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Bibliometric analysis of chitosan research for wastewater treatment: a review

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Abstract Wastewater has negative impacts on the environment, such as destroying aquatic ecosystems and creating a shortage of clean water sources for consumption. In this paper, we provide a comprehensive bibliometric analysis of chitosan to better understand the evolution in degrading various pollutants as a wastewater treatment research limited only by photocatalyst system published in 2001–2021. The number of publications analyzed a total of 456 documents, which was conducted from the Scopus database. All data in this paper was visualized by using open-source software, VOSviewer and Tableau, to perform bibliometric analysis and scientific mapping. The reason for choosing chitosan is its ability to degrade various pollutants with high adsorption performance (from various sources: degradation Congo red 98.4%, methylene blue 99.36%, rhodamine B 95%, and Cd(II) 94%), non-toxicity, biodegradability, and abundantly available sources in nature. The analysis results show that the highest number of publications in 2016 was 66, and the highest number of citations was 2258. The network of keywords and innovations for wastewater treatment is USA and China as the most productive countries with many cooperative relations. This paper helps scholars understand the evolution of composite chitosan-based photocatalyst systems as research on wastewater treatment from a bibliometric point of view and inspires them to develop new efficient methods in synthesizing chitosan from fish by-products (waste) with high adsorption efficiency for various type of waste.

Keywords Chitosan · Wastewater treatment · Bibliometric analysis · Efficiency

Introduction

Wastewater is mostly generated by textile, petroleum, and pharmaceutical industries, some also from seawater desalination, mining, metallurgical generators, and chemical sectors (Ding & Zeng, 2022; Wei & Kamali, 2022). Wastewater has several impacts, such as damaging aquatic ecosystems and creating deficiency of clean water sources for consumption (Fahri et al., 2022; Ulum et al., 2020). Usually, wastewater contains hazardous substances, heavy metals, and estrogenic that contaminated food. It is causing several mental illnesses, such as anxiety, depression, and Parkinson's, due to affected to endocrine system disorders that will affect brain development. The occurrence of mental retardation is dependent on time exposure and concentration of contamination, which also affects dangerous diseases such as asthma and even cancer (Ahamad et al., 2020; Weiss, 2005).

Chitosan is one of the abundant materials that can be reused in wastewater degradation. Chitosan is a polysaccharide obtained from chitin, which is an essential

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component of crustaceans such as crabs and shrimp and the world's second-richest polysaccharide after cellulose (Rahaman et al., 2021a). Chitosan was produced from the fish by-product (waste), which means it is an eco-friendly material with high thermal stability that is non-toxic and good biodegradable, making it a bio-absorber for almost all anionic dyes (You et al., 2022). Chitosan was reported widely applied in various fields such as wound dressing, bioplastic, and self-cleaning (Mutmainna et al., 2019; Ranjan, 2022; Suryani et al., 2022; Tenri Ola et al., 2022).

Bibliometric analysis uses statistical and visualization methods to detect scientific developments in various aspects of the topic by analyzing and visualizing research trends and summarizing bibliographic information into one document, making it easier for researchers to find historical trends in the target field (Nazaripour et al., 2021; Olisah et al., 2022; Yang et al., 2020). The bibliometric analysis identifies several features, such as the frequency of keywords, countries' productive publications and their citations, affiliation, the collaboration of authors, distribution of published journals and subject area categories, and analyzing social networks and their impact (Han et al., 2020; Yang et al., 2022).

Currently, chitosan has been developed and synthesized from various fish by-products, and in this review, we focus on statistical analysis by using bibliometric method of chitosan with various additional materials for wastewater treatment by photocatalyst system. This review also provided information on the relation between composite chitosan-based degradation performance and discussed pollutant type and information research direction for the development of composite chitosan-based wastewater treatment by photocatalyst system. In addition to the subject areas, the trend analysis of publication output (most cited articles and productive authors), journals actively publish composite chitosan-based, cooperation between countries, productive countries in developing chitosan for dealing with wastewater problems, chitosan studies in decomposing various wastewater, and research hotspots and tendencies are also discussed.

Photocatalyst mechanism

The photocatalyst technique is one of the most popular for wastewater treatment due to its use of materials that have optical characters (bandgap) for generating charge when getting energy from solar energy, low cost, high chemical stability, non-toxic, and high efficiency for removing organic pollutants from textile industries (Liu et al., 2019). Photocatalysts are the catalysts that degrade chemical and organic pollutants in wastewater that work in a specific wavelength of solar radiation (strongly depending on the bandgap of materials), which is about 45% of total solar energy and only 5% of ultraviolet radiation (Rusman et al., n.d.; Tenri Ola et al., 2022). A schematic of the photocatalyst mechanism is shown in Fig. 1. When the catalyst is irradiated by the photons (*hv*) for the energies greater than that of bandgap (Eg) material, it induces a pair of electrons (e^-) and hole (h^+). The bandgap energy (Eg) is the energy difference between the valence band (VB) and the conduction band (CB). The chemical reduction is caused by the reaction between electrons (e^-) in the CB with oxidant (O_2) to form oxygen radicals ($\cdot O_2$). Whereas chemical oxidation processes from reactions between holes (h^+) in the VB with reducing agents in the form of water (H_2O) to produce hydroxyl radicals ($\cdot OH$). The radical's atom will react with pollutants to break down the molecular structure of pollutants gradually from harmful to harmless substances (Feng et al., 2017; McCullagh et al., 2010; Tenri Ola et al., 2022; Ulum et al., 2020).

Document and methods

Document collection

During document collection with the keyword "chitosan, wastewater" shown in Fig. 2, we used the Scopus database, one of the most well-known online academic resources in the world (Souley Agbodjan et al., 2022), and found 3052 documents. The document is filtered by including the document year range "2001–2021" to capture the evolution of chitosan for wastewater research over the past decade (Marcal et al., 2021). In this study, we explore the following subject areas to review the performance of chitosan on its physical properties: environmental science; chemistry; chemical engineering; materials science; engineering; physics and astronomy; biochemistry, genetics, and molecular biology; energy; agricultural and biological sciences; earth and planetary science; immunology and microbiology; pharmacology,

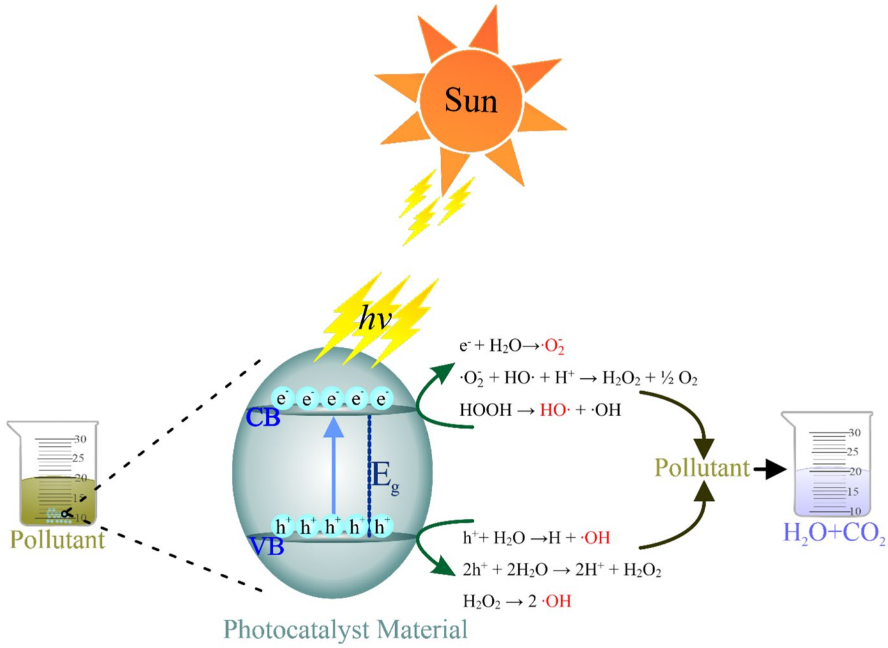


Fig. 1 Schematic illustration of photocatalyst mechanism which supplied energy from the sun to generates charge in the form of electron and hole (e^-/h^+)

toxicology, and pharmaceutics. We filter articles and journals considering document type and source type because they present research from the latest experiments and journal quality in the last 20 years. Hence, the final document is 456. Furthermore, documents are collected for analysis by the annual number of publications, number of citations, and annual co-occurrence network of keywords. Then continue for the h-index and international scientific index by top 10 subject areas of publications; authors, year, and author's country by top 10 documents cited; collaboration and productive countries with a strength link to show the cooperative relationship between countries.

Bibliometric analysis

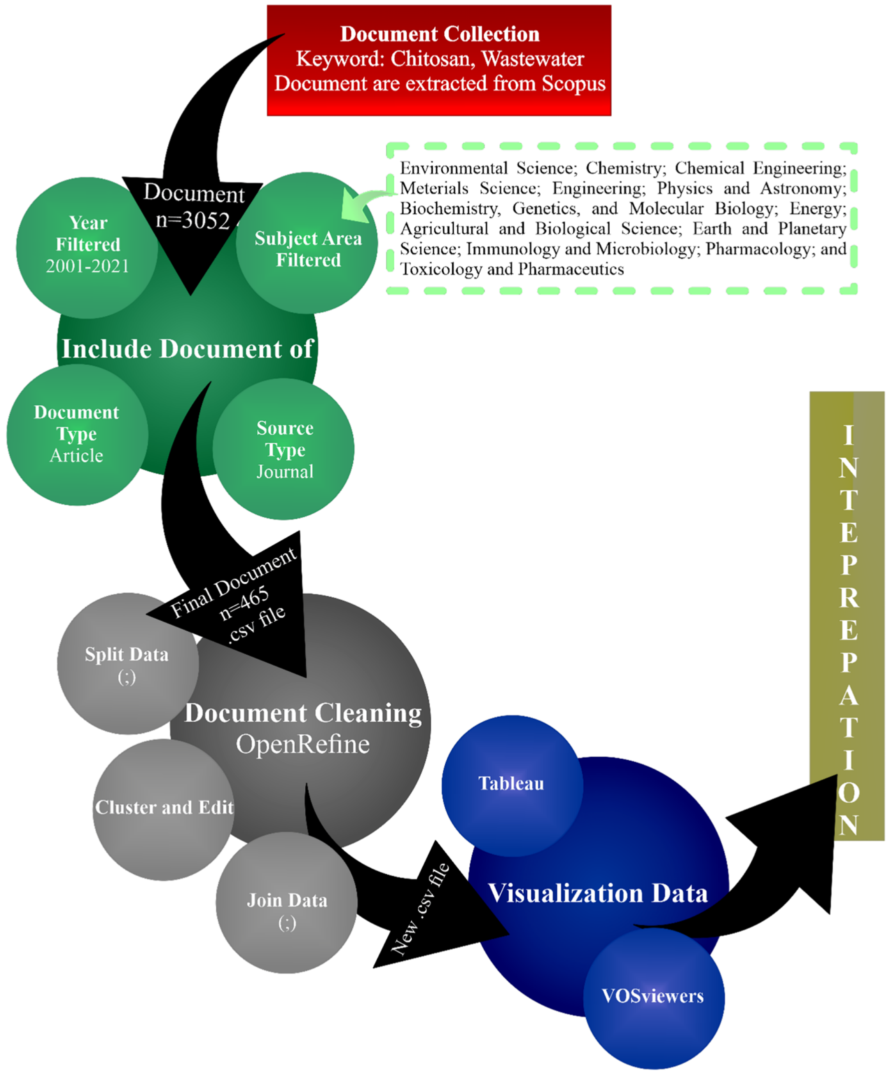
Document cleaning makes use of the OpenRefine website to clean up messy words by changing the form. OpenRefine is a website that transforms one word with the same meaning but different writing into one word with the same meaning with the same writing. The VOSviewers and Tableau applications are used to visualize the result of document cleaning. VOSviewers are used as bibliometric network visualization (Chen et al., 2022). VOSviewers is used in the visualization document of chitosan for wastewater treatment and Tableau for visualizing charts and graphs of chitosan research trends.

Result and discussion

Publication trend

The available sources of chitosan material are abundant in nature and can be reused in wastewater treatment. Chitosan is a material with good thermal stability, is non-toxic, and is good biodegradable as a bio-absorber for almost all anionic dyes, including acids and reactive and direct dyes due to electrostatic adsorption (You et al., 2022). This publication trends in 2001–2021 with 465 documents on field chitosan for wastewater treatment from the Scopus database, with the help of analysis done with Tableau, shown in Fig. 3. The publication has gradually increased in 2001–2015 there were < 50 publications, with the number of publications around 2–5 documents per year. In 2016–2021 there was a significant increase in the number of publications. Top year publication in the range 2001–2021 is 2016, with 66 documents published and 2258 citations. This indicates increasing scientist awareness for the environmental pollution from the industrial by continuous research for providing effective and efficient materials for photocatalyst with high efficiency as an alternative solution for industries to treat their wastewater (Nazaripour et al., 2021).

Fig. 2 Schematic illustration of selection document and visualization method



Co-occurrence of keyword

The occurrence-focused keywords were evaluated based on the number of publications on chitosan for wastewater treatment by photocatalyst system in 2001–2021, from a data threshold of 456 documents with 3199 words and get 171 keywords repeated ten times. The visualization of the keyword relationship by network analysis via VOSviewers is shown in Fig. 4. The bigger circle size times the keyword appear in all documents considered, and the color of the circle corresponds to the hotspot keyword in the publication year, from dark blue to yellow. The dark blue color shows the time interval 2012, and the yellow color shows the time interval 2018 (Ding & Zeng, 2022; Li et al., 2022). From 2001 to 2021, the development of the keyword chitosan for wastewater treatment by photocatalyst system. In 2014, the researchers at the first stage focused on the keyword "chitin," which was applied to "polymer," "wastewater," and used the "pH effect." Moving on to 2016, researchers focused on the keyword "chitosan" applied to "adsorption" and "catalysis," "dyes," or "heavy metal" in the middle stage. A new state of research in 2018 focuses on the keyword chitosan being developed as a "wastewater treatment" in view of "adsorption efficiency" and "adsorption mechanism." The network of keywords that appear together is shown in the development of chitosan in its various applications and new innovations in dealing with wastewater treatment.

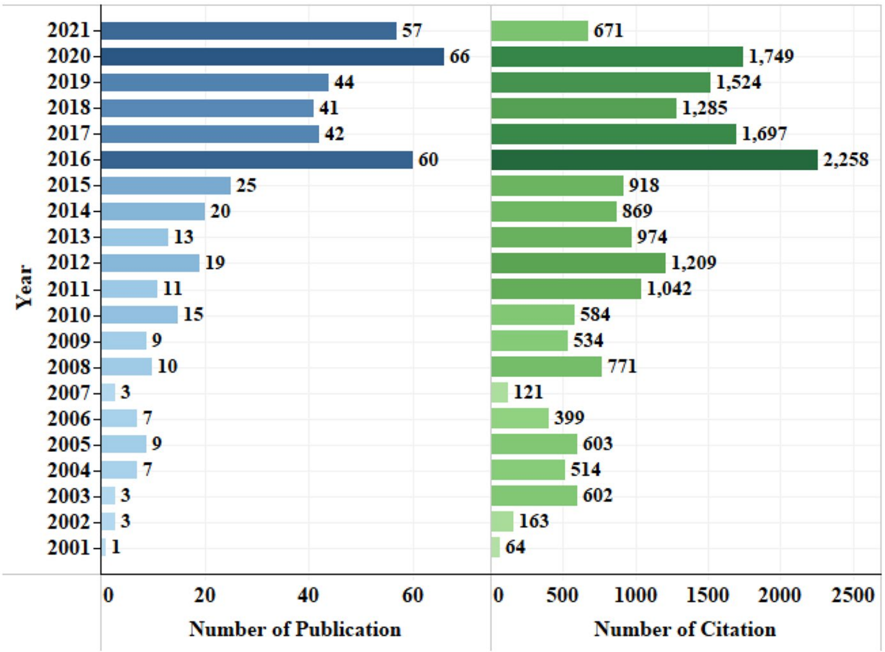


Fig. 3 Annual publication and citation in the field of chitosan for wastewater treatment

Publication sources

Research of chitosan for wastewater treatment in 2001–2021 obtained 465 documents with 89 subject areas of photocatalyst chitosan-based wastewater treatment. The top 10 active subject areas in publications in 2001–2021, which were analyzed by Tableau free program, are shown in Fig. 5. Subject areas that are active in publications are shown in Table 1. First is the journal *Carbohydrate Polymers*, with an *h*-index of 228 from scimagojr.com contributing to publications of 22.58% as the largest contributor, followed by desalination and water treatment with an *h*-index of 67 contributing of 21.94%, *Chemical Engineering Journal* with an *h*-index of 248 contributing of 19.35% publication, and *Journal of Applied Polymer Science* with *h*-index 175 contributed 10.65% publication percentage. The *Carbohydrate Polymers* was found to focus on biomaterial field applications. The IF is an international scientific index used to evaluate journals. It is one of the indexes proposed by Thomson Reuters in the *Journal Citation Report*. All subject areas are on the chitosan for the wastewater treatment field based on IF ranks. It ranks first in all journals, followed by *Water Research* (2.81) and *Chemical Engineering Journal* (2.42).

Most cited document

The field of chitosan for wastewater treatment by photocatalyst system has been found in document 465 and was analyzed by bibliometric analysis. Furthermore, the top 10 citation documents from 2001 to 2021 are shown in Table 2. The rank 1 with 458 citations is the article with authors Boddu VM, Abburi K., Talbott JL, and Smith ED from the USA with the article titled "Removal of hexavalent chromium from wastewater using a new composite chitosan biosorbent." (Boddu et al., 2003) This article discussed a material variation from pure alumina and dissolved alumina to oxalic acid, pure chitosan, and chitosan-coated alumina/oxalic acid. Solubility test results are on dissolved pure alumina 2.1% wt, alumina/oxalic acid 4.5%wt, 1:1 chitosan-alumina/dissolved oxalic acid 7.8%wt, 2:1 chitosan-alumina/dissolved oxalic acid 21.1%wt, and pure chitosan leaving a residue of 0.7%wt. The result of XPS characterization results obtained at 67% induced Cr (VI) to Cr (III). The equilibrium adsorption isotherm is obtained at Cr (VI) pH 4 at 25 ℃, 2:1. Chitosan-alumina/oxalic acid has a higher adsorption capacity than pure chitosan at low pH. This is because oxalic acid acts as a bridge between alumina and chitosan. as well as a coating that increases chitosan adsorption capacity

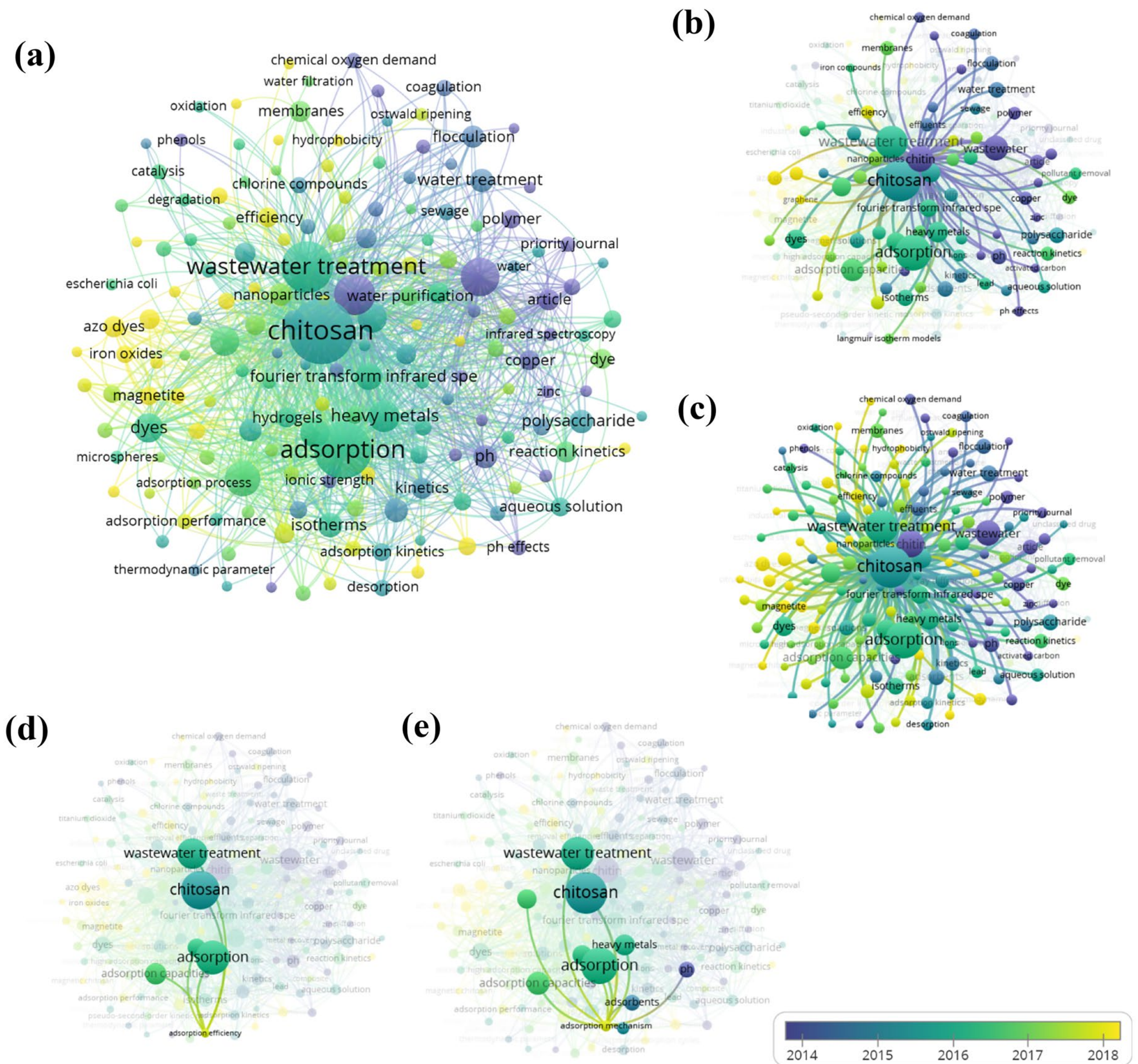


Fig. 4 Annual co-occurrence network of keywords **a** all keyword, **b** chitin, **c** chitosan, **c** adsorption efficiency, and **d** adsorption mechanism in the field of chitosan for wastewater treatment

by increasing its surface area and facilitating Cr ions transport to the binding site on chitosan. Rank 2 with 448 citations is the article with authors Ngah WSW and Fatinathan S. from Malaysia, with the article titled "Adsorption of Cu (II) ions in aqueous solution using chitosan beads, chitosan-GLA beads, and chitosan-alginate beads." (Ngah & Fatinathan, 2008) This article discusses variations of pure chitosan material: 1:1 chitosan-glutaraldehyde (GLA), 2:1 chitosan-glutaraldehyde (GLA), and chitosan-alginate. The solubility results reveal that in distilled water (neutral pH) and 0.1 M NaOH (alkaline pH), pure chitosan is insoluble but soluble in acetic acid (acidic pH). Chitosan and polymer will be damaged and ultimately dissolved because of the appearance of amino groups in the chains. Chitosan and chitosan-GLA cannot be dissolved at neutral and alkaline pH because of H^+ protonates (reaction of protons bound to a molecule) and fewer amino groups of chitosan. Due to the ionization of the alginate carboxy1 group, chitosan-alginate is partially soluble in acids via the interaction between chitosan and alginate and slightly

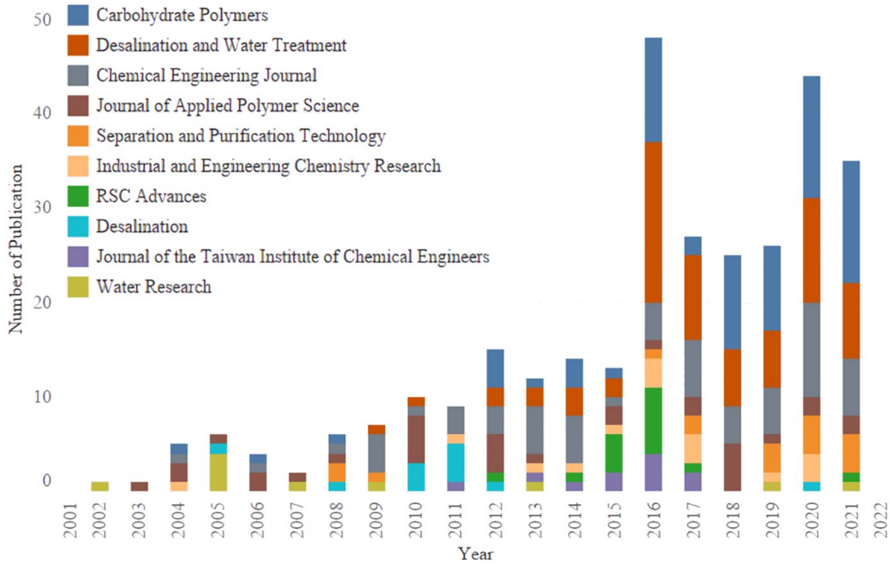


Fig. 5 Annual top 10 subject area of publication in the field of chitosan for wastewater treatment

swells in neutral pH. The equilibrium adsorption isotherm is obtained for pure 0.125 g of chitosan with 90 min of contact at pH 4.5, chitosan-GLA 1:1, 2:1, and chitosan-alginate 0.2 g with 100 min of contact at pH 4.5. While testing the effect of pH, it is found that for pH > 7, Cu (II) is precipitated, resulting in a good adsorption interpretation. The adsorption capacity of Cu (II) ions increased with an increase in the initial pH value of the solution. Because of the lower pH of all samples and the swelling of the adsorbent occurred, maximum adsorption was obtained at pH 4.5. It has many citation values because it describes in detail the behavior of chitosan against various tests, such as solubility testing and testing the effect of pH, based on the discussion of published documents with the highest citations.

Collaboration and productive country/region

Collaboration and distribution of the country/region by author's country and the strength link to show the cooperative relationship between countries. The evaluation was focused on a country based on the strength of link collaboration and the number of publications of chitosan for photocatalysts in 2001–2021, from a data threshold of 456 documents in 59 countries. As can be seen, the productive country is shown in Fig. 6 and clearer for 10 countries in Table 3. The

Table 1 The top 10 subject areas of publication in the field of chitosan for wastewater treatment

Subject area	*h*-index (2021)	IF (2021)	Number of publication	Percentage of publication (%)	Number of citation
Carbohydrate Polymers	228	1.61	70	22.58	3280
Desalination and Water Treatment	67	0.24	68	21.94	636
Chemical Engineering Journal	248	2.42	60	19.35	5356
Journal of Applied Polymer Science	175	0.53	33	10.65	995
Separation and Purification Technology	175	1.20	17	5.48	672
Industrial and Engineering Chemistry Research	231	0.82	15	4.84	600
RSC Advances	167	0.67	15	4.84	528
Desalination	203	1.63	11	3.55	994
Journal of the Taiwan Institute of Chemical Engineers	91	0.80	11	3.55	548
Water Research	327	2.81	10	3.23	1068

Table 2 Top 10 cited documents in the field of chitosan for wastewater treatment

Number of citation	Authors (ref.)	Title	Year	Country	Ref.
458	Boddu V.M., Abburi K., Talbott J.L., Smith E.D.	Removal of hexavalent chromium from wastewater using a new composite chitosan biosorbent	2003	USA	(Boddu et al., 2003)
448	Ngah W.S.W., Fatinathan S.	Adsorption of Cu (II) ions in aqueous solution using chitosan beads, chitosan-GLA beads, and chitosan-alginate beads	2008	Malaysia	(Ngah & Fatinathan, 2008)
274	Nair V., Panigrahy A., Vinu R.	Development of novel chitosan-lignin composites for adsorption of dyes and metal ions from wastewater	2014	India	(Nair et al., 2014)
246	Kyzas G.Z., Siafaka P.I., Pavlidou E.G., Chrissafis K.J., Bikiaris D.N.	Synthesis and adsorption application of succinyl-grafted chitosan for the simultaneous removal of zinc and cationic dye from binary hazardous mixtures	2015	Greece	(Kyzas et al., 2015)
231	Wang L., Zhang J., Wang A.	Fast removal of methylene blue from aqueous solution by adsorption onto chitosan-g-poly (acrylic acid)/attapulgite composite	2011	China	(Wang et al., 2011)
217	Gotoh T., Matsushima K., Kikuchi K.-I.	Preparation of alginate-chitosan hybrid gel beads and adsorption of divalent metal ions	2004	Japan	(Gotoh et al., 2004)
199	Cao N., Lyu Q., Li J., Wang Y., Yang B., Szunerits S., Boukherroub R.	Facile synthesis of fluorinated polydopamine/chitosan/reduced graphene oxide composite aerogel for efficient oil/water separation	2017	France	(Cao et al., 2017)
197	Zhu H., Jiang R., Fu Y., Guan Y., Yao J., Xiao L., Zeng G.	Effective photocatalytic decolorization of methyl orange utilizing TiO_2/ZnO/chitosan nanocomposite films under simulated solar irradiation	2012	China	(Zhu et al., 2012)
196	Ahmad A.L., Sumathi S., Hameed B.H.	Adsorption of residue oil from palm oil mill effluent using powder and flake chitosan: Equilibrium and kinetic studies	2005	Malaysia	(AHMAD et al., 2005)
190	Chen B., Zhao H., Chen S., Long F., Huang B., Yang B., Pan X.	A magnetically recyclable chitosan composite adsorbent functionalized with EDTA for simultaneous capture of anionic dye and heavy metals in complex wastewater	2019	USA	(Chen et al., 2019)
157	Liu T., Yang X., Wang Z.-L., Yan X.	Enhanced chitosan beads-supported Fe^0-nanoparticles for removal of heavy metals from electroplating wastewater in permeable reactive barriers	2013	China	(Liu et al., 2013)

five most cited documents based on their countries are those from China, the USA, India, Canada, and Brazil, but the most productive countries for publications are China, the USA, Canada, India, and South Korea. Visualization of country collaboration with the help of network analysis by VOSviewers is shown in Fig. 6(a). The thickness of the line connecting the two countries is supported by the frequency of collaboration in publications (Lam et al., 2022). The most collaborative countries are China with a total link strength of 16, followed by the USA with a total link strength of 14, Canada, India, and South Korea

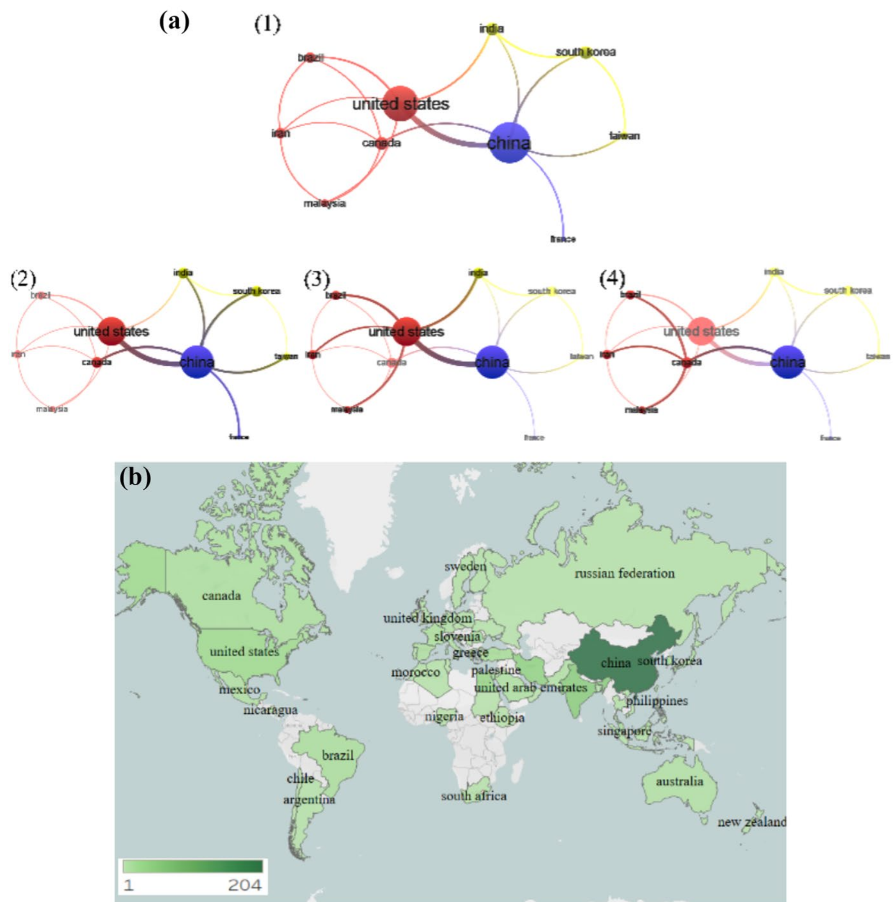


Fig. 6 The country/region **a** collaboration country (1), collaboration country (2), collaboration China (3), collaboration USA (4), collaboration Canada; **b** country map of productive country of chitosan for wastewater treatment

with a total link strength of 5, Iran with a total link strength of 4, Malaysia with a total link strength of 3, Taiwan with a total link strength of 2, and France with a total link strength of 1. Geographical visualization of productive countries analysis using Tableau is shown in Fig. 6(b). The darker color indicated more documents were released in that country/region (Olisah et al., 2022). The top five productive countries that were published are China with 204 articles and a number of citations of 8537, India 45 articles

Table 3 Collaboration and distribution of the country in the field of chitosan for wastewater treatment by photocatalyst system for 10 most productive countries

No.	Country	Link	Total link strength	Number of publication	Number of citation	Average publication year	Average citation
1	China	6	16	204	8537	2016.82	41.85
2	USA	3	5	45	2111	2014.89	46.91
3	Canada	4	4	36	1335	2017.06	37.08
4	India	5	14	21	1601	2013.81	76.24
5	South Korea	3	5	16	440	2015.06	27.50
6	Iran	2	3	15	256	2014.27	17.07
7	Brazil	3	3	13	1279	2014.63	98.38
8	Malaysia	3	4	11	526	2017.09	47.82
9	Taiwan	4	5	10	509	2014	50.90
10	France	1	1	10	528	2012.30	52.80

Table 4 Various composite chitosan for wastewater treatment of various pollutant; we have included dose information, type of irradiation sources (watt) and time, and efficiency from various references

Materials	Pollutant	Dose/information	Type of irradiation source (Watt) and time	Efficiency (%)	Ref.
5% AC/chitosan-$Ca_2Fe_2O_5$	Fipronil	Fipronil 25 mg L^{-1}	Irradiation halogen 300 for 60 min	76.95	(Tenri Ola et al., 2022)
		Catalyst 0.3 mg L^{-1}			
TiO_2-chitosan	Rhodamine B	Rh B 10 mgL^{-1}	Irradiation 25 W (254 nm) UV lamp	95	(Chen et al., 2021)
		Catalyst 5 mgL^{-1}	for 100 min		
Natrium lignosulfonate-chitosan	Pb (II)	Pb (II) 100 mg L^{-1}	180 min	92	(Zhang et al., 2021)
		Catalyst 0.2 g L^{-1}, pH 7, Temp. 20 ℃			
Fe_3O_4-chitosan	Congo red	Congo Red 200 mg L^{-1} pH 4		98.4	(Wang et al., 2022)
		Catalyst 0.2 g/200 mL			
g-C_3N_4-3% chitosan	Rhodamine B	Rh B 2 mgL^{-1}, pH 3		72.74	(Gharbani & Mehrizad, 2022)
		Catalyst 2 g			
Graphene oxide-chitosan (GO-C)	Methylene blue, Na_2SO_4, Na_2CO_3	0.5 g of MB	50 min	99.36	(Bryan et al., 2022)
		45 g of Na_2SO_4			
		10 g of Na_2CO_3 for 500 mL^{-1}			
		Catalyst 250 and 1250 mgL^{-1}			
CS/SnO_2NCs	Rhodamine B	Rh B CR (1 × 105 M)	Rh irradiation visible light (500–550 nm) in 60 min	Rh B 95	(Maruthupandy et al., 2022)
	Congo red	Catalyst 50 mg/100 ml	CR irradiation visible light (500–550 nm) in 40 min	CR 98	
Chitosan-montmorillonite/polyaniline	Methylene blue	MB 100 mg L^{-1}	Irradiation UV–visible for 2 h	98	(Minisy et al., 2021)
(CH-Mt/PANI)		Catalyst 0.05 g/10 ml			
α-cellulose-chitosan	Cr (III), Pb (II), Cd (II)	Cr (III), Pb (II), Cd (II) 60 ppm, pH 4		Cr (III) 56	(Rahaman et al., 2021b)
		Catalyst 1 gL^{-1}		Pb (II) 85	
				Cd (II) 94	
Chitosan-MMT NPs	Fe	Fe 10 mg L^{-1}	Irradiation 210 min	89.2	(Shehap et al., 2021)

with citations of 2111, Iran 36 articles with citations of 1335, Egypt 28 articles with citations of 720, and the USA with 21 articles with of 1601. China is the highest publication with concern for the environment and public health and worsening wastewater pollutant problems caused by industrial expansion (e.g., water reactor nuclear power plant project in coastal areas). (Han et al., 2020; Li et al., 2022).

Wastewater treatment is a serious environmental problem, mainly due to developments in the agricultural and industrial sectors that produce wastewater every day, which harms the environment if it is not treated. (Ahmed et al., 2020; Jariah et al., 2022). Some of the materials used in treating various wastewater and the efficiency of treating wastewater are shown in Table 4. $Ca_2Fe_2O_5$ material with a band gap of 1.8–2.2 eV shows good for wastewater treatment process under visible light. However, radiation absorbers of various wavelengths are needed with the addition of chitosan, which can absorb electromagnetic waves during irradiation. $Ca_2Fe_2O_5$-AC/chitosan can degrade fipronil (fipronil is an active ingredient to combat pests and increase agricultural production) up to 76.95% for 60 min (Tenri Ola et al., 2022). TiO_2 has non-toxic and chemically stable properties but has a relatively wide band gap (3.2 eV), which also hinders the adsorption process at certain irradiation by mixing chitosan. Due to its adsorption capacity, it is widely used as an adsorbent/catalyst for environmental applications. Moreover, their intercalation/peeling properties make them suitable for the adsorption of organic pollutants. TiO_2-chitosan material can degrade rhodamine B (a cationic dye causing environmental damage and negative impact on humans, such as irritating to the skin, eyes, and respiratory system) up to 95% in 100 min (Chen et al., 2021; Gharbani & Mehrizad, 2022).

Natrium lignosulfonate is reduced in carbon content, which can remove heavy metal waste. It shows good adsorption capacity with the addition of chitosan. It has a high adsorption capacity based on the content of hydroxyl and amino groups. Materials such as natrium lignosulfonate-chitosan can degrade Pb (II) (a toxic metal waste that can accumulate in human and animal tissues) by up to 92% in 180 min irradiation (Zhang et al., 2021). Hence, chitosan as an adsorption/catalyst material has advantages in increasing the efficiency of photocatalysts for wastewater treatment with eco-friendly concept.

Conclusion, perspective, and future direction

The chitosan was reported globally by scientists, as can be found in the Scopus database, especially for wastewater treatment by photocatalyst system. The bibliographic analysis was used to analyze 456 published articles worldwide between 2001 and 2021. The data included cooperation with universities, countries, current research themes, links between keywords, and the largest number of citations in articles. The top 10 most influential countries indicated by the largest contribution to chitosan, especially for photocatalyst publications, are China, the USA, Canada, India, South Korea, Iran, Brazil, Malaysia, Taiwan, and France.

Some of the researchers reported chitosan by photocatalyst system for wastewater treatment by additional polymer, metal oxide, and carbon-based materials for degrading various types of pollutants, mostly from textile industries. Chitosan as adsorption by photocatalyst system has the advantage of high efficiency in wastewater treatment, which was reported for Congo red at 98.4%, methylene blue at 99.36%, rhodamine B at 95%, and Cd(II) at 94%, but every composite only adsorb a single type of pollutant. To increase the ability of chitosan-based composite to adsorb multiple types of pollutants and extend from laboratory scale to real environmental wastewater application, future studies will need to focus on several areas:

- Development of new methods is needed for producing composite chitosan with high structural and electronic properties that match with polymer, metal oxide, and carbon for high performance when reusing the material several times.
- Chitosan is a more complicated material to synthesize from raw fish by-products (waste) for reproducibility; therefore, research needs to be done to develop easy mass-production methods with high purity.
- Research needs to be done for composite chitosan-based with additional natural polymers to provide materials that are eco-friendly and do not result in second-hand waste when used for wastewater treatment.
- Studies of chitosan-based materials for other applications such as wound dressing, bioplastic, and self-cleaning should be extended from the laboratory scale to the clinical trial and then continue for mass production.

Author contribution Andi Tessiwoja Tenri Ola: collection data, analysis, and writing—original draft. Heryanto Heryanto and Bidayatul Armynah: software, validation, and writing—original draft. Dahlang Tahir: writing—original draft, editing, review, and finalization.

Data availability All data and materials generated or analyzed during this study are included in this article.

Declarations

Ethics approval Not relevant. All authors have read, understood, and complied, as applicable, with the statement on "Ethical responsibilities of authors" as found in the instructions for authors.

Consent to participate Not relevant.

Consent for publication Not relevant.

Conflict of interest The authors declare no competing interests.

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