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CHEMICAL SCIENCES

A Bibliometric Analysis of Geosmin Removal and Treatment Technologies using Web of Science Database and VOSviewer

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Abstract: In the last few years, the presence of geosmin (GEO) in water bodies has caused serious problems related to water consumption by the population. Many studies focus on its occurrence and detection, but little is discussed about the technologies for treatment and removal of this contaminant. In this way, the present work aims to present a bibliographic search and a bibliometric analysis carried out in the Web of Science database and in VOSviewer software about geosmin remediation, in the last 10 years. 100 articles were found, of which only one, from 2021, was a review. It was possible to assess that the subject has gained greater notoriety in the last 7 years, since the year 2016 marked the increase of publications on the subject, as well as an increasing number of citations. Among the most published countries is the People's Republic of China, with 53% of publications. Bibliometric analysis showed that GEO is directly related to 2-methylisoborneol (2-MIB), since both occur simultaneously in water bodies. In addition, it was possible to identify that adsorptive processes are the most used in the removal of these contaminants, followed by advanced oxidative processes and biological processes, in that order.

Key words: Taste and Odor compounds, Remediation, Water, Technologies, Bibliometric Analysis.

INTRODUCTION

One of the challenges that many water supply companies often face is the problem of taste and odor in drinking water, mainly associated with geosmin (GEO) and 2-methylisoborneol (2-MIB). Both GEO and 2-MIB are saturated cyclic tertiary alcohols (Trans-1,10-Dimethyl-trans-9-decalol and 1,2,7,7-tetramethylbicyclo-[2.2.1] heptan-2-ol, respectively) and, therefore resistant to oxidation, boiling and degradation by conventional methods of water treatment (Izaguirre et al. 1982, Watson et al. 2016b, Silva et al. 2019). These compounds are mainly produced by the metabolism of blue-green algae (cyanobacteria), especially in summer. They occur naturally, and their concentrations increase during the cyanobacterial bloom period (Kim & Park 2021).

According to Paerl & Huisman (2008) anthropic activities, such as urban, agricultural and industrial development, are the main source of nutrient release in water, known as eutrophication. This is the most well-known cause of cyanobacterial blooms (Paerl & Huisman 2008, Liu et al. 2012, Paerl & Otten 2013, Huisman et al. 2018, Pham et al. 2021). However, in addition to eutrophication, cyanobacterial bloom activity is also related to high temperature environments (Paerl & Huisman 2008, Paerl et al. 2011, Paerl & Otten 2013, Huisman et al. 2018,

Rico et al. 2018, Lee et al. 2020, Kim & Park 2021), in times of high rainfall (Paerl & Otten 2013, Zhang et al. 2020, Pham et al. 2021) and below rising levels of carbon dioxide (CO_2) (Paerl et al. 2011, Huisman et al. 2018).

Several lakes in the world are constantly suffering from these cyanobacterial blooms and odorous compounds release, especially Lake Taihu in China (Duan et al. 2015, Qin et al. 2019, Xuwei et al. 2019, Zhang et al. 2019, Yao et al. 2020, Li et al. 2022), Lake Erie in the United States (Michalak et al. 2013, Smith et al. 2015, Watson et al. 2016a, Tewari et al. 2022) and Lake Victoria in Africa (Mchau et al. 2019, Olokotum et al. 2020, Roegner et al. 2020, Githukia et al. 2022). In 2020 and 2021, the Brazilian population in the state of Rio de Janeiro also witnessed an earthy odor and taste in drinking water, due to geosmin presence in Guandu river.

According to Butakova (2013), there are three fractions of GEO and 2-MIB in cyanobacteria: (i) extracellular (compounds secreted by cells in the medium); (ii) intracellular soluble (cytoplasm components); and (iii) bound intracellular (compounds linked to thylakoid membrane proteins). Alghanmi et al. (2018), when carrying out a study on the effect of light intensity and temperature under GEO and 2-MIB production by two cyanobacterial species (*Phormidium retzii* and *Microcoleus vaginatus*) observed that the compounds are retained in the intracellular fraction in the lag phase, partially released to the medium in the exponential phase and highly released in the stationary and death phases. Thus, odoriferous compounds are released when the destruction or death of cyanobacterial cells occurs, similar to what happens with cyanotoxins (Pham et al. 2021).

Despite not toxic to humans, these compounds significantly affect public confidence in relation to water consumption, since their threshold concentration for detection by humans is in the range of 4 to 10 ng L^{-1}, resulting in substantial treatment costs, affecting sectors that directly depend on this natural resource (Watson et al. 2016b). Although it has a high occurrence and detection rate, little is discussed about how to remediate these contaminants.

Bibliometric analysis has gained a lot of attention in recent years because it is a popular and rigorous method for exploring and analyzing large volumes of scientific data. In other words, bibliometric analysis is useful for deciphering and mapping the cumulative scientific knowledge and evolutionary nuances of well-established fields by means of mathematical and statistical methods for assessing bibliometric data (Donthu et al. 2021). In this way, Visualization of Similarities (VOS) viewer software, created by van Eck & Waltman (2010) appears as a tool for creating and viewing bibliometric maps to graphically present the similarity relationships between terms raised by the bibliographic data, facilitating the interpretation and visualization of the results (Tamala et al. 2022).

Thus, the current study aims to carry out a bibliographic survey and a bibliometric analysis regarding geosmin treatment and removal technologies to promote a discussion about this subject and propose new forms of remediation.

MATERIALS AND METHODS

Bibliographic data

Our bibliographic data was obtained on Web of Sciences (WOS) collection. The search was performed by filtering the presence of keywords "Geosmin", "Treatment", "Technology" and "Removal" in all collection fields, in the last ten years of publication, starting on January 1, 2012 and ending on August 31, 2022. The results were exported in tab-delimited format and the Full Record and Cited References option was selected, as directed in the program manual (van

Eck & Waltman 2022). In addition, the analysis of results provided by the database itself was verified and used.

Bibliometric Analysis

In version 1.6.18 of the VOSviewer program, maps based on WOS data were created with co-occurrence with all keywords as units of analysis, in full counting as couting method. The minimum number stipulated for the occurrence of keywords was equal to 10 and the network visualization was selected.

In this type of visualization, items are represented by their label and by default also by a circle. The size of the label and the circle of an item is determined by the weight of the item. The higher the weight of an item, the larger the label and the circle of the item. The color of an item is determined by the cluster to which the item belongs. Lines between items represent links. The stronger the link between two items, the thicker the line that is used to display the link in the visualization of the currently active map (van Eck & Waltman 2010, 2022).

RESULTS AND DISCUSSION

Bibliographic data

For the search in the WOS database with the terms “Geosmin”, “Treatment”, “Technology” and “Removal” in the last 10 years, 100 results were obtained. Of the 100, 99 are original articles and only 1 is a review. In addition, of the 100 articles, 99 are in English and only one in Portuguese (Brazil). It is observed that despite the long period of time filtered, the number of articles focused on this subject is not very expressive. Figure 1 presents the graph containing the ratio of the number of publications according to the years.

According to Figure 1, the year with the highest number of publications was 2020, with 16 articles published, followed by 2016 (15 articles), 2018 and 2021 (14 articles in both) and 2019 (11 articles). The other years had less than 10 published articles. Therefore, it is evident that this issue has been more relevant in the last 7 years. In addition, the only review article is from 2021, entitled “A critical review on geosmin and 2-methylisoborneol in water: sources, effects, detection, and removal techniques” by Mustapha et al. (2021).

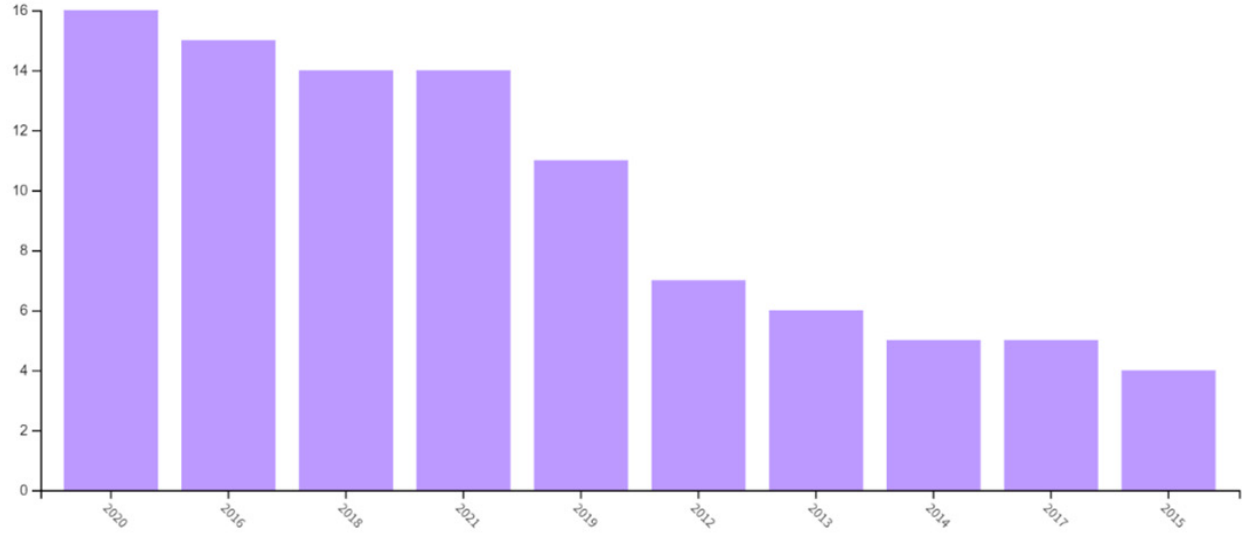

Figure 1. Number of publications over the years provided by Web of Science.

Figure 2 presents the 10 main countries responsible for publications. It is observed that more than half of the articles published (53) are from People's Republic of China, followed by South Korea (14), Japan (12) and USA (10) with equal or more than 10 publications. Brazil occupies the sixth position (5 publications), being the only country in South America to publish on the subject.

Table I presents the top 10 authors, publishers and journals. The author with the most publications is Yu, J.W., with 14 published articles, one in 2014, two in 2016, two in 2019, six in 2020 and three in 2021. The largest publisher is Elsevier, with half of the articles published (50) and among the journals with the highest number of publications, Water Research stands out with 19 articles.

Figure 3 presents the Citation Report provided by Web of Science database. The figure shows an increase in citations over the years, reinforcing the idea that this subject has gained notoriety in the last 7 years. The highest number of citations is found in 2021 (387 citations), followed by 2020 (233 citations), 2019 (203 citations), 2018 (127 citations), 2017 (104 citations) and 2016 (84 citations). Until the consulted date, 2022 presented 3 publications and 197 citations.

Thus, analyzing the results found in the WOS database, it is observed that the platform gives us general information about the researched subject, but does not promote terms similarity analysis, not informing us, for example, about the co-occurence of terms referring to technologies, treatment and removal of geosmin. Therefore, a bibliometric analysis was performed using the VOSviewer software.

Bibliometric Analysis

The bibliometric analysis map created in the VOSviewer program using de co-occurrence of keywords is presented in Figure 4. Thus, out of 598 keywords from 100 articles, 20 keywords satisfied the threshold. It is possible to observe the formation of 3 clusters, due to the 3 different colors (red, blue and green). The list of words of each cluster is presented in Table II.

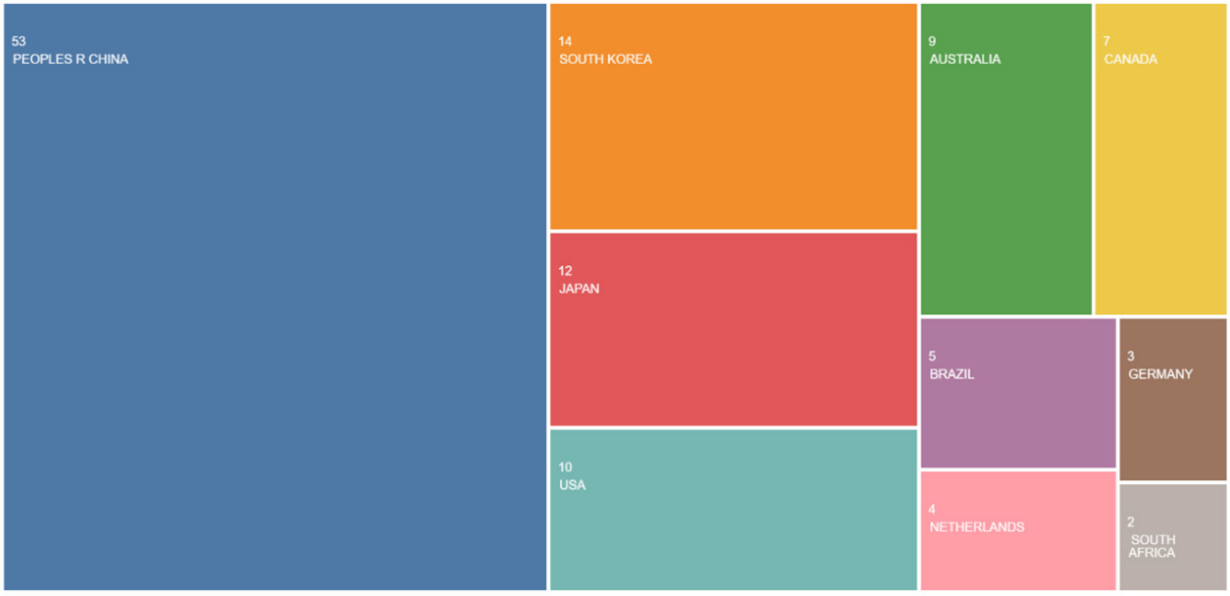

Figure 2. TreeMap graph of the top 10 countries responsible for publications provided by Web of Sciences database.

Cluster 1 (red) generically presents the main technologies found in the literature regarding the removal of GEO and 2-MIB from water bodies, with emphasis on adsorption and advanced oxidative processes. Geosmin, 2-methylisoborneol and drinking-water were the keywords with the highest co-occurrence with 67, 43 and 37 scores, respectively. Therefore, the appearance of these words in the 100 articles consulted corresponds to 67, 43 and 37% of the total publications analyzed. Then, mib, adsorption, powdered cativated carbon, natural organic matter and advanced oxidation processes appear with 27, 24, 15, 11 and 10 scores, respectively.

From Figure 4 it is possible to observe a strong relationship between the terms geosmin and 2-methylisoborneol (link strength equal to 40), due to the thickness of the line connecting the terms, which can be explained by the recurrent association of these terms in literature regarding its simultaneous presence in water (Bong et al. 2021, Kim & Park 2021, Mustapha et al. 2021).

The second most intense interaction (linking strength equal to 36) refers to the connection between the terms geosmin from cluster 1 with removal from cluster 2, followed by the association between the terms geosmin and drinking-water (linking strength equal to 26) and geosmin and adsorption (linking strength equal to 22). This is because this odorous compound is not removed by conventional water treatment processes, presenting a certain recalcitrance in water supply. As an alternative method of removal, adsorptive processes stand out.

Among the most studied adsorbents is activated carbon (AC), in its powder and superfine powder (PAC and SPAC, respectively), granular (GAC) and biological (BAC) forms (Mustapha et al. 2021). Its use as an adsorbent is due to its porosity and high surface area, thus enabling the sorption of different types of species.

Doederer et al. (2017) studied the adsorption efficiency of a BAC in a batch-scale filtration containing natural organic matter (NOM) and GEO and 2-MIB. The results indicated 99% and 97% of Geosmin and 2-MIB removal, respectively. Ma et al. (2019) obtained 99.2% and 98.0% of

Table I. Top 10 authors, publishers and journals according to Web of Science database results.

	Authors	Publishers	Journals
1	Yu, J.W. (14)	Elsevier (50)	Water Research (19)
2	Wang, C.M. (10)	IWA Publishing (16)	Chem. Eng. J. (10)
3	Yang, M. (10)	Desalination Publications (5)	Chemosphere (7)
4	Matsui, Y. (8)	Mdpi (5)	Desalin. Water Treat. (6)
5	Matsushita, T. (8)	Springer Nature (5)	J. Water Supply. Res. T. (5)
6	Guo, Q.Y. (6)	Royal Society of Chemistry (4)	Environ. Sci.: Water Res. Technol. (4)
7	Newcombe, G. (6)	Taylor & Francis (4)	Sep. Purif. Technol. (4)
8	Shirasaki, N. (6)	American Chemical Society (3)	Water Sci. Technol. (4)
9	Wang, Q. (6)	Destech Publications, Inc (2)	Water Sci. Tech.-W. Sup. (4)
10	An, W. (5)	Brazilian Chemical Society (1)	Environmental Technology (3)

*** The number in parentheses "( )" indicates the number of articles published.**

GEO and 2-MIB removal, respectively, after 2 h of contact time with GAC. Bong et al. (2021) when using a commercial PAC for GEO and 2-MIB removal, reached an efficiency above 80% for both compounds in just 20 min of contact time, the same efficiency obtained by the most recent study carried out by Chang et al. (2022) with BAC.

Thus, the use of activated carbon for adsorptive purposes is promising in terms of odorous compounds removal, even presenting poor regeneration efficiency (Mustapha et al. 2021). Alternative materials regarding the removal of contaminants via adsorptive processes are clay minerals. In addition to being economically viable and environmentally friendly, they have a porous structure, fine granulometry and high surface area (Simões et al. 2017, Novo et al. 2021), promoting the removal of different types of species, such as potentially toxic metals (Simões 2017, Esmaeili et al. 2019, Mu'azu et al. 2020), herbicides (Marco-Brown et al. 2019, Souza et al. 2019, Pereira et al. 2020) dyes (Tangaraj et al. 2017, Omer et al. 2018, Avila et al. 2021) and pharmaceuticals (Thiebault et al. 2019, Chauan et al. 2020, Silva et al. 2020, Novo et al. 2022).

In the bibliographic search carried out in the Web of Science database, only the work by Ma et al. (2013) used a clay mineral in the adsorption of odoriferous compounds. In their work, the efficiency of the removal of GEO and 2-MIB by a natural and thermally modified attapulgite was evaluated. The results indicated that the thermal process promoted significant gains in the specific surface area (14% increase) and total pore volume of the clay mineral (65% increase), improving its adsorptive capacity compared to the unmodified sample. However, low adsorption values were found (below 30% for both compounds), which were attributed by the authors to an insufficient shaking speed (160 r.p.m.) of the flasks. Thus, further studies focused on the use of this type of material in the remediation of odoriferous compounds should be carried out.

Cluster 2 (blue) more specifically points to advanced oxidative processes (AOPs), based on the removal of odorous compounds by means of ozonation. Removal was the term with the

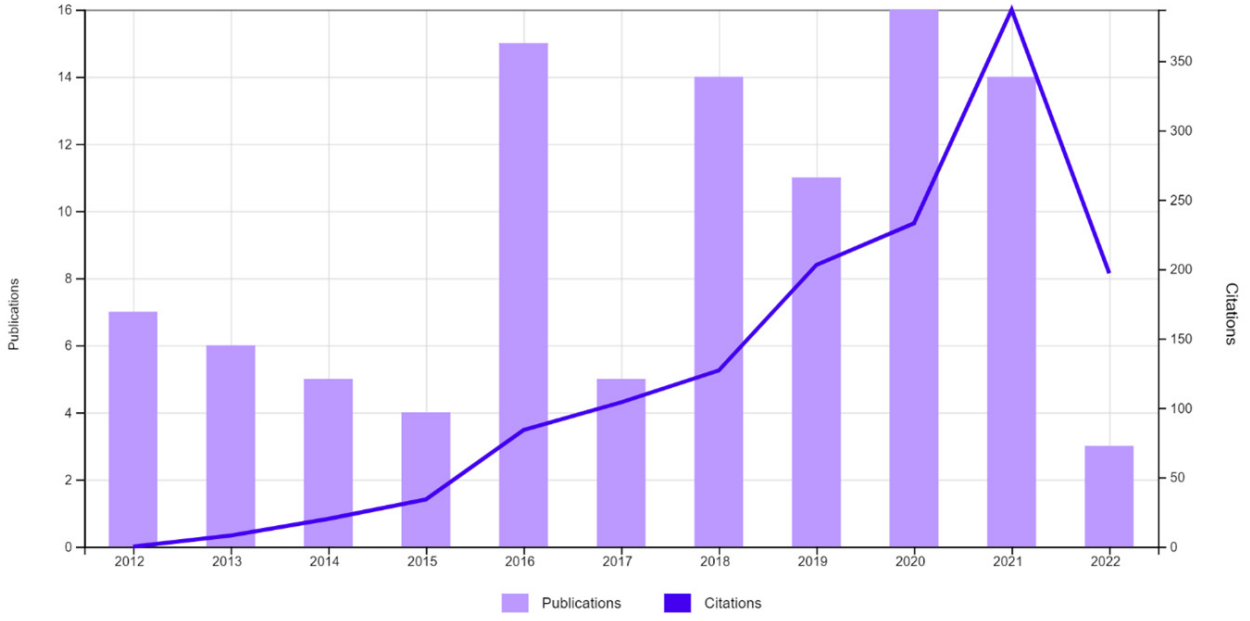

Figure 3. Times cited and publications overtime provided by Web of Science database.

highest co-occurrence in this cluster, being present in 53% of the articles. As previously described, its strongest association is with the cluster 1 geosmin term (red), followed by its association with the terms 2-methylisoborneol (link strength of 25) from cluster 1 (red) and taste (link strength of 20) from cluster 3 (green).

After removal, the most co-occuring keywords are ozonation, kinetics, degradation, disinfection by-products and ozone, with 14, 13, 12, 11 and 10 scores, respectively. Compared with the terms referring to adsorptive processes, it is observed that the co-occurrence of terms aimed at advanced oxidative processes is lower. This is because these processes are potentially costly and technically demanding (Mustapha et al. 2021), capable of producing disinfection by-products more toxic than the original target. Despite this, several studies use AOPs aiming the degradation of these compounds, obtaining significant results.

Park et al. (2017) evaluated the efficiency of GEO and 2-MIB oxidation through the photo-fenton process. For comparative purposes, they performed oxidative tests with UV-only, UV/H_2O_2 and Fe(II)/UV/H_2O_2. The results indicated 21.9% and 34.08% of GEO and 2-MIB removal, respectively, by UV-only; 32.28% and 52.10% of GEO and 2-MIB removal, respectively, by UV/H_2O_2 and 48.38% and 84.25% of GEO and 2-MIB removal, respectively, by Fe(II)/UV/H_2O_2. Thus, the authors proved the effectiveness of using the photo-fenton process, since with only 30 min of reaction, the off-flavor compounds reached a concentration under South Korea guideline level (20 ng L^{-1}). Furthermore, they

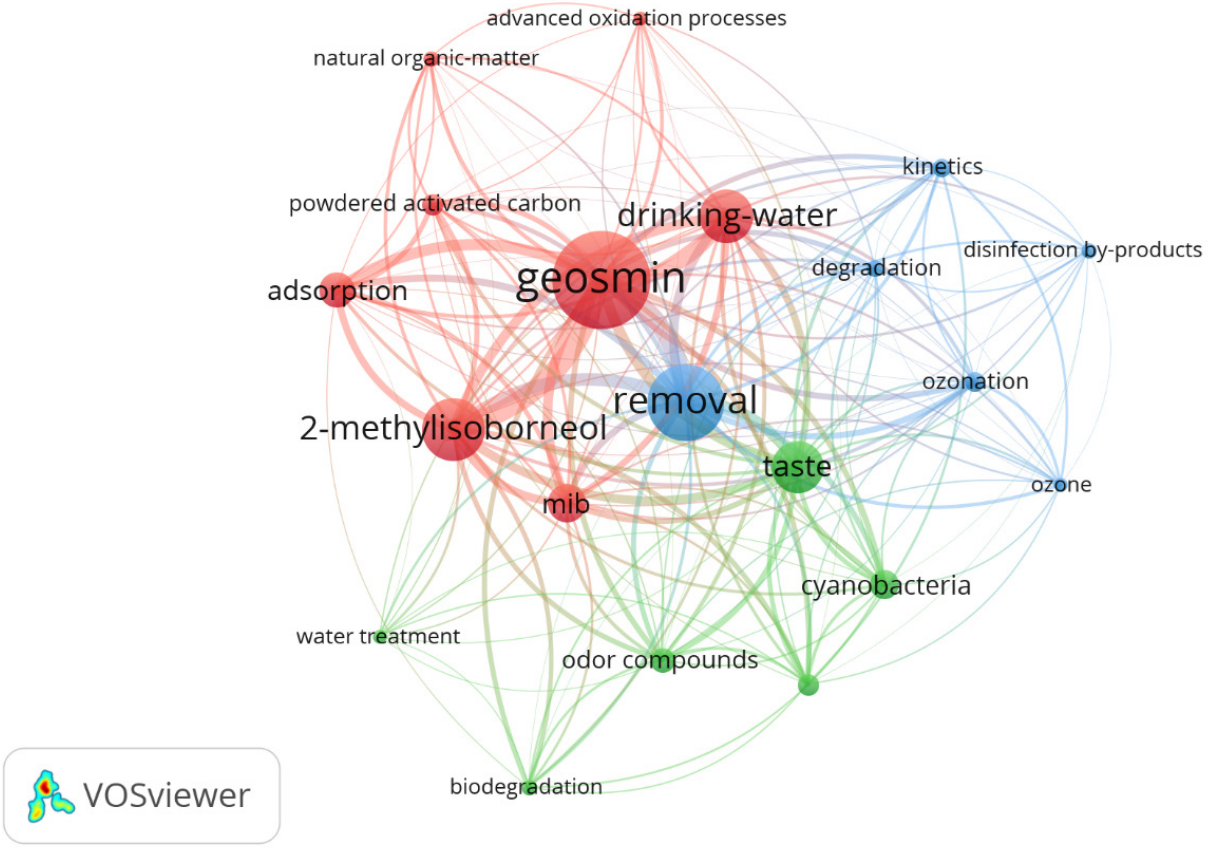

Figure 4. **Keywords co-occurence network visualization map created in VOSviewer software.**

claim that the oxidative process was also able to effectively degrade trihalomethanes (THMs) and microcystin-LR (MC-LR), derived from cyanobacterial blooms.

Visentin et al. (2019) evaluated the performance of Vacuum UV (VUV) for MC-LR, GEO and 2-MIB degradation from two canadian lakes impacted by cyanobacterial blooms. According to authors, under bloom conditions, removals of 40-60% for T&O compounds and MC-LR were achieved in the flow-through reactor. However, they observed a 20% increase of disinfection by-products formation, indicating that the implementation of this process in the off-flavors compounds remediation is promising, but should be further investigated and studied.

Pettersson et al. (2022) evaluated the removal of GEO and 2-MIB in circulating water to prevent its accumulation in fish, through four different types of oxidative treatments: O_3 low, O_3 high, H_2O_2 and O_3/H_2O_2. The results indicated that all treatments promoted a decrease in the concentration of odoriferous compounds. However, they were not effective enough to prevent their accumulation in fish flesh. Therefore, the authors state that there is a need for higher doses of O_3 and H_2O_2 to prevent the accumulation of these compounds more effectively in the circulating water and in fish flesh.

Thus, it is understood that, depending on the need for remediation, as well as the levels of contamination, the use of advanced oxidative processes ensures excellent results. However, there are still obstacles, whether financial, environmental or technical, that need more attention before being directly implemented. To minimize these disadvantages, several studies focus on the use of integrated remediation processes, that is, adsorptive coupled with oxidative processes.

Park et al. (2015) studied the comparison of the effectiveness of implementing GAC, O_3 + GAC and O_3 + H_2O_2 + GAC in NOM, GEO and 2-MIB removal in a pilot scale plant. The results indicate that O_3 + H_2O_2 + GAC was the most efficient among those studied, since, in relation to the removal of off-flavors compounds, it was 10 to 30% higher than the combination O_3 + GAC. Despite the excellent removal of the interest compounds by GAC (above 80% for both), the authors state that it was not possible to satisfy the objective of reducing the highest concentrations of GEO and 2-MIB to below 10 ng L^{-1}.

Xia et al. (2020) also evaluated the ozonation process coupled with GAC in the removal of taste and odor compounds from a Chinese river water. The results indicated that pre-ozonation alone was not sufficient to remove the two main responsible for the odor and taste of earth detected (2-MIB and bis (2-chloroisopropyl)

Table II. Keywords for each cluster of the network visualization map presented in Figure 4.

	Clusters		
	1 (Red)	**2 (Blue)**	**3 (Green)**
Keywords	2-methylisoborneol Adsorption Advanced oxidation processes Drinking-water Geosmin Mib Natural organic-matter Powdered activated carbon	Degradation Disinfection by-products Kinetics Ozonation Ozone Removal	Biodegradation Cyanobacteria Odor compounds Oxidation Taste Water treatment

ether). Best removal percentages (50%) were obtained when the pre-ozonation process was combined with coagulation, sedimentation, and sand filtration. Only after post-ozonation the desired removal was achieved with all the odorants decreased below the corresponding odor threshold concentrations in the effluents. The odor problem was only solved when GAC was coupled to the system.

Jiang et al. (2022) studied the organic and odor substances removal effects and mechanism of a pilot combined UV/H_2O_2-BAC process. The results indicated a removal of approximately 95% for both contaminants, since after the combination of the processes, both were with concentration below 5 ng L^{-1}. Thus, it is concluded that the integration of processes presents gains in the removal of contaminants, being an interesting option for the treatment of water bodies.

Cluster 3 (green) introduces biological processes as a methodology for treating these contaminants. Taste was the keyword with the highest co-occurrence from the cluster, with 36 score, followed by cyanobacteria, odor compounds, oxidation, biodegradation and water treatment with 20, 17, 15, 11 and 10 scores, respectively. In this cluster, the strengths of connection between the terms were practically the same, with no highlight. This indicates that the use of biological degradation processes in odoriferous compounds treatment is probably inferior to adsorption and advanced oxidative treatments. Furthermore, it is not found in the work of Mustapha et al. (2021), the main review article on the subject, mention of GEO and 2-MIB biodegradation processes.

It is believed that the smaller number of studies found is due to the greater difficulty in maintaining the analysis, since this process works with live microorganisms, involving greater rigor, monitoring and maintenance, in addition to the issue of biomass formed in the process. Although not so usual, possibly for these reasons, studies in the literature point to the effectiveness of this type of treatment.

Xue et al. (2012) evaluated the biodegradation of geosmin by microorganisms in biofilm from biological treatment unit of a Japan potable water treatment plant. The results showed that under the initial geosmin concentration of around 2,500 ng L^{-1}, the final geosmin removal was more than 90% (including loss rate) in most months of the year.

Ma et al. (2015) evaluated the removal of GEO and 2-MIB using bioflocs in suspended growth reactors (SGRs) produced with solid fish waste substrate from a recirculating aquaculture system (RAS). The tests occurred under in situ and in vitro conditions. The results indicated that for the analyzes performed in vitro, the highest removals were for nonsterilized bioflocs with percentages of 92.80% for GEO and 98.08% for 2-MIB. The results for in situ analyzes showed different removal percentages depending on the concentration of contaminants. The highest removals were obtained after 48 h for the lowest concentrations of GEO (100 ng L^{-1}) and 2-MIB (100 and 500 ng L^{-1}), being 85.56 ± 10.12 % and 81.5 ± 18.40 %, respectively.

Thus, it can be concluded that, despite demanding greater care, biological treatments present a high efficiency in terms of removing taste and odor compounds from water bodies.

CONCLUSIONS

From the bibliographic data carried out in the Web of Sciences database about geosmin treatment and removal technologies in the last 10 years, it was possible to assess that the subject has gained greater notoriety in the last 7 years, since the year 2016 marked the increase of publications on the subject, as well as an

increasing number of citations. 100 articles were found, only one of which was a review, published in 2021. More than half of the articles come from the People's Republic of China, which constantly suffers from cyanobacterial blooms.

Through bibliometric analysis of keywords co-occurrence performed in the VOSviewer software, it was possible to identify the main geosmin removal processes, being adsorption, advanced oxidative processes and biological processes, in that order. The material most used in adsorptive processes is activated carbon (AC), in its different forms (PAC, SPAC, GAC or BAC). Regarding advanced oxidative processes, the ozonation process deserves to be highlighted, since among the oxidative forms, it was the one with the highest frequency. In addition, many studies focus on the integration of adsorptive and oxidative processes, in order to improve the removal of these contaminants. On the other hand, biological processes, despite being apparent in the network visualization map, are still the least used for this purpose, probably due to greater difficulty in maintenance and analysis time.

All of them have high efficiency in removing odorous compounds, but also have disadvantages in terms of regeneration, operational cost and laboratory practicality. Therefore, the study of alternative materials must be carried out, aiming at a more economical and environmentally friendly process. One of the alternatives is the use of clay minerals as adsorbent materials, which in terms of odorous compounds removal needs to be further explored.

In this way, this work allowed a broad visualization of the processes currently used in geosmin remediation, as well as defining the next steps for a cleaner, more efficient and sustainable remediation.

Acknowledgments

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REFERENCES

ALGHANMI HA, ALKAM FM & AL-TAEE MM. 2018. Effect of light and temperature on new cyanobacteria producersfor geosmin and 2-methylisoborneol. J Appl Phycol 30: 319-328.

AVILA MC, LICK ID, COMELLI NA & RUIZ ML. 2021. Adsorption of an anionic dye from aqueous solution on a treated clay. Groundw Sustain Dev 15: 100688.

BONG T, KANG J-K, YARGEAU V, NAM H-L, LEE S-H, CHOI J-W, KIM S-B & PARK J-A. 2021. Geosmin and 2-methylisoborneol adsorption using different carbon materials: Isotherm, kinetic, multiple linear regression, and deep neural network modeling using a real drinking water source. J Clean Prod 314: 127967.

BUTAKOVA EA. 2013. Specific Features of Odor-Causing Compounds (Geosmin and 2-Methylisoborneol) as Secondary Metabolites of Cyanobacteria. Russ J Plant Physiol 60: 507-510.

CHANG H, YU H, LI X, ZHOU Z, LIANG H, SONG W, JI H, LIANG Y & VIDIC RD. 2022. Role of biological granular activated carbon in contaminant removal and ultrafiltration membrane performance in a full-scale system. J Membr Sci 644: 120122.

CHAUAN M, SAINI VK & SUTHAR S. 2020. Removal of pharmaceuticals and personal care products (PPCPs) from water by adsorption on aluminum pillared clay. J Porous Mater 27: 383-393.

DOEDERER K, DE VERA GA, ESPINO MP, PYPE M-L, GALE D & KELLER J. 2017. MIB and geosmin removal during adsorption and biodegradation phases of GAC filtration. Water Sci Technol 18: 1449-1455.

DONTHU N, KUMAR S, MUKHERJEE D, PANDEY N & LIM WM. 2021. How to conduct a bibliometric analysis: An overview and guidelines. J Bus Res 133: 285-296.

DUAN H, LOISELLE SA, ZHU L, FENG L, ZHANG Y & MA R. 2015. Distribution and incidence of algal blooms in Lake Taihu. Aquat Sci 77: 9-16.

ESMAEILI A, MOBINI M & ESLAMI, H. 2019. Removal of heavy metals from acid mine drainage by native natural clay minerals, batch and continuous studies. Appl Water Sci 9: 97.

GITHUKIA C, ONYANGO D, LUSWETI D, RAMKAT R, KOWENJE C, MIRUKA J, LUNG'AYIA H & ORINA P. 2022. An Analysis of Knowledge, Attitudes and Practices of Communities in Lake Victoria, Kenya on Microcystin Toxicity. Open J Ecol 12: 198-210.

HUISMAN J, CODD GA, PAERL HW, IBELINGS BW, VERSPAGEN JMH & VISSER PM. 2018. Cyanobacterial blooms. Nat Rev Microbiol 16: 471-483.

IZAGUIRRE G, HWANG CJ, KRASNER SW & MCGUIRE MJ. 1982. Geosmin and 2- Methylisoborneol from Cyanobacteria in Three Water Supply Systems. Appl Environ Microbiol 43: 708-714.

JIANG Q, WANG Y, TIAN L, LIU Y, LIU J, HE G & LI J. 2022. Pilot-scale and mechanistic study of the degradation of typical odors and organic compounds in drinking water by a combined UV/H2O2-BAC process. Chemosphere 292: 133419.

KIM K & PARK Y-G. 2021. Geosmin and 2-MIB Removal by Full-Scale Drinking Water Treatment Processes in the Republic of Korea. Water: 13: 628.

LEE JE, YOU S-J, BYEON M & YU S. 2020. Occurrence of cyanobacteria, actinomycetes, and geosmin in drinking water reservoir in Korea: a case study from an algal bloom in 2012. Water Supply 20: 1862-1870.

LI H, GU X, CHEN H, MAO Z, SHEN R, ZENG Q & GE Y. 2022. Co-occurrence of multiple cyanotoxins and taste-and-odor compounds in the large eutrophic Lake Taihu, China: Dynamics, driving factors, and challenges for risk assessment. Environ Pollut 294: 118594.

LIU Y, GAO B, YUE Q, GUAN Y, WANG Y & HUANG L. 2012. Influences of two antibiotic contaminants on the production, release and toxicity of microcystins. Ecotoxicol Environ Saf 77: 79-87.

MA C, ZUO X, SHI W, YU S, HAN S, HEIJMAN SGJ & RIETVELD LC. 2013. Adsorption of 2-methylisoborneol and geosmin from water onto thermally modified attapulgite. Desalin Water Treat 52: 999-1006.

MA L, PENG F, LI H, WANG C & YANG Z. 2019. Adsorption of geosmin and 2-methylisoborneol onto granular activated carbon in water: isotherms, thermodynamics, kinetics and influencing factors. Water Sci Technol 80: 644-653.

MA N, LUO G, TAN H, LI L & WANG X. 2015. Removal of geosmin and 2-methylisoborneol by bioflocs produced with aquaculture waste. Aquac Int 24: 345-356.

MARCO-BROWN JL, GAIGNEAUX EM, TORRES SÁNCHEZ RM & AFONSO MS. 2019. Adsorption of picloram on clays nontronite, illite and kaolinite: equilibrium and herbicide-clays surface complexes. J Environ Sciand Health B 54: 281-289.

MCHAU GJ, MAKULE E, MACHUNDA R, GONG YY & KIMANYA M. 2019. Harmful algal bloom and associated health risks among users of Lake Victoria freshwater: Ukerewe Island, Tanzania. J Water Health 17: 826-836.

MICHALAK AM ET AL. 2013. Record-setting algal bloom in Lake Erie caused by agricultural and meteorological trends consistent with expected future conditions. Proc Natl Acad Sci 110: 6448-6452.

MU'AZU ND, BUKHARI A & MUNEF K. 2020. Effect of montmorillonite content in natural Saudi Arabian clay on its adsorptive performance for single aqueous uptake of Cu(II) and Ni(II). J King Saud Univ Sci 32: 412-422.

MUSTAPHA S, TIJANI JO, NDAMITSO M, ABDULKAREEM AS, SHUAIB DT & MOHAMMED AK. 2021. A critical review on geosmin and 2-methylisoborneol in water: sources, effects, detection, and removal techniques. Environ Monit Assess 193: 204.

NOVO BL, BRASILEIRO FAG, BARBATO CN, SILVA FANG, BERTOLINO LC & YOKOYAMA L. 2021. Technological Evaluation of Cubati/Brazil Montmorillonite. Braz J Dev 7: 5203-5222.

NOVO BL, SILVA FANG, BERTOLINO LC & YOKOYAMA L. 2022. Amoxicillin Trihydrate Characterization and investigative adsorption using a Brazilian montmorillonite. Matéria 27: e20220109.

OLOKOTUM M, MITROI V, TROUSSELLIER M, SEMYALO R, BERNARD C, MONTUELLE B, OKELLO W, QUIBLIER C & HUMBERT J-F. 2020. A review of the socioecological causes and consequences of cyanobacterial blooms in Lake Victoria. Harmful Algae 96: 101829.

OMER OS, HUSSEIN MA, HUSSEIN BHM & MGAIDI A. 2018. Adsorption thermodynamics of cationic dyes (methylene blue and crystal violet) to a natural clay mineral from aqueous solution between 293.15 and 323.15 K. Arab J Chem 11: 615-623.

PAERL HW, HALL NS & CALANDRINO ES. 2011. Controlling harmful cyanobacterial blooms in a world experiencing anthropogenic and climatic-induced change. Sci Total Environ 409: 1739-1745.

PAERL HW & HUISMAN J. 2008. Blooms like it hot. Science 320: 57-58.

PAERL HW & OTTEN TG. 2013. Harmful cyanobacterial blooms: causes, consequences and controls. Microb Ecol 65: 995-1010.

PARK H, KIM T-Y, WOO D & CHO Y-S. 2015. Comparison of O3 + GAC, O3 + H2O2 + GAC, and GAC unit operation on natural organic matter and taste and odor causing compounds removal using a pilot plant study. Water Sci Technol 15: 1383-1395.

PARK J-A, NAM H-L, CHOI J-W, HA J & LEE S-H. 2017. Oxidation of geosmin and 2-methylisoborneol by the photo-Fenton process: Kinetics, degradation intermediates, and the removal of microcystin-LR and trihalomethane from Nak-Dong River water, South Korea. Chem Eng J 313: 345-354.

PEREIRA RC, DA COSTA ACS, IVASHITA FF, PAESANO A & ZAIA DAM. 2020. Interaction between glyphosate and montmorillonite in the presence of artificial seawater. Heliyon 6: e03532.

PETTERSSON SJ, LINDHOLM-LEHTO PC, PULKKINEN JT, KIURU T & VIELMA J. 2022. Effect of ozone and hydrogen peroxide on off-flavor compounds and water quality in a recirculating aquaculture system, Aquac Eng 98: 102277.

PHAM T-L, BUI MH, DRISCOLL M, SHIMIZU K & MOTOO U. 2021. First report of geosmin and 2-methylisoborneol (2-MIB) in Dolichospermum and Oscillatoria from Vietnam. Limnology 22: 43-56.

QIN B, PAERL HW, BROOKES JD, LIU J, JEPPESEN E, ZHU G, ZHANG Y, XU H, SHI K & DENG J. 2019. Why Lake Taihu continues to be plagued with cyanobacterial blooms through 10 years (2007-2017) efforts. Sci Bull 64: 354-356.

RICO A, ZHAO W, GILLISSEN F, LÜRLING M & VAN DEN BRINK PJ. 2018. Effects of temperature, genetic variation and species competition on the sensitivity of algae populations to the antibiotic enrofloxacin. Ecotoxicol Environ Saf 148: 228-236.

ROEGNER A ET AL. 2020. Harmful Algal Blooms Threaten the Health of Peri-Urban Fisher Communities: A Case Study in Kisumu Bay, Lake Victoria, Kenya. Expo Health 12: 835-848.

SILVA DTC, FONSECA MG, BORREGO-SÁNCHEZ A, SOARES MFR, VISERAS C, SAINZ-DÍAZ C & SOARES-SOBRINHO JL. 2020. Adsorption of tamoxifen on montmorillonite surface. Microporous Mesoporous Mater 297: 110012.

SILVA GSP, DE LIMA LS & QUINÁIA SP. 2019. Remoção dos Compostos MIB e Geosmina de Água de Abastecimento Usando Carvão Ativado de Caroço de Pêssego. Rev Virtual Quim 11: 673-685.

SIMÕES KMA. 2017. Caracterização tecnológica e beneficiamento da Palygorskita do Piauí para aplicação como adsorvedor de chumbo e cádmio em efluentes. Master's Thesis in Science. Federal University of Rio de Janeiro. Rio de Janeiro. (Unpublished).

SIMÕES KMA, NOVO BL, FELIX AAS, AFONSO JC, BERTOLINO L & SILVA FANG. 2017. Ore Dressing and Technological Characterization of Palygorskite from Piauí/Brazil for Application as Adsorbent of Heavy Metals. Characterization Of Minerals, Metals, And Materials 2017, p. 261-267.

SMITH DR, KING KW & WILLIAMS MR. 2015. What is causing the harmful algal blooms in Lake Erie? J Soil Water Conserv 70: 27A-29A.

SOUZA FM, SANTOS OAA & VIEIRA MGA. 2019. Adsorption of herbicide 2,4-D from aqueous solution using organo-modified bentonite clay. Environ Sci Pollut Res 26: 18329-18342.

TAMALA JK, MARAMAG EI, SIMEON KA & IGNACIO JJ. 2022. A bibliometric analysis of sustainable oil and gas production research using VOSviewer, Cleaner Eng Tech 7: 100437.

TANGARAJ V, JANOT JM, JABER M, BECHELANY M & BALME S. 2017. Adsorption and photophysical properties of fluorescent dyes over montmorillonite and saponite modified by surfactant. Chemosphere 184: 1355-1361.

TEWARI M, KISHTAWAL CM, MORIARTY VW, RAY P, SINGH T, ZHANG L, TREINISH L & TEWARI K. 2022. Improved seasonal prediction of harmful algal blooms in Lake Erie using large-scale climate indices. Commun Earth Environ 3: 195.

THIEBAULT T, BOUSSAFIR M, FOUGÈRE L, DESTANDAU E, MONNIN L & MILBEAU CL. 2019. Clay minerals for the removal of pharmaceuticals: Initial investigations of their adsorption properties in real wastewater effluents. Environ Nanotechnol Monit Manag 12: 100266.

VAN ECK NJ & WALTMAN L. 2010. Software survey: VOSviewer, a computer program for bibliometric mapping. Scientometrics 84: 523-538.

VAN ECK NJ & WALTMAN L. 2022. VOSviewer Manual. Manual for VOSviewer version 1 .6.18.

VISENTIN F, BHARTIA S, MOHSENI M, DORNER S & BARBEAU B. 2019. Performance of vacuum UV (VUV) for the degradation of MC-LR, geosmin, and MIB from cyanobacteria-impacted waters. Environmental Science: Water Res Technol 5: 2048-2058.

WATSON SB ET AL. 2016a. The re-eutrophication of Lake Erie: Harmful algal blooms and hypoxia. Harmful Algae 56: 44-66.

WATSON SB, MONIS P, BAKER P & GIGLIO S. 2016b. Biochemistry and genetics of tast and odor-producing cyanobacteria. Harmful Algae 54: 112-127.

XIA P, ZHANG S, YU J, YE H, ZHANG D, JIANG L, WANG Z & YIN D. 2020. Complex odor control based on ozonation/GAC advanced treatment: optimization and application in one full-scale water treatment plant. EnvironSci Eur 32.

XUE Q, SHIMIZU K, SAKHARKAR MK, UTSUMI M, CAO G, LI M, ZHANG Z & SUGIURA N. 2011. Geosmin degradation by seasonal biofilm from a biological treatment facility. Environ Sci Pollut Res 19: 700-707.

XUWEI D, MIN Q, REN REN, JIARUI L, XIAOXUE S, PING X & JUN C. 2019. The relationships between odors and environmental factors at bloom and non-bloom area in Lake Taihu, China. Chemosphere 218: 569-576.

YAO X, ZHANG Y, ZHANG L, ZHU G, QIN B, ZHOU Y & XUE J. 2020. Emerging role of dissolved organic nitrogen in supporting algal bloom persistence in Lake Taihu, China: Emphasis on internal transformations. Sci Total Environ 736: 139497.

ZHANG Q ET AL. 2020. Cyanobacterial blooms contribute to the diversity of antibiotic-resistance genes in aquatic ecosystems. Commun Biol 3.

ZHANG R, QI F, LIU C, ZHANG Y, WANG Y, SONG Z, KUMIRSKA J & SUN D. 2019. Cyanobacteria derived taste and odor characteristics in various lakes in China: Songhua Lake, Chaohu Lake and Taihu Lake. Ecotoxicol Environ Saf 181: 499-507.

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