, and 118 articles, respectively, have not been cited anywhere.

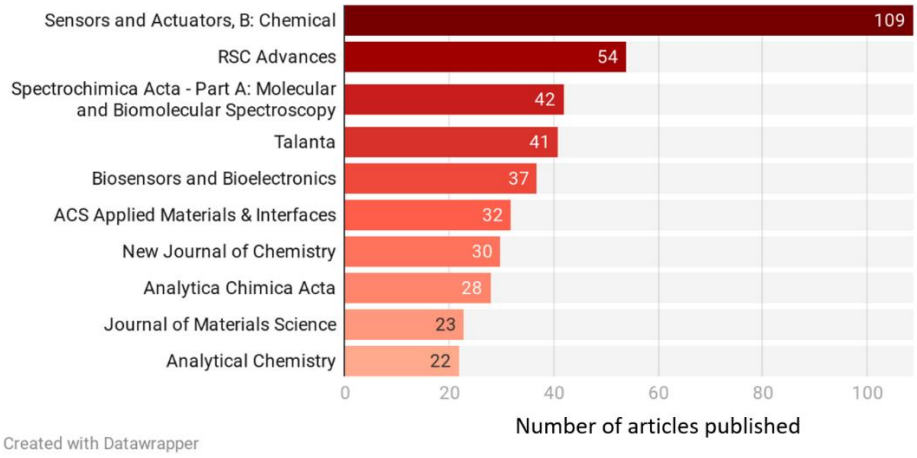

Figure 2. Top 10 Most Relevant Sources

For the journal's sources, the literature in this field is from 207 journals. Figure 2 displays the top 10 most relevant sources. The journal distribution is concentrative, similar to the situation of the national distribution [74]. Sensors and Actuators, B: Chemical had the highest productivity with 109 published articles. Meanwhile, RSC Advances has the second productivity with half the total number of articles published by Sensors and Actuators, B: Chemical, which is 54 articles.

Bibliometric Analysis for Co-occurrence

Visualization of the most frequently encountered terms in titles, keywords, and abstracts of the retrieved documents (a threshold number of 20 occurrences was selected in the VOSviewer analysis) yielded four clusters representing four research topics. VOSviewer can display bibliometric mapping in network visualization, as in Figure 3. The first cluster (red) had 632, 593, 519, and 148 occurrences of carbon, fluorescence properties, carbon dots, and nanoprobes, respectively. The second cluster (green) is focused on the limit of detection, quantum dots, fluorescence spectroscopy, and sensors, with a total occurrence of 233, 221, 138, and 113, respectively. The third cluster (blue) focused on nanomaterials, biosensors, genetic procedures, and metal nanoparticles, with a total occurrence of 165, 109, 79, and 72, respectively. The last cluster (yellow) focused on humans, nitrogen, biocompatibility, and fluorescence quantum yield, totaling 129, 124, 105, and 87, respectively. Retrieved documents focused on different populations of interest.

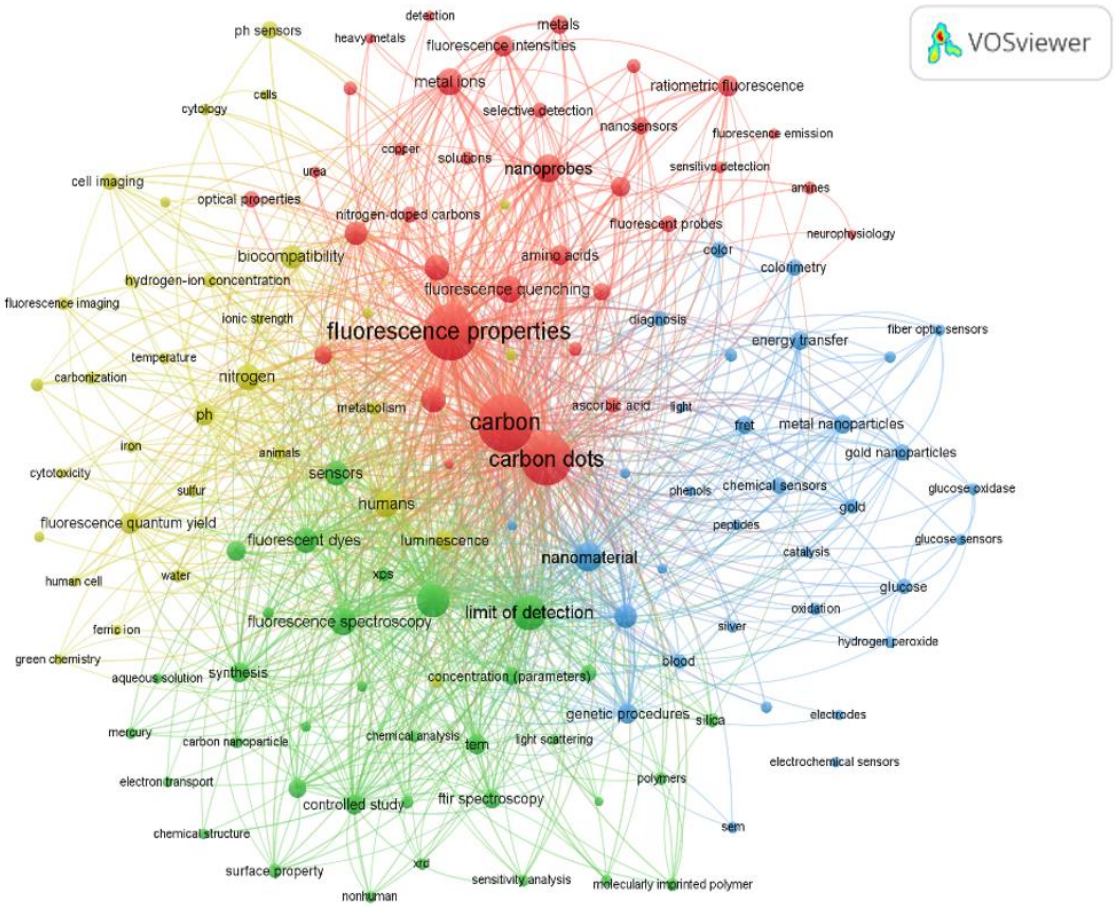

Figure 3. Network Visualization for Co-occurrence Relationships Between All Keywords

Keywords with colored circles have been labeled. In the titles and abstracts, the circle's size is positively correlated with the appearance of keywords. The size of letters and circles was, therefore, determined by the frequency of occurrences. The more frequently a keyword appears, the larger the scale of the circles and letters [75].

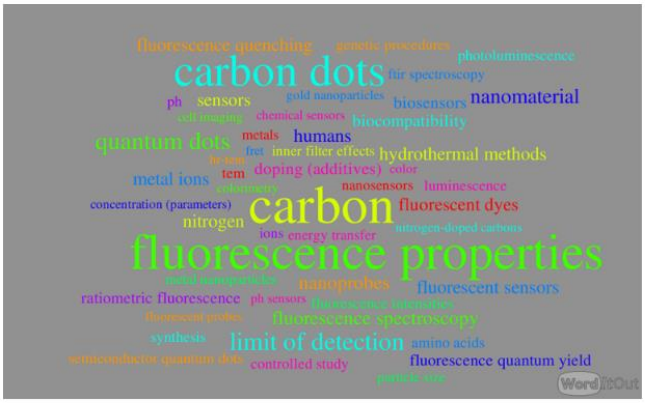

Figure 4. Word Cloud Visualization from the Keywords in the Publication Profile

We summarize the co-occurrence mapping based on keywords in Figure 3: carbon (632 occurrences, fluorescence properties (593 occurrences), and carbon dots (519 occurrences). To maximize its performance, the research hotspots related to this topic are analyzed using Word Cloud (Figure 4) based on the number of co-occurrence keywords extracted from VOSviewer. A word cloud is a special tool for text visualization that illustrates more commonly used words by encouraging their representation more prominently [76]. The co-occurrence of the numerous words that occur in a piece of text is disclosed by word clouds. The composition of the commonly used words helps readers to provide an overview of the key topics and the main themes in a text to a certain degree and may explain the main points of view held by the text's writer. The differences between the ideas contained in these texts should be quickly exposed by the comparison of word clouds created from different texts. In this context, we decided to see if the word cloud approach might be useful for the text's qualitative analysis [77].

Bibliometric Co-authorship

Figure 5 shows the study of joint writers and networks linked to patterns of collaboration between people. In this network, in each writing relation, each node represents the author. This research can incorporate several different dimensions to visualize groups and relationships between time-shift dimensions [69]. An overview of the author's network seen from the year the authors were together is shown in Figure 5. In this case, the authors' relationship can be categorized as their annual relationship. It has been demonstrated that Liu Y., with 56 total posts, is the author with the most relationships with others. In the meantime, the most recent research, such as Liu S. G., Li N. B., and Luo H. Q., is called yellow. With 10 publications overall, respectively.

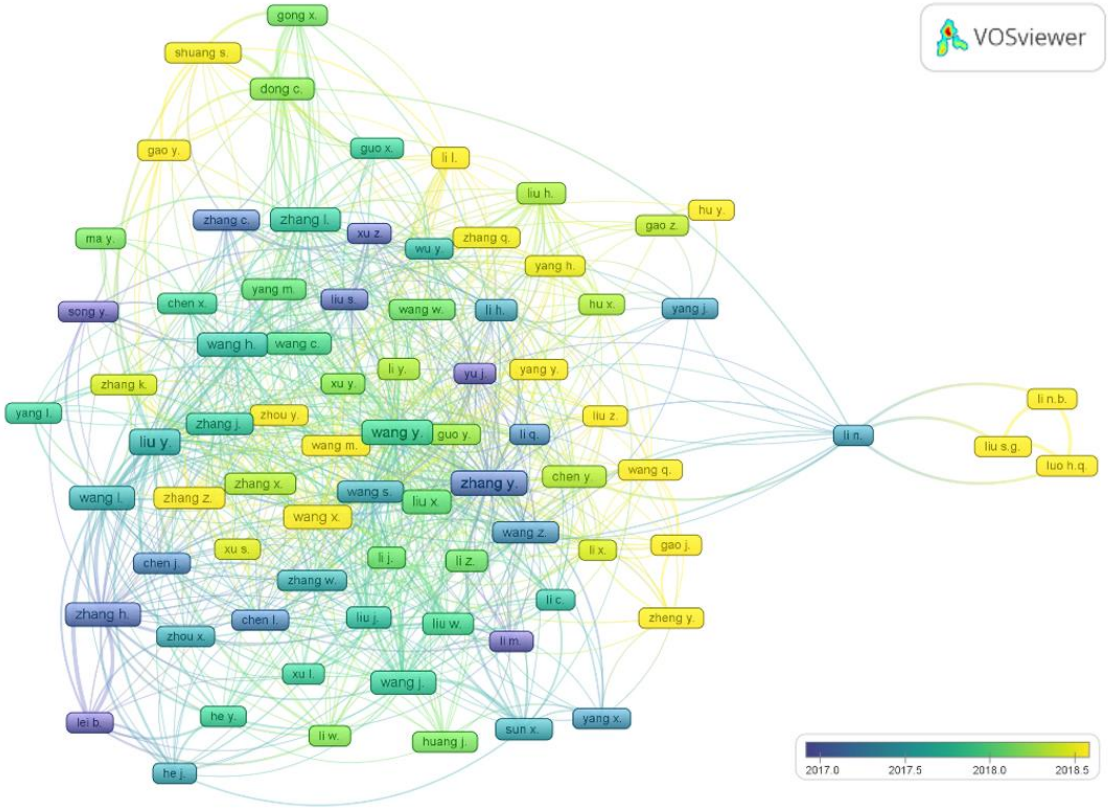

Figure 5. Overlay Visualization for Co-authorship Relation

Figure 6 illustrates the geographical distribution of the total publications of the top 30 productive countries. Publications in this area are mainly distributed in China, India, the United States, Iran, and South Korea. China is the first country that has received very close attention, as indicated by the number of published authors up to 664. In the meantime, India ranks second with 127 published authors. However, in third to fifth place are the United States, Iran, and South Korea, with a number of authors of 92, 77, and 40, respectively. This shows that the performance of carbon dots research as a sensor is receiving less attention in four countries besides China. The ratio of the number of published authors between China and the other four countries is 5.23, 7.22, 8.62, and 16.6, respectively. The comparison of these ratios shows a very significant difference, and China shows its concern and consistency towards this research topic, as indicated by Tables 1-5.

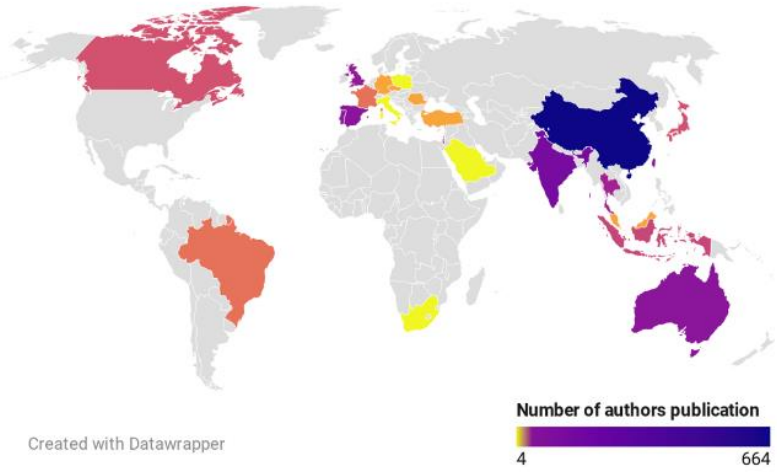

Figure 6. Geographical Distribution Based on Authors' Contribution

Bibliometric Analysis for Citation

Publications and citations are the most important catalogs and the best way to evaluate papers [78]. Additionally, the paper quality can be assessed through the number of citations [65]. Table 1 lists the 10 articles with the highest citations out of 1023 published articles. Additionally, the citations of these ten articles constituted 22.94% of the citations.

Table 1. Top 10 Articles with the Highest Number of Citations

Authors	Journals	Citations	% Citations
Zhu *et al.* [79]	Angewandte Chemie - International Edition	1945	6.39
Shen *et al.* [80]	Chemical Communications	1350	4.44
Ding *et al.* [81]	Accounts of Chemical Research	597	1.96
Nieh *et al.* [82]	Chemistry of Materials	547	1.80
Yang *et al.* [83]	Nanoscale	520	1.71
Qu *et al.* [84]	Chemistry - A European Journal	481	1.58
Zheng *et al.* [85]	ACS Applied Materials & Interfaces	472	1.55
Zhua [86]	Angewandte Chemie - International Edition	402	1.32
Yu [87]	Chemical Communications	353	1.16
Shen [88]	Analytical Chemistry	312	1.03

In addition to the ten most-cited articles, the ten most popular articles were also determined. An article was considered popular if its average number of yearly citations since the publication was high [65]. Seven of the top ten most popular articles are also among the top ten most-cited articles. For a complete list of the top ten most popular articles, see Table 2. The top ten most popular articles were published in 2012, 2013, 2014, 2017, and 2018. Unsurprisingly, there was a lot of overlap between the most-cited and popular articles. These articles constituted a fair portion of the total number of citations, with the ten most-cited articles of all citations.

Table 2. Top 10 Most Popular Articles

Authors	Journal	Average citations per year
Zhu *et al.* [79]	Angewandte Chemie - International Edition	277.86
Shen *et al.* [80]	Chemical Communications	168.75
Ding *et al.* [81]	Accounts of Chemical Research	99.50
Nieh *et al.* [82]	Chemistry of Materials	91.17
Yang *et al.* [83]	Nanoscale	86.67
Qu *et al.* [84]	Chemistry - A European Journal	68.71
Zheng *et al.* [85]	ACS Applied Materials and Interfaces	67.43
Liu *et al.* [89]	ACS Applied Materials and Interfaces	64.33
Yan *et al.* [90]	Analytical Chemistry	59.50
Lin *et al.* [91]	Analytical Chemistry	57.00

The publishing journals were analyzed based on their number of articles and the number of citations to determine whether the publishing journal affected how often the articles were cited [65]. Table 3 illustrates that the ten highest journals were responsible for publishing all the articles based on the total number of citations. In general, articles in any of these ten journals resulted in a high probability of citation.

Table 3. Top 10 Active Journals in Publishing Carbon Dots as Sensor-related Research Articles Based on the Total Number of Citations

Sources	Doc.	Country of the Journal	Citations	% Citations
Sensors and Actuators, B: Chemical	109	Netherlands	3148	10.345
Biosensors and Bioelectronics	37	United Kingdom	2561	8.4160
Angewandte Chemie - International Edition	3	United Kingdom	2360	7.7555
Chemical Communications	7	United Kingdom	2162	7.1048
Analytical Chemistry	22	United States	2093	6.8781
Nanoscale	21	United Kingdom	1912	6.2833
ACS Applied Materials & Interfaces	32	United States	1691	5.5570
Talanta	41	Netherlands	964	3.1679
RSC Advances	54	United Kingdom	915	3.0069
Analytica Chimica Acta	28	Netherlands	895	2.8229

The quality or impact of the journal was measured using the quartile ranking obtained from the Scimago Journal Rank, better known by the acronym SJR (https://www.scimagojr.com/). Journals in the Q1 rank had the highest impact, while those in the Q4 had the least impact [92].

All international journals in Table 3 have the first rank (Q1) of the four international journal rankings obtained from the Scimago Journal Rank. Table 3 shows the three dominating countries by the country's journal. First, the United Kingdom has five journals, namely Biosensors and Bioelectronics, Angewandte Chemie - International Edition, Chemical Communications, Nanoscale, and RSC Advances. Second, the Netherlands has three journals, namely Sensors and Actuators, B: Chemical, Talanta, and Analytica Chimica Acta. The third is the United States, with a total of two journals, namely Analytical Chemistry and ACS Applied Materials & Interfaces.

According to the results of Scopus, all the journals on the list do not have open access. Hence, only institutions subscribed to Scopus can access the journal. If the journals have more specific subjects and the subjects also match the research hotspots in these topics, such as journals of Talanta, RSC Advances, and Analytica Chimica Acta, they receive more citations per publication. As for journals of Sensors and Actuators, B: Chemical, and Biosensors and Bioelectronics, their subjects fit in with the theme of ''carbon dots as sensors" of this area, so they also have higher citations per publication.

Table 4. Top 10 Organizations with the Highest Number of Citations

Organization	Citations	% Citations
State Key Laboratory of Supramolecular Structure and Materials, College of Chemistry, Jilin University, China	2492	3.8992
School of Stomatology, Jilin University, China	1945	3.0433
State Key Laboratory on Integrated Optoelectronics, College of Electronic Science and Engineering, Jilin University, China	1945	3.0433
Key Laboratory for Ultrafine Materials of Ministry of Education, School of Materials Science and Engineering, East China University of Science and Technology, China	1350	2.1124
Department of Chemistry, Tongji University, China	1153	1.8041
Key Laboratory for Molecular Enzymology and Engineering, Ministry of Education, Jilin University, China	547	0.8559
Key Laboratory for Thin Film and Microfabrication of Ministry of Education, Research Institute of Micro/Nano Science and Technology, Shanghai Jiao Tong University, China	520	0.8136
State Key Laboratory of Polymer Physics and Chemistry, Changchun Institute of Applied Chemistry, Chinese Academy of Sciences, China	484	0.7573
Graduate School of the Chinese Academy of Sciences, China	481	0.7526
Laboratory of Chemical Biology, Changchun Institute of Applied Chemistry, Chinese Academy of Sciences, China	481	0.7526

The organizations which have published the highest numbers of articles are listed in Table 4. As shown, all the publishing institutes are in China. Table 4 shows that research performance in China has greatly improved, not only in the number of authors, articles published, and citations but also in organizations' contributions. Thus, it can be concluded that China is a country that has a research trend with very significant performance with the theme "carbon dots as sensor" among other countries.

Table 5. Top 10 Countries with the Highest Number of Citations

Country	Doc.	Citations	% Citations
China	664	23680	67.18
United States	92	2199	6.24
India	127	2161	6.13
Iran	77	1046	2.97
Spain	21	728	2.07
South Korea	40	714	2.03
Portugal	14	593	1.68
Australia	14	554	1.57
Germany	5	343	0.97
Hong Kong	10	341	0.97

In order to gain a better understanding of the quality and impact of articles published by each country, the number of publications, the number of citations, and the percentage of citations were provided for the top 10 countries with the highest number of citations. These results can be viewed in Table 5. China was ranked first in the number of citations because it had the highest number of cited articles (23680 citations) with 664 articles and the highest percentage of published articles cited with 67.18%. Additionally, China remains tied for first in the total number of articles published among other countries. China significantly differs from other countries based on the number of articles published and cited. Because the number of citations often indicates article quality, there were clear differences in the number of articles published versus the quality of such articles from different countries [65].

CONCLUSION

This bibliometric study provided an overview of current research. In the carbon dots as sensor field, 1023 articles were found in the Scopus database from 2010 to 2020. Beginning in 2014, there was a significant increase in the number of articles published per year, which is expected to continue in the coming years. The most cited and most impactful articles were published before 2014—the top two productive journals, i.e., Sensors and Actuators, B: Chemical, and RSC Advances. China was the largest contributor to the research on carbon dots as a sensor, and performance-related research was dominant in the research performance-related in almost all bibliometric analysis criteria. Carbon dots research, especially in sensor applications, will remain essential to support the advancement of sensor technology in the upcoming years. Thus, this study's research trends will lead researchers to establish future directions in carbon dots as a sensor technology and applications.

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AUTHOR CONTRIBUTIONS

Permono Adi Putro: Conceptualization, Methodology, Software, Data Curation, Investigation, Visualization, Validation, Writing - Original Draft, Writing - Review and Editing; Hendradi Hardhienata: Methodology, Formal Analysis, Resources, and Writing - Original Draft, Funding Acquisitions, Project Administration, Supervision; Isnaeni Isnaeni: Methodology, Formal Analysis, Resources, and Writing - Original Draft; Faozan Ahmad: Formal Analysis, Validation; Deni Shidqi Khaerudini: Methodology, Formal Analysis, Writing - Review and Editing; Andhika Prima Prasetyo: Methodology, Formal Analysis, Resources, and Writing - Original - Review and Editing; and Akhiruddin Maddu: Data Curation, Formal Analysis, and Writing - Original Draft, Supervision.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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