Supporting Information

A quantitative analysis of drinking water treatments for the removal of dissolved microcystins

Yanyan Zhang[a,b,c,e*], Joann K. Whalen[b], Chen Cai[d], Sung Vo Duy[c], Gabriel Munoz[c], Sébastien Sauvé[c]

[a] Sichuan Agricultural University, College of Resources, Chengdu, 611130, China

[b] McGill University, Department of Natural Resource Science, Macdonald Campus, 21,111 Lakeshore Road, Ste-Anne-de Bellevue, Quebec, H9X 3V9, Canada

[c] Université de Montréal, Department of Chemistry, C.P. 6128, Succursale Centre-Ville, Montréal, Quebec, H3C 3J7, Canada

[d] Tongji University, State Key Laboratory of Pollution Control and Resources Reuse, School of Environmental Science and Engineering, Shanghai, 200092, China

[e] Key Laboratory of Investigation and Monitoring, Protection and Utilization for Cultivated Land Resources, Ministry of Natural Resources, China

* Corresponding author. yanyan.zhang@sicau.edu.cn

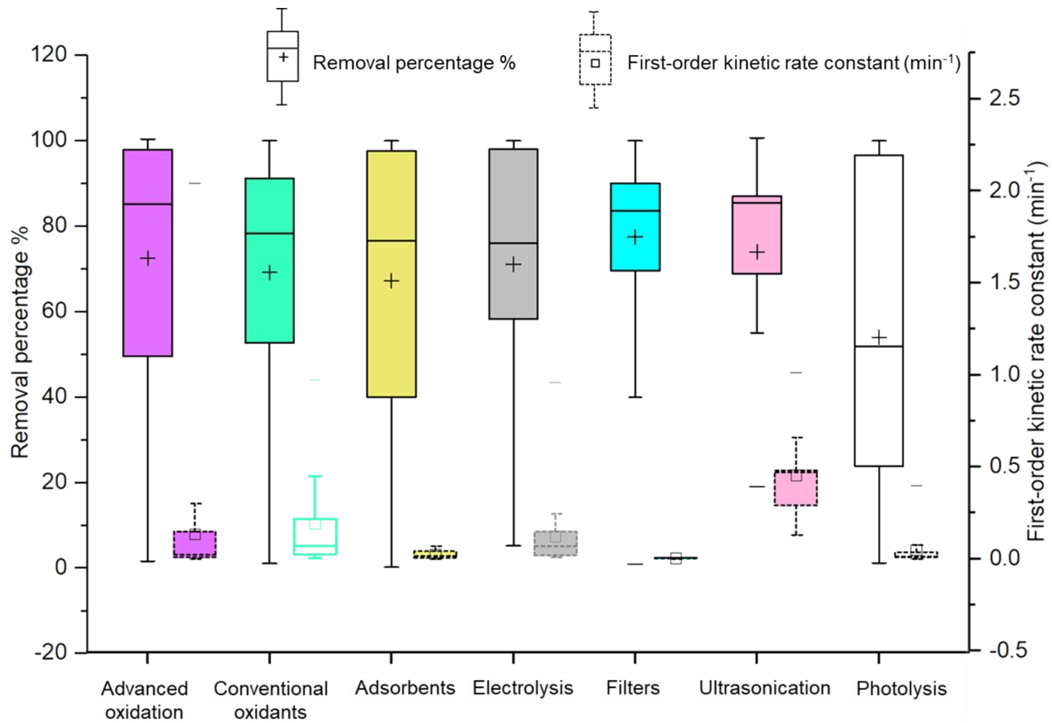
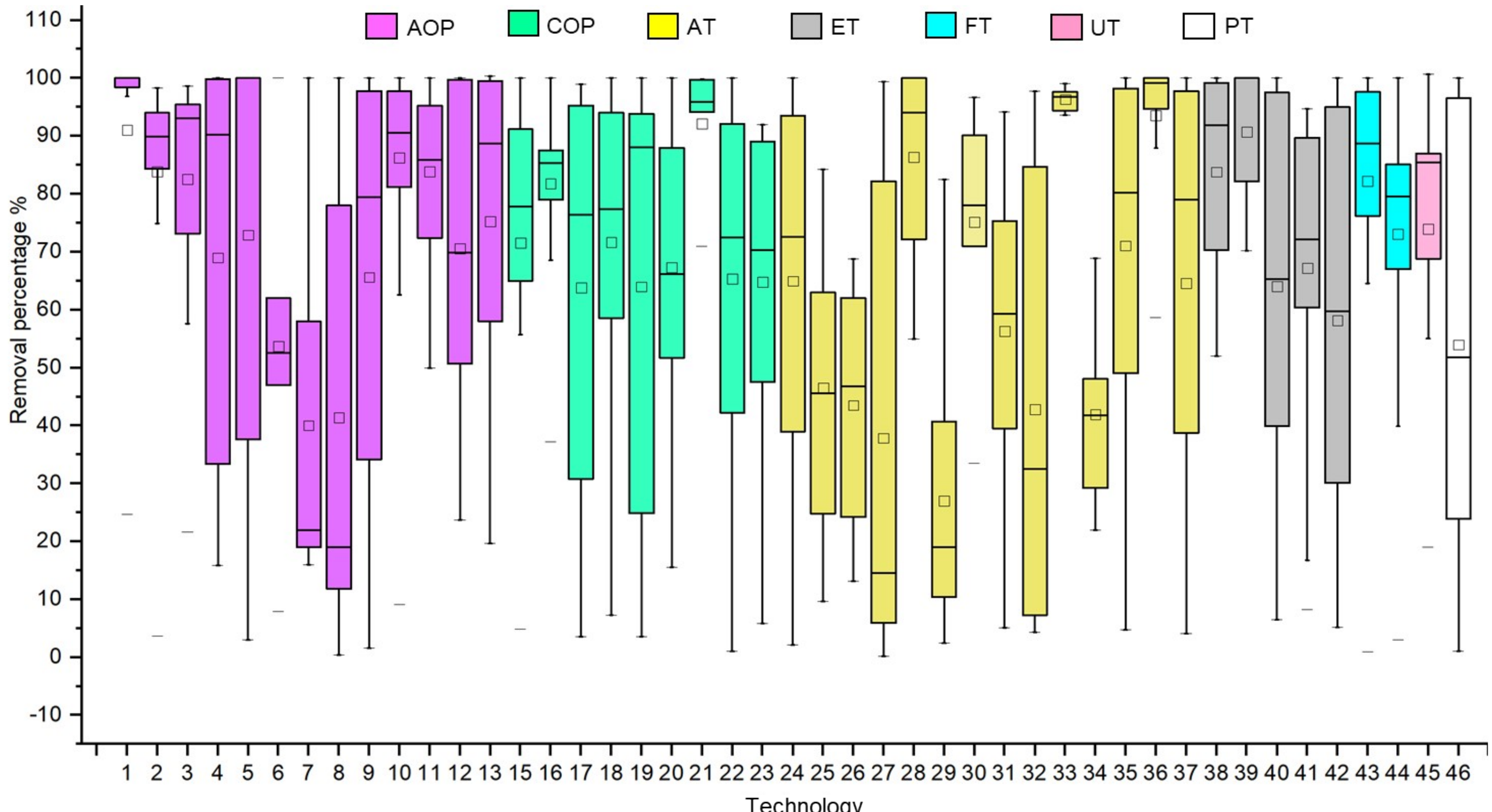


Figure S1. Mean microcystin removal from water (%) and first-order kinetic rate constant (min^{-1}) of 7 technologies that treated microcystins-contaminated water with adsorbents, advanced oxidation, conventional oxidants, photolysis, electrolysis, filters and ultrasonication. Boxplots display interquartile range, median (horizontal line), min and max (whiskers), and mean (+,▫).



1	Ag_3PO_4 photocatalyst	8	Ozone/H_2O_2	15	Chlorine	22	O_3	29	Graphene oxide	36	Rich husk	43	Membrane filter
2	Bi_2WO_6 photocatalyst	9	TiO_2 photocatalyst	16	Chlorine dioxide	23	Peroxymonosulfate	30	Graphitized sand	37	Sillica	44	Sand filter
3	ZnO nanoparticle	10	UV/H_2O_2	17	Fe(II)	24	Activated carbon	31	Iron oxide nanoparticles	38	BDD electrode	45	Ultrasound
4	Fenton reagent	11	UV/O_3	18	Fe(VI)	25	Bamboo-based charcoal	32	Magnetite	39	$PbCrO_4$ nanorod	46	UV
5	GO@nano-silver	12	$ZnFe_2O_4$ nanocomposite	19	H_2O_2	26	Carbon nanotube	33	Microgel-Fe(III)	40	RuO_2-TiO_2/Ti anode		
6	Maghemite	13	WO_3 photocatalyst	20	$KMnO_4$	27	Clay	34	Plastic	41	Ti/Pt electrode		
7	Ozone/Fenton	14	Plasma	21	Magnetic bentonite	28	Gel	35	Resin	42	TiO_2@carbon electrode		

Figure S2. Mean removal (%) of microcystins amongst the 46 water treatments. Boxplots display interquartile range, median (horizontal line), min and max (whiskers), and mean (square).

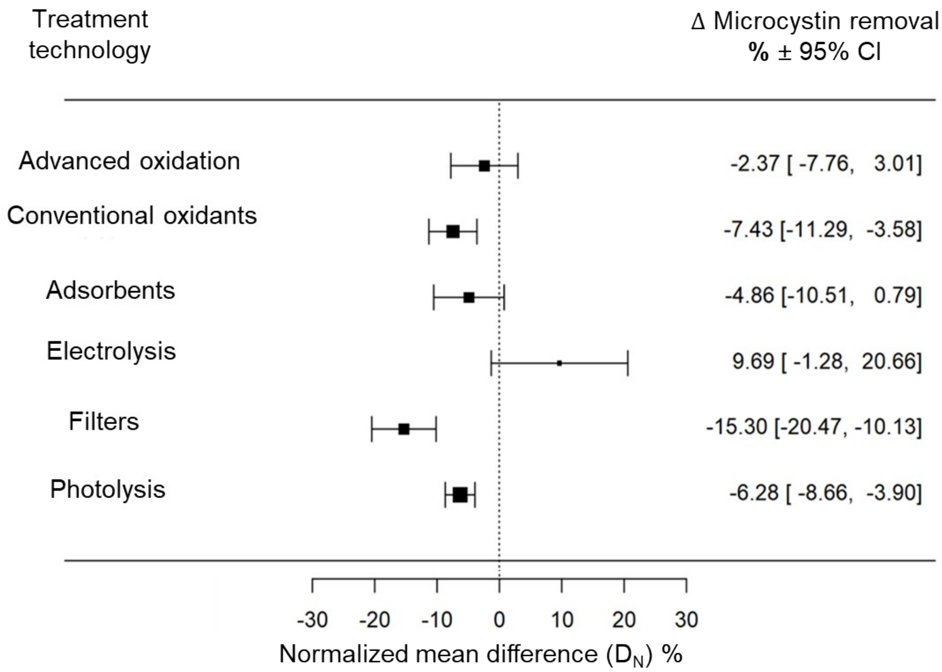


Figure S3. Normalized mean difference of Standardized Removal Efficiency (SRE) for microcystin removal between pure and natural water under different water treatments.

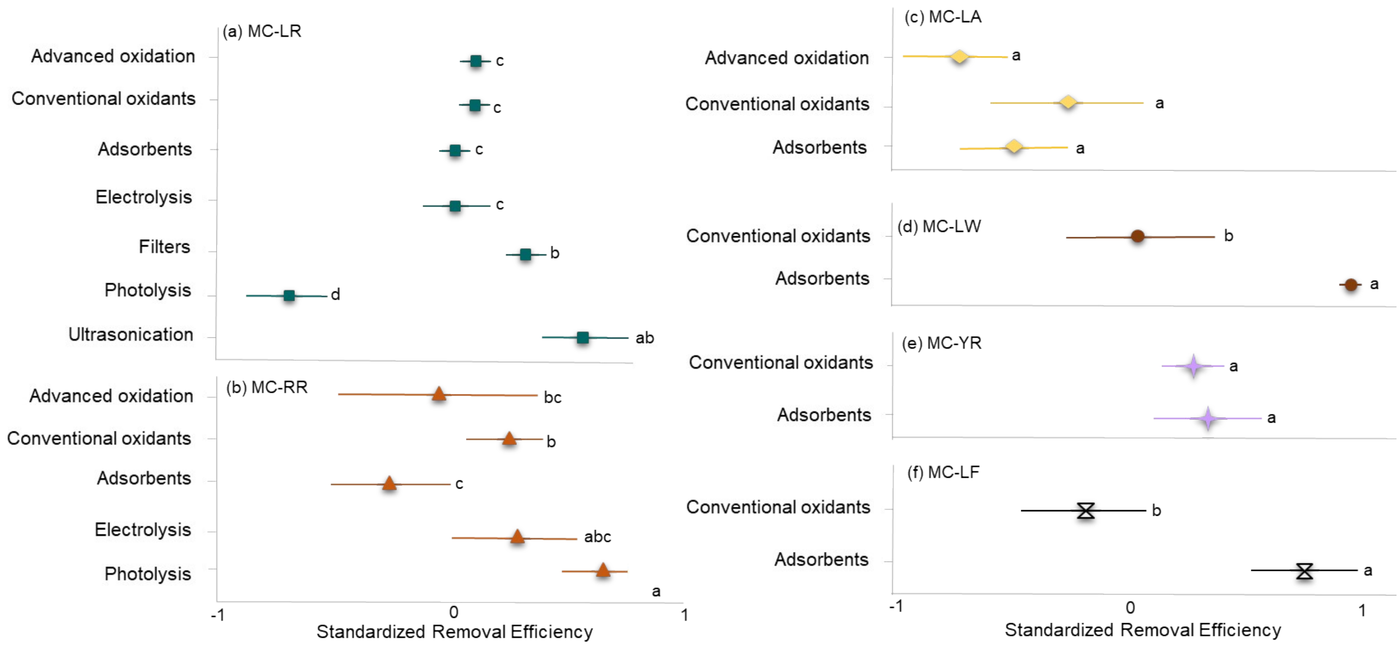


Figure S4. Standard microcystin removal efficiencies (mean ± 95% confidential interval; SRE), grouped by technologies that treated microcystin-contaminated water with adsorbents, advanced oxidation, and conventional oxidants, as affected by the presence of distinct microcystin congeners (a) MC-LR, (b) MC-RR, (c) MC-LA, (d) MC-LW, (e) MC-YR, and (f) MC-LF. Different letters in the same microcystin congener indicate a significance difference between treatment technologies ($\alpha = 0.05$) using meta-analysis test.

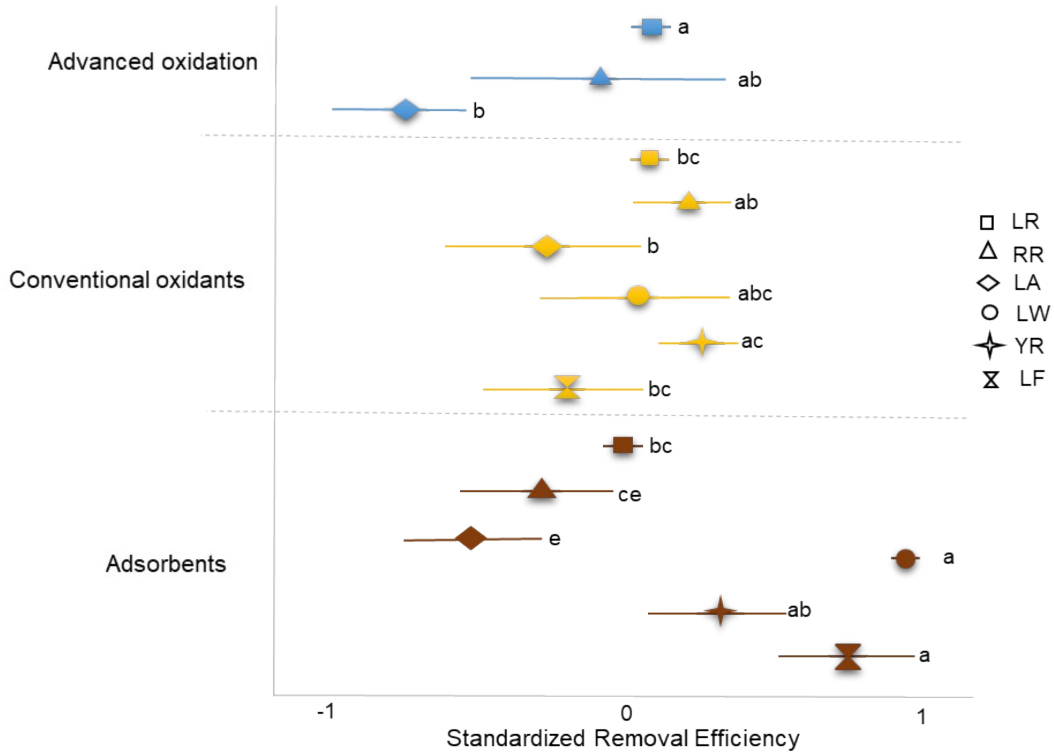


Figure S5. Standard removal efficiencies (mean ± 95% confidential interval; SRE) for the full dataset categorized by microcystin congeners. Different letters in the same color indicate a significance difference between congeners under the same treatment technology (α = 0.05).

Table S1. Data associated with multi-criteria decision analysis.

		Criteria			
		R% (Mean)	Kinetic rate (Mean)	Maturity (Number of study (%))	Applicability (Normalized mean difference between pure and field water)
	Weight	0.34	0.21	0.17	0.28
Technology	Advanced oxidation	73	0.12	20	-2
	Conventional oxidants	69	0.19	23	-7
	Adsorbents	67	0.02	26	-5
	Electrolysis	71	0.12	7	10
	Filters	77	0.004	5	-15
	Ultrasonication	74	0.46	2	NA
	Photolysis	54	0.05	13	-6

Appendix. S1. Bibliography of studies included in the meta-analysis.

1. Acero, J.L., Rodriguez, E., Meriluoto, J., 2005. Kinetics of reactions between chlorine and the cyanobacterial toxins microcystins. Water Research 39, 1628-1638.
2. Albuquerque Júnior, E.C.d., Méndez, M.O.A., Coutinho, A.d.R., Franco, T.T., 2008. Removal of cyanobacteria toxins from drinking water by adsorption on activated carbon fibers. Materials Research 11, 371-380.
3. Antoniou, M.G., Boraei, I., Solakidou, M., Deligiannakis, Y., Abhishek, M., Lawton, L.A., Edwards, C., 2018. Enhancing photocatalytic degradation of the cyanotoxin microcystin-LR with the addition of sulfate-radical generating oxidants. Journal of Hazardous Materials 360, 461-470.
4. Antoniou, M.G., Nicolaou, P.A., Shoemaker, J.A., de la Cruz, A.A., Dionysiou, D.D., 2009. Impact of the morphological properties of thin TiO2 photocatalytic films on the detoxification of water contaminated with the cyanotoxin, microcystin-LR. Applied Catalysis B: Environmental 91, 165-173.
5. Badar, M., Khan, S., Khokhar, I., Batool, F., 2015. Removal of cyanobacterial toxins from drinking water sources by aluminium sulphate treatment. Brazilian Journal of Biological Sciences 2, 135-145.
6. Bakheet, B., Islam, M.A., Beardall, J., Zhang, X., McCarthy, D., 2018. Effective electrochemical inactivation of Microcystis aeruginosa and degradation of microcystins via a novel solid polymer electrolyte sandwich. Chemical Engineering Journal 350, 616-626.
7. Bandala, E.R., Martínez, D., Martınez, E., Dionysiou, D.D., 2004. Degradation of microcystin-LR toxin by Fenton and Photo-Fenton processes. Toxicon 43, 829-832.
8. Bavithra, G., Azevedo, J., Oliveira, F., Morais, J., Pinto, E., Ferreira, I.M., Vasconcelos, V., Campos, A., Almeida, C.M.R., 2020. Assessment of Constructed Wetlands' Potential for the Removal of Cyanobacteria and Microcystins (MC-LR). Water 12, 10.
9. Baziar, M., Azari, A., Karimaei, M., Gupta, V.K., Agarwal, S., Sharafi, K., Maroosi, M., Shariatifar, N., Dobaradaran, S., 2017. MWCNT-Fe_3O_4 as a superior adsorbent for microcystins LR removal: Investigation on the magnetic adsorption separation, artificial neural network modeling, and genetic algorithm optimization. Journal of Molecular Liquids 241, 102-113.
10. Bober, B., Pudas, K., Lechowski, Z., Bialczyk, J., 2008. Degradation of microcystin-LR by ozone in the presence of Fenton reagent. Journal of Environmental Science and Health, Part A 43, 186-190.
11. Camacho-Muñoz, D., Fervers, A.-S., Pestana, C.J., Edwards, C., Lawton, L.A., 2020. Degradation of microcystin-LR and cylindrospermopsin by continuous flow UV-A photocatalysis over immobilised TiO_2. Journal of Environmental Management 276, 111368.
12. Campinas, M., Rosa, M.J., 2010. Removal of microcystins by PAC/UF. Separation and Purification Technology 71, 114-120.
13. Chae, S., Noeiaghaei, T., Oh, Y., Kim, I.S., Park, J.-S., 2019. Effective removal of emerging dissolved cyanotoxins from water using hybrid photocatalytic composites. Water Rresearch 149, 421-431.

14. Chang, J., Chen, Z., Wang, Z., Kang, J., Chen, Q., Yuan, L., Shen, J., 2015. Oxidation of microcystin-LR in water by ozone combined with UV radiation: the removal and degradation pathway. Chemical Engineering Journal 276, 97-105.
15. Chang, S.C., Lu, B.L., Lin, J.J., Li, Y.H., Lee, M.R., 2017. A Method to Prepare Magnetic Nanosilicate Platelets for Effective Removal of Microcystis aeruginosa and Microcystin-LR, Microbial Toxins. Springer, pp. 85-94.
16. Chen, G., Ding, X., Zhou, W., 2020. Study on ultrasonic treatment for degradation of Microcystins (MCs). Ultrasonics Sonochemistry 63, 104900.
17. Chen, P., Zhu, L., Fang, S., Wang, C., Shan, G., 2012. Photocatalytic Degradation Efficiency and Mechanism of Microcystin-RR by Mesoporous Bi_2WO_6 under Near Ultraviolet Light. Environmental Science & Technology 46, 2345-2351.
18. Chen, X., Xiao, B., Liu, J., Fang, T., Xu, X., 2005. Kinetics of the oxidation of MCRR by potassium permanganate. Toxicon 45, 911-917.
19. Chen, Y., Zhang, X., Liu, Q., Wang, X., Xu, L., Zhang, Z., 2015. Facile and economical synthesis of porous activated semi-cokes for highly efficient and fast removal of microcystin-LR. Journal of Hazardous Materials 299, 325-332.
20. Cheng, R., Zhu, H., Shutes, B., Yan, B., 2020. Treatment of microcystin (MC-LR) and nutrients in eutrophic water by constructed wetlands: performance and microbial community. Chemosphere, 128139.
21. Chintalapati, P., Mohseni, M., 2020. Degradation of cyanotoxin microcystin-LR in synthetic and natural waters by chemical-free UV/VUV radiation. Journal of Hazardous Materials 381, 120921.
22. Choi, H., Antoniou, M.G., Pelaez, M., De la Cruz, A.A., Shoemaker, J.A., Dionysiou, D.D., 2007. Mesoporous nitrogen-doped TiO_2 for the photocatalytic destruction of the cyanobacterial toxin microcystin-LR under visible light irradiation. Environmental Science & Technology 41, 7530-7535.
23. Cornish, B.J., Lawton, L.A., Robertson, P.K., 2000. Hydrogen peroxide enhanced photocatalytic oxidation of microcystin-LR using titanium dioxide. Applied Catalysis B: Environmental 25, 59-67.
24. Couto, R.S.P., Guarino, A.W.S., Branco, C.W.C., Palermo, E.F.A., Azero, E.G., 2013. Application of clay minerals and polymeric resins to remove dissolved microcystin-LR from water. International Journal of Environmental Research 7, 435-442.
25. Dai, G., Gan, N., Song, L., Fang, S., Peng, N., 2018. Fast adsorption of microcystin-LR by Fe (III)-modified powdered activated carbon. Journal of Oceanology and Limnology 36, 1103-1111.
26. Dai, G., Quan, C., Zhang, X., Liu, J., Song, L., Gan, N., 2012. Fast removal of cyanobacterial toxin microcystin-LR by a low-cytotoxic microgel-Fe(Ⅲ) complex. Water Research 46, 1482-1489.
27. de Almeida Torres, M., Micheletto, J., de Liz, M.V., Pagioro, T.A., Martins, L.R.R., de Freitas, A.M., 2020. Microcystis aeruginosa inactivation and microcystin-LR degradation by the photo-Fenton process at the initial near-neutral pH. Photochemical & Photobiological Sciences.
28. de Freitas, A.M., Sirtori, C., Lenz, C.A., Peralta Zamora, P.G., 2013. Microcystin-LR degradation by solar photo-Fenton, UV-A/photo-Fenton and UV-C/H_2O_2: a comparative study. Photochemical & Photobiological Sciences 12, 696-702.
29. Ding, J., Shi, H., Timmons, T., Adams, C., 2010. Release and removal of microcystins

from *Microcystis* during oxidative-, physical-, and UV-based disinfection. Journal of Environmental Engineering 136, 2-11.

30. Dixit, F., Barbeau, B., Mohseni, M., 2018. Simultaneous uptake of NOM and Microcystin-LR by anion exchange resins: effect of inorganic ions and resin regeneration. Chemosphere 192, 113-121.
31. Duan, X., Sanan, T., de la Cruz, A., He, X., Kong, M., Dionysiou, D.D., 2018. Susceptibility of the algal toxin microcystin-LR to UV/chlorine process: comparison with chlorination. Environmental Science & Technology 52, 8252-8262.
32. Dubrawski, K., Cataldo, M., Dubrawski, Z., Mazumder, A., Wilkinson, D., Mohseni, M., 2018. In-situ electrochemical Fe (VI) for removal of microcystin-LR from drinking water: Comparing dosing of the ferrate ion by electrochemical and chemical means. Journal of Water and Health 16, 414-424.
33. Edmiston, P.L., Carter, K.A., Graham, A.L., Gleason, E.J., 2018. Chemisorption of microcystins to a thiol and amine functionalized organosilica. Separation and Purification Technology 197, 244-252.
34. El-Sheikh, S.M., Zhang, G., El-Hosainy, H.M., Ismail, A.A., O'Shea, K.E., Falaras, P., Kontos, A.G., Dionysiou, D.D., 2014. High performance sulfur, nitrogen and carbon doped mesoporous anatase–brookite TiO_2 photocatalyst for the removal of microcystin-LR under visible light irradiation. Journal of Hazardous Materials 280, 723-733.
35. Fan, G., Chen, Z., Hong, L., Du, B., Yan, Z., Zhan, J., You, Y., Ning, R., Xiao, H., 2020a. Simultaneous removal of harmful algal cells and toxins by a Ag_2CO_3-N: GO photocatalyst coating under visible light. Science of The Total Environment 741, 140341.
36. Fan, G., Hong, L., Luo, J., You, Y., Zhang, J., Hua, P., Du, B., Zhan, J., Ning, R., Bao, M., 2020b. Photocatalytic inactivation of harmful algae and degradation of cyanotoxins microcystin-LR using GO-based Z-scheme nanocatalysts under visible light. Chemical Engineering Journal 392, 123767.
37. Fang, Y., Zhang, Y., Ma, W., Johnson, D.M., Huang, Y.-p., 2014. Degradation of Microcystin-LR in water: Hydrolysis of peptide bonds catalyzed by maghemite under visible light. Applied Catalysis B: Environmental 160-161, 597-605.
38. Feng, X., Rong, F., Fu, D., Yuan, C., Hu, Y., 2006. Photocatalytic degradation of trace-level of Microcystin-LR by nano-film of titanium dioxide. Chinese Science Bulletin 51, 1191-1198.
39. Fotiou, T., Triantis, T.M., Kaloudis, T., Pastrana-Martínez, L.M., Likodimos, V., Falaras, P., Silva, A.M.T., Hiskia, A., 2013. Photocatalytic Degradation of microcystin-LR and off-odor compounds in water under UV-A and solar light with a nanostructured photocatalyst based on reduced graphene oxide–TiO2 composite. Identification of Intermediate Products. Industrial & Engineering Chemistry Research 52, 13991-14000.
40. Gajdek, P., Bober, B., Mej, E., Bialczyk, J., 2004. Sensitised decomposition of microcystin-LR using UV radiation. Journal of Photochemistry and Photobiology B: Biology 76, 103-106.
41. Gajdek, P., Lechowski, Z., Bochnia, T., Kępczyński, M., 2001. Decomposition of microcystin-LR by Fenton oxidation. Toxicon 39, 1575-1578.
42. Gao, Y., Wang, F., Wu, Y., Naidu, R., Chen, Z., 2016. Comparison of degradation

mechanisms of microcystin-LR using nanoscale zero-valent iron (nZVI) and bimetallic Fe/Ni and Fe/Pd nanoparticles. Chemical Engineering Journal 285, 459-466.
43. Garcia, A.C.d.A., Rodrigues, M.A.S., Xavier, J.L.N., Gazulla, V., Meneguzzi, A., Bernardes, A.M., 2015. Degradation of cyanotoxins (microcystin) in drinking water using photoelectrooxidation. Brazilian Journal of Biology 75, 45-49.
44. Gurbuz, F., Ceylan, Ş., Odabaşı, M., Codd, G.A., 2016. Hepatotoxic microcystin removal using pumice embedded monolithic composite cryogel as an alternative water treatment method. Water Research 90, 337-343.
45. He, X., Pelaez, M., Westrick, J.A., O'Shea, K.E., Hiskia, A., Triantis, T., Kaloudis, T., Stefan, M.I., de la Cruz, A.A., Dionysiou, D.D., 2012. Efficient removal of microcystin-LR by UV-C/H2O2 in synthetic and natural water samples. Water Research 46, 1501-1510.
46. He, Y., Wu, P., Li, G., Li, L., Yi, J., Wang, S., Lu, S., Ding, P., Chen, C., Pan, H., 2020. Optimization on preparation of Fe_3O_4/chitosan as potential matrix material for the removal of microcystin-LR and its evaluation of adsorption properties. International Journal of Biological Macromolecules 156, 1574-1583.
47. Ho, L., Hoefel, D., Saint, C.P., Newcombe, G., 2007. Degradation of microcystin-LR through biological sand filters. Practice Periodical of Hazardous, Toxic, and Radioactive Waste Management 11, 191-196.
48. Ho, L., Onstad, G., Von Gunten, U., Rinck-Pfeiffer, S., Craig, K., Newcombe, G., 2006. Differences in the chlorine reactivity of four microcystin analogues. Water Research 40, 1200-1209.
49. Huang, C., Zhang, W., Yan, Z., Gao, J., Liu, W., Tong, P., Zhang, L., 2015. Protonated mesoporous graphitic carbon nitride for rapid and highly efficient removal of microcystins. RSC Advances 5, 45368-45375.
50. Huang, W.J., Cheng, B.L., Cheng, Y.L., 2007. Adsorption of microcystin-LR by three types of activated carbon. Journal of Hazardous Materials 141, 115-122.
51. Jacobs, L.C.V., Peralta-Zamora, P., Campos, F.R., Pontarolo, R., 2013. Photocatalytic degradation of microcystin-LR in aqueous solutions. Chemosphere 90, 1552-1557.
52. Jasim, S., Uslu, M., Seth, R., Biswas, N., 2020. Removal of cyanotoxins in detroit river water using ozone-based advanced oxidation processes. Ozone: Science & Engineering 42, 461-468.
53. Jeong, B., Oh, M.S., Park, H.M., Park, C., Kim, E.J., Hong, S.W., 2017. Elimination of microcystin-LR and residual Mn species using permanganate and powdered activated carbon: oxidation products and pathways. Water Research 114, 189-199.
54. Jiang, W., Chen, L., Batchu, S.R., Gardinali, P.R., Jasa, L., Marsalek, B., Zboril, R., Dionysiou, D.D., O'Shea, K.E., Sharma, V.K., 2014. Oxidation of microcystin-LR by ferrate (VI): kinetics, degradation pathways, and toxicity assessments. Environmental Science & Technology 48, 12164-12172.
55. Jiang, X., Lee, S., Mok, C., Lee, J., 2017. Sustainable methods for decontamination of microcystin in water using cold plasma and UV with reusable TiO_2 nanoparticle coating. International Journal of Environmental Research and Public Health 14, 480.

56. Karci, A., Wurtzler, E.M., Armah, A., Wendell, D., Dionysiou, D.D., 2018. Solar photo-Fenton treatment of microcystin-LR in aqueous environment: Transformation products and toxicity in different water matrices. Journal of Hazardous Materials 349, 282-292.
57. Khadgi, N., Upreti, A.R., 2019. Photocatalytic degradation of Microcystin-LR by visible light active and magnetic, $ZnFe_2O_4$-Ag/rGO nanocomposite and toxicity assessment of the intermediates. Chemosphere 221, 441-451.
58. Kim, S., Yun, Y.S., Choi, Y.E., 2018. Development of waste biomass based sorbent for removal of cyanotoxin microcystin-LR from aqueous phases. Bioresource Technology 247, 690-696.
59. Kinley, C.M., Hendrikse, M., Calomeni, A.J., Geer, T.D., Rodgers, J.H., 2018. Solar Photocatalysis using fixed-Film TiO_2 for microcystins from colonial *Microcystis aeruginosa*. Water, Air, & Soil Pollution 229, 167.
60. Kohler, E., Villiger, J., Posch, T., Derlon, N., Shabarova, T., Morgenroth, E., Pernthaler, J., Blom, J.F., 2014. Biodegradation of microcystins during gravity-driven membrane (GDM) ultrafiltration. PloS One 9, e111794.
61. Kull, T.P., Sjövall, O.T., Tammenkoski, M.K., Backlund, P.H., Meriluoto, J.A., 2006. Oxidation of the cyanobacterial hepatotoxin microcystin-LR by chlorine dioxide: influence of natural organic matter. Environmental Science & Technology 40, 1504-1510.
62. Kumar, P., Hegde, K., Brar, S.K., Cledon, M., Kermanshahi-Pour, A., Roy-Lachapelle, A., Galvez-Cloutier, R., 2019a. Novel fluidized-bed biofilm reactor for concomitant removal of microcystin-LR and organics. Chemical Engineering Journal 359, 99-111.
63. Kumar, P., Hegde, K., Brar, S.K., Cledon, M., Kermanshahi-pour, A., Roy-Lachapelle, A., Sauvé, S., Galvez-Cloutier, R., 2020a. Co-culturing of native bacteria from drinking water treatment plant with known degraders to accelerate microcystin-LR removal using biofilter. Chemical Engineering Journal 383, 123090.
64. Kumar, P., Kaur Brar, S., Surampalli, R.Y., 2020b. Ozonation in tandem with biosand filtration to remove microcystin-LR. Journal of Environmental Engineering 146, 04020124.
65. Kumar, P., Pérez, J.A.E., Cledon, M., Brar, S.K., Duy, S.V., Sauvé, S., Knystautas, É., 2020c. Removal of microcystin-LR and other water pollutants using sand coated with bio-optimized carbon submicron particles: graphene oxide and reduced graphene oxide. Chemical Engineering Journal, 125398.
66. Kumar, P., Rehab, H., Hegde, K., Brar, S.K., Cledon, M., Kermanshahi-pour, A., Duy, S.V., Sauvé, S., Surampalli, R.Y., 2020d. Physical and biological removal of Microcystin-LR and other water contaminants in a biofilter using Manganese Dioxide coated sand and Graphene sand composites. Science of The Total Environment 703, 135052.
67. Kumar, P., Rubio, H.D.P., Hegde, K., Brar, S.K., Cledon, M., Kermanshahi-Pour, A., Sauvé, S., Roy-Lachapelle, A., Galvez-Cloutier, R., 2019b. Agro-industrial residues as a unique support in a sand filter to enhance the bioactivity to remove microcystin-Leucine aRginine and organics. Science of the total environment 670, 971-981.
68. Laszakovits, J.R., MacKay, A.A., 2019. Removal of cyanotoxins by potassium

permanganate: Incorporating competition from natural water constituents. Water Research 155, 86-95.
69. Lee, D.K., Kim, S.C., Kim, S.J., Chung, I.S., Kim, S.W., 2004. Photocatalytic oxidation of microcystin-LR with TiO_2-coated activated carbon. Chemical Engineering Journal 102, 93-98.
70. Lee, J., Walker, H.W., 2006. Effect of process variables and natural organic matter on removal of microcystin-LR by PAC−UF. Environmental Science & Technology 40, 7336-7342.
71. Lee, J., Walker, H.W., 2011. Adsorption of microcystin-Lr onto iron oxide nanoparticles. Colloids and Surfaces A: Physicochemical and Engineering Aspects 373, 94-100.
72. Li, L., Gao, N., Deng, Y., Yao, J., Zhang, K., Li, H., Yin, D., Ou, H., Guo, J., 2009. Experimental and model comparisons of H_2O_2 assisted UV photodegradation of Microcystin-LR in simulated drinking water. Journal of Zhejiang University-SCIENCE A 10, 1660-1669.
73. Lian, H., Xiang, P., Xue, Y., Jiang, Y., Li, M., Mo, J., 2020. Efficiency and mechanisms of simultaneous removal of *Microcystis aeruginosa* and microcystins by electrochemical technology using activated carbon fiber/nickel foam as cathode material. Chemosphere, 126431.
74. Lian, L., Cao, X., Wu, Y., Sun, D., Lou, D., 2014. A green synthesis of magnetic bentonite material and its application for removal of microcystin-LR in water. Applied Surface Science 289, 245-251.
75. Liang, W., Qu, J., Wang, K., Wang, J., Liu, H., Lei, P., 2008. Electrochemical degradation of cyanobacterial toxin microcystin-LR using Ti/RuO_2 electrodes in a continuous tubular reactor. Environmental Engineering Science 25, 635-642.
76. Liang, Y., He, X., Chen, L., Zhang, Y., 2014. Preparation and characterization of TiO_2–Graphene@Fe_3O_4 magnetic composite and its application in the removal of trace amounts of microcystin-LR. RSC Advances 4, 56883-56891.
77. Liao, W., Murugananthan, M., Zhang, Y., 2014. Electrochemical degradation and mechanistic analysis of microcystin-LR at boron-doped diamond electrode. Chemical Engineering Journal 243, 117-126.
78. Liao, W., Zhang, Y., Zhang, M., Murugananthan, M., Yoshihara, S., 2013. Photoelectrocatalytic degradation of microcystin-LR using Ag/AgCl/TiO_2 nanotube arrays electrode under visible light irradiation. Chemical Engineering Journal 231, 455-463.
79. Liu, G., Zhang, G., Zhang, S., Xu, Y., Yang, X., Zhang, X., 2020. Degradation and mechanism of microcystin-LR by $PbCrO_4$ nanorods driven by visible light. Chemosphere 239, 124739.
80. Liu, G., Zheng, H., Zhai, X., Wang, Z., 2018. Characteristics and mechanisms of microcystin-LR adsorption by giant reed-derived biochars: Role of minerals, pores, and functional groups. Journal of Cleaner Production 176, 463-473.
81. Liu, I., Lawton, L.A., Bahnemann, D.W., Liu, L., Proft, B., Robertson, P.K.J., 2009. The photocatalytic decomposition of microcystin-LR using selected titanium dioxide materials. Chemosphere 76, 549-553.
82. Liu, I., Lawton, L.A., Cornish, B., Robertson, P.K., 2002. Mechanistic and toxicity studies of the photocatalytic oxidation of microcystin-LR. Journal of

Photochemistry and Photobiology A: Chemistry 148, 349-354.
83. Liu, J., Ye, J., Ou, H., Lin, J., 2017. Effectiveness and intermediates of microcystin-LR degradation by UV/H_2O_2 via 265 nm ultraviolet light-emitting diodes. Environmental Science and Pollution Research 24, 4676-4684.
84. Liu, S., Hu, X., Jiang, W., Ma, L., Cai, M., Xu, H., Wu, M., Ma, F., 2016a. Degradation of Microcystins from *Microcystis aeruginosa* by 185-nm UV Irradiation. Water, Air, & Soil Pollution 227, 129.
85. Liu, X., Chen, Z., Zhou, N., Shen, J., Ye, M., 2010. Degradation and detoxification of microcystin-LR in drinking water by sequential use of UV and ozone. Journal of Environmental Sciences 22, 1897-1902.
86. Liu, Y., Ren, J., Wang, X., Fan, Z., 2016b. Mechanism and reaction pathways for microcystin-LR degradation through UV/H_2O_2 treatment. PloS One 11, e0156236.
87. Loaiza-González, J.M., León-Salazar, M.C., Rubio-Clemente, A., Rodríguez, D.C., Peñuela-Mesa, G.A., 2020. Efficiency of the removal of microcystin-LR by UV-radiation and hydrogen peroxide. Revista Facultad de Ingeniería Universidad de Antioquia, 9-19.
88. Lobón, G.S., Yepez, A., Garcia, L.F., Morais, R.L., Vaz, B.G., Carvalho, V.V., De Oliveira, G.A.R., Luque, R., de Souza Gil, E., 2017. Efficient electrochemical remediation of microcystin-LR in tap water using designer TiO_2@ carbon electrodes. Scientific Reports 7, 1-8.
89. Mashile, G.P., Mpupa, A., Dimpe, M.K., Nomngongo, P.N., 2018a. Magnetic activated carbon@ iron oxide@ manganese oxide composite as an adsorbent for preconcentration of microcystin–LR in surface water, tap water, water and wastewater. Environmental Nanotechnology, mMonitoring & Management 10, 199-205.
90. Mashile, P.P., Mpupa, A., Nomngongo, P.N., 2018b. Adsorptive removal of microcystin-LR from surface and wastewater using tyre-based powdered activated carbon: Kinetics and isotherms. Toxicon 145, 25-31.
91. Miao, H.F., Qin, F., Tao, G.J., Tao, W.Y., Ruan, W.Q., 2010. Detoxification and degradation of microcystin-LR and -RR by ozonation. Chemosphere 79, 355-361.
92. Morón-López, J., Molina, S., 2020. Optimization of recycled-membrane biofilm reactor (R-MBfR) as a sustainable biological treatment for microcystins removal. Biochemical Engineering Journal 153, 107422.
93. Mrdjen, I., Lee, J., 2018. Simple and practical on-site treatment of high microcystin levels in water using polypropylene plastic. Journal of Environmental Science and Health, Part A 53, 1000-1005.
94. Munoz, M., Nieto-Sandoval, J., Cirés, S., de Pedro, Z.M., Quesada, A., Casas, J.A., 2019. Degradation of widespread cyanotoxins with high impact in drinking water (microcystins, cylindrospermopsin, anatoxin-a and saxitoxin) by CWPO. Water Research 163, 114853.
95. Narasimha, G., Mahesh, A.G., Manorama, S.V., 2017. Citrate stabilized hierarchical SPIO nanostructures: synthesis and application towards effective rRemoval of toxin, Microcystin-LR from water. ChemistrySelect 2, 5226-5233.
96. Nawaz, M., Moztahida, M., Kim, J., Shahzad, A., Jang, J., Miran, W., Lee, D.S., 2018. Photodegradation of microcystin-LR using graphene-TiO_2/sodium alginate aerogels. Carbohydrate Polymers 199, 109-118.

97. Opoku-Duah, S., Johnson, D., 2020. Removal of perfluorooctanoic acid and microcystins from drinking water by electrocoagulation. Journal of Chemistry 2020.
98. Palagama, D.S., Devasurendra, A.M., Baliu-Rodriguez, D., Kirchhoff, J.R., Isailovic, D., 2019. Treated rice husk as a recyclable sorbent for the removal of microcystins from water. Science of the Total Environment 666, 1292-1300.
99. Park, J.A., Jung, S.M., Yi, I.G., Choi, J.W., Kim, S.B., Lee, S.H., 2017a. Adsorption of microcystin-LR on mesoporous carbons and its potential use in drinking water source. Chemosphere 177, 15-23.
100. Park, J.A., Nam, H.L., Choi, J.W., Ha, J., Lee, S.H., 2017b. 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. Chemical Engineering Journal 313, 345-354.
101. Pavagadhi, S., Tang, A.L.L., Sathishkumar, M., Loh, K.P., Balasubramanian, R., 2013. Removal of microcystin-LR and microcystin-RR by graphene oxide: Adsorption and kinetic experiments. Water Research 47, 4621-4629.
102. Pelaez, M., Baruwati, B., Varma, R.S., Luque, R., Dionysiou, D.D., 2013. Microcystin-LR removal from aqueous solutions using a magnetically separable N-doped TiO_2 nanocomposite under visible light irradiation. Chemical Communications 49, 10118-10120.
103. Pelaez, M., de la Cruz, A.A., O'Shea, K., Falaras, P., Dionysiou, D.D., 2011. Effects of water parameters on the degradation of microcystin-LR under visible light-activated TiO_2 photocatalyst. Water Research 45, 3787-3796.
104. Pelaez, M., de la Cruz, A.A., Stathatos, E., Falaras, P., Dionysiou, D.D., 2009. Visible light-activated N-F-codoped TiO_2 nanoparticles for the photocatalytic degradation of microcystin-LR in water. Catalysis Today 144, 19-25.
105. Pelaez, M., Falaras, P., Kontos, A.G., de la Cruz, A.A., O'Shea, K., Dunlop, P.S.M., Byrne, J.A., Dionysiou, D.D., 2012. A comparative study on the removal of cylindrospermopsin and microcystins from water with NF-TiO_2-P_{25} composite films with visible and UV–vis light photocatalytic activity. Applied Catalysis B: Environmental 121-122, 30-39.
106. Pelaez, M., Falaras, P., Likodimos, V., Kontos, A.G., de la Cruz, A.A., O'Shea, K., Dionysiou, D.D., 2010. Synthesis, structural characterization and evaluation of sol–gel-based NF-TiO_2 films with visible light-photoactivation for the removal of microcystin-LR. Applied Catalysis B: Environmental 99, 378-387.
107. Pestana, C.J., Edwards, C., Prabhu, R., Robertson, P.K., Lawton, L.A., 2015. Photocatalytic degradation of eleven microcystin variants and nodularin by TiO_2 coated glass microspheres. Journal of Hazardous Materials 300, 347-353.
108. Pinho, L.X., Azevedo, J., Miranda, S.M., Ângelo, J., Mendes, A., Vilar, V.J., Vasconcelos, V., Boaventura, R.A., 2015. Oxidation of microcystin-LR and cylindrospermopsin by heterogeneous photocatalysis using a tubular photoreactor packed with different TiO_2 coated supports. Chemical Engineering Journal 266, 100-111.
109. Qi, X., Zheng, Y., Tang, N., Zhou, J., Sun, S., 2020. Bioconversion of citrus peel wastes into bioflocculants and their application in the removal of microcystins. Science of The Total Environment 715, 136885.
110. Qiao, R.P., Li, N., Qi, X.H., Wang, Q.S., Zhuang, Y.Y., 2005. Degradation of

microcystin-RR by UV radiation in the presence of hydrogen peroxide. Toxicon 45, 745-752.

111. Ren, G., He, X., Wu, P., He, Y., Zhang, Y., Tang, S., Song, X., He, Y., Wei, Y., Ding, P., 2020. Biodegradation of microcystin-RR and nutrient pollutants using Sphingopyxis sp. YF1 immobilized activated carbon fibers-sodium alginate. Environmental Science and Pollution Research, 1-11.
112. Sampaio, M.J., Pastrana-Martínez, L.M., Silva, A.M., Buijnsters, J.G., Han, C., Silva, C.G., Carabineiro, S.A., Dionysiou, D.D., Faria, J.L., 2015a. Nanodiamond–TiO_2 composites for photocatalytic degradation of microcystin-LA in aqueous solutions under simulated solar light. RSC advances 5, 58363-58370.
113. Sampaio, M.J., Silva, C.G., Silva, A.M., Pastrana-Martinez, L.M., Han, C., Morales-Torres, S., Figueiredo, J.L., Dionysiou, D.D., Faria, J.L., 2015b. Carbon-based TiO_2 materials for the degradation of Microcystin-LA. Applied Catalysis B: Environmental 170, 74-82.
114. Sathishkumar, M., Pavagadhi, S., Vijayaraghavan, K., Balasubramanian, R., Ong, S.L., 2010. Experimental studies on removal of microcystin-LR by peat. Journal of Hazardous Materials 184, 417-424.
115. Sathya, K., Saranya, P., Swarnalatha, S., Mandal, A., Sekaran, G., 2015. Removal of microcystin-RR, a membrane foulant using exocellular polymer from Enterobacter ludwigii: Kinetic and isotherm studies. Desalination 369, 175-187.
116. Şengül, A.B., Ersan, G., Tüfekçi, N., 2018. Removal of intra-and extracellular microcystin by submerged ultrafiltration (UF) membrane combined with coagulation/flocculation and powdered activated carbon (PAC) adsorption. Journal of Hazardous Materials 343, 29-35.
117. Shawwa, A.R., Smith, D.W., 2001. Kinetics of microcystin-LR oxidation by ozone. Ozone: Science & Engineering 23, 161-170.
118. Shephard, G.S., Stockenström, S., de Villiers, D., Engelbrecht, W.J., Wessels, G.F., 2002. Degradation of microcystin toxins in a falling film photocatalytic reactor with immobilized titanium dioxide catalyst. Water Research 36, 140-146.
119. Sidelev, S., Babanazarova, O., 2020. Detection of Cyanobacterial toxins in water supply sources and tap water in some russian cities: searching producers and testing removal methods. Water Resources 47, 304-314.
120. Song, H.L., Li, X.N., Lu, X.W., Inamori, Y., 2009. Investigation of microcystin removal from eutrophic surface water by aquatic vegetable bed. Ecological Engineering 35, 1589-1598.
121. Song, W., Bardowell, S., O'Shea, K.E., 2007. Mechanistic study and the influence of oxygen on the photosensitized transformations of microcystins (cyanotoxins). Environmental Science & Technology 41, 5336-5341.
122. Song, W., Teshiba, T., Rein, K., O'Shea, K.E., 2005. Ultrasonically induced degradation and detoxification of microcystin-LR (cyanobacterial toxin). Environmental Science & Technology 39, 6300-6305.
123. Spoof, L., Jaakkola, S., Važić, T., Häggqvist, K., Kirkkala, T., Ventelä, A.M., Kirkkala, T., Svirčev, Z., Meriluoto, J., 2020. Elimination of cyanobacteria and microcystins in irrigation water—effects of hydrogen peroxide treatment. Environmental Science and Pollution Research 27, 8638-8652.
124. Su, Y., Deng, Y., Zhao, L., Du, Y., 2013. Photocatalytic degradation of microcystin-

LR using TiO_2 nanotubes under irradiation with UV and natural sunlight. Chinese Science Bulletin 58, 1156-1161.
125. Sudrajat, H., Babel, S., 2019. Ultrahigh photoactivity of ZnO nanoparticles for decomposition of high-concentration microcystin-LR in water environment. International Journal of Environmental Science and Technology 16, 695-706.
126. Sun, J., Bu, L., Deng, L., Shi, Z., Zhou, S., 2018. Removal of Microcystis aeruginosa by UV/chlorine process: Inactivation mechanism and microcystins degradation. Chemical Engineering Journal 349, 408-415.
127. Szlag, D.C., Spies, B., Szlag, R.G., Westrick, J.A., 2019. Permanganate oxidation of microcystin-LA: kinetics, quantification, and implications for effective drinking water treatment. Journal of Toxicology 2019.
128. Teng, W., Wu, Z., Fan, J., Chen, H., Feng, D., Lv, Y., Wang, J., Asiri, A.M., Zhao, D., 2013a. Ordered mesoporous carbons and their corresponding column for highly efficient removal of microcystin-LR. Energy & Environmental Science 6, 2765-2776.
129. Teng, W., Wu, Z., Feng, D., Fan, J., Wang, J., Wei, H., Song, M., Zhao, D., 2013b. Rapid and efficient removal of microcystins by ordered mesoporous silica. Environmental Science & Technology 47, 8633-8641.
130. Terin, U., Sabogal-Paz, L., 2019. *Microcystis aeruginosa* and microcystin-LR removal by household slow sand filters operating in continuous and intermittent flows. Water Research 150, 29-39.
131. Tran, C.D., Duri, S., Delneri, A., Franko, M., 2013. Chitosan-cellulose composite materials: Preparation, Characterization and application for removal of microcystin. Journal of Hazardous Materials 252-253, 355-366.
132. Vilela, W.F.D., Minillo, A., Rocha, O., Vieira, E.M., Azevedo, E.B., 2012. Degradation of [D-Leu]-Microcystin-LR by solar heterogeneous photocatalysis (TiO_2). Solar Energy 86, 2746-2752.
133. 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 Research & Technology 5, 2048-2058.
134. Wang, F., Gao, Y., Sun, Q., Chen, Z., Megharaj, M., Naidu, R., 2014. Degradation of microcystin-LR using functional clay supported bimetallic Fe/Pd nanoparticles based on adsorption and reduction. Chemical Engineering Journal 255, 55-62.
135. Wang, F., Wu, Y., Gao, Y., Li, H., Chen, Z., 2016. Effect of humic acid, oxalate and phosphate on Fenton-like oxidation of microcystin-LR by nanoscale zero-valent iron. Separation and Purification Technology 170, 337-343.
136. Wang, R., Tai, Y., Wan, X., Ruan, W., Man, Y., Wang, J., Yang, Y., Yang, Y., 2018. Enhanced removal of microcystis bloom and microcystin-lr using microcosm constructed wetlands with bioaugmentation of degrading bacteria. Chemosphere 210, 29-37.
137. Wang, X., Utsumi, M., Yang, Y., Li, D., Zhao, Y., Zhang, Z., Feng, C., Sugiura, N., Cheng, J.J., 2015a. Degradation of microcystin-LR by highly efficient $AgBr/Ag_3PO_4/TiO_2$ heterojunction photocatalyst under simulated solar light irradiation. Applied Surface Science 325, 1-12.
138. Wang, X., Utsumi, M., Yang, Y., Shimizu, K., Li, D., Zhang, Z., Sugiura, N., 2013.

Removal of microcystins (-LR, -YR, -RR) by highly efficient photocatalyst Ag/Ag_3PO_4 under simulated solar light condition. Chemical Engineering Journal 230, 172-179.
139. Wang, X., Zhang, J., Sun, W., Yang, W., Cao, J., Li, Q., Peng, Y., Shang, J.K., 2015b. Anti-algal activity of palladium oxide-modified nitrogen-doped titanium oxide photocatalyst on *Anabaena* sp. PCC 7120 and its photocatalytic degradation on Microcystin LR under visible light illumination. Chemical Engineering Journal 264, 437-444.
140. Wu, P., Li, G., He, Y., Luo, D., Li, L., Guo, J., Ding, P., Yang, F., 2020. High-efficient and sustainable biodegradation of microcystin-LR using Sphingopyxis sp. YF1 immobilized Fe_3O_4@ chitosan. Colloids and Surfaces B: Biointerfaces 185, 110633.
141. Wu, S., Lv, J., Wang, F., Duan, N., Li, Q., Wang, Z., 2017. Photocatalytic degradation of microcystin-LR with a nanostructured photocatalyst based on upconversion nanoparticles@TiO_2 composite under simulated solar lights. Scientific Reports 7, 14435.
142. Xia, W., Zhang, X., Xu, L., Wang, Y., Lin, J., Zou, R., 2013. Facile and economical synthesis of metal–organic framework MIL-100(Al) gels for high efficiency removal of microcystin-LR. RSC Advances 3, 11007-11013.
143. Xiao, F., Xu, J., Wang, Z., Jiang, S., Zhang, Q., Wang, L., 2020. Construction of oxygen vacancy modified Bi/BiOI nanocomposite with improved photocatalytic activity for microcystin-LR degradation. Journal of Materials Science: Materials in Electronics, 1-10.
144. Xin, Q., Zhang, Y., Li, Z., Lei, L., Yang, B., 2015. Mn/Ti-doped carbon xerogel for efficient catalysis of microcystin-LR degradation in the water surface discharge plasma reactor. Environmental Science and Pollution Research 22, 17202-17208.
145. Xin, Q., Zhang, Y., Wu, K.B., 2013. Mn-doped carbon xerogels as catalyst in the removal of microcystin-LR by water-surface discharge plasma. Journal of Environmental Science and Health, Part A 48, 293-299.
146. Xing, H., Yuan, B., Wang, Y., Qu, J., 2002. Photocatalytic detoxification of microcystins combined with ferrate pretreatment. Journal of Environmental Science and Health, Part A 37, 641-649.
147. Yan, H., Pan, G., Zou, H., Li, X., Chen, H., 2004. Effective removal of microcystins using carbon nanotubes embedded with bacteria. Chinese Science Bulletin 49, 1694-1698.
148. Yan, S., Zhang, D., Song, W., 2014. Mechanistic considerations of photosensitized transformation of microcystin-LR (cyanobacterial toxin) in aqueous environments. Environmental Pollution 193, 111-118.
149. Yang, B., Park, H.D., Hong, S.W., Lee, S.H., Park, J.A., Choi, J.W., 2020. Photocatalytic degradation of microcystin-LR and anatoxin-a with presence of natural organic matter using UV-light emitting diodes/TiO_2 process. Journal of Water Process Engineering 34, 101163.
150. Ying, J., Huang, J.L., Jiao, F., Wu, M.S., Cui, C.W., 2008. Degradation of microcystin-RR in water by chlorine dioxide. Journal of China University of Mining and Technology 18, 623-628.
151. Yuan, B.L., Qu, J.H., Fu, M.L., 2002. Removal of cyanobacterial microcystin-LR by

ferrate oxidation–coagulation. Toxicon 40, 1129-1134.
152. Yuan, B., Li, Y., Huang, X., Liu, H., Qu, J., 2006. Fe (VI)-assisted photocatalytic degradating of microcystin-LR using titanium dioxide. Journal of Photochemistry and Photobiology A: Chemistry 178, 106-111.
153. Zhang, C., Fu, D., Gu, Z., 2009. Degradation of microcystin-RR using boron-doped diamond electrode. Journal of Hazardous Materials 172, 847-853.
154. Zhang, G., Zhang, Y.C., Nadagouda, M., Han, C., O'Shea, K., El-Sheikh, S.M., Ismail, A.A., Dionysiou, D.D., 2014. Visible light-sensitized S, N and C co-doped polymorphic TiO_2 for photocatalytic destruction of microcystin-LR. Applied Catalysis B: Environmental 144, 614-621.
155. Zhang, H., Huang, Q., Ke, Z., Yang, L., Wang, X., Yu, Z., 2012. Degradation of microcystin-LR in water by glow discharge plasma oxidation at the gas–solution interface and its safety evaluation. Water Research 46, 6554-6562.
156. Zhang, H., Zhu, G., Jia, X., Ding, Y., Zhang, M., Gao, Q., Hu, C., Xu, S., 2011. Removal of microcystin-LR from drinking water using a bamboo-based charcoal adsorbent modified with chitosan. Journal of Environmental Sciences 23, 1983-1988.
157. Zhang, X., He, J., Lei, Y., Qiu, Z., Cheng, S., Yang, X., 2019. Combining solar irradiation with chlorination enhances the photochemical decomposition of microcystin-LR. Water Research 159, 324-332.
158. Zhang, X., Li, J., Yang, J.Y., Wood, K.V., Rothwell, A.P., Li, W., Blatchley III, E.R., 2016a. Chlorine/UV process for decomposition and detoxification of microcystin-LR. Environmental Science & Technology 50, 7671-7678.
159. Zhang, Y., Shao, Y., Gao, N., Chu, W., Sun, Z., 2016b. Removal of microcystin-LR by free chlorine: Identify of transformation products and disinfection by-products formation. Chemical Engineering Journal 287, 189-195.
160. Zhang, Y., Zhang, Y., Yang, N., Liao, W., Yoshihara, S., 2013. Electrochemical degradation and mechanistic analysis of microcystin-LR. Journal of Chemical Technology & Biotechnology 88, 1529-1537.
161. Zhao, C., Li, D., Liu, Y., Feng, C., Zhang, Z., Sugiura, N., Yang, Y., 2015. Photocatalytic removal of microcystin-LR by advanced WO_3-based nanoparticles under simulated solar light. The Scientific World Journal 2015.
162. Zhao, C., Yang, Y., Zhang, Z., 2012. Photocatalytic treatment of microcystin-LR-containing wastewater using Pt/WO nanoparticles under simulated solar light. Open Journal of Applied Sciences Vol.02No.02, 7.
163. Zhao, Y., Fan, Q., Wang, X., Zhang, W., Hu, X., Liu, C., Liang, W., 2019. Photoelectrocatalytic degradation of microcystin-LR using a dimensionally stable anode and the assessment of detoxification. Chemical Engineering Journal 368, 968-979.
164. Zhong, Y., Jin, X., Qiao, R., Qi, X., Zhuang, Y., 2009. Destruction of microcystin-RR by Fenton oxidation. Journal of Hazardous Materials 167, 1114-1118.
165. Zhou, S., Bu, L., Yu, Y., Zou, X., Zhang, Y., 2016. A comparative study of microcystin-LR degradation by electrogenerated oxidants at BDD and MMO anodes. Chemosphere 165, 381-387.
166. Zhou, S., Yu, Y., Zhang, W., Meng, X., Luo, J., Deng, L., Shi, Z., Crittenden, J., 2018. Oxidation of microcystin-LR via activation of peroxymonosulfate using ascorbic

acid: kinetic modeling and toxicity assessment. Environmental Science & Technology 52, 4305-4312.
167. Zuo, X., Cao, Y., Gong, A., Ding, S., Zhang, T., Wang, Y., 2016. Removal of microcystins by highly efficient photo-catalyst Bi_2WO_6-activated carbon under simulated light. Water, Air, & Soil Pollution 227, 97.