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Magnetic Graphene Oxide Conjugated with Polyamidoamine Dendrimer (MGO-PAMAM) as Heavy Metal Adsorbent: Bibliometric Analysis using Google Scholar Indexed VOSViewer

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Abstract

This study aims to analyses the scope of research related to magnetic graphene oxide conjugated with polyamidoamine dendrimer (MGO-PAMAM) material as an adsorbent for heavy metals using bibliometric evaluation and data mapping with VOSViewer software. MGO-PAMAM material research data was collected from the Google Scholar database with criteria in the form of MGO journals and keywords, dendrimers, polyamidoamine, PAMAM, synthesis, and adsorption in 2018–2023. Based on the search results, 175 relevant journal articles were found. The number of articles has fluctuated from 2018 to 2023. This is due to the COVID-19 pandemic that is happening globally. This study can provide information on the pattern of distribution of journal articles and the quality of research developments related to polyamidoamine dendrimer material as an adsorbent for heavy metals in the last 5 years. This bibliometric analysis is expected to help researchers recognize research trends related to polyamidoamine dendrimer materials as heavy metal adsorbents globally and recommend future research prospects.

Keywords: Bibliometrics, Dendrimer, Heavy metal adsorbent, PAMAM, Polyamidoamine, VOSViewer.

1. Introduction

Population growth, urbanization, and industrialization promote deterioration of water quality (Sunardi *et al.*, 2021, Aisyah *et al.*, 2021), one of them is heavy metal pollution or contamination (Sari & Soeprobowati, 2021, Muthmainnah & Rais, 2021).Heavy metal ion contamination has become a concern because of its non-biodegradability and severe toxicity to human life even at minimal doses (Xiong *et al.*, 2015). One of the most dangerous heavy metals is mercury (Hg (II)). Mercury is widely used in the mining, battery manufacturing, pharmaceutical, metallurgical and electronics sectors (Cui *et al.*, 2015a). At the same time, a lot of waste water containing Hg(II) is discharged into the environment, which is very harmful to human neurodevelopment, reproduction, brain, kidney and digestive system (Wang *et al.*, 2016). Several methods, including solvent extraction, reduction, coagulation, reverse osmosis, chemical precipitation, membrane filtration, ion exchange, and adsorption, have been used to remove Hg(II) from industrial wastewater (Gunatilake, 2015; Parmar & Singh Thakur, 2013; Peng & Guo, 2020; Zunita, 2021). Among them, adsorption has been developed as a promising method with its low cost, simplicity of design, high effectiveness, and good selectivity. Adsorbents play a major role in the adsorption process (Awual, 2016; Crini, 2006; Liu *et al.*, 2018).

One material that has good ability as an adsorbent is a graphene-based material such as graphene oxide (GO) (Velusamy *et al.*, 2021). This material has a significant specific surface area and rich in functional groups that include oxygen, such as hydroxyl, carboxyl, and epoxy groups, which create various active sites for modification as well as adsorption for target pollutants (Wang *et al.*, 2019). However, GO materials require further modification because they are easily dispersible in water, making it difficult to separate GO from aqueous solutions, which may result in secondary pollution (Duan *et al.*, 2020). Therefore, for simple separations and high adsorption efficiency, the surface properties of GO need to be improved by further functionalization (Cui *et al.*, 2015b). Magnetic nanomaterials, such as nano-Fe_3O_4, have attracted interest as modified materials in GO because of their large specific surface area, good chemical stability, good biological compatibility, and ease of separation under external magnetic fields (Wang *et al.*, 2010).

Materials in the form of branched, monodisperse 3D polymeric complexes known as dendrimers exhibit properties such as a large surface area relative to volume, large interior cavities, and the capacity to envelop visiting molecules (Xiao *et al.*, 2016). The number of branch interactions in this material is used to calculate dendrimer generation (Defever *et al.*, 2015). Due to their high density of surface active groups, outstanding structural uniformity, and adaptable size, polyamidoamine dendrimers (PAMAMs) have received significant interest in metal ion adsorption. Using the "grafting" technique, Zhang *et al.* (2014) made graphene oxide/polyamidoamine dendrimers (GO/PAMAM) and examined the adsorption behaviour for Pb(II), Cd(II), Cu(II), and Mn(II). It was shown that these materials can adsorb Hg (II). However, at each stage of the grafting reaction, the propagation process and the adsorption process are difficult processes (Zhang *et al.*, 2014).

Ma *et al.* (2017) have made various generations of PAMAM dendrimers conjugated with magnetic graphene oxide (MGO-PAMAM) through a chemical grafting approach with gradual growth and magnetic separation technology. They introduced magnetic Fe_3O_4 nanoparticles into GO, which caused the chemical to react with the PAMAM dendrimer. Meanwhile, product collection is made easier and more convenient by magnetic separation. The effect of MGO-PAMAM as an adsorbent for Hg (II) in aqueous solutions has been investigated (Ma *et al.*, 2017).

Based on these findings, there have been many studies on magnetic graphite oxide conjugated polyamidoamine dendrimer material as a heavy metal adsorbent. However, there are no studies that discuss bibliometric analysis and the mapping process using VOSViewer on this material. Therefore, this analysis is important to determine the quantity and novelty of the MGO-PAMAM topic as an adsorbent for Hg(II) in aqueous solution.

The purpose of this study is to analyze the scope of research related to magnetic graphite oxide conjugated polyamidoamine dendrimer material as a heavy metal adsorbent using bibliometric evaluation and data mapping with Google Scholar indexed VOSViewer software. A total of 175 journal articles over the last five years (2018-2023) have been found using the keywords: MGO, dendrimer, polyamidoamine, PAMAM, synthesis and adsorption. It is considered that bibliometric analysis will be useful for producing data sets that are used to improve the quality of future research (Nandiyanto *et al.*, 2020). The bibliometric analysis in this study uses the distribution of publication types and the scope of the topics studied.

2. Method

The bibliometric analysis was carried out in several stages:

i. *Data Collection.* The data collection was carried out using Harzing Publish or Perish 8 software. Data was collected on 25th April 2023, by searching journal articles using the keywords MGO, dendrimer, polyamidoamine, PAMAM, synthesis, and adsorption. Research data was taken for the last 5 years (2018-2023) using the Google Scholar database. The results obtained were 175 journal articles which were then processed using Microsoft Excel software. Google Scholar was chosen as the database for bibliometric analysis because Google Scholar is a scientific article database that is free and easy to access.

ii. *Data Screening.* The data that has been collected is selected based on the relevance of the topic, the title of the article, and the year of publication. The data that has been screened is then processed using Microsoft Excel and VOSViewer software.

iii. *Data analysis and visualization.* The data that has been screened and processed is then sorted by year and ranking using Microsoft Excel. Clusters, network visualization, and density mapping are analyzed using VOSViewer. Information regarding the process of analysis and data visualization has been explained in previous studies (Al Husaeni & Nandiyanto, 2021).

3. Results and Discussion

The results of the bibliometric analysis related to the development of research on polyamidoamine dendrimer materials as heavy metal adsorbents will be broken down into several sections, as follows:

3.1. Research Development on the Topic MGO-PAMAM Dendrimer Material as a Heavy-Metal Adsorbent

The results of material research developments on polyamidoamine dendrimer materials as heavy metal adsorbents over the last 5 years (2018–2023) are processed into the graph shown in Figure 1. Based on **Figure 1**, it is shown that the total number of published articles has fluctuated in the last 5 years. In 2018, there were 22 journal articles. Then, the number of journal articles decreased to 18 in 2019. This decrease in 2019 could be caused by the COVID-19 pandemic that is happening globally. The COVID-19 pandemic has affected laboratory access, the distribution of raw materials for synthesis, and the application of strict regulations regarding physical distancing (Durant *et al.*, 2020). However, from 2020 to 2021, the highest increase in journal articles was between 37 and 43. And it decreased again in 2022 and 2023.Based on 175 journal articles that have been obtained from the Google Scholar database, there are 20 articles with the highest Google Scholar Rank (GSRank) shown in **Table 1**. Based on **Table 1**, three journal articles with the highest GSRank were published in the Journal of the Taiwan Institute of Chemical Engineers, Journal of materials research and technology, and Journal of Food Measurement and Characterization.

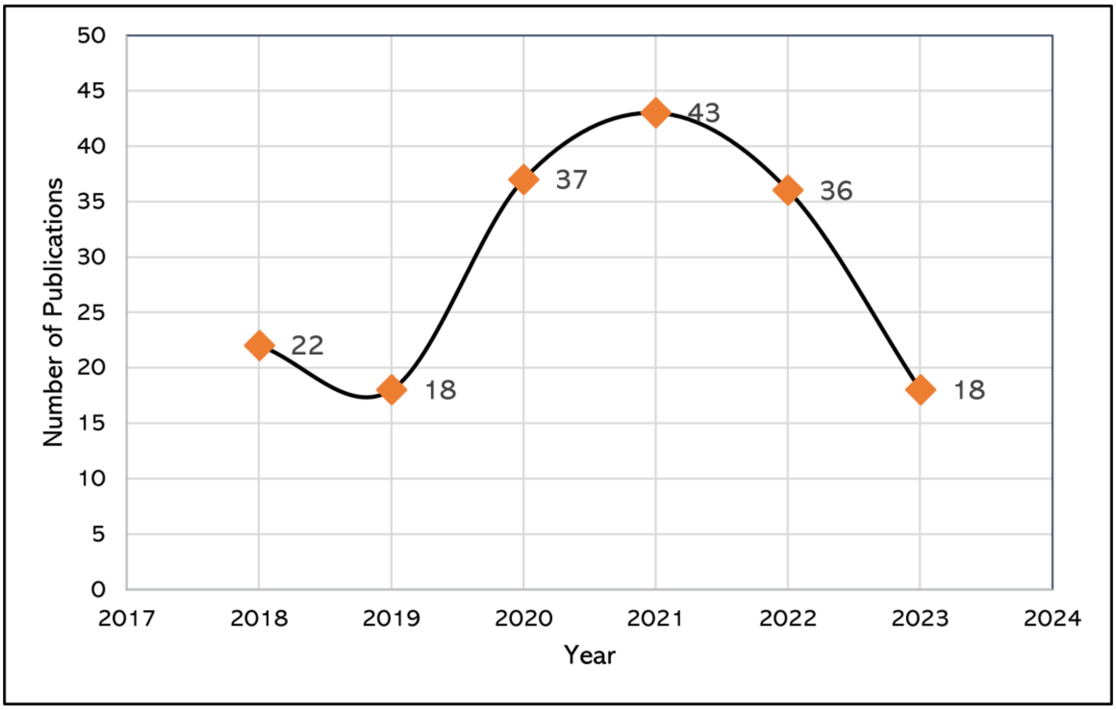

Figure 1. Level of research development related to polyamidoamine dendrimer material as heavy metal adsorbent.

Table 1. List of articles with the highest GSRank

GS-Rank	Year	Author (Reference)	Title	Journal	Cites
1	2018	F. Peer, N Bahramifar, H Younesi (Einollahi Peer et al., 2018)	Removal of Cd (II), Pb (II) and Cu (II) ions from aqueous solution by polyamidoamine dendrimer grafted magnetic graphene oxide nanosheets	Journal of the Taiwan Institute of Chemical Engineers	94
2	2020	Saima Noreen, Ushna Khalid, Sobhy M. Ibrahim, Tariq Javed, Ambreen Ghani, Saima Naz, Munawar Iqbal (Noreen et al., 2020)	ZnO, MgO and FeO adsorption efficiencies for direct sky blue dye: equilibrium, kinetics and thermodynamics studies	Journal of materials research and technology	72
3	2020	Z Lotfi, HZ Mousavi, SM Sajjadi (Lotfi et al., 2020)	Covalently bonded dithiocarbonate-terminated hyperbranched polyamidoamine polymer on magnetic graphene oxide nanosheets as an efficient sorbent for preconcentration and separation of trace levels of some heavy metal ions in food samples	Journal of Food Measurement and Characterization	8
4	2018	A Almasian, F Najafi, L Maleknia, M Giahi (Almasian et al., 2018)	Mesoporous MgO/PPG hybrid nanofibers: synthesis, optimization, characterization and heavy metal removal property	New Journal of Chemistry	32
5	2021	Rasmeet Singh, Mandeep Singh, Nisha Kumari, Janak Sthitapragyan Maharana, Pragyansu Maharana (Singh et al., 2021)	A comprehensive review of polymeric wastewater purification membranes	Journal of Composites Science	15
6	2020	Yongyong Yuan, Yalin Wu, Hongyuan Wang, Yayan Tong, Xueying Sheng, Yi Sun, Xianqi Zhou, Qingxiang Zhou (Yuan et al., 2020)	Simultaneous enrichment and determination of cadmium and mercury ions using magnetic PAMAM dendrimers as the adsorbents for magnetic solid phase extraction …	Journal of hazardous material	79
7	2021	Herlys Viltres, Yeisy C. López, Carolina Leyva, Nishesh Kumar Gupta, Adrián Ges Naranjo, Próspero Acevedo–Peña, Alejandro Sanchez-Diaz, Jiyeol Bae, Kwang Soo Kim (Viltres et al., 2021)	Polyamidoamine dendrimer-based materials for environmental applications: A review	Journal of Molecular Liquids	23
8	2018	Jianjian Zhao, Yuzhong Niu, Bing Ren, HouChen, Shengxiao Zhang, Juan Jin, Yao Zhang (Zhao et al., 2018)	Synthesis of Schiff base functionalized superparamagnetic Fe3O4 composites for effective removal of Pb (II) and Cd (II) from aqueous solution	Chemical Engineering Journal	197
9	2022	F Einollahipeer, N Okati (Einollahipeer & Okati, 2022)	Removal of Pb (II) from Aqueous Solution Using Response Surface Methodology with Aminated Magnetic Graphene Oxide Synthesized from Typha Latifolia	Journal of Water and Wastewater; Ab va Fazilab (in persian)	0
10	2018	Shengfan Wang, Xin Li, YunguoLiu, Chang Zhang, Xiaofei Tan, Guangming Zeng, Biao Song, Luhua Jiang (S. Wang et al., 2018)	Nitrogen-containing amino compounds functionalized graphene oxide: synthesis, characterization, and application for the removal of pollutants from wastewater: a review	Journal of Hazardous Materials	133
11	2023	Ali Dehghani, Amir Hossein Mostafatabar, Ghasem Bahlakeh, Bahram Ramezanzadeh, (Dehghani et al., 2023)	Poppy-leaf extract-derived biomolecules adsorption on the rGO-nanoplatforms and application as smart self-healing material for epoxy coating	Journal of Molecular Liquids	0
12	2021	E Ehsani, F Shojaie (Ehsani & Shojaie, 2021)	DFT computational investigation of the reaction behavior of polyamidoamine dendrimer as nanocarrier for delivery of melphalan anticancer drug	Journal of Molecular Liquids	8
13	2022	Z Iqbal, MS Tanweer, M Alam (Iqbal et al., 2022)	Recent advances in adsorptive removal of wastewater pollutants by chemically modified metal oxides: A review	Journal of Water Process Engineering	21
14	2020	Susan Bagheri, Ali Esrafili, Majid Kermani,	Performance evaluation of a novel rGO-Fe0/Fe3O4-PEI nanocomposite for lead and cadmium removal from aqueous solutions	Journal of Molecular Liquids	21

GS-Rank	Year	Author (Reference)	Title	Journal	Cites
		Jamal Mehralipour, Mitra Gholami, (Bagheri et al., 2020)			
15	2018	H Hosseinzadeh, S Ramin (Hosseinzadeh & Ramin, 2018)	Effective removal of copper from aqueous solutions by modified magnetic chitosan/graphene oxide nanocomposites	International Journal of Biological Macromolecules	126
16	2022	Tiago Fernandes, Natércia C.T. Martins, Sara Fateixa, Helena I.S. Nogueira, Ana L. Daniel-da-Silva, Tito Trindade (Fernandes et al., 2022)	Dendrimer stabilized nanoalloys for inkjet printing of surface-enhanced Raman scattering substrates	Journal of Colloid and Interface Science	9
17	2021	F Hajizadeh, B Maleki, FM Zonoz, A Amiri (Hajizadeh et al., 2021)	Application of structurally enhanced magnetite cored polyamidoamine dendrimer for Knoevenagel condensation	Journal of the Iranian Chemical Society	22
18	2020	MJ Ndolomingo, N Bingwa, R Meijboom (Ndolomingo et al., 2020)	Review of supported metal nanoparticles: synthesis methodologies, advantages, and application as catalysts	Journal of Materials Science	191
19	2021	F Jamshaid, RU Khan, A Islam (Jamshaid et al., 2021)	Performance tuning of glass fibre/epoxy composites through interfacial modification upon integrating with dendrimer functionalized graphene oxide	Journal of Applied Polymer Science	6
20	2018	Melvin S. Samuel, Sk Sheriff Shah, Jayanta Bhattacharya, Kalidass Subramaniam, N. D. Pradeep Singh (Samuel et al., 2018)	Adsorption of Pb (II) from aqueous solution using a magnetic chitosan/graphene oxide composite and its toxicity studies	International Journal of Biological Macromolecules	151

3.2. VOSViewer Visualization on MGO-PAMAM Dendrimer Material as a Heavy-Metal Adsorbent Topic

Based on the mapping analysis, studies relevant to the topic of polyamidoamine dendrimers as heavy metal adsorbents can be divided into four clusters with the following details.

i. Cluster 1 is marked in red which contains 8 items, namely adsorbent, adsorption, adsorption capacity, carbon, composite, heavy metal, removal, and wastewater.
ii. Cluster 2 is marked in green which contains 5 items, namely absorption, magnesium oxide, nanomaterials, nanoparticles, and recent advances.
iii. Cluster 3 is marked in blue which contains 5 items, namely carbon nanotubes, dendrimers, PAMAM, polyamidoamine, polyamidoamine dendrimers.
iv. Cluster 4, marked with a key color which contains 5 items, namely application, graphene oxide, MGO, structure and synthesis.

3.3. Network Visualization on the MGO-PAMAM Dendrimer Material as a Heavy-Metal Adsorbent Topic

The relationships between items in the four clusters are illustrated through the network visualization shown in **Figure 2.** The relationships in the network visualization are depicted by connected lines between one item and another. Meanwhile, the summary related to the total strength and occurrences based on the polyamidoamine dendrimer as a heavy metal adsorbent for each cluster is shown in **Table 2**.

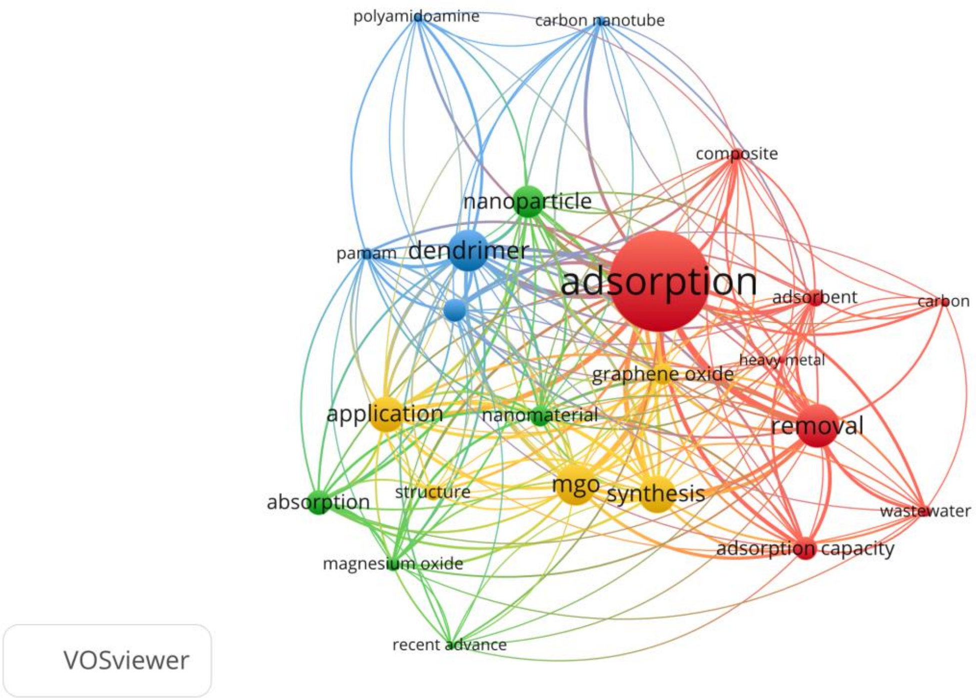

Figure 2. Network Visualization on the topic of polyamidoamine dendrimers as heavy metal adsorbents

Table 2. Total strength and occurrence based on polyamidoamine dendrimer items as heavy metal adsorbents.

Cluster	Total Link Strength	Occurrence
1	487	191
2	195	82
3	229	80
4	331	128

3.4. Density Visualization on MGO-PAMAM Dendrimer Material as a Heavy-Metal Adsorbent Topic

Density visualization related to the development of the topic of polyamidoamine dendrimers as heavy metal adsorbents is shown in **Figure 3**. The intense yellow color of an item indicates the closeness between these items in the published article and the green color indicates the distance between these items. Adsorption, dendrimer, and removal items in clusters 1 and 3 are the items that have the closest relationship to the topic.

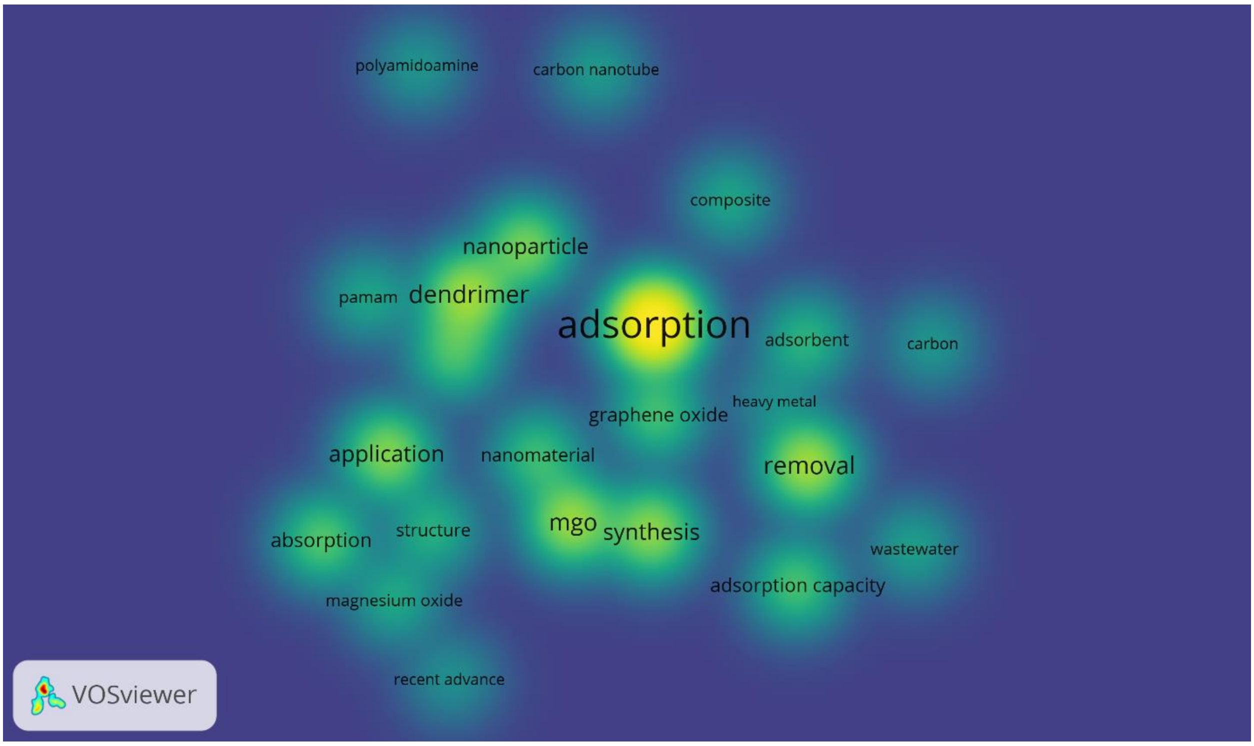

Figure 3. Density mapping on the topic of polyamidoamine dendrimer material as a heavy metal adsorbent

4. Conclusion

Based on the results of bibliometric analysis and mapping using the VOSViewer software regarding material topics and applications in the last 5 years (2018-2023), 175 relevant journal articles were obtained. The highest number of published articles was 43 in 2021. The decrease in the number of articles in 2019 was due to the COVID-19 pandemic. The items that are very closely related to the topic of polyamidoamine dendrimers as heavy metal adsorbents are adsorption, dendrimers, and removal in clusters 1 and 3. It is expected that this bibliometric analysis can be used as material consideration for material research on MGO-PAMAM Dendrimer Material as heavy metal adsorbents in the future.

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