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A Scientometric analysis and bibliometric review of IOEX as a treatment to remove pollutants

Zuhal Abdul Hadi Hamza[1], Ahmed Makki AL-Sulaiman* [2], and Hussein I. Abdel-Shafy [3]

[1]Department of Civil Engineering, College of Engineering, University of Basrah, Basrah, Iraq
[2] Department of Civil Engineering, College of Engineering, University of Al-Qadisiyah, Qadisiyah, Iraq
[3]Department of Water Research and Polluted Control Department, National Research Centre, Cairo

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ABSTRACT

Pollutants in water bodies pose a serious threat to both the aquatic ecosystem and human health. Ion exchange is used as a chemical process to remove unwanted dissolved ions from water and wastewater. It is widely accepted in developing countries. This analysis provides a bibliometric examination to consider the status and trends of advanced ion exchange worldwide. This study was conducted using the Dimensions website to identify and collect the most important research papers. The retrieved manuscripts were organized through Microsoft Excel and then VOS viewer was used to analyze the data by reviewing previous studies related to ion exchange as a contaminant removal treatment. To create maps and find out which countries, universities, and journals have published research articles on topics related to ion exchange, as well as authors who have studied the topic of ion exchange and their research, cooperation. To benefit from these studies and learn the importance of ion exchange as a treatment for removing pollutants. The electro neutrality of the ion exchange (IOEX) process must always be maintained because it is a stoichiometric process. Search results for IOEX were exported from Dimensions to a CSV file, both coexistence, cooperation with affiliate countries and consortia were implemented on the full search results. Ion exchange treatment has proven effective in treating industrial wastewater and domestic wastewater. Professionals and practitioners in the field are provided with important information through this examination of ion exchange research. The analysts learned about leading academic and research institutions, the state of the exploration field, and the most controversial issues surrounding advanced ion exchange. In addition, this lesson will provide the opportunity to learn basic facts that will develop the extent of ion exchange knowledge. The bibliometric survey method can also be used to visualize the trend of research and study in various fields.

1. Introduction

Ion exchange (IOEX) occurs frequently in nature. It is a chemical reaction that occurs between two stages of given systems that are either solid-gas and/or liquid-solid. The electro neutrality of the IOEX process must always be maintained because it is a stoichiometric process. As a result, each ion that is removed from the framework should be replaced with an identically charged ion from the solution. This process can be utilized for a variety of purposes, including purity, segregation, and depollution of ion-containing solutions. Common materials used for ion exchange include

* *Corresponding author.*
E-mail address: ahmed.jabbar@qu.edu.iq(Ahmed Al-Sulaiman)

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Nomenclature & Abbreviation:

Al_2O_3	Activated alumina		
C	The concentration (mg/L)		
Ca^{2+}	Calcium ions	Mg^2	Magnesium ions
Cd	cadmium	n	Experimental value
Cl	Chlorine	Na^+	Sodium ions
CSV	Comma Separated Values	$NaCl$	Sodium chloride
Cu	copper	$NaHCO_3$	Sodium Bicarbonate
IOEX	Ion exchange	NH_3	Ammonia
HCO_3	Bicarbonate	Pb	lead
k	Experimental value	q	Substance absorbed (g/cm^2)
K^+	Potassium ions	R	Resin
KNDV	Knowledge domain visualization	SiO_2	Silica gel
$M^{n+}_{1/n}(AlO_2)^-(SiO_2)_x \cdot yH_2O$	Zeolite	*VOS*	Visualizing scientific landscape
		Zn	Zinc

resins, soil humus, zeolites, and clay. These materials are capable of effectively removing impurities and unwanted ions from certain solutions, making them valuable tools in several industrial activities and in scientific applications [1]. Over a period of a century ago, this phenomenon was identified as ion exchange (IOEX). In the 1850s, two agricultural chemists, namely Thompson and Way, found that some soils were able to absorb more NH_3 than others [2,3]. Later, several researchers conducted extensive research on IOEX methods using different ion exchangers [4-7].

The discharge of wastewater into waterways without proper handling is a major threat to aquatic ecosystems and the environment [8, 9-11]. In this respect, it is important to adopt the concept of "converting waste to product" by extracting as many resources as possible. It is important to achieve such a goal using environmentally friendly, cost-effective, and eco-friendly technologies. Technologies such as adsorption and ion-exchange processes could be employed. As a result, resources are recovered and safe reused by treating wastewater with adsorption and/or ion exchange processes [12]. These processes are more effective and efficient than traditional treatment processes. The main purpose is simply to remove contaminants without extracting and/or recovering any valuable resources. Furthermore it, The process of converting waste into valuable products and reducing environmental risks by using adsorption and IOEX processes in wastewater treatment promotes sustainable development. Ultimately, these technologies are important in achieving a circular economy and promoting sustainable development practices. It is therefore necessary to conduct a comprehensive review of current studies and a comprehensive understanding of current developments in ion exchange, to identify any gaps in knowledge. A quantitative and statistical method for studying the links between information and literature presented in books using bibliometric analysis. This method allows the identification of major research trends in a particular field of study and research to also facilitate future predictions. Scientometrics is a subfield of bibliometric research that uses the use of knowledge domain visualization (KNDV) to perform statistical analysis of scientific literature. KNDV uses various technologies, such as VOS viewer and Bib Excel, including co-authorship, co-citation and co-citation networks, to provide a comprehensive knowledge map [13,14].

By utilizing visualization analysis, KNDV adopts a comprehensive approach to reveal the interconnections and structural links of the given information through the use of easily understandable diagrams [16]. As previously mentioned, such studies employ bibliometric analysis and several information areas as analytical tools by utilizing the VOS viewer software to investigate the state of the art, frontiers, and upward trend of ion exchange, as well as similar studies. In contrast to traditional review papers, such review methodologies are less susceptible to potential biases and inaccuracies. To better classify the current state of the art and developments in ion exchange, earlier studies focusing on this topic for almost a decade between years 2014 to 2023 were assessed and deliberated upon. The purpose is to direct researchers, academics, and practitioners in this field to the most and latest valuable research of their concern.

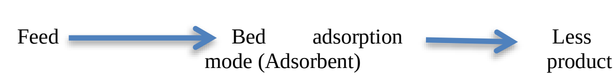
2.Adsorption and ion exchange

Adsorption is the process by which molecules from a solution gather on the porous solid's internal or external surface. Adsorption can happen through chemisorption or physisorption. Physisorption is a weak van der Waals force interaction between an adsorbed molecule and the solid surface. On the other hand, chemisorption is a strong ionic and / or covalent bonding interaction [16-22]. The IOEX and the adsorption process share some fundamental traits. The mass transfer of molecules from an aqueous phase to a solid phase is the most frequent step in both processes. Due to the fact that IOEX and adsorption are both diffusion processes, they are combined into one process and referred to as the sorption process [16, 23]. For the adsorption of liquid solutions, the amount of substance adsorbed in liquid solutions is measured in grams per square centimetre of surface area can be calculated as, Eq. 1:

$$q = K\,C^n \tag{1}$$

where K and n are experimentally determined constant values (n = 0.2-0.5) and C represents the concentration.

The mechanisms of adsorption can be made with some steps.



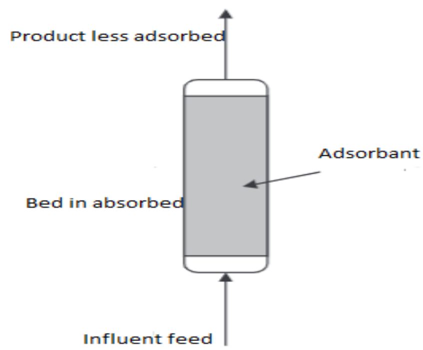


Figure 1 Schematic of an adsorption process

The commercial porous adsorbents are displayed in Table 1.

Table 1 Commercial porous adsorbents [24]

Adsorbent	Nature	Surface area(m^2/g)
Activated alumina (Al_2O_3)	Great affinity for water	320
Silica gel (SiO_2)	High affinity for water and other polar compounds	
Small pore		750-850
Large pore		300-350
Activated carbon	Hydrophobic (affinity for nonpolar and weakly polar compounds)	
Small pore		400-1200
Large pore		200-600
Molecular-sieve carbon	Hydrophobic	400
Molecular-sieve zeolites	Polar-hydrophilic, crystalline, highly selective $M^{n+}_{1/n}(AlO_2)^-(SiO_2)_x\cdot yH_2O$	600-700

3. Ion exchange applications

The IOEX method is a sophisticated and successful approach. The benefit of the IOEX method is that it takes up little space and is straightforward to be use [25-28]. It is a technological advancement that is comparatively inexpensive and applicable over wider temperature ranges [27]. It can also withstand the shock loading accordingly [5]. That is why different major IEX applications are used in water and wastewater treatment systems.

3.1 Softening of water

In water-using appliances like pipes, boilers, dishwashers, and solar heating systems, hard water causes scale deposits. Scale buildup harms appliances and lowers efficiency. Water becomes hard due to the presence of both calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions. Such hardness can be eliminated by exchanging both calcium and magnesium ions with other cations, such as Sodium (Na^+) and Potassium (K^+) ions. For instance, for this reason, Na-zeolite softening is frequently used in industrial water treatment applications and steam boilers [29]. The softening process is illustrated in figure 2.

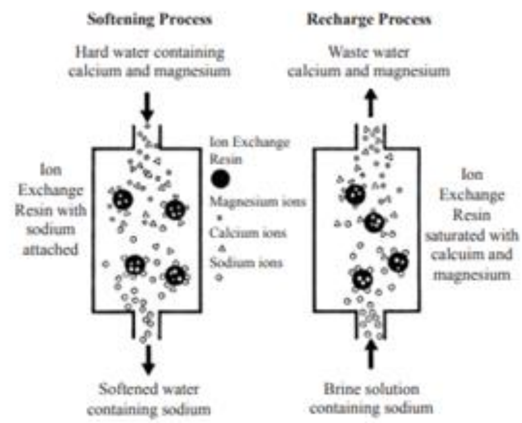


Figure 2. The water softening and recharge process [29]

3.2 De-alkalization

De-alkalization, which eliminates temporary hardness in water typically brought on by bicarbonates (HCO_3^-), is a process. Weak H^+ cation exchange resin is used to treat the raw water. The Na^{+1}, Ca^{2+} and Mg^{2+} ions can be removed by such a resin process. The bicarbonate ion is present as a carbon dioxide and water solution in the outlet effluent. Water is passed through a degasser column to remove the carbon dioxide in the solution [30]. Additionally, it reduces water salinity. To gain a clear understanding of how ion exchange "R" represents the resin, refer to the equation below.

$$2NaHCO_3+2R\text{-}Cl \rightarrow 2NaCl+2R\text{-}HCO_3 \qquad (2)$$

3.3 Demineralization

Demineralization is the process of removing dissolved minerals and salts from water. It also goes by the name of deionization. Demineralized water is used in a wide range of processes, including wastewater treatment, electricity production, petrochemical production, steel production, food and beverage production, electronics production, pharmaceutical production, metal finishing, and paper production [31]. Figure 3 shows the schematic diagram of Demineralization.

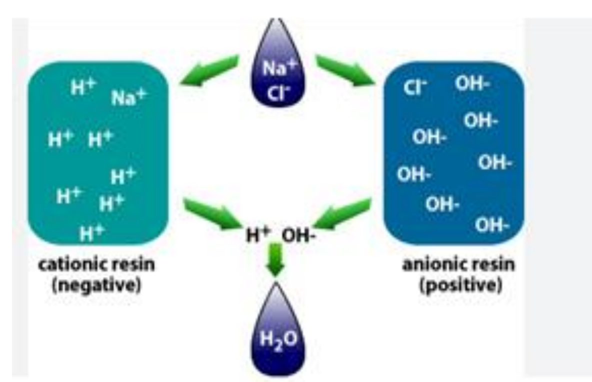


Figure 3. Diagrammatic representation of water demineralization

3.4 Heavy metal removal

Before releasing heavy metals into the environment, wastewater treatment systems should be removed. They are highly toxic and hazardous. One of the most frequently employed treatment methods for removing heavy metals is IOEX [32-34]. Metal removal from wastewater has been accomplished using both natural and artificial materials, including chemical coagulation and carbon adsorption, as well as other effective processes [42,43,44]. Zeolite is a naturally occurring material that is highly selective for heavy metals like lead (Pb), zinc (Zn), copper (Cu), and cadmium (Cd). Thus, heavy metals can be eliminated from the waste system using zeolite. Zeolite is selective for certain ions, though, and the presence of other ions makes it harder to find adsorption sites. Similar to natural materials, synthetic materials that are more selective for the desired metals can be used. Removing and recovering valuable metals can improve IOEX's economic viability [32]. As seen in Fig. 4, heavy metal ions can generally be adsorbed onto the surface of the adsorbent.

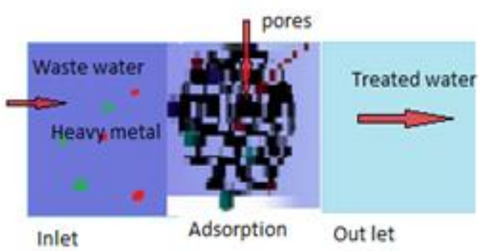


Figure 4. The process of adsorbing heavy metal ions

4. Collection of data and methodology

Researchers can look up and evaluate valuable publications, clinical trials, policy documents, grants, and patents using Dimensions, an integrated database. A fresh scholarly search database that concentrates on the wider range of cases of use that academic now encounter has been compared to this program.

Unlike other databases, it has a free version with links to all the other various entities and a searchable publication index [36]. The DIMENSIONS core database was chosen as the data source for this research. The DIMENSIONS database consulted studies on the use of ion exchange in water and wastewater treatment. Search results for the term "ion exchange" were exported from DIMENSIONS to a CSV file, and co-occurrence, collaboration with nations, and affiliations were all carried out on the full search results. Microsoft Excel was used to properly organize the recovered manuscripts, and VOS viewer was used to create the maps. The various thematic areas, indexed journals, key studies, nations, key authors, and collaborations could all be located. (Figure 5) shows how the 2867 bibliographic records will be moved between 2020 and 2023. It was noted that the total number of the records bibliographic before 2020 was almost low until 2014. All are almost very close to zero, while the total number of records increased significantly after this year. The total number of records has increased significantly over time.

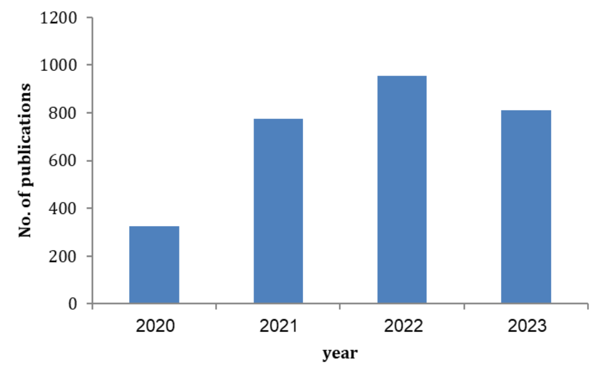


Figure 5 Annual scientific No. of publication for period (2020~2023).

5. Analytical Method

In this day and age of quick advancement in technology, the visual display of bibliometric data analyses using mapping tools is essential [37, 39]. To obtain the outcomes of the description and various data on the advancement of science and the effectiveness of the research that has been conducted, mapping tools are extensively used. VOS Viewer is an example of a mapping tool that can be utilized for mapping bibliometric data analysis [39]. In this study, bibliometric visual maps were made using the VOS viewer. Computer software called VOS viewer can be used for the following;

Maps based on network data may be produced using the VOS viewer. VOS clustering and mapping techniques are used to create maps. To view and explore maps, use the VOS viewer and Map Viewer 1. It may display a map in a variety of ways, each emphasizing a different feature of the map. Its zooming, scrolling, and searching capabilities enable a more thorough analysis of a map.

When working with maps that contain at least a relatively significant number of elements (for example, at least 100 or 200 items), the viewing capabilities of the VOS viewer are especially useful. The analysis of bibliometric networks is the main objective of the VOS viewer. By using a citation, co-citation, or bibliographic coupling network, the application can be used to create maps of publications, authors, or journals, as well as maps of keywords based on a co-occurrence network. However, the VOS viewer is not restricted to bibliometric networks. In reality, any type of network can be used with the VOS viewer to create maps [39]. The results of the overall studied data are presented in (Figure 6). In five clusters, 68 items, 1005 links and 2301 total link strength are identified. It is noteworthy that the studies that mentioned ion exchange were found to have garnered a significant number of citations, indicating the importance of this topic in the field.

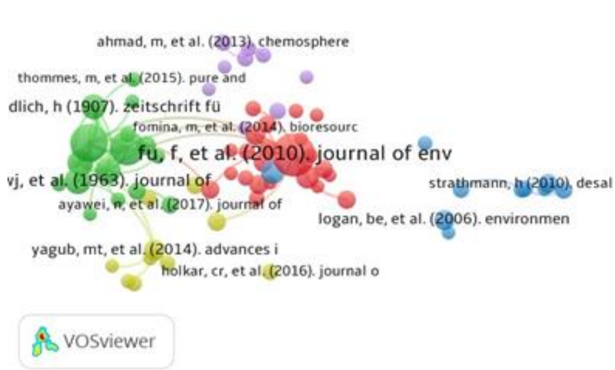


Figure 6 The relation between co-citation and cited reference

6. Organization analysis of citations

A thorough investigation was conducted in this particular section, where extensive research was conducted on the most frequently referenced organizations, and the minimum number of documents for an organization was established to be five. Out of a total of 2969, 285 organizations were found to meet the criteria, with the highest average citation being attributed to King Saud University, with 53 documents, and the University of Johannesburg, with 30 documents. Furthermore, Alexandria University, which belongs to cluster 10 out of 18 clusters, had the largest number of documents, with 28 documents in 2021, as shown in (Figure 7)

Figure 7 Citation of organization

6.1 Co-citation cited sources

The minimum number required for consideration was set at 20, and only 744 papers out of 6845 were found to meet this threshold. As depicted in (Figure 8), a network comprising 5 main clusters, 178464 links, and 5119022 total link strengths was generated. It is noteworthy that each group identified in the network represents a leading journal that has published research articles on topics pertaining to ion exchange. This analysis offers valuable insights into the scholarly landscape of ion exchange research, highlighting the most prominent journals in the field.

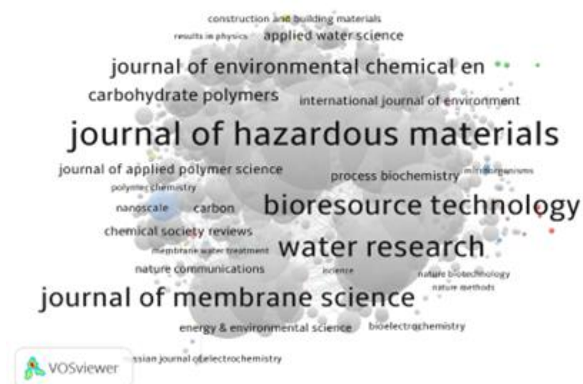


Figure 8 Co-citation Cited sources

6.2 Co-citation cited authors analysis

In the present assessment, the reference was cited with at least as many as established at twenty, resulting in 4144 out of the 290492 meeting the threshold. A visual representation of the findings in (Figure 9) indicates that Zeng Guangming is the most commonly cited author. This information highlights the significant influence of this author's work in the field.

Figure 9 Co-citation cited authors

6.3 Authors co-authors

The research study depicted in (Figure 10) utilized a threshold of 2 papers as the minimum number of publications required for an author to be considered in the calculation of the overall strength link of the author's connections to other authors. The density visualization presented in this figure revealed that out of 12570 writers, only 1369 met this threshold. In (Figure 7), the meeting point symbolizes the authors, with the size of the nodes indicating the number of publications attributed to each author. The interconnectedness among the nodes represents the relationships among authors that suggest co-authorship. The densest collection of linked items consists of 22 elements belonging to cluster number 1. Collectively, the two figures contain 148 meeting points, 14 clusters, 477 links, and a full link strength of 741.Author output in relation to publications of IOEX around the world was analyzed, approximately 12,570 posts on IOEX worldwide were found. Whether they are technical research or literature review texts, the size of the circles on the map, as shown in Figure 11, corresponds to the number of articles that the author leads in that field. In addition, the primary authors are seen to vary in terms of publications and citations, including Sarkar Binoy (10 publications; 362 citations), Ngo, Huu Hao (8; 480), Sillanpaa Mika (11; 131), and Ali, Shafaqat (6; 142).

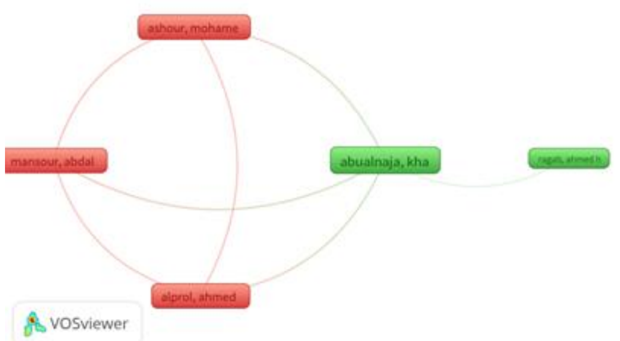


Figure 10 Co-authorship Author density Visualization

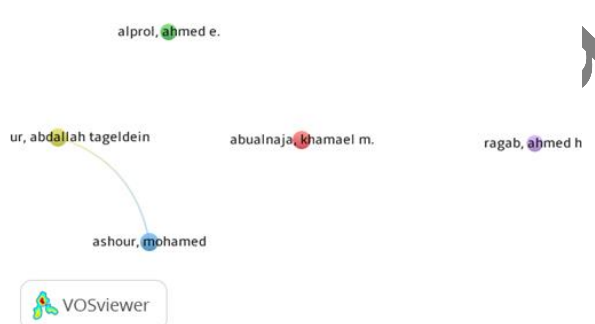


Figure 11 Co-authorship, Author–network

6.4 Co-authorship country analysis

According to reports, IOEX is typically regarded as an effective and affordable solution to wastewater issues. A diverse range of publications on the subject were found in 83 countries, which was supported by an investigation of the application of this technology globally (Figure 8). This illustrates the significance of IOXE as a field of study for the issue of water contamination. Even then, there is nonetheless a shortage in wastewater treatment since only 39% of the world's population has access to a properly run sanitation system [41,45].

Only 83 of the 950 nations fulfilled the boundary needs, which stipulated that each nation had to submit at least five documents. The largest circles in (Figure 12) show the number of publications by country, with China and the United States ranking first and second, respectively, and Saudi Arabia coming in third. These results imply that the research communities in these nations are more engaged in the relevant fields. It is important to understand that the findings of this study are constrained to a specific dataset and may not be generalizable to the total population of co-authors.

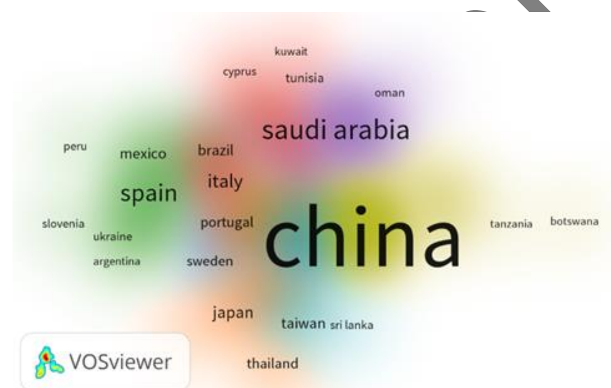


Figure 12 Publications on IOXE by countries during 2014–2023 around the world (Network of co-authors by country)

7. Conclusions

Ion exchange is the process of substituting more desirable ions for undesirable dissolved ions.

The different applications for ion exchange resins have been covered, along with a synopsis of the fundamental ideas behind the ion exchange process. In this review the advantages of ion exchange therapy are emphasized, including intrinsic treatment selectivity, excellent separation, and reusability. At the same time, there are many ways to treat water and wastewater, but some of them have disadvantages such as poor filtration, difficult and expensive maintenance, as well as high energy requirements.

Despite all this, ion exchange therapy provides an affordable, long-term solution. The review covers specific applications of ion exchange resins.

They are effective in removing copper, lead, nickel and zinc from industrial effluents due to their selectivity and ease of use. Ion exchange resins can also be used to remove some ions, such as calcium and magnesium, which are involved in the water hardening process, useful in softening or treating it. Additionally, it was determined that hardness, dissolved minerals, and salts could be eliminated by combining cation exchange and magnetic ion exchange resins. The use of ion exchange resins for pollution monitoring and detection in industrial and agricultural areas is also covered in this study. All things considered, the review's focus on ion exchange resins' many applications and advantages in environmental contexts emphasizes both their potential and realistic viability in various industries.

Using the VOS viewer software, a review of the literature on ion exchange investigations can yield the following findings: VOS viewer is particularly interested in how bibliometric maps are represented graphically. It functionality is particularly helpful for providing large bibliometric maps in an easily comprehensible manner. Finally, creating and displaying a co-citation map of over 1000 prestigious scientific journals demonstrate VOS viewers' capacity to handle large maps. It is advised that others will find VOS viewer advantageous for reviewing literature on any subject.

Authors' contribution

All authors contributed equally to the preparation of this article.

Declaration of competing interest

The authors declare no conflicts of interest.

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This study didn't receive any specific funds.

Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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