Oxidative sorption of arsenite from water by iron: A mechanistic perspective

Puthiya Veetil Nidheesh[a,*], Govindaraj Divyapriya[b], Elizabeth B. Cerkez[c], Ashitha Gopinath[a], Tuhin Banerji[d,e], Daniel R. Strongin[c]

[a]Environmental Impact and Sustainability Division, CSIR National Environmental Engineering Research Institute, Nagpur, Maharashtra, India

[b] Institute of Robotics and Intelligent System (IRIS), Swiss Federal Institute of Technology (ETH) Zurich, CH-8092, Switzerland

[c]Department of Chemistry, Temple University, Philadelphia, Pennsylvania 19122, United States

[d]R.D. Aga Research Technology and Innovation Centre, Thermax Limited, Pune 411019, India

[e]Mumbai Zonal Centre, CSIR National Environmental Engineering Research Institute, Worli, Mumbai 400018, India

*Corresponding author: pv_nidheesh@neeri.res.in (P. V. Nidheesh); dstrongi@temple.edu (Daniel Strongin)

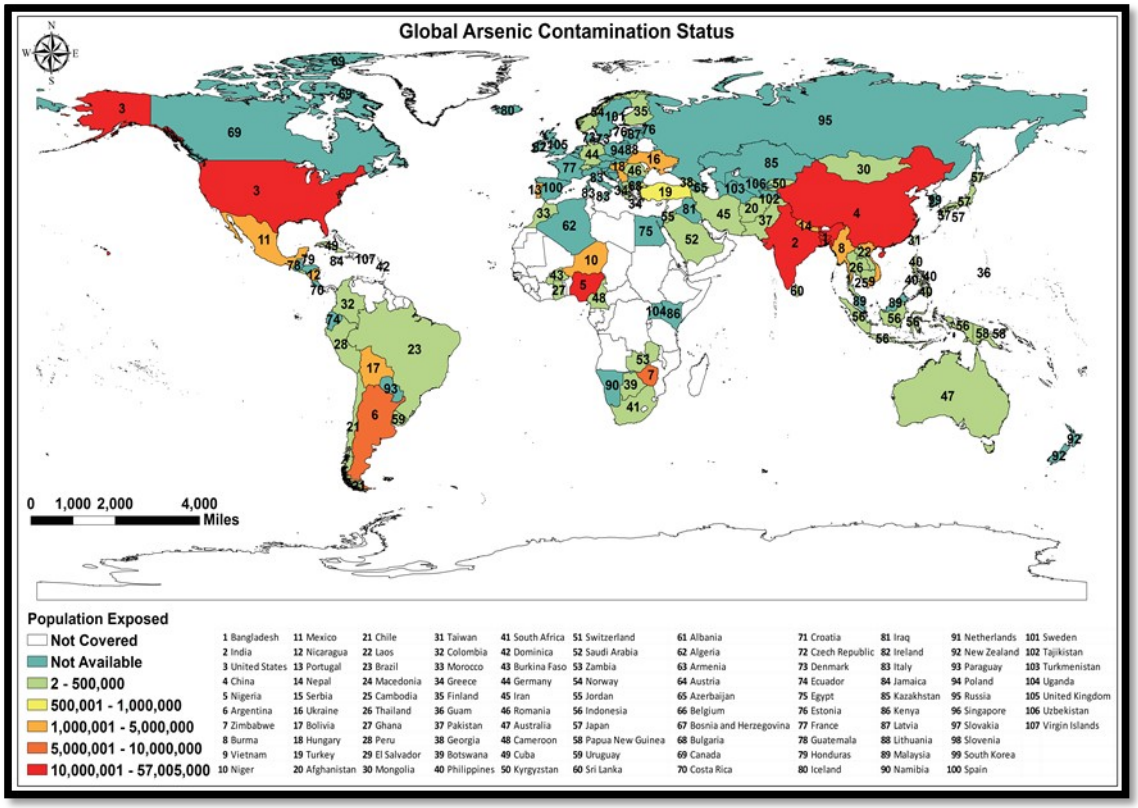

Fig. 1. Contamination of drinking water due to arsenic in different parts of the world. Reprinted with permission from Ref. [1]. Copyright © Taylor & Francis

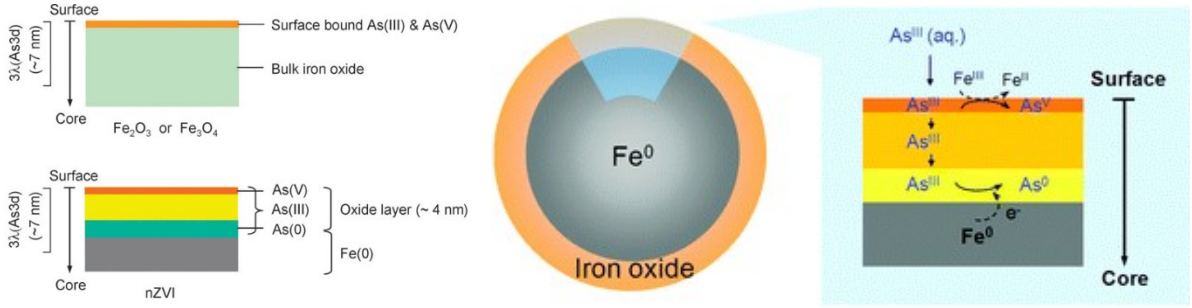

Fig. 2 Distribution of arsenic species at different depths of iron oxide (left top) and ZVI (left down); and overall reactions occurs at the surface of ZVI for arsenite removal in adsorption/surface-oxidation mechanism. Reprinted with permission from Ref. [2] Copyright © Royal Society of Chemistry

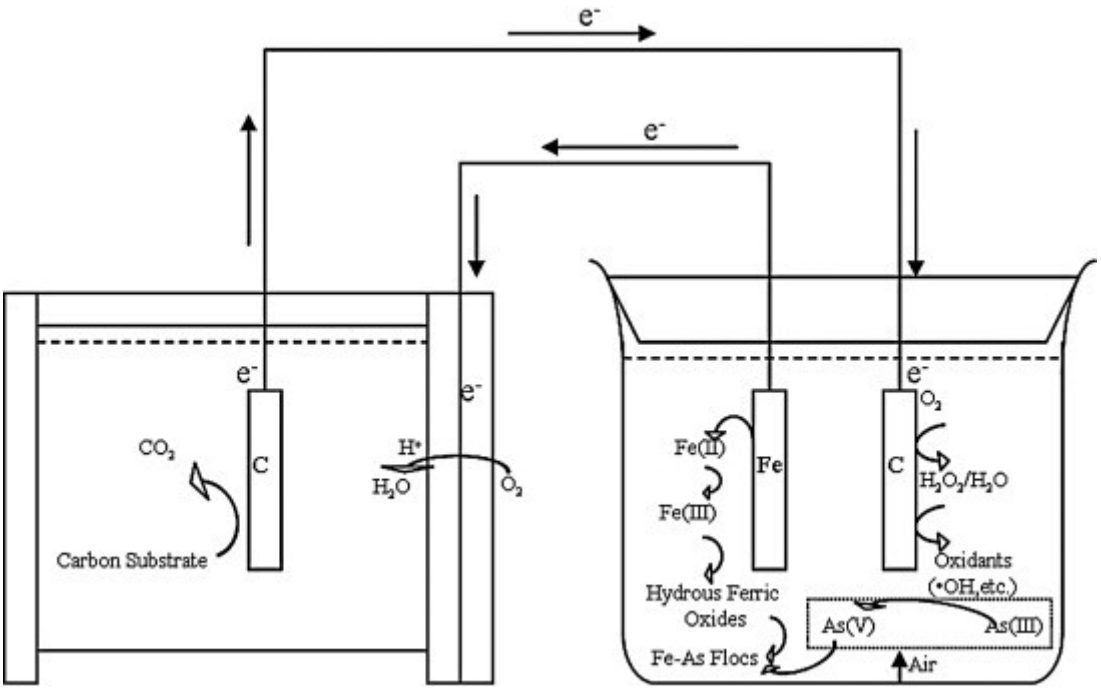

Fig. 3: Schematic illustration of MFC-ZVI hybrid electrochemical cell. Reprinted with permission from Ref. [3] Copyright © 2013 Elsevier B.V.

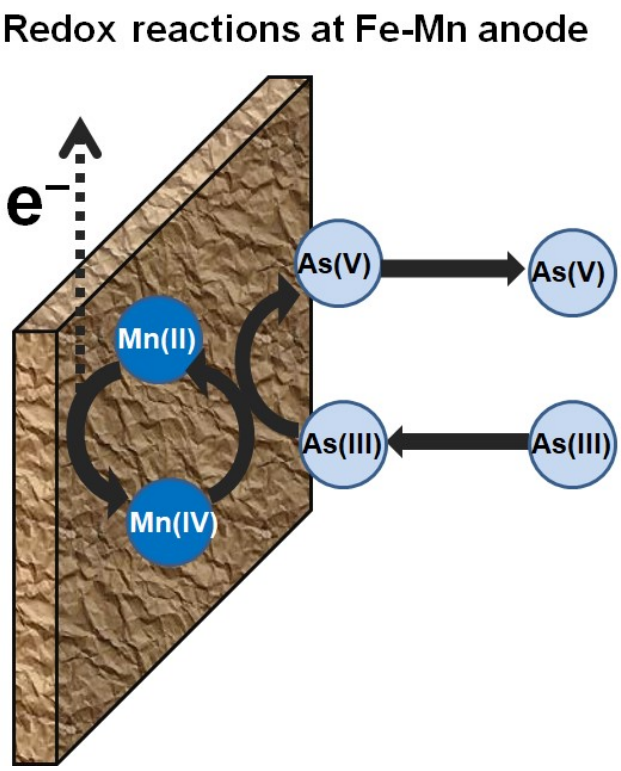

Fig. 4: Possible electrochemical based redox reactions at Fe-Mn anode

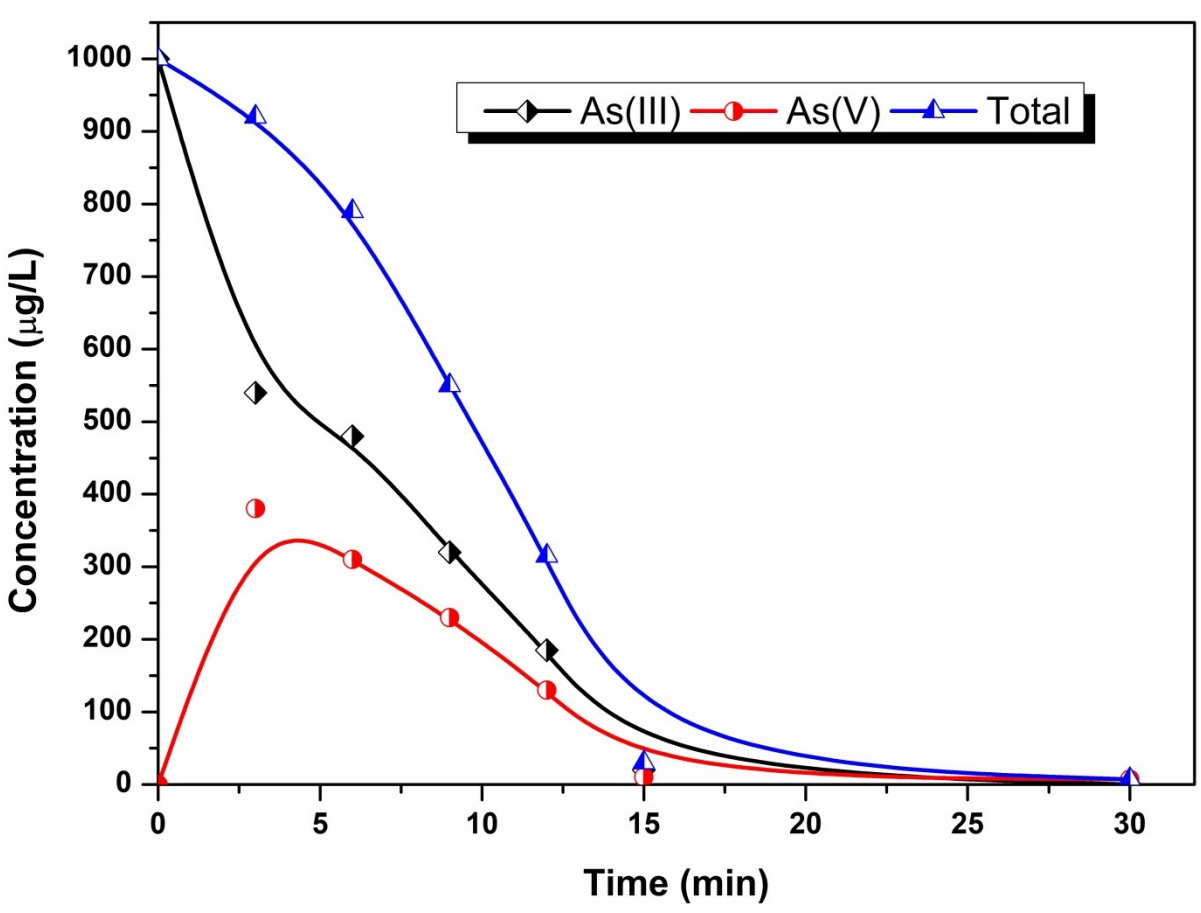

Fig. 5 Arsenite, arsenate and total arsenic concentration variations during aerated iron electrocoagulation. Reprinted with permission from Ref. [4] Copyright © Taylor & Francis

Table 1. List of review papers on arsenite removal technologies since 2000

Title	Work reviewed	Reference
An Overview of Arsenic Removal Technologies in Bangladesh and India	Updates on developments in arsenic removal methods particularly tested in rural Indian and Bangladesh as well as its difficulties incurred in the implementation in the field was reviewed.	[5]
Arsenic removal by reverse osmosis	Reviewed the natural and anthropogenic sources of As, its geochemistry, regulation and elimination mechanism of As specifically by reverse osmosis	[6]
Arsenic – a Review. Part II: Oxidation of Arsenic and its Removal in Water Treatment	Removal of arsenic from drinking water by technologies involving oxidation methods were reviewed in detail. Additionally, the performance of installed technologies in developing countries was also discussed.	[7]
Arsenic removal technologies for drinking water treatment	An overview of conventional technologies and hybrid membrane technologies employed for arsenic removal were given along with the limitations associated with the membrane filtration processes	[8]
An overview of arsenic removal by pressure-driven membrane processes	Provided an overview of the distribution of As, its regulation, symptoms on As exposure and applications of membrane technologies for As removal. In particular, different membrane materials, types and processes involving As removal in pilot as well as bench scale were reviewed.	[9]
Review of Coagulation Technology for Removal of Arsenic: Case of Chile	The concepts related to coagulation technology and its operational parameters for the removal of arsenic in Chile was summarized	[10]
Arsenic removal from water/wastewater using adsorbents-A critical review	Remediation of As contaminated water by adsorption using low-cost adsorbents, soil constituents, oxides, metals and commercial adsorbents were critically reviewed. In addition to this, desorption studies, competitive adsorption and cost estimation data were also discussed.	[11]
Use of iron-based technologies in contaminated land and groundwater remediation: A review	Reviewed the development of various technologies using iron for the application of As removal from land and groundwater along with their limitations.	[12]
Rejection of arsenic minerals in sulfide flotation — A literature review	Specific review was provided on the floatation behaviour as well as selective floatation of arsenic minerals and the advances made in this area	[13]

Possible treatments for arsenic removal in Latin American waters for human consumption	Arsenic removal methods suitable for water systems in Latin America were reviewed. Moreover, technologies that are being practised for As removal are described by emphasizing on economic aspects.	14
Iron and aluminum based adsorption strategies for removing arsenic from water	The adsorption of As using iron and aluminum based minerals were extensively reviewed with specific importance given to oxidation of As in 3^+ states.	15
Removal of Arsenic from Water by Electrocoagulation and Electrodialysis Techniques	Arsenic removal using electro dialysis and electrocoagulation were explained in detail with specific attention given to optimization of parameters for maximum removal. Mechanisms related to these techniques were also summarized.	16
Technological options for the removal of arsenic with special reference to South East Asia	Various treatment technologies involving oxidation, precipitation, adsorption and ion-exchange to remediate groundwater contamination by As, particularly in South east Asia were described.	17
Application of titanium dioxide in arsenic removal from water: A review	A comprehensive review on photocatalytic oxidation of As on TiO_2, improvements in As elimination by TiO_2, influence of co-existing factors and mechanisms involved in the removal of As by TiO_2 was provided.	18
Arsenic Removal from Water by Adsorption Using Iron Oxide Minerals as Adsorbents: A Review	Elimination of arsenic by adsorption process form contaminated water on iron oxide minerals by highlighting the mechanism of arsenic sorption was reviewed in detail.	19
Application of low-cost adsorbents for arsenic removal: A review	The applicability of waste products from various industries and natural materials as adsorbent material for arsenic removal was summarized. The cost effectiveness and feasibility of using such adsorbents were discussed.	20
Use of chitosan and chitosan-derivatives to remove arsenic from aqueous solutions—a mini review	Mechanisms and kinetics pertaining to arsenite and arsenate removal from water using chitosan and chitosan derivatives were reviewed	21
A review on sources, toxicity and remediation technologies for removing arsenic from drinking water	Natural and anthropogenic sources of arsenic, its toxic effects in humans and various technologies adopted for the treatment of arsenic bearing water were discussed in detail.	22
Arsenic Removal from Natural Water Using Low	A detailed review on utilization of granular adsorbents for arsenic removal	23

Cost Granulated Adsorbents: A Review	was given with particular importance to regeneration of spent adsorbents and cost involved in the treatment processes	
Arsenic contamination, consequences and remediation techniques: A review	Provided an extensive review of various sources of As, elimination of As from water and soil by different conventional as well as the advanced integrated technologies. A brief description of sludge disposal was also given.	24
Arsenic and fluoride contaminated groundwaters: A review of current technologies for contaminants removal	Processes that are used for the removal of As and F individually and simultaneously were reviewed along with the discussion of disposal of As/F laden concentrate.	25
Application of biopolymer composites in arsenic removal from aqueous medium: A review	A specific review on the application of arsenic adsorption by biopolymers and its composites was provided by including the adsorption capacity and LD_{50} of the arsenic species.	26
Arsenic removal by nanoparticles: a review	Benefits of metal and metal oxide nanoparticles and their composites as adsorbents in arsenic removal when compared to conventional adsorbents were discussed in detail. Additionally, mechanisms pertaining to removal process were explained.	27
Inorganic nano-adsorbents for the removal of heavy metals and arsenic: a review	Different types of nanoadsorbents and their various forms towards arsenic elimination were reviewed with importance given to morphology of nanoadsorbents and functional groups present on the adsorbent site	28
Removal of arsenic from water using nano adsorbents and challenges: A review	Different nanoadsorbent materials employed for arsenic elimination from water environment along with their challenges were reviewed. Factors influencing As removal using these materials were also critically discussed.	29
Arsenic removal from naturally contaminated waters: a review of methods combining chemical and biological treatments	A brief discussion on the conventional technologies and biological methods for arsenic removal was provided with prime importance given to biological oxidation of arsenite. A case study based on arsenic bacterial communities in aquatic environment of Italy was also provided.	30
Technologies for Arsenic Removal from Water: Current Status and Future Perspectives	An overview of conventional technologies for the removal of arsenic from water was provided along with the applicability of nanoparticles to treat arsenic contaminated water	31

The global menace of arsenic and its conventional remediation – A critical review	Presence of arsenic in the environment, its occurrence across the globe and its toxicity effects on humans were summarized. A brief overview on conventional remediation techniques for arsenic was also provided.	[32]
Removal of As(III) and As(V) from water by chitosan and chitosan derivatives: a review	A wide review was provided on the elimination of arsenate and arsenite using chitosan and modified chitosan with special attention given to the effect of pH and kinetics of adsorption	[33]
Recent progress of arsenic adsorption on TiO_2 in the presence of coexisting ions: A review	Elimination of arsenic by adsorption onto TiO_2 by both batch and column studies in the presence of various ions that co-exist along with arsenic in the groundwater were explored in detail.	[34]
Electrocoagulation treatment of arsenic in wastewaters: A comprehensive review	Developments in arsenic removal by electrocoagulation method were summarized with specific importance given to parameter optimization, reactor configuration and final product characterization based on different electrodes.	[35]
Arsenic adsorption from water using graphene-based materials as adsorbents: a critical review	Performances of various 2-D dimensional and 3-D grapheme based adsorbents for arsenic elimination were reviewed. Mechanism and factors affecting the adsorption process were critically discussed.	[36]
Arsenic Removal from Drinking Water: Experiences with Technologies and Constraints in Practice	Provided an overview of treatment technologies for the elimination of As which are installed at full scale in different parts of the world as well as the practical difficulties associated with the same.	[37]
Arsenic-related microorganisms in groundwater: a review on distribution, metabolic activities and potential use in arsenic removal processes	The potential of arsenic related microbes to oxidize As^{3+} in groundwater and the various technologies that utilize microbes to eliminate arsenic from groundwater were reviewed.	[38]
Conventional as well as Emerging Arsenic Removal Technologies—a Critical Review	Arsenic chemistry, sources and effects were briefly discussed. An elaborative and critical review was provided on the conventional and emerging techniques for arsenic removal along with the discussion of their advantages and disadvantages.	[39]
Arsenic removal by electrocoagulation process: Recent trends and removal	Arsenic contamination in drinking water, mechanism involved in electrocoagulation process, recent trends in arsenic removal,	[40]

mechanism	sludge disposal issues and challenges incurred in the real field implementation were elaborated in detail.	
Recent advances in exploitation of nanomaterial for arsenic removal from water: a review	Synthesis, characterization and performance of Zr-based, Cu based, TiO_2 based and Fe based nanomaterials towards arsenic removal were reviewed.	41
Iron-based subsurface arsenic removal technologies by aeration: A review of the current state and future prospects	Reviewed the significance of in-situ arsenic remediation technology, its operational attributes and different conditions of iron dosing and aeration.	42
A critical review on arsenic removal from water using iron-based adsorbents	A review on arsenic removal from water was provided by critically discussing the importance of iron-based minerals as well as low cost and natural adsorbents. A brief discussion on mathematical modelling related to adsorption was also given.	43
Arsenic removal from water/wastewater using layered double hydroxide derived adsorbents, a critical review	Significance of layered double hydroxides and its composites as an adsorbent material for arsenic removal from water as well as wastewater were explained in detail. Moreover, insights into the influence of competing ions were also provided.	44
Rare-earth metal-based adsorbents for effective removal of arsenic from water: A critical review	Adsorptive behavior of rare earth metals including yttrium, cerium and lanthanum and their oxides were elaborated by highlighting their mechanism of adsorption was overviewed. Applicability of these adsorbents from industrial perspective was also mentioned.	45
Review of processes controlling Arsenic retention and release in soils and sediments of Bengal basin and suitable iron-based technologies for its removal	Causes of arsenic retention in sediment and soil particularly in Bengal basin, domestic and community level removal technologies and iron-based technologies for arsenic removal were discussed well.	46
Metal-organic frameworks for aquatic arsenic removal	Systematically reviewed the characteristics and performance of MOF materials for As elimination from aqueous media. Moreover, the mechanisms of As interaction with MOF were also provided.	47
Biochar versus bone char for a sustainable inorganic arsenic mitigation in water: What needs to be done in future research?	Critically reviewed the preparation and modification of various types of biochar and bone char materials used for the sorptive removal of As. In addition to this, mechanisms pertaining to immobilization	48

	of As on these materials were discussed.	
Promising prospects of nanomaterials for arsenic water remediation: A comprehensive review	Extensively reviewed the nanomaterials employed for As elimination from water, its shortcomings and ways to modify to enhance the removal efficiency. They have also summarized the mechanism of As with virgin and modified nanomaterials.	[49]
Metal-air fuel cell electrocoagulation techniques for the treatment of arsenic in water	Arsenic removal using conventional technologies and electrocoagulation in particular was described. The significance, mechanism, configuration, operational parameters and performance of metal air fuel cell electrocoagulation were elaborated.	[50]
Titanium-based nanocomposite materials for arsenic removal from water: A review	Nano composites prepared from titania with metal and metal oxides for the elimination of arsenic from water were summarized.	[51]
Technology alternatives for decontamination of arsenic-rich groundwater—A critical review	Different physicochemical biological methods which are currently practiced and which are under investigation were extensively reviewed with specific focus given to their mechanism, cost and sustainability aspects.	[52]
Applications of biological sulfate reduction for remediation of arsenic - A review	An overview on bioremediation of arsenic contaminated area with sulphate reducing bacteria, its fundamentals and mechanism was provided.	[53]
Detoxification of water and wastewater by advanced oxidation processes	A critical review was provided on the detoxification of wastewater by advance oxidation processes with special importance given to arsenic elimination. Challenges incurred after the treatment processes were also discussed with major focus given to the toxicity of the by-products.	[54]
Alginate-based biotechnology: a review on the arsenic removal technologies and future possibilities	The potential of alginate-based adsorbents for removing arsenic from drinking water and the possibilities of regenerating adsorbents were discussed in detail.	[55]
Use of (modified) natural adsorbents for arsenic remediation: A review	Arsenic remediation using modified natural adsorbents including minerals, bio sorbents and industrial by-products were extensively reviewed.	[56]
Arsenic reduction to < 1 µg/L in Dutch drinking water	Specifically reviewed the As occurrence, its mobility and treatment technologies prevailing in Netherlands and the current investigations which are involved in	[57]

	reducing As below 1 μg L^{-1}	
A review of functional sorbents for adsorptive removal of arsenic ions in aqueous systems	A comparative evaluation of the performance of both conventional and advanced adsorbents based on partition coefficient was reviewed. Factors affecting adsorption, the regeneration of adsorbents and their disposal were also summarized.	58
A review on coal fly ash-based adsorbents for mercury and arsenic removal	A systematic review was provided on coal fly ash-based adsorbents for capturing As and Hg from flue gas and water.	59
A review on decontamination of arsenic-contained water by electrocoagulation: Reactor configurations and operating cost along with removal mechanisms	A detailed review was given by highlighting the mechanistic and theoretical aspects of electrocoagulation. The influence of operational parameters, reactor configurations and sludge disposal were also discussed.	60
Exploring carbonaceous nanomaterials for arsenic and chromium removal from wastewater	The applicability of carbon nanomaterials and their composites in arsenic removal was elaborated extensively by considering their adsorption capacity, reusability and toxicity aspects of the nanomaterials	61
The role of plant growth promoting bacteria on arsenic removal: A review of existing perspectives	The characteristics of plant growth promoting bacteria that can assist phytoremediation of As and the mechanisms that reduce the adversities of As in plants were reviewed.	62
MOFs for the treatment of arsenic, fluoride and iron contaminated drinking water: A review	Synthesis and modifications of metal organic frameworks and its advancement in the treatment of As, F and Fe contaminated water were extensively discussed with specific insight given on the mechanism	63
Arsenic (V) removal from water using hydrotalcites as adsorbents: A critical review	The significance of hydrotalcites in As elimination by adsorption mechanism was summarized. Additionally, the dissolution of components present in the hydrotalcites during adsorption process and its implications was discussed.	64
A review on electrochemical treatment of arsenic from aqueous medium	A detailed review on electrochemical based As separation technologies were provided. Complete oxidative removal by combination of various electrochemical techniques was also discussed.	65
Recent advances of graphene-based strategies for arsenic remediation	Design criteria adopted for the development of graphene based nano adsorbents and membranes for As remediation was reviewed.	66
Removal of arsenic from contaminated groundwater	As adsorption by biochar and modified biochar was reviewed with special	67

using biochar: a technical review	attention given to real time monitoring and treatment scenarios.	
Remediation of arsenic by metal/ metal oxide-based nanocomposites/ nanohybrids: contamination scenario in groundwater, practical challenges, and future perspectives	Nano adsorbents employed for As removal was reviewed with a discussion on the polymorphic structure and stability of the adsorbents.	68
Arsenic removal from water by nanofiltration membrane: potentials and limitations	An overview on nanofiltration membranes employed for the As removal and operational parameters governing the filtration process was provided.	69
Nanofiltration for arsenic removal: challenges, recent developments, and perspectives	Various types of nanofiltration membranes, their fabrication process, performance in As removal was deliberated.	70
Removal of arsenic, chromium and uranium from water sources by novel nanostructured materials including graphene-based modified adsorbents: a mini review of recent developments	An overview on nano metal oxide composites and graphene-based composites developed for the elimination of arsenic, uranium and chromium from groundwater was provided.	71
Arsenic removal technologies and future trends: A mini review	Various physico-chemical processes, biological methods and other advanced technologies adopted for As removal was reviewed. The practicability of employing adsorption process and the use of various functional materials was discussed.	72
Treatment of aqueous arsenic – A review of biosorbent preparation methods	An overview on biomasses that have been used for As sorption was provided. The significance of modified biomass over untreated biomass in enhancing the sorption capacity was highlighted	73
A critical review on arsenic removal from water using biochar-based sorbents: The significance of modification and redox reactions	The potential of biochar and modified biochar in arsenic remediation were critically reviewed. Various factors that govern the As removal by biochar, removal mechanisms, fate and redox transformations were discussed in detail.	74
Review: Efficiently performing periodic elements with modern adsorption technologies for arsenic removal	Various adsorbents employed for the removal of As from water was reviewed. Emphasis was given to the periodic elements that have been used in As removal.	75
Advanced application of nano-technological and biological processes as well	Nanoparticles, advanced iron nanoparticles, composites, advanced adsorbent materials used for As removal	76

as mitigation options for arsenic removal	was reviewed. Phytoremediation and bioremediation by various microbial species were deliberated.	
Arsenic and fluoride removal by electrocoagulation process: A general review	Removal of As and fluoride from groundwater and wastewater by electrocoagulation (EC) process, parameters influencing the EC process, energy consumption and operating cost were reviewed.	[77]
Arsenic contamination, effects and remediation techniques: A special look onto membrane separation processes	An overview on the sources, occurrence, mobilization and exposure pathways of As were given. Further, As removal using physico-chemical process and membrane separation processes were reviewed.	[78]
Insights into conventional and recent technologies for arsenic bioremediation: A systematic review	As removal using algae, fungi, yeast and bacteria were reviewed by emphasizing the mechanisms involved in remediation process. Various phytoremediation technologies and their potential in As remediation were discussed.	[79]
Selective removal of arsenic in water: A critical review	Various methods, mechanism of factors and selective removal of As, were reviewed. An overview on microbiological methods were also provided.	[80]

References

1 S. K. Singh and E. A. Stern, *Environment*, 2017, **59**, 24–28.

2 W. Yan, M. A. V. V Ramos, B. E. Koel and W. X. Zhang, *Chem. Commun.*, 2010, **46**, 6995–6997.

3 A. Xue, Z. Z. Shen, B. Zhao and H. Z. Zhao, *J. Hazard. Mater.*, 2013, **261**, 621–627.

4 D. Syam Babu, P. V. Nidheesh and M. Suresh Kumar, *Sep. Sci. Technol.*, 2021, **56**, 184–193.

5 M. F. Ahmed, *Civ. Eng.*, 2001, 251–269.

6 R. Y. Ning, *Desalination*, 2002, **143**, 237–241.

7 M. Bissen and F. H. Frimmel, *Acta Hydrochim. Hydrobiol.*, 2003, **31**, 9–18.

8 K. S. Ng, Z. Ujang and P. Le-Clech, *Rev. Environ. Sci. Bio/Technology*, 2004, **3**, 43–53.

9 M. C. Shih, *Desalination*, 2005, **172**, 85–97.

10 A. M. Sancha, *J. Heal. Popul. Nutr.*, 2006, **24**, 267–272.

11 D. Mohan and C. U. Pittman, *J. Hazard. Mater.*, 2007, 142, 1–53.

12 A. B. Cundy, L. Hopkinson and R. L. D. Whitby, *Sci. Total Environ.*, 2008, **400**, 42–51.

13 X. Ma and W. J. Bruckard, *Int. J. Miner. Process.*, 2009, **93**, 89–94.

14 M. I. Litter, M. E. Morgada and J. Bundschuh, *Environ. Pollut.*, 2010, **158**, 1105–1118.

15 D. E. Giles, M. Mohapatra, T. B. Issa, S. Anand and P. Singh, *J. Environ. Manage.*, 2011, **92**, 3011–3022.

16 I. Ali, T. A. Khan and M. Asim, *Sep. Purif. Rev.*, 2011, **40**, 25–42.

17 C. K. Jain and R. D. Singh, *J. Environ. Manage.*, 2012, **107**, 1–18.

18 X. Guan, J. Du, X. Meng, Y. Sun, B. Sun and Q. Hu, *J. Hazard. Mater.*, 2012, **215**–**216**, 1–16.

19 M. Gallegos-Garcia, K. Ramírez-Muñiz and S. Song, *Arsenic removal from water by adsorption using iron oxide minerals as adsorbents: A review*, 2012, vol. 33.

20 Mohamed CHIBAN, *J. Environ. Chem. Ecotoxicol.*, 2012, **4**, 91–102.

21 L. Pontoni and M. Fabbricino, *Carbohydr. Res.*, 2012, **356**, 86–92.

22 A. Basu, D. Saha, R. Saha, T. Ghosh and B. Saha, *Res. Chem. Intermed.*, 2014, **40**, 447–485.

23 S. A. Baig, T. Sheng, Y. Hu, J. Xu and X. Xu, *Clean - Soil, Air, Water*, 2015, **43**, 13–26.

24 R. Singh, S. Singh, P. Parihar, V. P. Singh and S. M. Prasad, *Ecotoxicol. Environ. Saf.*, 2015, **112**, 247–270.

25 S. V. Jadhav, E. Bringas, G. D. Yadav, V. K. Rathod, I. Ortiz and K. V. Marathe, *J. Environ. Manage.*, 2015, **162**, 306–325.

26 M. Rahim and M. R. H. Mas Haris, *J. Radiat. Res. Appl. Sci.*, 2015, **8**, 255–263.

27 M. Habuda-Stanić and M. Nujić, *Environ. Sci. Pollut. Res.*, 2015, 22, 8094–8123.

28 P. Z. Ray and H. J. Shipley, *RSC Adv.*, 2015, **5**, 29885–29907.

29 S. Lata and S. R. Samadder, *Removal of arsenic from water using nano adsorbents and challenges: A review*, Elsevier Ltd, 2016, vol. 166.

30 S. Fazi, S. Amalfitano, B. Casentini, D. Davolos, B. Pietrangeli, S. Crognale, F. Lotti and S. Rossetti, *Rend. Lincei*, 2016, **27**, 51–58.

31 N. R. Nicomel, K. Leus, K. Folens, P. Van Der Voort and G. Du Laing, *Int. J. Environ. Res. Public Health*, 2015, **13**, 62.

32 A. Sarkar and B. Paul, *Chemosphere*, 2016, **158**, 37–49.

33 X. Wang, Y. Liu and J. Zheng, *Environ. Sci. Pollut. Res.*, 2016, **23**, 13789–13801.

34 L. Yan, S. Hu and C. Jing, *J. Environ. Sci. (China)*, 2016, **49**, 74–85.

35 P. Song, Z. Yang, G. Zeng, X. Yang, H. Xu, L. Wang, R. Xu, W. Xiong and K. Ahmad, *Chem. Eng. J.*, 2017, **317**, 707–725.

36 X. Yang, L. Xia and S. Song, *Surf. Rev. Lett.*, 2017, **24**, 1–12.

37 J. G. Hering, I. A. Katsoyiannis, G. A. Theoduloz, M. Berg and S. J. Hug, *J. Environ. Eng. (United States)*, 2017, **143**, 1–9.

38 S. Crognale, S. Amalfitano, B. Casentini, S. Fazi, M. Petruccioli and S. Rossetti, *Rev. Environ. Sci. Biotechnol.*, 2017, **16**, 647–665.

39 D. Mohanty, *Water. Air. Soil Pollut.*, , DOI:10.1007/s11270-017-3549-4.

40 P. V. Nidheesh and T. . S. A. Singh, *Chemosphere*, 2017, **181**, 418–432.

41 W. W. and H. Y. W. and A. B. M. B. and H. H. G. and M. Zaman, *Nanotechnology*, 2017, **28**, 42001.

42 V. T. Luong, E. E. Cañas Kurz, U. Hellriegel, T. L. Luu, J. Hoinkis and J. Bundschuh, *Water Res.*, 2018, **133**, 110–122.

43 L. Hao, M. Liu, N. Wang and G. Li, *RSC Adv.*, 2018, **8**, 39545–39560.

44 J. Wang, T. Zhang, M. Li, Y. Yang, P. Lu, P. Ning and Q. Wang, *RSC Adv.*, 2018, **8**, 22694–22709.

45 Y. Yu, L. Yu, K. Y. Koh, C. Wang and J. P. Chen, *Crit. Rev. Environ. Sci. Technol.*, 2018, **48**, 1127–1164.

46 T. Banerji, K. Kalawapudi, S. Salana and R. Vijay, *Groundw. Sustain. Dev.*, 2019, **8**, 358–367.

47 C. Wang, J. Luan and C. Wu, *Water Res.*, 2019, **158**, 370–382.

48 S. S. A. Alkurdi, I. Herath, J. Bundschuh, R. A. Al-Juboori, M. Vithanage and D. Mohan, *Environ. Int.*, 2019, **127**, 52–69.

49 S. I. Siddiqui, M. Naushad and S. A. Chaudhry, *Process Saf. Environ. Prot.*, 2019, **126**, 60–97.

50 H. A. Maitlo, J. H. Kim, K. H. Kim, J. Y. Park and A. Khan, *J. Clean. Prod.*, 2019, **207**, 67–84.

51 S. Ashraf, A. Siddiqa, S. Shahida and S. Qaisar, *Heliyon*, 2019, **5**, e01577.

52 S. G. (Nath), A. Debsarkar and A. Dutta, *Environ. Technol. Innov.*, 2019, **13**, 277–303.

53 R. Alam and K. McPhedran, *Chemosphere*, 2019, **222**, 932–944.

54 D. S. Babu, V. Srivastava, P. V. V Nidheesh and M. S. Kumar, *Sci. Total Environ.*, 2019, **696**, 133961.

55 S. Chowdhury, I. R. Chowdhury, F. Kabir, M. A. J. Mazumder, M. H. Zahir and K. Alhooshani, *J. Water Supply Res. Technol. - AQUA*, 2019, **68**, 369–389.

56 T. G. Asere, C. V. Stevens and G. Du Laing, *Sci. Total Environ.*, 2019, **676**, 706–720.

57 A. Ahmad, P. van der Wens, K. Baken, L. de Waal, P. Bhattacharya and P. Stuyfzand, *Environ. Int.*, 2020, **134**, 105253.

58 B. Liu, K. H. Kim, V. Kumar and S. Kim, *J. Hazard. Mater.*, 2020, **388**, 121815.

59 F. O. Ochedi, Y. Liu and A. Hussain, *J. Clean. Prod.*, 2020, **267**, 122143.

60 M. Kobya, R. D. C. Soltani, P. I. Omwene and A. Khataee, *Environ. Technol. Innov.*, 2020, **17**, 100519.

61 S. Lal, A. Singhal and P. Kumari, *J. Water Process Eng.*, 2020, **36**, 101276.

62 S. Alka, S. Shahir, N. Ibrahim, T. T. Chai, Z. Mohd Bahari and F. Abd Manan, *Environ. Technol. Innov.*, 2020, **17**, 100602.

63 D. Haldar, P. Duarah and M. K. Purkait, *Chemosphere*, 2020, **251**, 126388.

64 A. C. Dias and M. P. F. Fontes, *Appl. Clay Sci.*, 2020, **191**, 105615.

65 D. Syam Babu and P. V. Nidheesh, *Chem. Eng. Commun.*, 2021, **208**, 389–410.

66 C. Foti, P. G. Mineo, A. Nicosia, A. Scala, G. Neri and A. Piperno, *Front. Chem.*, 2020, **8**, 608236.

67 O. M. Siddiq, B. S. Tawabini, P. Soupios and D. Ntarlagiannis, *Int. J. Environ. Sci. Technol.*, , DOI:10.1007/s13762-020-03116-x.

68 A. Kumar, H. Joshi and A. Kumar, *Sep. Purif. Rev.*, 2021, **50**, 283–314.

69 C. N. Worou, Z.-L. Chen and T. Bacharou, *Water Pract. Technol.*, 2021, **16**, 291–319.

70 T. A. Siddique, N. K. Dutta and N. Roy Choudhury, *Nanomater.* , 2020, 10.

71 A. K. Tolkou, I. A. Katsoyiannis and A. I. Zouboulis, *Appl. Sci.* , 2020, 10.

72 S. Alka, S. Shahir, N. Ibrahim, M. J. Ndejiko, D. V. N. Vo and F. A. Manan, *J. Clean. Prod.*, , DOI:10.1016/j.jclepro.2020.123805.

73 K. Zoroufchi Benis, A. Motalebi Damuchali, K. N. McPhedran and J. Soltan, *J. Environ. Manage.*, 2020, **273**, 111126.

74 R. Amen, H. Bashir, I. Bibi, S. M. Shaheen, N. K. Niazi, M. Shahid, M. M. Hussain, V. Antoniadis, M. B. Shakoor, S. G. Al-Solaimani, H. Wang, J. Bundschuh and J. Rinklebe, *Chem. Eng. J.*, , DOI:10.1016/j.cej.2020.125195.

75 M. J. Uddin and Y.-K. Jeong, *Environ. Sci. Pollut. Res.*, 2020, **27**, 39888–39912.

76 J. P. Maity, C.-Y. Chen, P. Bhattacharya, R. K. Sharma, A. Ahmad, S. Patnaik and J. Bundschuh, *J. Hazard. Mater.*, 2021, **405**, 123885.

77 M. A. Sandoval, R. Fuentes, A. Thiam and R. Salazar, *Sci. Total Environ.*, 2021, **753**, 142108.

78 V. R. Moreira, Y. A. R. Lebron, L. V. S. Santos, E. Coutinho de Paula and M. C. S. Amaral, *Process Saf. Environ. Prot.*, 2021, **148**, 604–623.

79 S. Irshad, Z. Xie, S. Mehmood, A. Nawaz, A. Ditta and Q. Mahmood, *Environ. Sci. Pollut. Res.*, 2021, **28**, 18870–18892.

80 L. Weerasundara, Y.-S. Ok and J. Bundschuh, *Environ. Pollut.*, 2021, **268**, 115668.