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A Bibliometric Analysis on the Application of Biopolymers in Water Purification

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1.1 Introduction

Biopolymers are macromolecules that are biologically synthesized from living organisms [1]. Biopolymers come from animals, microbes, plants, and algae. Their abundance, low cost, expandability, and chemical structure make them promising materials for water treatment applications [2].

It is known that for the sustainable progress and development of human society in the twenty-first century, freshwater is essential, and its scarcity has been a terrible threat [3]. So, biopolymers emerge as ideal candidates for water treatment, besides being widely used in the literature in wastewater treatment. Other applications in the field of water and wastewater treatment are the removal of heavy metals,environmental remediation, among many others.

Bibliometric analysis is a powerful tool to provide an outline and to summarize results of an issue, subject, or field based on the available literature (by using quantitative methods), including the trends, information about authors, and sources, among many others. Several research areas take advantage of this approach, proving that this analysis is relevant and interdisciplinary. Some recent examples of using bibliometric analysis are in the analysis of human–wildlife conflict [4], aerobic digestion technology [5], consumer awareness of plastics [6], plastic effects on marine and freshwater environments [7], open innovation and tourism relationship [8], and multicriteria decision making [9], among many others.

In the present work, a bibliometric analysis of the use of biopolymers in water purification was performed using Bibliometrix R-package. The analysis was focused on the discussion of the sources, authors, affiliations, countries, publications, and keywords, mainly showing an overview of the research area.

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1.2 Methodology

The Scopus search was performed on 6th December 2021 by using the keywords biopolymer* AND (water purification* OR water treatment*), and resulted initially in 2562 publications (from 1972 to 2022). All the *h*-index values were calculated by Bibliometrix.

The initial result was limited to articles and reviews in English from 2002 to 2021, resulting in 2017 publications: 1802 articles and 215 reviews. The first 2000 publications were exported to a .bib file and analyzed using Bibliometrix, an R-package.

1.3 Results

1.3.1 Bibliometric Analysis

The annual scientific production from 2002 and the subject area of the publications are shown in Figure 1.1.

The results show that the area is interdisciplinary, with a predominance of publications in the environmental science area. Concerning the annual scientific production, the increase in the number of publications during the period with an annual growth rate of 19.26% can be observed. These results depict the relevance of biopolymers in the water purification research field. The discussion of results will be divided into sources, authors, affiliations, countries, publications, and keywords, which will be discussed in sequence.

1.3.1.1 Sources

The five most relevant sources concerning the number of publications are (number of publications in parenthesis). Water Research (130), Bioresource Technology (127), Journal of Applied Polymer Science (64), Carbohydrate Polymers (61), and Journal of Membrane Science (54). The dynamics of the number of publications of these most relevant sources in the last 10 years are shown in Figure 1.2.

On the other hand, the most locally cited sources, i.e. the ones most cited from the reference lists of the 2000 analyzed publications, are (number of citations in parenthesis): Water Research (4987), Bioresource Technology (2669), Carbohydrate Polymers (2288), Environmental Science and Technology (2020), and Journal of Membrane Science (1912).

In Figure 1.2, the two most important journals in the research field of biopolymers in water purification point to an increase in the annual number of publications between 2013 and 2014, with a reduction and a tendency to stabilize by the year 2021. The other journals show greater stability regarding the annual number of publications within the analyzed period.

All the mentioned sources are relevant in the field of biopolymers for water purification. These journals are peer-reviewed and of high quality, providing the authors the confidence to publish their works in these journals [10].

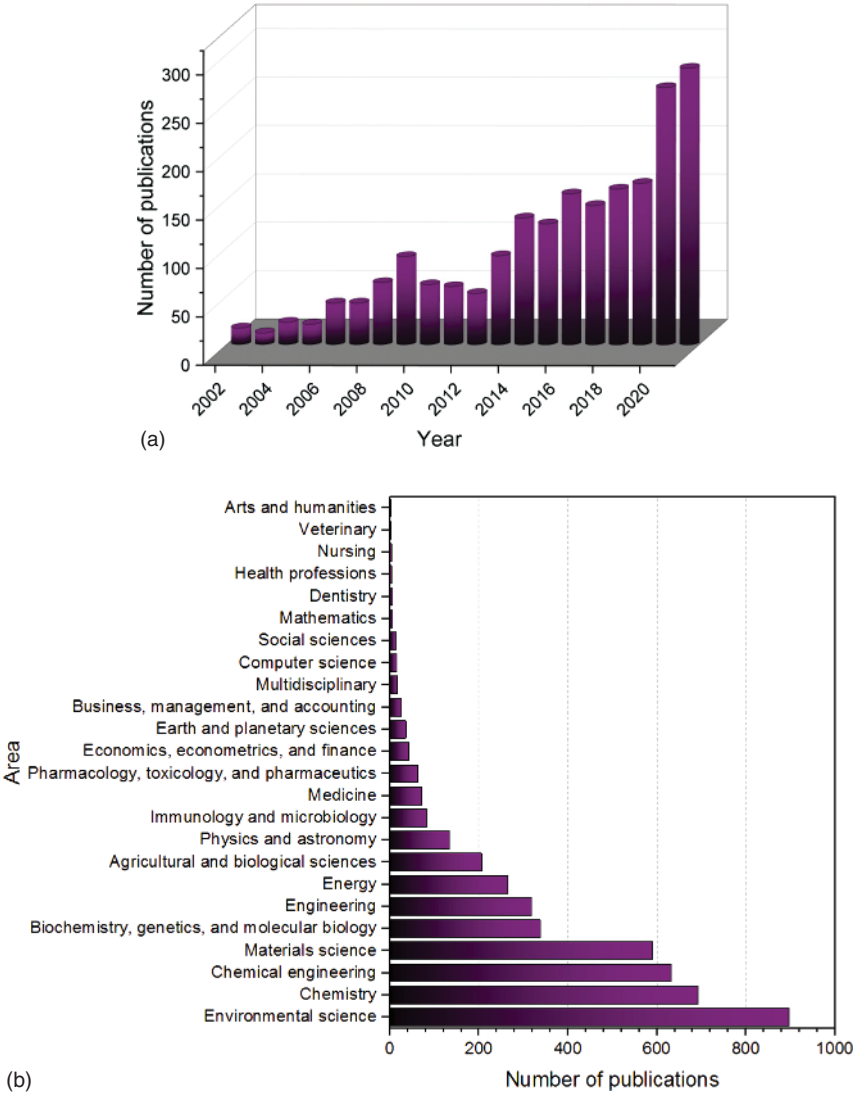


Figure 1.1 (a) Annual scientific production from 2002, and (b) subject area of the publications.

1.3.1.2 Authors, Affiliations, and Countries

The most relevant authors of the research field according to their *h*-index are presented in Table 1.1.

In the list of the most important authors, Zhang W. is the one with the highest *h*-index and number of publications. However, the author with the highest local citations is Wang J. (from the reference lists of 2000 analyzed publications). The largest number of publications of the author deals with sludge and correlated

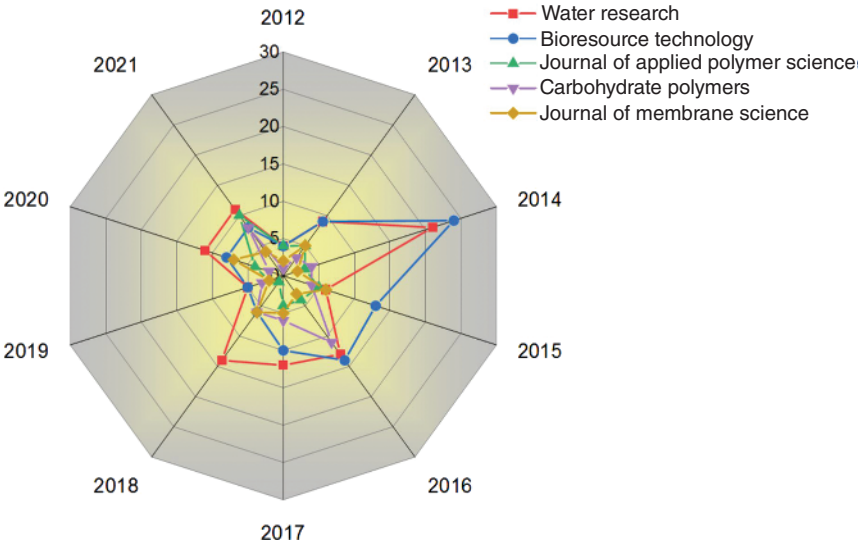


Figure 1.2 Dynamics of the number of publications of the most relevant sources in last 10 years.

Table 1.1 Most relevant authors of the research field of biopolymers for water purification, with their number of publications and local citations.

Author	*h*-Index	Number of publications	Local citations
Zhang W.	16	28	38
Jekel M.	13	16	5
Wang J.	13	20	46
Wang Z.	13	21	14
Chang I.	11	14	8
Vigneswaran S.	11	13	4
Wang Y.	11	18	6
Zhang L.	11	21	22
Zhang Y.	11	18	15
Zhang Z.	11	17	14

aspects. The second most important author based on Bibliometrix, Jekel M., studies the purification of wastewater by using membrane filtration and ultrafiltration. No consensus is shown in the literature about which of the measures is more effective for analyzing the importance of a certain author in a given research area (the number of publications/citations or the *h*-index) [11]. An inaccurate interpretation of the measure of the author's influence may occur when the number of publications

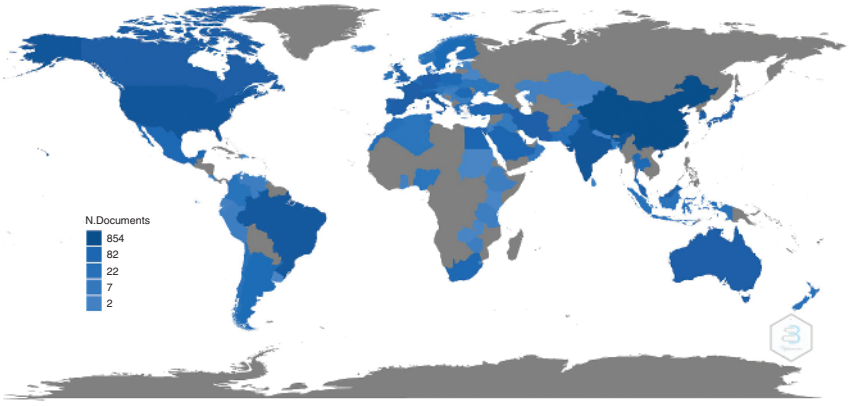


Figure 1.3 Country's scientific production.

is analyzed, since in some cases the author can be at the beginning of career, whose scientific trajectory is in growth stage [12].

The most relevant affiliations according to the number of publications are (number of publications in parenthesis). Tsinghua University (40), China University of Geosciences (31), Tongji University (31), Nanyang Technological University (27), Chinese Academy of Sciences (25), and Delft University of Technology (25). Nanyang Technological University is from Singapore, Delft University of Technology is from the Netherlands, and all the others are Chinese.

The country's scientific production is shown in Figure 1.3.

In Figure 1.3, the chart shows the scientific production which is presented on a scale of shades of blue, in which the darkest blue in the chart represents the most productive, and gray represents the countries with no publications. Through this general overview, it can be observed that the subject is studied across the globe, given its importance, showing that this issue is an international concern [11, 13]. The most productive countries are (number of publications in parenthesis). China (854), the USA (394), India (381), Brazil (283), Italy (211), South Korea (195), Canada (171), Australia (170), Spain (165), and France (162). However, when the most cited countries are presented, the scenario changes (number of citations in parenthesis): China (12502), the USA (7574), France (6511), India (5183), Canada (3512), Malaysia (3327), Italy (2580), Korea (2535), Australia (2083), and Germany (2073), being the countries with the highest average citations per publication France (155), Serbia (109), Switzerland (89), Hong Kong (81), Malaysia (70), Greece (69), Ethiopia (69), Egypt (63), the USA (54), and Singapore (53). These results depict the importance of countries such as China, the USA, and France in the literature about biopolymers for water purification, even knowing that each country, no matter the number of publications, plays an important role in the construction of the whole literature.

The results of the most prominent countries are in accordance with the most important authors since the most relevant authors in the field of biopolymers for water purification are Chinese.

1.3.1.3 Publications

Table 1.2 brings the 10 most relevant publications (top 10) concerning the total number of local citation scores (LCS), and 10 more relevant publications according to the total number of global citation scores (GCS). LCS refers to the documents resulting from the Scopus search (the number of citations of publications in the local data set). The higher the LCS, the more important the publication about biopolymers for water purification. GCS denotes the total number of citations of publications in the Scopus database, but the cited publications may be from fields different than biopolymers for water purification. The analysis allows benchmark studies in the research field of biopolymers for water purification to be identified [31].

Among the 2000 analyzed publications, the most globally cited one is Azizi Samir et al. [14] with 1897 citations, and the most locally cited is Sheng et al. [15] with 40 citations. According to Farrukh et al. [32], the citation analysis provides the value of the publication.

Among the top 10 GCS publications, most of them are reviews. The subjects addressed by the authors differ greatly – Azizi Samir et al. [14] reviewed recent

Table 1.2 Citation scores of the most relevant publications.

Group	Publication	GCS	LCS
Top 10 GCS	Azizi Samir et al. [14]	1897	5
	Sheng et al. [15]	1750	40
	Crini [16]	1578	19
	Wan Ngah et al. [17]	1460	30
	Kenawy et al. [18]	1178	4
	Leenheer and Croué [19]	1008	6
	Renault et al. [20]	572	5
	McSwain et al. [21]	567	17
	Wang et al. [22]	527	1
	Meng et al. [23]	517	11
Top 10 LCS	Sheng et al. [15]	1750	40
	Hallé et al. [24]	125	36
	Tian et al. [25]	151	32
	Kimura et al. [26]	132	30
	Wan Ngah et al. [17]	1460	30
	Zheng et al. [27]	126	24
	Bala Subramanian et al. [28]	247	21
	Baghoth et al. [29]	354	19
	Haberkamp et al. [30]	152	19
	Crini [16]	1578	19

LCS, local citation score and GCS, global citation score.

research into cellulosic whiskers, their properties, and their application in nanocomposite field; Sheng et al. [15] reviewed extracellular polymeric substances (EPSs) of microbial aggregates in biological wastewater treatment systems; Crini [16] studied the recent developments in polysaccharide-based materials used as adsorbents in wastewater treatment; Wan Ngah et al. [17] reviewed the adsorption of dyes and heavy metal ions by chitosan composites; Kenawy et al. [18] reviewed the chemistry and applications of antimicrobial polymers; Leenheer and Croué [19] featured the organic matter dissolved in water for the better treatment of drinking water; Renault et al. [20] reviewed chitosan for coagulation/flocculation processes; McSwain et al. [21] analyzed the composition and distribution of EPSs in aerobic flocs and granular sludge; Wang et al. [22] studied the recent advances in regenerated cellulose materials; and Meng et al. [23] reviewed the fouling in membrane bioreactors. All the themes addressed in these publications have paramount importance in the field of biopolymers for water treatment due to the high number of citations.

Concerning the top 10 LCS publications, Hallé et al. [24] studied the performance of biological filtration as pretreatment to low-pressure membranes for drinking water; Tian et al. [25] analyzed the correlations of relevant membrane foulants with ultrafiltration membrane fouling in different waters; Kimura et al. [26] studied the microfiltration of different surface waters with/without coagulation; Zheng et al. [27] identified and quantified major organic foulants in treated domestic wastewater, which affect filterability in dead-end ultrafiltration; Bala Subramanian et al. [28] analyzed the EPS in the production of bacterial strains of municipal wastewater sludge; Baghoth et al. [29] investigated the natural organic matter (NOM) in a drinking water treatment plant using fluorescence excitation–emission matrices and parallel factor analysis (PARAFAC); Haberkamp et al. [30] studied the impact of coagulation and adsorption on dissolved organic carbon (DOC) fractions of secondary effluent and resulting fouling behavior in ultrafiltration. All the cited publications have utmost importance in the literature regarding biopolymers for water purification, and their subject can be considered hotspots in the research field, as can be observed in the sequence. Based on the results, it seems that the literature is more focused on the use of biopolymers for wastewater treatment, and the high number of citations overall (global and local), in publications addressing membrane fouling subject, depicts its importance in the research field.

1.3.1.4 Keywords

The word cloud containing the 50 most frequently used authors' keywords is presented in Figure 1.4.

Around 5057 authors' keywords are present in the 2000 analyzed publications. From this total, the most frequent are shown in the word cloud present in Figure 1.4, in which the size of the letters represents the frequency of the keyword. It can be observed that the keywords with the highest frequency are biopolymer and biopolymers, which were expected since they were keywords used in the Scopus search.

The keywords with the highest frequency (except for the keywords biopolymer, biopolymers, and extracellular polymeric substances that is not present due to its length) are as follows (frequency in parenthesis): chitosan (159), adsorption (145),

Figure 1.4 Word cloud containing the 50 most frequently authors' keywords.

membrane fouling (96), wastewater treatment (86), water treatment (67), ultrafiltration (59), coagulation (50), EPSs (47), polysaccharides (39), and heavy metals (38). According to Yunfeng et al. [33], the higher the frequency of a keyword, the more research results, and the more hotspot it reflects in a given field. So, the most frequent authors' keywords depict the hotspots of the research field of biopolymers for water purification [6].

"The deep analysis of the strongest keywords can provide a panorama of the field" [11]. In the present work, a panorama of the literature regarding the use of biopolymers for water purification is obtained. Like so, the literature appoints some processes used for water purification such as microfiltration [34, 35], ultrafiltration [36–40], adsorption [41–46], pretreatment [47, 48], flocculation [49–52], coagulation [44, 52–54], electrospinning [55–58], reverse osmosis [59–62]; different materials such as chitosan [17, 20, 42, 43, 49, 52, 63–78], cellulose [2, 38, 66, 79–85], nanoparticles [3, 36, 38, 51, 64, 69, 71, 86, 87] (both used for water purification or their presence in the environment as contaminants resulting from human activity, causing problems in drinking water purification [51]), lignin [46, 55, 58, 85, 88], starch [70, 76, 77, 84, 89–91], chitin [65, 75], alginate [64, 68, 72, 80, 92], polysaccharides [65, 75], composites [41, 45, 68, 73, 93, 94], hydrogel [78, 85, 93, 95, 96], polyhydroxyalkanoates [97–99]; revaluation of biomass [80, 87]; characterization [56, 74, 84, 100]; removal of arsenic [52, 86, 100–102]; membrane fouling [36]; among others.

The thematic map is presented in Figure 1.5. In the production of the map, the parameters used were 50 as the number of words, with a minimum cluster frequency of 10 (per 1000 documents). Based on this, the map contains 31 authors' keywords divided into 4 different clusters. The map presents the authors' keywords grouped according to the relevance and development degree of the research field. It is divided

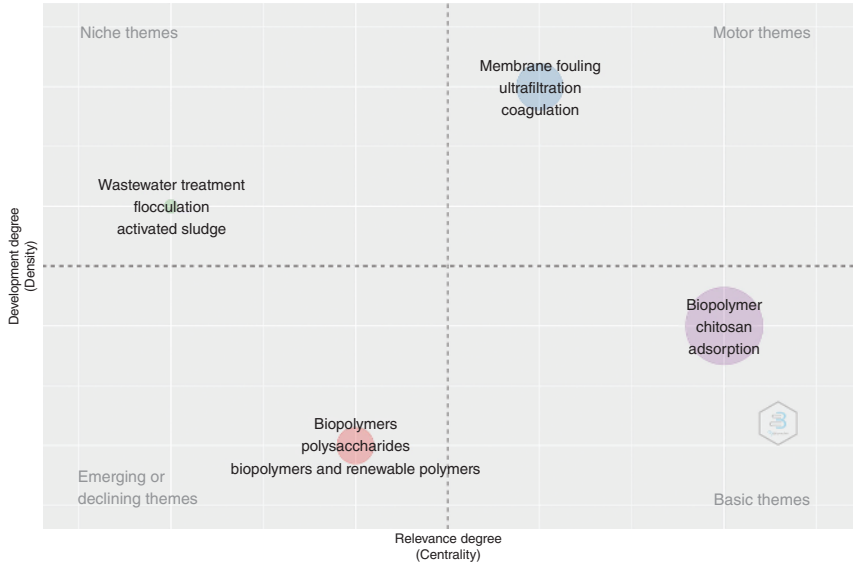


Figure 1.5 Thematic map.

into four quadrants: (i) motor themes, (ii) basic themes, (iii) emerging or declining themes, and (iv) very specialized/niche themes [5].

The clusters with the highest development degree and relevance degree, i.e. the motor themes, are the ones containing the keywords membrane fouling, ultrafiltration, and coagulation (cluster 1). However, these are only the keywords with the highest number of occurrences; all the keywords from cluster 1 are as follows (number of occurrences in parenthesis): membrane fouling (96), ultrafiltration (59), coagulation (50), EPSs (47), fouling (36), membrane bioreactor (28), NOM (28), anaerobic digestion (22), and microfiltration (21). According to Su et al. [4], these themes play a fundamental role in defining the structure of this field and have the highest degree of relevance.

The keywords present in cluster 2, which are considered niche themes are (number of occurrences in parenthesis): wastewater treatment (86), flocculation (34), activated sludge (27), and EPSs (27). This cluster presents very specialized themes in the research field of biopolymers for water treatment.

The keywords present in cluster 3, which is present in the emerging or declining quadrant, are as follows (number of occurrences in parenthesis): biopolymers (185), polysaccharides (39), biopolymers and renewable polymers (29), mechanical properties (28), and surface modification (26). Given their high relevance level and the presence of these keywords in the word cloud, these themes can be considered emerging themes. These themes require further development.

In cluster 4, i.e. the cluster present in the basic themes quadrant, the keywords contained are as follows (number of occurrences in parenthesis): biopolymer (177), chitosan (159), adsorption (145), water treatment (67), heavy metals (38), wastewater

(37), cellulose (33), alginate (32), biosorption (26), and chitin (26). According to Su et al. [4], this quadrant groups transversal, general, and basic themes, which are important for a research field but are not highly developed. Once the research around these keywords is further corroborated, they may turn into motor themes [5].

The conceptual structure map of the keywords according to the multiple correspondence analysis (MCA) method and the dendrogram of hierarchical cluster analysis of the keywords are presented in Figure 1.6.

MCA uses measurable strategies for disentangling the complex keyword connection into few relative groups, which is based on the repetition of the coexisting rate of two keywords [103]. The compression of large data with multiple variables forms a two- or three-dimensional structure and the similarity between the keywords is demonstrated by the plane distance. The proximity to the central point of the cluster shows the relevance of the keyword, and narrow themes are near the edge [7, 10].

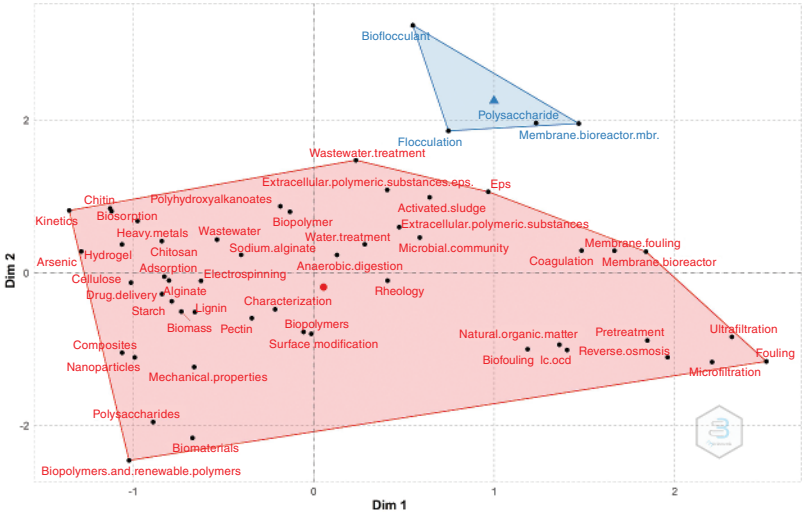
In Figure 1.6a, two clusters can be observed: a red and a blue. The red cluster contains the keywords belonging to a central theme, while the blue the ones belonging to other themes [104]. The red one contains a higher number of keywords, and demonstrates, among others, some materials used for water purification and their applications being central themes in the research field of the use of biopolymers in water purification. The blue cluster seems to be focused on flocculation.

The keywords closer to the center point, i.e. the most popular in the literature, are in the red cluster, anaerobic digestion, water treatment, rheology, characterization, biopolymers, and surface modification. On the other hand, there are only keywords on the edge in the blue cluster, which means that all of them are narrow themes. But since the distance from keywords polysaccharide and flocculation to the center point of the cluster are similar to those of the most popular keywords in the red cluster, they can also be considered hotspots in the research field. It is important to mention that all the keywords close to the center point of a cluster are trend topics in the current literature [10]. In the red cluster, the narrow themes are kinetics, wastewater treatment, EPS, membrane bioreactor, fouling, polymers and renewable polymers, and arsenic.

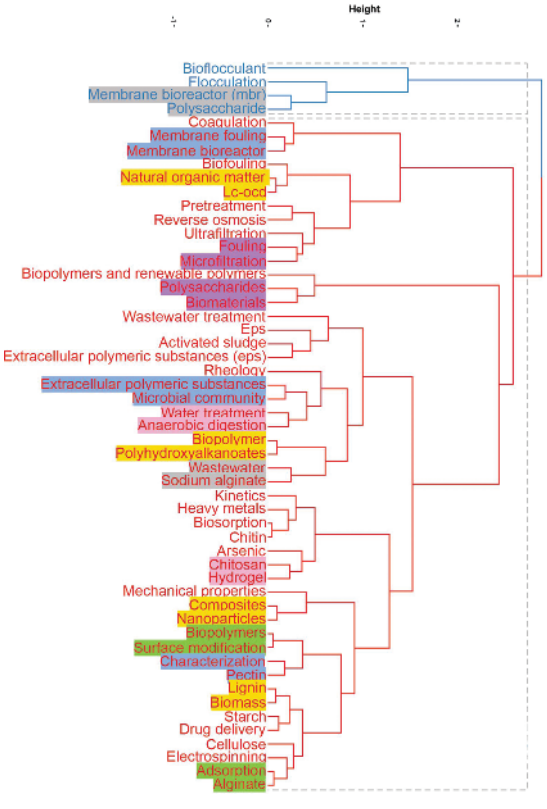
Regarding the dendrogram, the association between the research areas can be obtained through its analysis [105]. In Figure 1.6b, two strands can be observed, a blue and a red, containing the keywords present in the two clusters (Figure 1.6a). Topics with the same height present a strong connection [10] and are shown in the dendrogram with the same background color. As an example, the keywords with the background gray, i.e. membrane bioreactor (mbr), polysaccharide, wastewater, and sodium alginate, have a close connection among them.

Since the dendrogram demonstrates the hierarchy of keywords, the pairs with the highest weight are those in purple, containing the keywords fouling, microfiltration, polysaccharides, and biomaterials. These keywords can also be considered hotspots in the research field, as previously observed in the word cloud.

Another interesting thing to notice is that the height of the keyword wastewater treatment is higher than the keyword water treatment. In other words, it seems that, in the literature, the use of biopolymers has more relevance for wastewater treatment, which can also be observed in the word cloud (Figure 1.4).

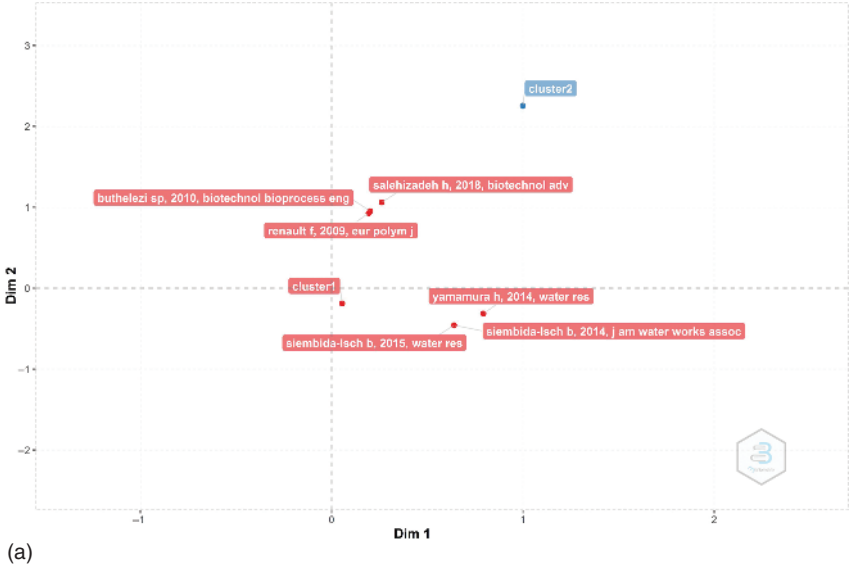


(a)

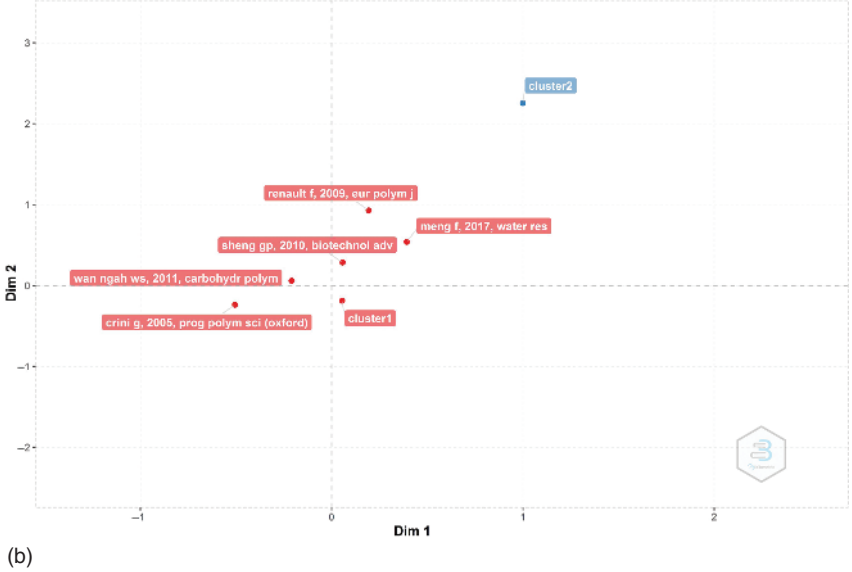


(b)

Figure 1.6 (a) Conceptual structure map of the keywords according to the MCA method. (b) Topic dendrogram regarding the use of biopolymers in water purification.



(a)



(b)

Figure 1.7 (a) Factorial maps of the publications with the highest contribution, and (b) the most cited publications.

The factorial maps of the publications with the highest contribution and of the most cited publications from each cluster (Figure 1.6a) are shown in Figure 1.7.

According to Figure 1.7a, the publications with the highest contribution to the red cluster are Renault et al. [20], Buthelezi et al. [106], Salehizadeh et al. [107], Yamamura et al. [108], and Siembida-Lösch et al. [109, 110]. Some authors [20, 106, 107] deal with flocculation/bioflocculation from eco-friendly materials,

and other research groups [108–110] study microfiltration, ultrafiltration, and biofiltration processes membranes.

Even if Bibliometrix did not provide results on the publications with the highest contribution to the blue cluster, by limiting the search results of Scopus it was possible to obtain the publications with the greatest contribution to the blue cluster. The publications with the highest contribution to the blue cluster, according to Scopus, are as follows: Fabris et al. [67], Kumar et al. [111], Hijnen et al. [112], Mugesh et al. [113], and Manikandan et al. [114]. Some research groups analyzed the use of biopolymers for drinking water [67, 111, 112], such as Fabris et al. [67], who evaluated the use of chitosan as a natural coagulant for drinking water treatment, Mugesh et al. [113] studied the defluoridation of water by using a bacterial cellulosic material, and Manikandan et al. [114] the emerging nanostructured innovative materials as adsorbents in wastewater treatment.

Concerning the most cited publications, all of them are part of the top 10 GCS previously shown in Table 1.2 [15–17, 20, 23]. It can be observed that the most cited publications are closer to the central point since these publications deal with the hotspot themes.

From these results, it can be observed that chitosan, an important biopolymer obtained from marine sources, is a significant material used for water purification according to the literature [42, 43, 49, 52, 63, 64, 66, 68–75, 78, 115–119], as previously observed in the word cloud results (Figure 1.4).

1.4 Conclusions

A bibliometric analysis based on the results of a Scopus search by using the keywords biopolymer* AND (water purification* OR water treatment*) was performed and the most recent 2000 publications (articles and reviews in English) from 2002 to 2021 were selected. The .bib document generated was analyzed by Bibliometrix R-package. The analysis provided a general overview of the literature about biopolymers for water purification.

The research field is interdisciplinary, with an annual growth rate in publications of 19.26%. Water Research is the most locally cited journal, with the highest number of publications as well. Concerning the most prominent authors, Zhang W. is the one with the highest *h*-index and the highest number of publications, and Wang J. is the author with the highest local citation. China is the frontrunner country, and some of the most relevant affiliations are Chinese. Azizi Samir et al. [14] is the top GCS publication, whereas Sheng et al. [15] is the top LCS publication.

Regarding the analysis of the authors' keywords, the ones more frequently used are chitosan, adsorption, and membrane fouling. Keywords with high relevance are membrane fouling, ultrafiltration, and coagulation. Some very specialized themes in the field are water treatment, flocculation, and activated sludge, whereas some popular themes are anaerobic digestion, water treatment, rheology, characterization, and surface modification. The analysis is important since it may provide a panorama of the research field of the use of biopolymers for water purification.

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