applied sciences

MDPI

*Editorial*

# Advancements in Biomonitoring and Remediation Treatments of Pollutants in Aquatic Environments, 2nd Edition

**Elida Nora Ferri**

Department of Pharmacy and Biotechnology, University of Bologna, 40127 Bologna, Italy; elidanora.ferri@unibo.it

Worldwide anthropogenic activities continuously produce and release hundreds of potentially toxic chemicals that contaminate ecosystems, leaving devastating effects on the environment and living beings, humans included.

Water pollution has received more and more concern because of the increasing contemporary requests for clean and safe drinking water and the general awareness of the severe conditions of water sources. Freshwater contaminants include industrial effluents containing metals, dyes, pharmaceuticals, other organic compounds, wastewater treatment plant effluents, a complex mixture of municipal, hospital, runoff agrochemicals, and mining activity residues [1–4]. Additional environmental stressors are eutrophication, overfishing, excess exploitation, and land-use changes. The microbiological contamination is a different but equally serious threat to ecosystem stability and human health [5,6]. Seawater is particularly affected by antifouling agents, paints, petrol additives, ship maintenance activities, and existing river contaminants. Moreover, water bodies and their inhabitants are now facing the threats of this century via contamination with nanomaterials, notably plastic debris [7–11]. The requested global efforts to face these problems can probably find significant help in the new tools developed in the research of biomonitoring and remediation technologies.

To design proper remediation strategies, both the origin and impacts of the threats must be accurately diagnosed using chemical, biological, spatial, and temporal integrated data [12–14]. Accordingly, biomonitoring is a transdisciplinary activity that evaluates the type, source, and extent of pollution and its consequences on a single species, the ecosystems' structure, and the food chain.

In monitoring water quality, the physicochemical analyses represent the backbone of the activity. However, even with enforcing the most innovative analytical technologies, physicochemical analyses alone cannot assess or predict the consequences of environmental stressors on the ecosystem inhabitants. The aquatic organisms, animal and vegetal, are exploited to investigate different aspects of the ecosystem. Up to now, they have been irreplaceable as passive samplers, or bioaccumulators, of the xenobiotics present in water, and their tissues are analyzed to determine the presence and concentration of a specific contaminant, even present in traces. This practice allows evaluating over time the appearance and modification of the contaminant content, following or not following a remediation treatment [15–18].

Information about the structural and physiological damages suffered by aquatic biota comes from studying the alteration that occurred to selected biomarkers in cells, individuals, populations, and communities [19–23]. The in vitro tests are still of outstanding importance since, in these simplified systems, it is easier to ascertain the toxic potential and biomarker modifications produced by a compound. Moreover, new sensitive organisms can be identified and selected, and more suitable biomarkers can be identified.

In analyzing the more complex environmental samples, all parameters concerning both the organisms and the environmental conditions must be considered. To address this problem statistically, relevant multimetric indices have been developed to integrate

check for updates

**Citation:** Ferri, E.N. Advancements in Biomonitoring and Remediation Treatments of Pollutants in Aquatic Environments, 2nd Edition. *Appl. Sci.* **2023**, *13*, 9737. https://doi.org/10.3390/app13179737

Received: 22 August 2023
Accepted: 25 August 2023
Published: 28 August 2023

**Copyright:** © 2023 by the author. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

the complex biomarker responses, provide a holistic approach, and help optimize the monitoring campaigns [13,14,24–26].

The endpoints of ecotoxicological tests have evolved in parallel with biotechnological progress [27]. Morphological and biochemical-based approaches are now supported using transcriptomic analysis and metabolomic studies, allowing us to identify the exact genetic or metabolic function altered by the pollutants. The appearance of genetic damages prolongs the negative impact of pollutants even after their removal [22,28–32].

An analysis of eDNA and eRNA is applied to elucidate the changes in biodiversity and communities' structure. The environmental DNA and RNA metabarcoding technologies represent non-invasive sampling methods since only environmental genetic material is collected and offer more precise and complete population fingerprinting concerning the classic morphological assessment [33–38].

To meet the growing water-pollution-based issues, traditional and innovative technologies for organic and heavy metal remediation are continuously being improved. Remediation procedures must consider the presence of microbial contamination, not in wastewater only, and then these methods must be applied according to the reclaimed water application [39].

Bioremediation procedures proved to be among the most sustainable for environmental remediation. The addition of suitable microorganisms can be effective in the presence of organic contaminants; they can metabolize, absorb, or modify [40–43].

Biosorption phenomena are exploited in constructed wetlands or with the addition of macrophytes or algal species to contaminated water [44,45]. Various natural origin materials are used alone or in combination in bio-physical adsorption treatments [46–49]. Absorption can be a simple and effective solution, but the regeneration of the adsorbent materials and/or their safe disposal are problems still not completely solved.

Forced aeration, floating aquatic plants, and submerged macrophytes increase the oxygen content and inhibit algal growth, reversing eutrophication in lakes and ponds [50]. The in situ phytoremediation is not widely used because it requires longer treatment times for physicochemical methods, but the low cost and the environmentally friendly characteristics deserve greater attention [51].

The physical removal of contaminants from the water now exploits the most innovative tools, such as nanomaterials. Nanotechnologies represent a deeply studied and applied solution for removing heavy metals, organic pollutants, and microorganisms with the enhanced adsorption and degradation capacity of pollutants via redox reactions [52–55]. These techniques can also employ different solutions, such as metal-organic framework materials [56] or magnetic nanoparticles [57,58]. The zero-valent iron nanoparticles, simple or modified, demonstrate very high efficiency in removing both organic and inorganic pollutants [59].

A different kind of adsorbent is the polyelectrolyte-incorporated material, of which practical application needs further improvements [60]. On the other hand, continuous research efforts are made to obtain optimized filtration membranes for efficient and rapid water remediation [61].

The degradation of pollutant molecules to less harmful derivatives is the main remediation strategy of chemical methods. Photoreactions and catalyst-based photoreactions are successfully employed to treat contaminated water, where the catalysts are nanomaterials, usually metal oxides or carbon dots [62,63]. The potential of these and similar Advanced Oxidation Processes (AOPs) is extensively investigated, especially in tertiary wastewater treatment. Most compounds of emerging concerns are particularly recalcitrant [64–66].

Bio-electrochemical methods developed to repair surface waters can be based on floating bed–microbial electrochemical systems [67,68] or on bio-electrochemical systems (BES), the latter able to remove contaminants while generating electricity [69]. In particular cases, e.g., fluoride remediation, the electrocoagulation process can reach the goal [70]. On the other hand, the piezoelectric effect can degrade the pollutants directly or enhance photocatalysis [71].

Most of the described innovative techniques are effective at the lab-scale level, and various have the potential for real-life applications. Future research should focus on the most promising technologies to scale up and use on environmental, industrial, or urban contaminated water.

**Conflicts of Interest:** The author declares no conflict of interest.

## References


1. Cabecinhas, A.S.; Novais, S.C.; Santos, S.C.; Rodrigues, A.C.M.; Pestana, J.L.T.; Soares, A.M.V.M.; Lemos, M.F.L. Sensitivity of the sea snail *Gibbula umbilicalis* to mercury exposure–Linking endpoints from different biological organization levels. *Chemosphere* **2015**, *119*, 490–497. [CrossRef]
2. Perez-Iglesias, J.M.; Bach, N.C.; Colombetti, P.L.; Acuna, P.; Colman-Lerner, J.E.; Gonzalez, S.P.; Brodeur, J.C.; Almeida, C.A. Biomonitoring of alterations in fish that inhabit anthropic aquatic environments in a basin from semi-arid regions. *Toxics* **2023**, *11*, 73. [CrossRef] [PubMed]
3. Khalil, A.Q.M. Toxicological effects and oxidative stress responses in freshwater snail, *Lanistes carinatus*, following exposure to chlorpyrifos. *Ecotoxicol. Environ. Saf.* **2015**, *116*, 137–142. [CrossRef] [PubMed]
4. Popovic, N.C.; Cizmek, L.; Babic, S.; Strunjak-Perovic, I.; Coz-Rakovac, R. Fish liver damage related to the wastewater treatment plant effluents. *Environ. Sci. Pollut. Res.* **2023**, *30*, 48739–48768. [CrossRef]
5. Chahouri, A.; Yacoubi, B.; Moukrim, A.; Banaoui, A. Integration assayof bacteriological risks in marine environment using Salmonella sppand multimarker response in the bivalve Donax trunculus: Novel biomonitoring approach. *Chemosphere* **2022**, *297*, 134149. [CrossRef]
6. Mostafa-Hedeab, G.; Allayeh, A.K.; Elhady, H.A.; Eledrdery, A.Y.; Mraheil, M.A.; Mostafa, A. Viral eco-genomic tools: Development and implementation for aquatic biomonitoring. *Int. J. Environ. Res. Public Health* **2022**, *19*, 7707. [CrossRef] [PubMed]
7. Multisanti, C.R.; Merola, C.; Perugini, M.; Aliko, V.; Faggio, C. Sentinel species selection for monitoring microplastic pollution: A review on one health approach. *Ecol. Indic.* **2022**, *145*, 109587. [CrossRef]
8. Rozman, U.; Kalcikova, G. The response of Duckweed *Lemna minor* to microplastics and its potential use as a bioindicator of microplastic pollution. *Plants* **2022**, *11*, 2953. [CrossRef]
9. Truchet, D.M.; Ardusso, M.G.; Forero-Lopez, A.D.; Rimondino, G.N.; Buzzi, N.S.; Malanca, F.; Spetter, C.V.; Fernandez-Severini, M.D. Tracking synthetic microdebris contamination in a highly urbanized estuary through crabs as sentinel species: An ecological trait-based approach. *Sci. Total Environ.* **2022**, *837*, 155631. [CrossRef]
10. Bobori, D.C.; Dimitriadi, A.; Feidantsis, K.; Samiotaki, A.; Fafouti, D.; Sampsonidis, I.; Kalogiannis, S.; Kastrinaki, G.; Lambropoulou, D.A.; Kyzas, G.Z.; et al. Differentiation in the expression of toxic effects of polyethylene microplastics on two freshwater fish species: Size matters. *Sci. Total Environ.* **2022**, *830*, 154603. [CrossRef]
11. Sun, L.; Sun, S.Q.; Bai, M.; Wang, Z.J.; Zhao, Y.J.; Huang, Q.G.; Hu, C.W.; Li, X. Internalization of polystyrene microplastics in *Euglena gracilis* and its effects on the protozoan photosynthesis and motility. *Aquatic Toxicol.* **2021**, *236*, 105840. [CrossRef]
12. Saoca, C.; Arfuso, F.; Giannetto, C.; Piccione, G.; Fazio, F. Seasonal biodistribution of some trace elements (Cd, Pb, Cr, Hg) and "Blood Biomarkers" response in *Mugil cephalus* (Linnaeus, 1758). *Biol. Trace Element Res.* **2023**, *201*, 1987–1995. [CrossRef] [PubMed]
13. Beghin, M.; Paris-Palacios, S.; Mandiki, S.N.; Schmitz, M.; Palluel, O.; Gillet, E.; Bonnard, I.; Nott, K.; Robert, C.; Porcher, J.M.; et al. Integrative multi-biomarker approach on caged rainbow trout: A biomonitoring tool for wastewater treatment plant effluents toxicity assessment. *Sci. Total Environ.* **2022**, *838*, 155912. [CrossRef] [PubMed]
14. Ofogh, A.R.E.; Dorche, E.E.; Birk, S.; Btuder, A. Effect of seasonal variability on the development and application of a novel Multimetric Index based on benthic macroinverterbrate communities -A case study from streams in the Karun river basin (Iran). *Ecol. Indic.* **2023**, *146*, 109843. [CrossRef]
15. Banerjee, S.; Deoli, N.T.; Withlow, H.J.; Klerks, P.L. Invasive or biomonitoring species? Use of *Pomacea maculata* operculum as a tool to determine metal pollutants: A micro-PIXE investigation. *Water Air Soil Pollut.* **2023**, *234*, 353. [CrossRef]
16. Diganta, M.T.M.; Saifullah, A.S.M.; Siddique, M.A.; Mostafa, M.; Sheikh, M.S.; Uddin, M.J. Macroalgae for biomonitoring of trace elements in relation to environmental parameters and seasonality in a sub-tropical mangrove estuary. *J. Cont. Hydrol.* **2023**, *256*, 104190. [CrossRef]
17. Redzovic, Z.; Erk, M.; Gottstein, S.; Peric, M.S.; Dautovic, J.; Fiket, Z.; Brkic, A.L.; Cindric, M. Metal bioaccumulation in stygophilous amphipod Synurella ambulans in the hyporheic zone: The influence of environmental factors. *Sci. Total Environ.* **2023**, *866*, 161350. [CrossRef]
18. Polechonska, L.; Klink, A. Macrophytes as passive bioindicators of trace element pollution in the aquatic environment. *Wiley Interdiscip. Rev.-Water* **2023**, *10*, e1630. [CrossRef]
19. Curpan, A.-S.; Impellitteri, F.; Plavan, G.; Ciobica, A.; Faggio, C. Review: *Mytilus galloprovincialis*: An essential, low-cost model organism for the impact of xenobiotics on oxidative stress and public health. *Comp. Biochem. Physiol. C* **2022**, *256*, 109302. [CrossRef]

20. Han, S.; Zhang, Q.; Zhang, X.; Liu, X.; Lu, L.; Wei, J.; Li, Y.; Wang, Y.; Zheng, G. A digital microfluidic diluter-based microalgal motion biosensor for marine pollution monitoring. *Biosens. Bioelectron.* **2019**, *143*, 111597. [CrossRef]
21. Negi, S.; Han, T.J.; Park, J.; Bergey, E.A.; Sangeeta, J.; Chaubey, J.; Kumar, A.; Gupta, D.; Gupta, M.; Singh, S.; et al. Qualitative and quantitative assessment of diatom deformities and protoplasmic condition under metal and metalloid stress. *Protoplasma* **2023**. [CrossRef]
22. Shen, H.; Nzabanita, D.; Sinclair, G.M.; Vu, H.; Grist, S.; Nugegoda, D.; Long, S.M. Changes in metabolic profiles of amphipods *Allorchestes compressa* after acute exposures to copper, pyrene, and their mixtures. *Environ. Toxicol. Pharmacol.* **2023**, *99*, 104120. [CrossRef]
23. Dellali, M.; Mardassi, K.; Harrath, A.H.; Mansour, L.; Pacioglu, O.; Aldahmash, W.; Nahdi, S.; Badraoui, R.; Alrefaei, A.F.; Boufahja, F. Physiological responses of the bivalves *Mytilus galloprivincialis* and *Ruditapes decussatus* following exposure to phenanthrene: Toxicokinetics, dynamics and biomarkers study. *Animals* **2023**, *13*, 151. [CrossRef]
24. Sripanya, J.; Vongsombath, C.; Vannachak, V.; Rattanachan, K.; Hanjavanit, C.; Mahakham, W.; Sangpradub, N. Benthic macroinvertebrate communities in wadable rivers and streams of Lao PDR as a useful tool for biomonitoring water quality: A multimetric index approach. *Water* **2023**, *15*, 625. [CrossRef]
25. Zhou, S.B.; Li, Z.Q.; Peng, S.C.; Zhang, D.J.; Li, W.C.; Hong, M.Y.; Li, X.; Yang, J.H.; Lu, P.L. Combining eDNA and morphological approaches to reveal the impacts of long-term discharges of shale gas wastewaters on receiving waters. *Water Res.* **2022**, *222*, 118869. [CrossRef] [PubMed]
26. Akyildiz, G.K.; Duran, M. Evaluation of the impact of heterogeneous environmental pollutants on benthic macroinvertebrates and water quality by long-term monitoring of the buyuk menderes river basin. *Environ. Monit. Assess.* **2021**, *193*, 280. [CrossRef]
27. Schuijt, L.M.; Peng, F.J.; van den Berg, S.J.P.; Dingemans, M.M.L.; Van den Brink, P.J. (Eco)toxicological tests for assessing impacts of chemical stress to aquatic ecosystems: Facts, challenges, and future. *Sci. Total Environ.* **2021**, *795*, 148776. [CrossRef]
28. Okeke, E.S.; Feng, W.W.; Mao, G.H.; Chen, Y.; Qian, X.; Luo, M.N.; Xu, H.; Qiu, X.C.; Wu, X.Y.; Yang, L.Q. A transcriptomic-based analysis predicts the neuroendocrine disrupting effect on adult male and female zebrafish (Danio rerio) following long-term exposure to tetrabromobisphenol A bis(2-hydroxyethyl) ether. *Comp. Biochem. Physiol. C Toxicol. Pharmacol.* **2023**, *264*, 109527. [CrossRef]
29. Lepretre, M.; Geffard, O.; Espeyte, A.; Faugere, J.; Ayciriex, S.; Salvador, A.; Delorme, N.; Chaumot, A.; Degli Esposti, D. Multiple reaction monitoring mass spectrometry for the discovery of environmentally modulated proteins in an aquatic invertebrate sentinel species, *Gammarus fossarum*. *Environ. Pollut.* **2022**, *315*, 120393. [CrossRef]
30. Kim, W.S.; Park, K.; Park, J.W.; Lee, S.H.; Kim, J.H.; Kim, Y.J.; Oh, G.H.; Ko, B.S.; Park, J.W.; Hong, C.; et al. Transcriptional responses of stress-related genes in pale chub (*Zacco platypus*) inhabiting different aquatic environments: Application for biomonitoring aquatic ecosystems. *Int. J. Environ. Res. Public Health* **2022**, *19*, 11471. [CrossRef] [PubMed]
31. Lari, E.; Jeong, T.Y.; Labine, L.M.; Simpson, M.J. Metabolomic analysis predicted changes in growth rate in Daphnia magna exposed to acetaminophen. *Aquatic Toxicol.* **2022**, *249*, 106233. [CrossRef] [PubMed]
32. Raza, S.H.A.; Abdelnour, S.A.; Alotaibi, M.A.; AlGabbani, Q.; Naiel, M.A.; Shokrollahi, B.; Noreldin, A.E.; Jahejo, A.R.; Shah, M.A.; Alagawany, M.; et al. MicroRNAs mediated environmental stress responses and toxicity signs in teleost fish species. *Aquaculture* **2022**, *546*, 737310. [CrossRef]
33. Yang, J.H.; Zhang, L.J.; Mu, Y.W.; Wang, J.Y.; Yu, H.X.; Zhang, X.W. Unsupervised biological integrity assessment by eDNA biomonitoring of multitrophic aquatic taxa. *Environ. Int.* **2023**, *175*, 107950. [CrossRef]
34. Takahashi, M.; Saccò, M.; Kestel, J.H.; Nester, G.; Campbell, M.A.; Van Der Heyde, M.; Heydenrych, M.J.; Juszkiewicz, D.J.; Nevill, P.; Dawkins, K.L.; et al. Aquatic environmental DNA: A review of the macro-organismal biomonitoring revolution. *Sci. Total. Environ.* **2023**, *873*, 162322. [CrossRef] [PubMed]
35. Wee, A.K.; Salmo, S.G.; Sivakumar, K.; Then, A.Y.; Basyuni, M.; Fall, J.; Habib, K.A.; Isowa, Y.; Leopardas, V.; Peer, N.; et al. Prospects and challenges of environmental DNA (eDNA) metabarcoding in mangrove restoration in Southeast Asia. *Front. Mar. Sci.* **2023**, *10*, 1033258. [CrossRef]
36. Meng, H.; Lin, Y.Y.; Zhong, W.J.; Zhao, Z.; Shen, L.; Ling, Z.; Zhao, K.S.; Xu, S. Fish biomonitoring and ecological assessment in the Dianchi lake basin based on environmental DNA. *Water* **2023**, *15*, 399. [CrossRef]
37. Duarte, S.; Vieira, P.E.; Leite, B.R.; Teixeira, M.A.L.; Neto, J.M.; Costa, F.O. Macrozoobenthos monitoring in Portuguese transitional waters in the scope of the water framework directive using morphology and DNA metabarcoding. *Estuar. Coast. Shelf Sci.* **2023**, *281*, 108207. [CrossRef]
38. Borrego-Ramos, M.; Becares, E.; Garcia, P.; Nistal, A.; Blanco, S. Epiphytic diatom-based biomonitoring in Mediterranean ponds: Traditional microscopy versus metabarcoding approaches. *Water* **2021**, *13*, 1351. [CrossRef]
39. Bej, S.; Swain, S.; Bishoyi, A.K.; Mandhata, C.P.; Sahoo, C.R.; Padhy, R.N. Wastewater-associated infections: A public health concern. *Water Air Soil Pollut.* **2023**, *234*, 444. [CrossRef]
40. Takahashi, A.; Masuda, K.; Sugimoto, T.; Hamada-Sato, N. Synthetic dye decolorization using the marine filamentous fungus Pestalotiopsis disseminate AN-7 and toxicity evaluation using Daphnia magna. *Int. J. Environ. Sci. Technol.* **2023**. [CrossRef]
41. Derbalah, A.S.; Ismail, A.A. Efficiency of different remediation technologies for fenitrothion and dimethoate removal in the aquatic system. *Agrochimica* **2012**, *56*, 234–246.
42. Tian, D.; Cheng, X.; Wang, L.; Hu, J.; Zhou, N.; Xia, J.; Xu, M.; Zhang, L.; Gao, H.; Ye, X.; et al. Remediation of lead contaminated water by red yeast and different types of phosphate. *Front. Bioeng. Biotechnol.* **2022**, *10*, 775058. [CrossRef] [PubMed]

43. Giripunje, M.D.; Fulke, A.B.; Meshram, P.U. Remediation techniques for heavy metals contamination in lakes: A mini-review. *Clean Soil Air Water* **2015**, *43*, 1350–1354. [CrossRef]
44. Ziegler, P.; Sree, K.S.; Appenroth, K.J. The uses of duckweed in relation to water remediation. *Desal. Water Treatm.* **2017**, *63*, 327–342. [CrossRef]
45. Wilkinson, S.R.; Naeth, M.A.; Dhar, A. Potential of macrophytes for wastewater remediation with constructed floating wetlands in cold climates. *Water* **2023**, *15*, 2479. [CrossRef]
46. Baigorria, E.; Fraceto, L.F. Low-cost biosorbent hybrid hydrogels for paraquat remediation of water. *J. Water Proc. Eng.* **2022**, *49*, 103088. [CrossRef]
47. Septevani, A.A.; Rifathin, A.; Sari, A.A.; Sampora, Y.; Ariani, G.N.; Sudiyarmanto; Sondari, D. Oil palm empty fruit bunch-based nanocellulose as a super-adsorbent for water remediation. *Carb. Pol.* **2020**, *229*, 115433. [CrossRef]
48. Varamesh, A.; Abraham, B.D.; Wang, H.; Berton, P.; Zhao, H.; Gourlay, K.; Minhas, G.; Lu, Q.; Bryant, S.L.; Hu, J. Multifunctional fully biobased aerogels for water remediation: Applications for dye and heavy metal adsorption and oil/water separation. *J. Haz. Mat.* **2023**, *457*, 131824. [CrossRef]
49. Qiao, A.; Cui, M.; Huang, R.; Ding, G.; Qi, W.; He, Z.; Klemes, J.J.; Su, R. Advances in nanocellulose-based materials as adsorbents of heavy metals and dyes. *Carb. Pol.* **2021**, *272*, 118471. [CrossRef]
50. Wang, D.; Gan, X.; Wang, Z.; Jiang, S.; Zheng, X.; Zhao, M.; Zhang, Y.; Fan, C.; Wu, S.; Du, L. Research status on remediation of eutrophic water by submerged macrophytes: A review. *Proc. Saf. Environ. Prot.* **2023**, *169*, 671–684. [CrossRef]
51. Khan, S.; Ullah, A.; Ayaz, T.; Aziz, A.; Aman, K.; Habib, M.; Yilmaz, S.; Farid, A.; Yasmin, H.; Ali, Q. Phycoremediation of industrial wastewater usin *Vaucheria debaryana* and *Cladophora glomerata*. *Environ. Monit. Assess.* **2023**, *195*, 825. [CrossRef] [PubMed]
52. Alomar, T.; Qiblawey, H.; Almomani, F.; Al-Raoush, R.I.; Han, D.S.; Ahmad, N.M. Recent advances on humic acid removal from wastewater using adsorption process. *J. Water Proc. Eng.* **2023**, *53*, 103679. [CrossRef]
53. El-sayed, M.E.A. Nanoadsorbents for water and wastewater remediation. *Sci. Total Environ.* **2020**, *739*, 139903. [CrossRef]
54. Jain, A.; Kumari, S.; Agarwal, S.; Khan, S. Water purification via novel nano-adsorbents and their regeneration strategies. *Proc. Saf. Environ. Prot.* **2021**, *152*, 441–454. [CrossRef]
55. Barelli, M.; Casado, S.; Cassin, F.; Pimentel, C.; Pina, C.M.; Giordano, M.C.; de Mongeot, F.B.; Gnecco, E. Highly efficient sequestration of aqueous lead on nanostructured calcite substrates. *Nanotechnology* **2023**, *34*, 365301. [CrossRef] [PubMed]
56. Bian, Y.N.; Xiong, N.N.; Zhu, G.C. Technology for the remediation of water pollution: A review on the fabrication of metaal organic frameworks. *Processes* **2018**, *6*, 122. [CrossRef]
57. Leonel, A.G.; Mansur, A.A.P.; Mansur, H.S. Advanced functional nanostructures based on magnetic Iron Oxide nanomaterials for water remediation: A review. *Water Res.* **2021**, *190*, 116693. [CrossRef]
58. Aberdeen, S.; Cali, E.; Vandeperre, L.; Ryan, M.P. Selective radionuclide and heavy metal sorption using functionalized magnetic nanoparticles for environmental remediation. *J. Mater. Chem. A* **2023**, *11*, 15855. [CrossRef]
59. Zafar, A.M.; Javed, M.A.; Hassan, A.A.; Mohamed, M.M. Groundwater remediation using zero-valent iron nanoparticles (nZVI). *Groundw. Sust. Dev.* **2021**, *15*, 100694. [CrossRef]
60. Bediako, J.K.; El Ouardi, Y.; Mouele, E.S.M.; Mensah, B.; Repo, E. Polyelectrolyte and polyelectrolyte complex-incorporated adsorbents in water and wastewater remediation-A review of recent advances. *Chemosphere* **2023**, *325*, 138418. [CrossRef]
61. Gupta, R.S.; Mandal, S.; Arya, S.; Dutta, S.; Manna, K.; Islam, S.S.; Pathan, S.; Bose, S. Copper-substituted polyoxometalate-soldered interpenetrating polymeric networks membranes for water remediation. *Chem. Eng. J.* **2023**, *461*, 141949. [CrossRef]
62. Lin, J.; Tao, Y.; Liu, J.; Zheng, C.; Song, X.; Dai, P.; Wang, Q.; Li, W.; Chen, W. TiO2@carbon microsphere core-shell micromotors for photocatalytic water remediation. *Optical. Mater.* **2022**, *124*, 111989. [CrossRef]
63. Beker, S.A.; Cole, I.; Ball, A.S. A review on the catalytic remediation of dyes by tailored carbon dots. *Water* **2022**, *14*, 1456. [CrossRef]
64. Bermudez, L.A.; Pascual, J.M.; Martinez, M.d.M.M.; Capilla, J.M.P. Effectiveness of advanced oxidation processes in wastewater treatment: State of the art. *Water* **2021**, *13*, 1094. [CrossRef]
65. Esposito, B.R.; Capobianco, M.L.; Martelli, A.; Navacchia, M.L.; Pretali, L.; Saracino, M.; Zanelli, A.; Emmi, S.S. Advanced water remediation from ofloxacin by ionizing radiation. *Rad. Phys. Chem.* **2017**, *141*, 118–124. [CrossRef]
66. Wanninayake, D.M. Comparison of currently available PFAS remediation technologies in water: A review. *J. Environ. Man.* **2021**, *283*, 111977. [CrossRef] [PubMed]
67. Wu, Q.; Liu, J.Q.; Li, Q.N.; Mo, W.J.; Wan, R.H.; Peng, S. Effect of electrode distances on remediation of eutrophic water and sediment by sediment microbial fuel cell coupled floating beds. *Int. J. Environ. Res. Public Health* **2022**, *19*, 10423. [CrossRef]
68. Li, Z.; Qiu, Y.; Yu, Y.; Ji, Y.; Li, H.; Liao, M.; Li, D.; Liang, D.; Liu, G.; Feng, Y. Long-term operation of cathode-enhanced ecological floating bed coupled with microbial electrochemical system for urban surface water remediation: From lab-scale research to engineering application. *Water Res.* **2023**, *237*, 119967. [CrossRef]
69. San-Martin, M.I.; Alonso, R.M.; Ivars-Barceló, F.; Escapa, A.; Morán, A. Complete arsenic removal from water using biocatalytic systems based on anaerobic films grown on carbon fibers. *Catal. Today* **2023**, *423*, 114269. [CrossRef]

70. Betancor-Abreu, A.; Mena, V.F.; González, S.; Delgado, S.; Souto, R.M.; Santana, J.J. Design and optimization of an electrocoagulation reactor for fluoride remediation in underground water sources for human consumption. *J. Water Process Eng.* **2019**, *31*, 100865. [CrossRef]
71. Liu, J.H.; Qi, W.L.; Xu, M.M.; Thomas, T.; Liu, S.Q.; Yang, M. Piezocatalytic techniques in environmental remediation. *Angew. Chem.-Int. Ed.* **2023**, *62*, e202213927. [CrossRef] [PubMed]


**Disclaimer/Publisher's Note:** The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.