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EXAMINING CARBON QUANTUM DOTS RESEARCH IN TURKEY: A SCIENTIFIC MAPPING ANALYSIS

TÜRKİYE'DEKİ KARBON KUANTUM NOKTALARI ARAŞTIRMALARININ İNCELENMESİ: BİLİMSEL BİR HARİTALAMA ANALİZİ

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ABSTRACT

The bibliometric analysis presented in this work is thorough and comprehensive, carefully examining the wide range of contributions related to "carbon dots" and "carbon quantum dots" in Turkish research from 2014 to 2023. Using Biblioshiny as the major analytical tool and the Web of Science database, this study methodically breaks down the annual trends, regional spreads, institutional ties, authorship trends, and the complex clusters of keywords in this field. After a comprehensive analysis of international and local citations, the research identifies a noteworthy yearly growth rate of 14.72% for Turkey's carbon dot project. Starting with one manuscript in 2014, the research output increased rapidly, reaching sixty critical documents by the end of May 2024. This thorough study clarifies important publication sources; in particular, it emphasizes ChemistrySelect and the publication of Fluorescence as two of the field's top contributors. This thorough evaluation significantly contributes to our knowledge of the state of carbon studies in Turkey, providing priceless insights and a guide to advise and set the direction for future research projects in this continuously developing field, especially for researchers and academics connected with "carbon dots".

Keywords: Bibliometric, carbon dots, carbon quantum dots, carbon nanodot.

ÖZET

Bu çalışmada sunulan bibliyometrik analiz, 2014'ten 2024'e kadar Türkiyede yapılan araştırmalarda "karbon noktaları" ve "karbon kuantum noktaları" ile ilgili geniş kapsamlı katkıları dikkatle inceleyen ayrıntılı ve kapsamlı bir analizdir. Biblioshiny'yi ana analitik araç olarak ve Web of Science veritabanını kullanan bu çalışma, bu alandaki yıllık eğilimleri, bölgesel dağılımları, kurumsal bağları, yazar eğilimlerini ve karmaşık anahtar kelime kümelerini metodik olarak incelemektedir. Çalışmada uluslararası ve yerel atıfların kapsamlı bir analizinin ardından, Türkiye'nin karbon nokta projesi için yıllık %14.72'lik kayda değer bir büyüme oranı tespit edilmiştir. 2014 yılında bir makaleyle başlayan araştırma çıktıları hızla artarak 2024 Mayıs itibarıyla altmış kritik belgeye ulaşmıştır. Bu kapsamlı çalışma, önemli yayın kaynaklarını açıklığa kavuşturuyor; özellikle ChemistrySelect'i ve Floresan'ın yayınlanmasını alana en çok katkıda bulunan iki kaynak olarak vurgulamaktadır. Bu kapsamlı değerlendirme, Türkiye'deki karbon çalışmalarının durumu hakkındaki bilgimize önemli ölçüde katkıda bulunmakta, paha biçilemez öngörüler sağlamakta ve özellikle "karbon noktaları" ile ilgili araştırmacılar ve akademisyenlere sürekli gelişen bu alanda gelecekteki araştırma projeleri için tavsiyelerde bulunmakta ve yön belirlemek için bir rehberlik sağlamaktadır.

Anahtar Kelimeler: Bibliyometrik, karbon noktalar, karbon kuantum noktalar, karbon nanonokta.

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INTRODUCTION

In the context of growing scientific research, novel materials with remarkable qualities have become more popular. Among these improvements, nanostructured materials stand out as especially interesting. Mainly, carbon-based nanostructures have attracted much interest (Akkurt, 2014). Carbon dots, also known as Carbon Quantum Dots (CQDs), are one of the newest trends in this field. It was accidentally discovered in 2004 while purifying carbon nanotubes (Alas et al., 2020; Dinc & Kara, 2018; Kavgacı et al., 2023). Due to several critical characteristics, carbon dots—distinguished by their quasi-spherical particle morphology—are becoming increasingly important in a wide variety of applications. Their notable qualities, which all contribute to their attraction in the scientific and industrial domains, include water solubility, low toxicity, adjustable photoluminescence characteristics, outstanding chemical and physical stability, and cheap synthesis cost (Sagbas & Sahiner, 2019). Two main approaches are used in the production of CQDs: the top-down technique and the bottom-up approach. The bottom-up approach uses various techniques, including microwave irradiation, pyrolysis, and hydrothermal treatment, to create CQDs from tiny molecules (Eskalen & Çeşme, 2021). On the other hand, the top-down approach uses methods such as arc discharge, electrochemical oxidation, and laser ablation to produce CQDs. Because of its efficiency and adaptability, hydrothermal synthesis is one of these processes that is most frequently used to produce carbon dots (Aslan & Eskalen, 2021; Budak & Ünlü, 2021; Çeşme & Eskalen, 2020; Eskalen, 2020). This flexible nanostructures' potential for varied and sustainable resource consumption is further demonstrated by the fact that they may be produced from a wide range of organic precursors, including plant-based, agricultural-forestry, human and animal-derived, industrial, and algae waste materials (Başkaya et al., 2022; Çeşme et al., 2022; Dinç et al., 2022; Eskalen et al., 2023; Simsek et al., 2019).

CQDs are now being explored from a variety of perspectives to maximize their potential uses in many different kinds of industries. Their adaptability has drawn a lot of interest, particularly in the fields of chemistry, sensing (Burcu & Genç, 2017; Eskalen et al., 2021.b), and biosensor technologies (Akbıyık et al., 2023; Bodur et al., 2021; Dinç & Günhan, 2020). CQDs have shown potential for protecting against security risks associated with counterfeiting. Because of their special qualities, they may be used as luminous markers or tagging agents in security inks or papers, greatly aiding anti-counterfeiting procedures (Eskalen et al., 2021.a). Moreover, CQDs show great potential for bioimaging, utilizing their superior photoluminescence qualities and little cytotoxicity (Eskalen et al., 2020). These nanostructures' large surface area and electron transport characteristics also make them promising for use in supercapacitors and other energy storage devices (Genc et al., 2017; Çolak et al., 2023). While their capacities as drug carriers offer promise in pharmaceuticals, notably in cancer therapy where focused drug delivery systems are critical for effective treatment techniques for biomedical applications (Abraham et al., 2022; Suner et al., 2022; Sutekin et al., 2021). Their photocatalytic qualities make them ideal for efficient photocatalysis applications (Eskalen et al., 2022). Finally, food packing and wound dressing properties of carbon dots are also studied (Alaş et al., 2022; Başkaya et al., 2022; Sahiner et al., 2022). The investigation of CQDs in many fields highlights their adaptability and potential benefits in various scientific and industrial environments (Aslan et al., 2023; Korkmaz et al., 2023; Navidfar et al., 2022).

As originally described, the bibliometric technique is a powerful tool for identifying and understanding research trends within certain topics (Özğan & Aluçla, 2023.a; Özğan & Aluçlu, 2023.b). There are two key components to this analytical approach. First of all, it describes in detail how publications are distributed across several categories, such as subjects, fields of study, sources, authors, organizations, and nations. Second, it serves as an essential tool for examining research output and trend analysis across a range of disciplines, including publication numbers and citation counts. A bibliometric study was carried out to investigate the state of "carbon dots" research in Turkey using the Web of Science database. The principal aim of this work is to conduct a thorough evaluation of Turkish carbon quantum dots researchers from 2014 to 2023 using statistical and mathematical techniques in the context of bibliometric analysis. The purpose of this study is to evaluate the quantitative characteristics and identify common and emerging patterns in the Turkish environment, particularly in the area of "carbon dots." By doing this, it aims to provide a thorough foundation for charting the course of this field's research activity in Turkey. In addition to defining the current state of situations, this assessment seeks to identify and highlight important patterns and areas that require further investigation. This will lay a solid foundation for future research activities in this domain within the Turkish scholarly landscape.

MATERIAL AND METHOD

The scientometric study's dependability depends upon the collection of trustworthy data from well-established databases, including ISI WoS, Scopus, and Google Scholar. Because of its broad coverage and comprehensive content, the ISI WoS Core Collection records (http://apps.webofknowledge.com) were chosen as the primary information source for this study. The data collection process began by using the search field "Carbon dots" OR "Carbon quantum dots" OR "Carbon nanodots" OR “CQDs" OR “Carbon dot" OR "Carbon quantum dot" OR “Carbon nanodot" OR "CQD". Initially, 24.043 documents were identified. To refine the results, the focus was narrowed to documents related to Turkey and Türkiye, reducing the count to 281. 28 studies not related to carbon quantum dots were removed, and 2 correlation studies were removed. In total, 251 studies related to carbon quantum dots were taken into consideration. These resources were further analyzed using Biblioshiny, extracting detailed information such as publication years, author names, affiliations, and keywords.

RESULTS AND DISCUSSION

The yearly distribution of papers on CQDs (Carbon Quantum Dots) published in Turkey is shown in Figure 1. The red section represents research articles (214), the blue section represents review articles (28), the orange section represents book chapters (5), and the yellow section represents conference titles and presentations (4). A total of 251 documents were analyzed. The figure depicts the distribution of 251 academic studies on CQDs. The size of the red part indicates that the majority of studies in this field are original research articles. The blue segment indicates that review articles contribute significantly to the literature but not as much as original research. The orange and yellow sections have a smaller proportion, indicating that the contribution of book chapters and conference content in this field is less significant.

This visualization is useful for understanding academic interest in CQDs and the nature of research in this area. For example, the density of original articles indicates that there is still interest in this area and that it is a current area of study. In contrast, the presence of review articles indicates that these findings are being synthesized and that work in this area is maturing. Such bibliometric analyses are beneficial for comprehending the structure of a specific research field and the scope of academic contributions. There was a clear rising trend from 2014 to 2018, even if the number of publications stayed relatively modest. A notable spike in publications occurred in 2019 and throughout the previous five years. There has been a noticeable rise in the number of published documents, and most of them were published in the last two years. The maximum number of published documents was in 2023. This year corresponds to 28% of the total documents. This increase indicates the field's rapid growth and the growing interest in CQDs. The large number of articles in 2023 suggests that researchers are getting more involved with and interested in CQDs. The results indicate a strong previous interest in CQDs and predict even more interest in the future. The increased publications that will result from the growing interest in CQDs in the coming years could considerably improve our scientific understanding of the topic. This situation emphasizes the dynamic and ever-changing nature of CQDs research, underlining the possibility for further scientific findings and advances in this topic.

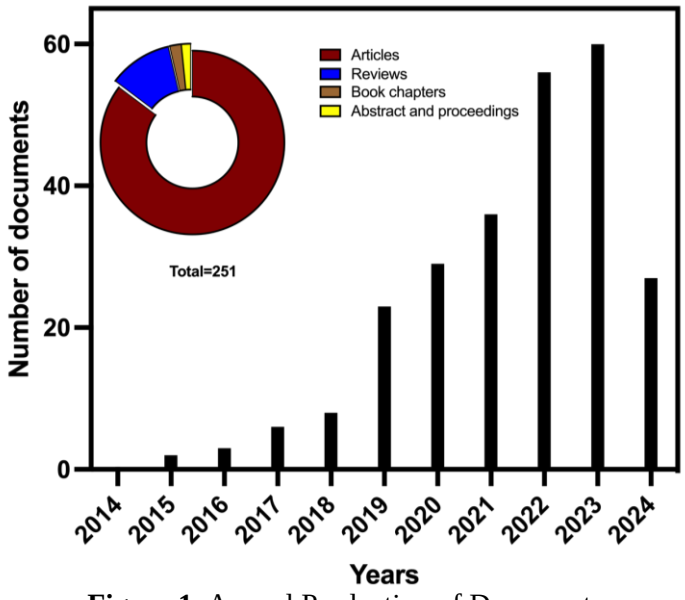

Figure 1. Annual Production of Documents

Figure 2 contains a three-axis Sankey diagram of the authors, keywords, and the universities they are affiliated with, which can provide various insights by relating the flows between various parameters. The graphic has three fields that display the academic works of Turkish writers on CQDs, the universities to which they are related, and the research keywords. The bars on the graph's left side include the names of CQDs researchers. The color intensity and size of these bars signify the number of publications and the researchers' influence. The Authors-institutions column in the center displays the authors' affiliations with the institutions. Universities are represented by different colors in this column, and the size of the bars reflects the number of academic research on CQDs conducted at each university. The DE column on the right side displays the keywords from the studies that were examined. In this column, terms such as 'carbon dots', 'carbon quantum dots', and 'quantum dots' are followed by keywords such as 'green synthesis', 'graphene', and 'antimicrobial'. This suggests that the research is primarily concerned with carbon dots, although it also includes green synthesis, graphene, and antimicrobial uses. The graph is a useful tool for understanding the academic studies on CQDs in Turkey. It is easy to identify research themes and the universities and researchers that are most active in this area. Furthermore, extensive data on the state of affairs, research patterns, joint venture prospects, and research networks in this domain may be acquired.

As can be seen from the graph, the first four researchers working on CQDs and their affiliated universities are as follows: Genç R. is a very active researcher who has done a significant part of the research in this field in Turkey. Eskalen H. is a prominent name in the field of CQDs. It is understood that researchers Ünlü C., Alas M. Ö. And Sahiner N. have an important influence on this issue. Mersin University, Istanbul Technical University, Kahramanmaraş Sütçü İmam University, Selçuk University, and Çanakkale Onsekiz Mart University are major research centers in this field of study, as shown by the colors and breadth of their bars. This demonstrates that these universities play an essential role in CQDs research and that there is considerable interest in the issue at these universities.

The highest score and association with the intensive use of the indicated keywords is important as it demonstrates the expertise of the indicated institutions and authors in this field. These researchers contribute significantly to the generation of scientific knowledge on the production and applications of carbon quantum dots. In this context, the authors and institutions have the potential to increase their scientific impact through international cooperation and to shed light on future research. Pioneering and knowledge in the field of CQDs can not only encourage discoveries and guide future Turkish scientists but also improve existing application areas related to CQDs and encourage finding new application areas. This visual analysis has the potential to guide researchers in understanding the factors involved in the diffusion of scientific knowledge and inspire future research.

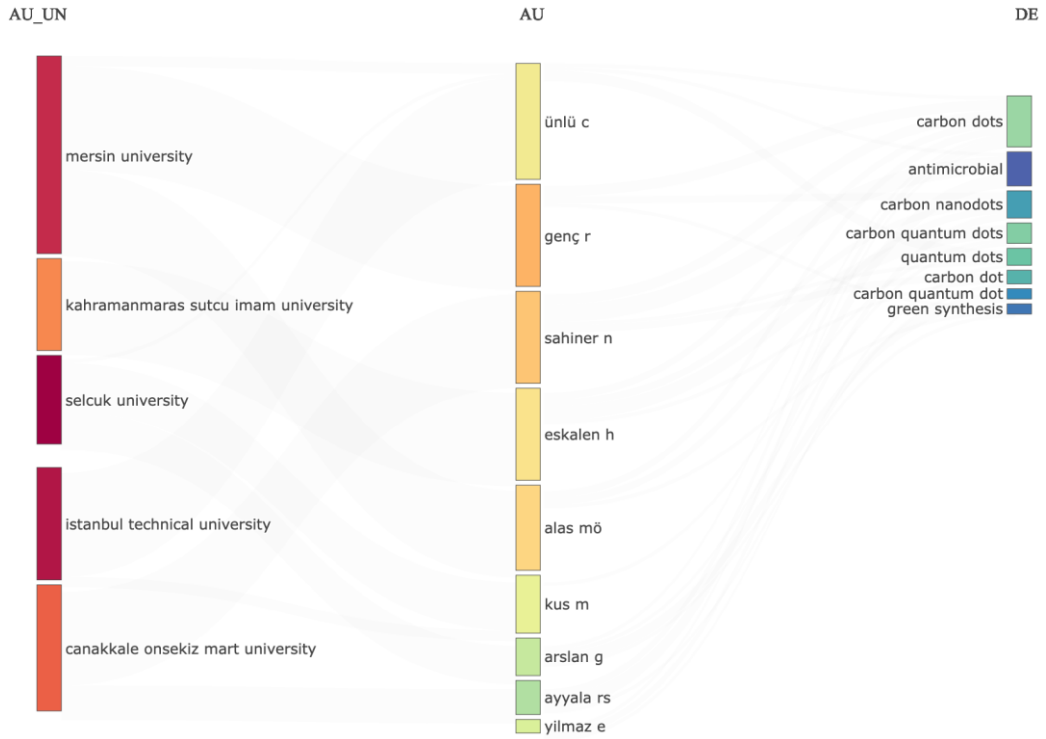

Figure 2. Three Field plot of CQDs Research Conducted in Turkey

The h-index and m-index values of authors producing papers on CQDs are highly relevant for determining their academic contributions, research plans and collaborations, and their impact on other work in this field. h-index is an indicator that measures citations to an author's published papers. A high h-index indicates that the author's work has had a significant impact and is frequently cited. The m-index, on the other hand, is an indicator of how sustainable a researcher's h-index is throughout their career and is calculated by dividing the researcher's active career years by their h-index. It reflects the ability of researchers to create an impact throughout their careers. Figure 3 depicts the h-index and m-index values of Turkey's top ten writers who have published the most scholarly publications on CQDs over the last decade. The graph shows two separate index values as blue and green columns: the blue columns indicate the authors' h-index and the green columns reflect their m-index. The heights of the blue (0-10) and green (0-1.4) columns in the graph represent the magnitudes of each author's h-index and m-index values. Genç R., Alas M.Ö., has the highest h-index values. This demonstrates that their CQDs study has a large citation network and a long-term effect on academic impact. The author Eskalen H., has high m-index values, indicating that his research has a significant influence.

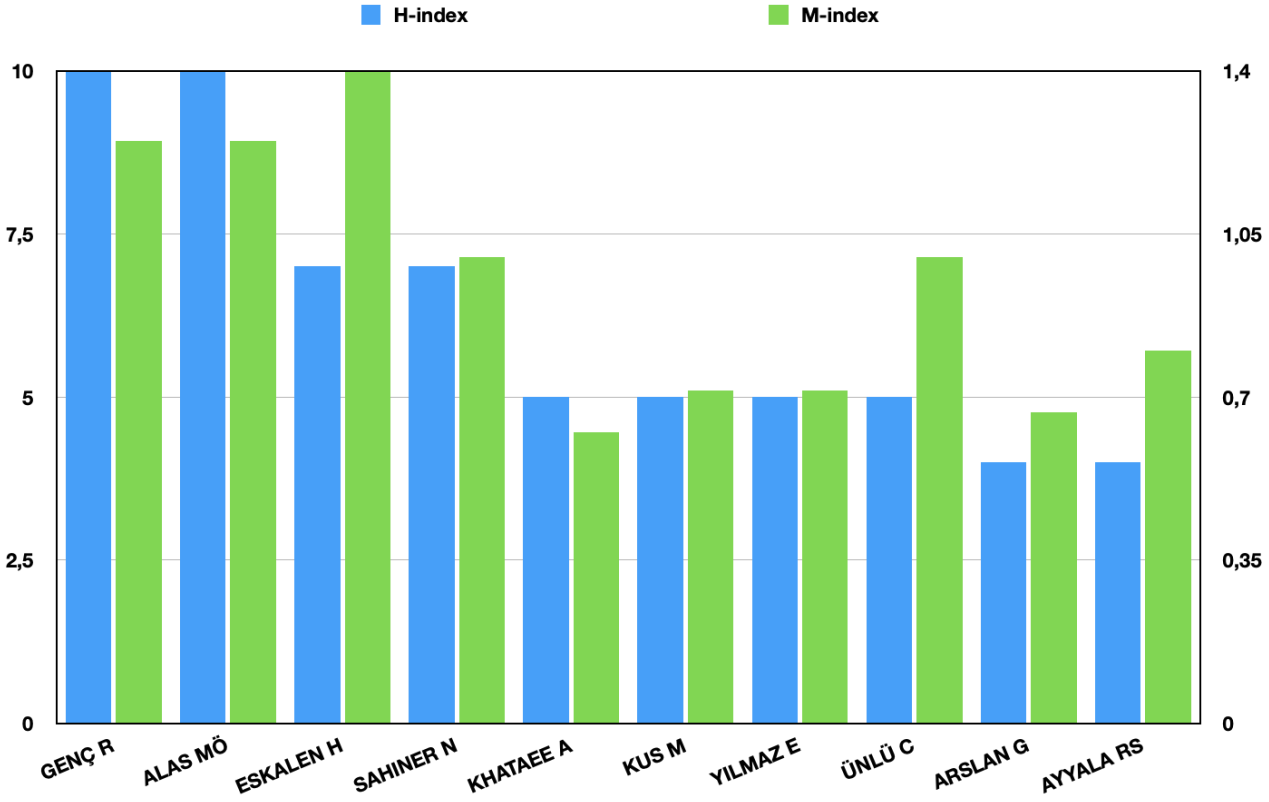

Figure 3. Ten Authors with the Highest h-and m-index

Figure 4 depicts a network map of Turkish academics' collaboration on CQDs during the previous decade. Each node represents a researcher, while the linkages indicate partnerships between researchers. The size of the nodes shows the number of connections the researcher has in the network. The colors indicate various institutions or research groups. This figure shows fifteen research groups actively working in this field. The largest node is labelled Şahiner N. and has a central position indicating their important role in the collaborative network for CQDs research. The nodes labelled as Genç R. and Alas M. Ö. are also quite large and interconnected, indicating their collaboration and important partnerships in this field.

Figure 5 shows a comparison of national and international citation counts for the top ten scholarly publications published in CQDs. The green columns reflect each article's local citations, whereas the dark green columns represent worldwide citations. In general, a high global citation count suggests that the publication has a broad international influence and is cited by scholars throughout the world. A high local citation count, on the other hand, suggests that the publication has had a considerable influence on the author's own geographic or regional academic community. The relationship between national and international citation counts in the graph may be an indicator of the national and international recognition of the research. If an article has more national citations than international citations, it means that the work is interesting or important to the local scientific community. The graph shows that national citation counts for CQDs research in Turkey range from 0 to 10, but international citation counts range from 0 to

218. It can be observed from the graph that the publications of Genc R. took the most globally cited documents related to this topic.

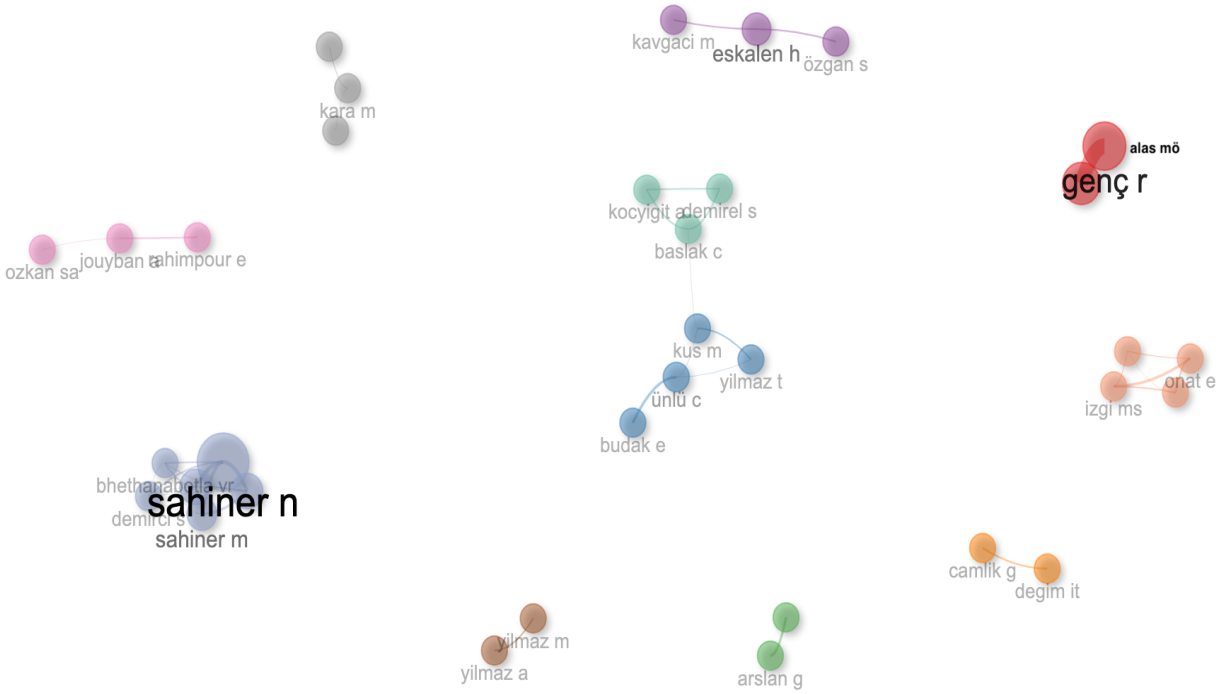

Figure 4. Collaboration Network

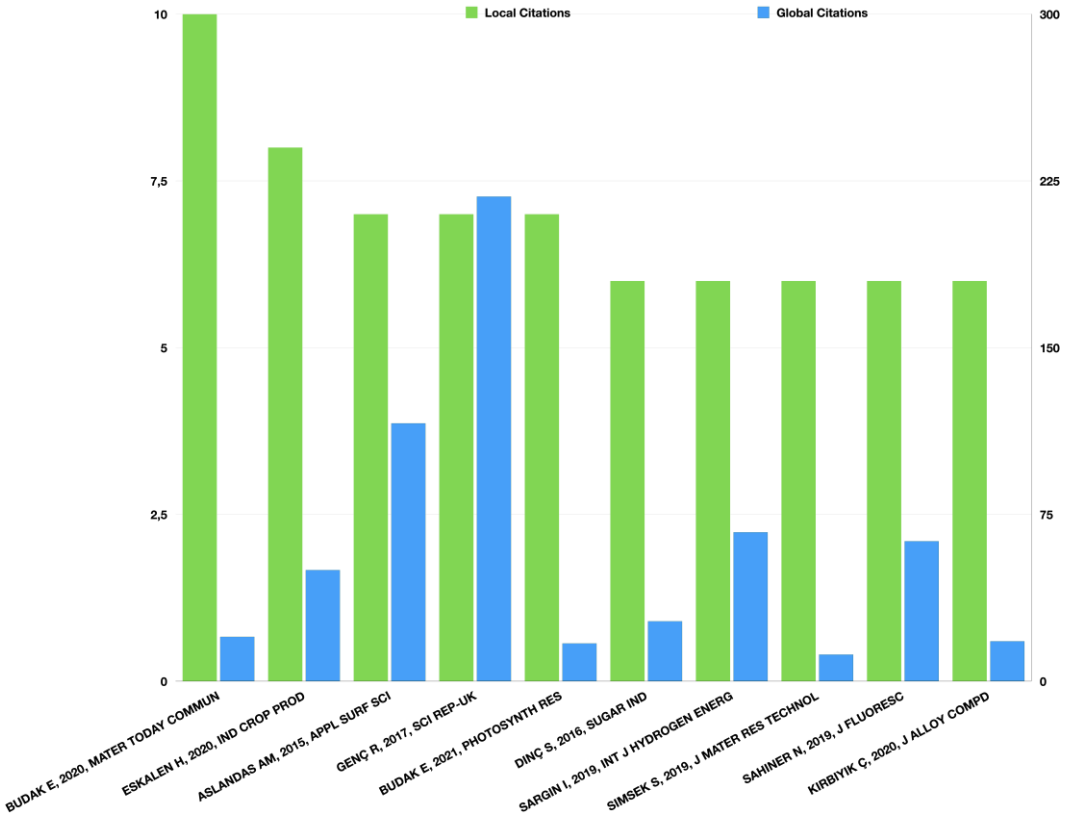

Figure 5. The Local and Global Citations of The Most Published Authors

A comparison of the number of articles and the fractional number of articles of the top ten authors from Turkey publishing on CQDs is presented in Figure 6. The graph is represented by two columns with different colors: one color represents the total number of articles and the other color represents the fractional number of articles. The fractional number of articles is calculated by taking into account the contribution of each author in multi-authored articles. The blue columns represent the total number of articles by each author and the green columns represent the fractional number of articles by each author. The height of the blue columns indicates the total number of articles of the author, while the green columns represent the contribution of the author to the publication. As can be seen from the graph, some authors were involved in more than one co-authored article and this is reflected in the fractional number of articles. In addition, when an author's blue and green columns are of equal height, it suggests that the author either works alone or with a small group of authors. This may indicate the influence of the author's leadership in studies and research.

In general, the graph also shows the collaboration trends, academic impact, and contributions of authors working on CQDs. These data can be used to assess the authors' research areas and their impact in this field. For example, it can be very useful in finding suitable partners for interdisciplinary projects or mentoring, forming new research teams, or planning research strategies. As can be seen from the graph showing the number of articles and a fractional number of articles of researchers publishing in CQDs, the vertical axis represents numerical values between 0 and 5 and shows how many articles each author has published or contributed to. Genç R. has the highest column, indicating that he has the most articles on CQDs. Also, Genç R. and Eskalen H.'s high fractional number of articles indicates that he is probably the main author or significant contributing author in many publications and has made significant contributions to this field. Sahiner N. and Alas M. Ö. also stand out as other researchers with a high number of articles. Eskalen H. and Ünlü C. are also included in the graph as authors with a medium number of articles.

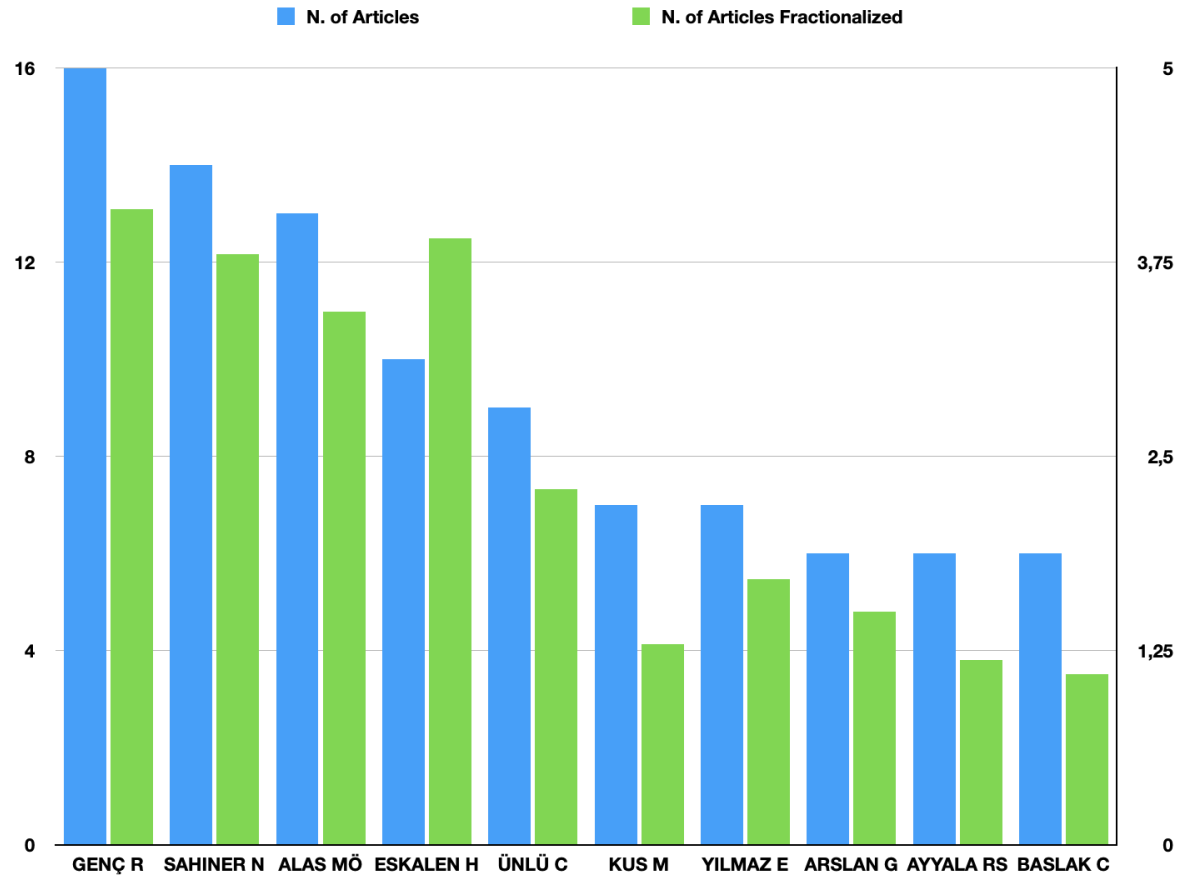

Figure 6. Top Ten Authors with Number of Articles and Fractionalized Articles

A timeline showing the publication data of authors working on CQDs over time is presented in Figure 7. Each horizontal line represents a different author and the dots on the line indicate articles published in specific years. The size of the dots represents the number of citations of the articles or the prestige of the journal in which they were

published, with larger dots representing more highly cited articles or articles published in higher prestige journals, and smaller dots representing less highly cited articles or articles published in lower prestige journals. This graph is very useful for analyzing authors' academic careers and assessing their research trends.

As can be seen from Figure 7, the annual production of authors publishing on 'Carbon Quantum Dots' from 2017 to 2024, Genç R., has the highest productivity. As can be seen from the number of articles and consistency of publications, Alas M.Ö. was very active in this period and carried out influential research in the field. The graph shows that Sahiner N., who stands out with a significant number of publications, has been active in recent years and has continuously contributed to the research on 'Carbon Quantum Dots'. Although Eskalen H. and Ünlü C. have published fewer papers in this period, the continuity of their work demonstrates their consistent research efforts in this field.

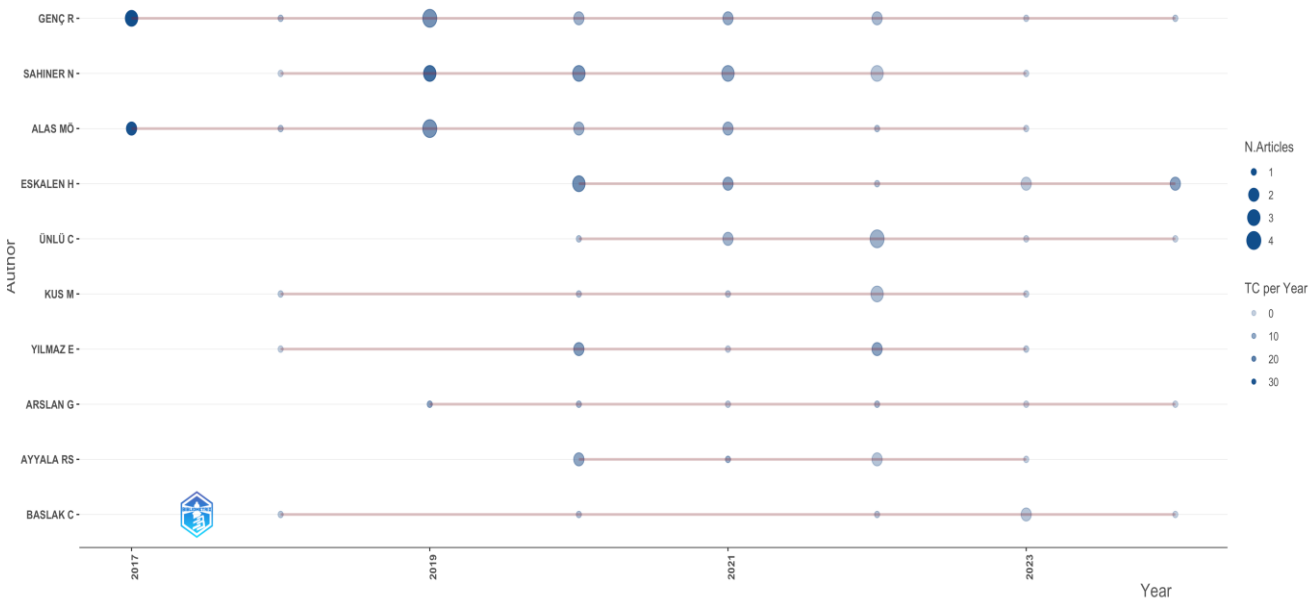

Figure 7. Authors Production Over Time

The keyword networks created to show the relationships between authors' keywords are shown as circular nodes representing the most frequently used ones (Figure 8). The graph shows the relationships between keywords and specific topics and how often these keywords are linked to each other. The relationships between nodes are highlighted by nodes with similar colors, increasing in size as their frequency increases. Two main clusters illustrate the most important aspects of CQDs research of keywords were identified. One group, colored blue (Cluster 1), contains 8 keywords and includes terms such as nanoparticles, sensor, and carbon dots. The other group, colored purple (Cluster 2), consists of 12 keywords and includes terms such as quantum dots, green synthesis, and hydrothermal synthesis.

The largest node in the center belongs to the term nanoparticles, indicating its importance in the research field and its frequent use as a keyword. Following this, the terms nitrogen and photoluminescence also stand out as major nodes, indicating their importance in the field. This word association map also allows us to understand which topics researchers focus on and the relationship between these topics. Terms clustered around keywords such as nanoparticles, quantum dots, and nitrogen show the relationship of these keywords to various subfields and applications.

The keywords chosen by the authors are the cornerstones of research, and these words have an important place in the analyses (Makhija et al., 2023). Among the keywords obtained during the database analysis process, the 40 most frequently occurring words were identified and the frequency and percentages of these words were presented in detail in a tree map (Figure 9). This figure shows the frequency of keywords and their relationships with each other. Each colored box represents a keyword used in the research, and the number and percentage within each box indicate how often that term is used. For example, the term nanoparticles occurs 59 times and accounts for 9% of the total terms used, indicating that it is an important keyword in research in this field. In Figure 9, it is observed that 'nanoparticles'

is the most frequently used word, followed by 'quantum dots'. This emphasizes the importance of nano sizes for carbon quantum dots. Furthermore, the intensive use of the words “sensor”, “carbon dots”, “nanodots” and “green synthesis” draws attention to the importance of the synthesis and application areas of CQDs. In this context, the determination of keywords not only expresses the essence of research but also is an indicator reflecting the importance and interests that scholars attribute to certain topics. At the same time, it can be seen that authors also take into account the prominent aspects of their research and interdisciplinary interactions when choosing keywords. In this way, the analysis of keywords director on the general state of CQDs research in Turkey guides future studies on this subject.

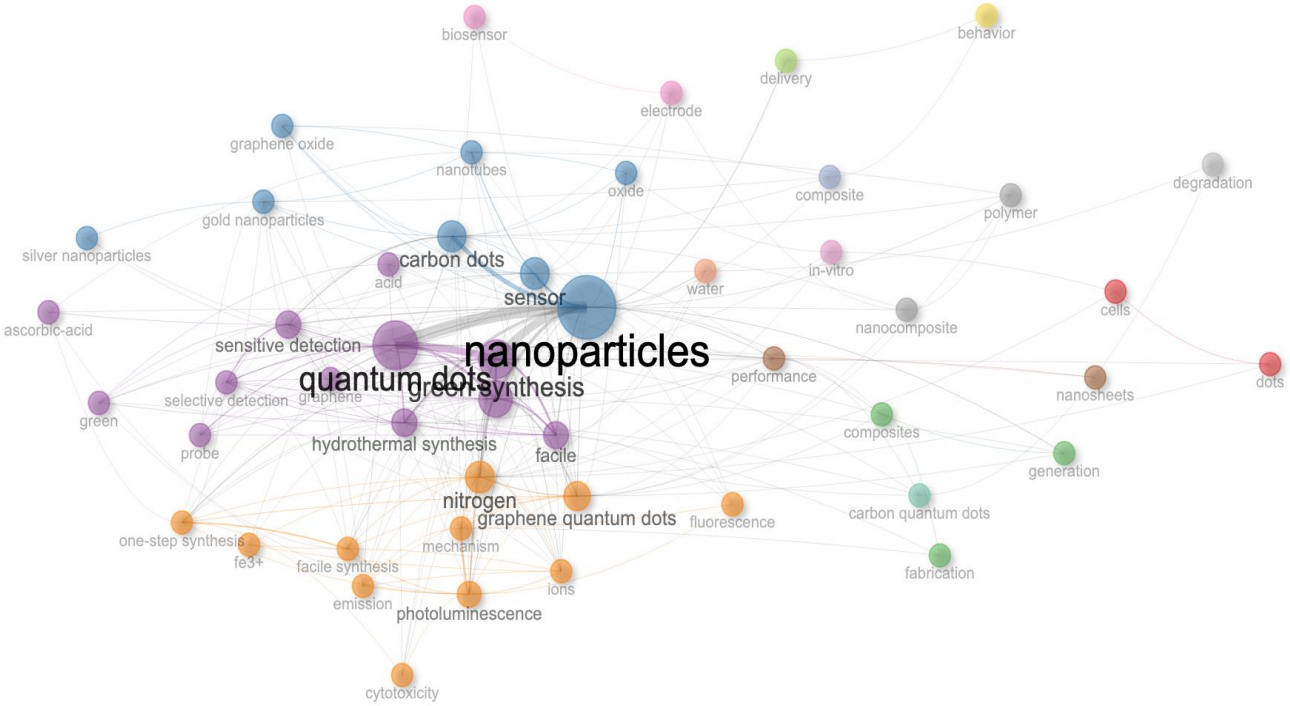

Figure 8. Analysis of The Highest Occurrence of Author Keywords

Carbon quantum dots attract the attention of researchers in terms of various aspects such as synthesis methods, application areas, and sensor properties (Umar et al., 2023). For a better understanding of the research on this topic, it is important to focus on the relationship between keywords and studies. By analyzing the keywords and literature related to carbon quantum dots over about ten years (2014-2024), articles in the Web of Science database were searched to examine the frequency of these keywords and the importance of their links. Word cloud keywords that the authors used related to CQDs are presented in Figure 10. The size of each word reflects how often it occurs in the literature and the importance it is in terms of the subject matter, and reflects the position of the keywords. The word cloud keywords emphasized notable words including " carbon quantum dots ", "carbon dots", "quantum dots", "carbon nanodots", "green synthesis" and "carbon quantum dots". This illustration of the links between keywords, their closeness to each other, and how relevant they are, can contribute to a better understanding of their interactions in the CQDs research field. In this context, analyzing the keywords can help us better understand the areas where scientists focus on this topic and potential research avenues in Turkey.

Among other terms are words expressing specific processes and properties such as 'hydrothermal synthesis, photoluminescence, facile synthesis, and selective detection. These terms reflect the diversity of methodologies examined in research related to CQDs and the potential application areas of these nanoparticles. This word cloud provides a summary of research agendas, industrial and academic interests, as well as potential research and development opportunities. By highlighting the focal points of studies in this field and revealing the interests of the research community, it shows researchers which topics are popular and how concepts are related to each other.

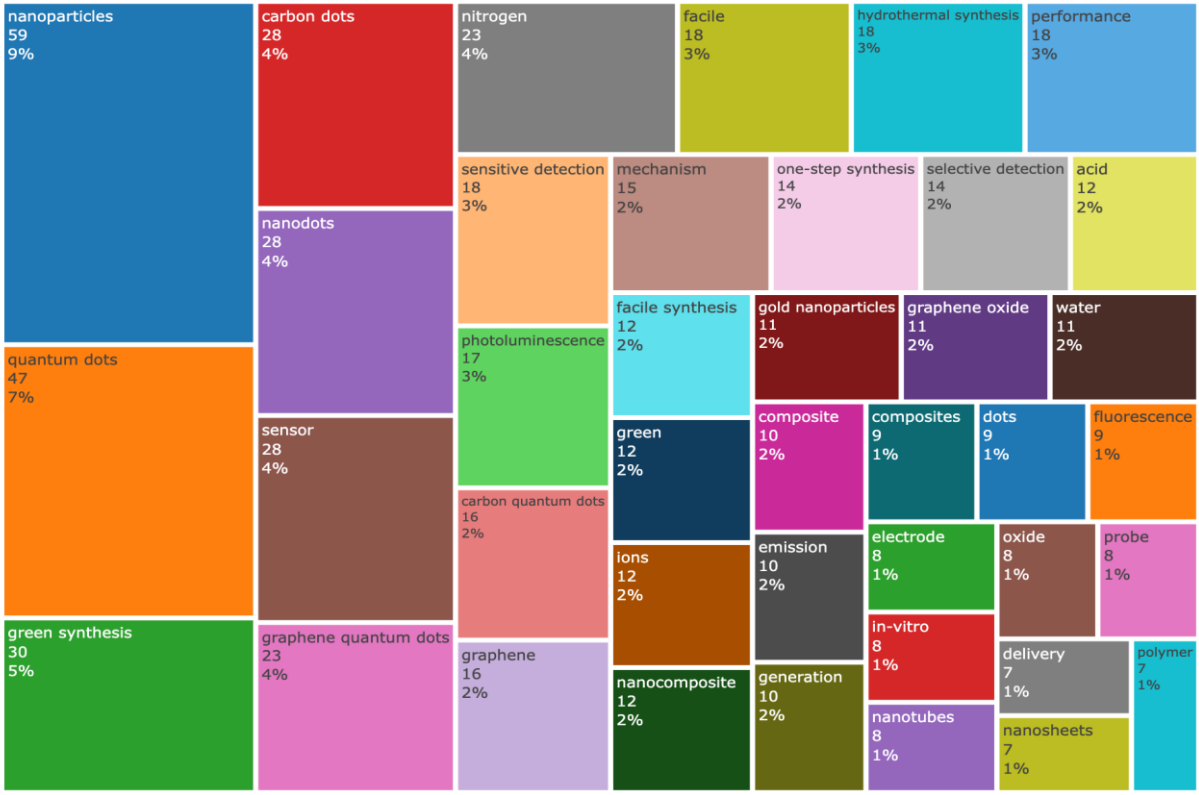

Figure 9. Represents The Conceptual Structure Map Plotted by The Multiple Correspondence Analysis (MCA) Method

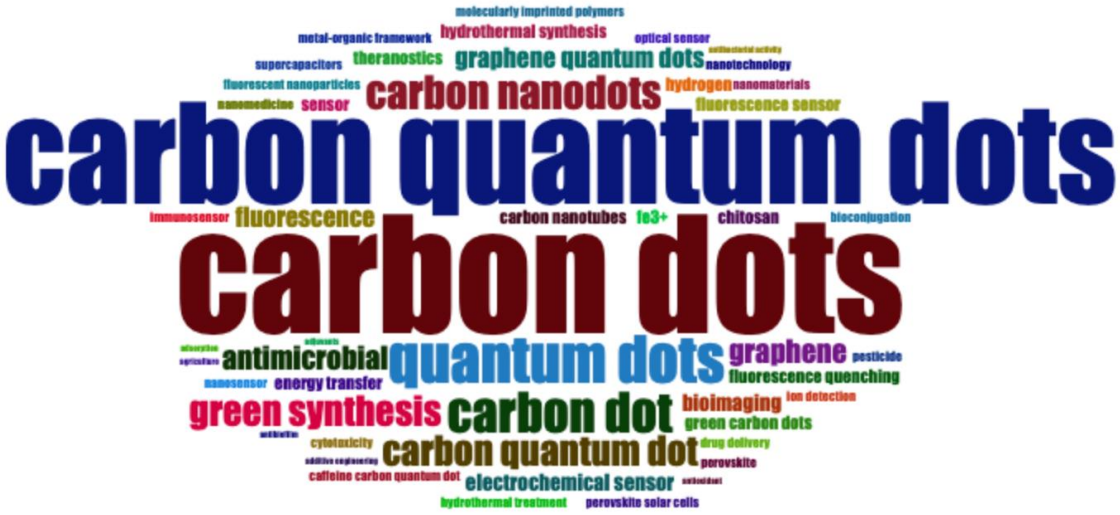

Figure 10. Visualized Word Clouds from Author's Keywords

CONCLUSIONS

The bibliometric analysis of academic studies on CQDs in Turkey clearly demonstrates a noticeable growth and development in this field over the past decade. The increase in publication numbers between 2014 and 2024 indicates the growing interest of Turkish researchers and universities in the field of CQDs and the intensification of research in this area. CQDs have been an important research area in the literature in Turkey in the last 10 years. It is observed that there has been a significant increase in the number of publications, especially in 2023, and the publications in this year constitute 24% of the total publications. The increase in the number of research in the field of CQDs reveals the momentum and interest in this subject. The word clouds highlight the relationships and frequencies of keywords. Frequently used terms such as "carbon quantum dots", "quantum dots" and "green synthesis" emerge as the main

focal points of CQDs research. h-index and m-index show that Turkish researchers are included and influential in international literature. Turkey is gaining more visibility in international literature with new studies in this field and contributing to international scientific development. This impact can open the doors for national academic institutions to establish international cooperation and partnerships.

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