Chapter 21
Nanomaterials for Wastewater Remediation: Resolving Huge Problems with Tiny Particles

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21.1 Introduction

Water is the prime requirement for the endurance of animals and human beings. The earth is covered by 70% of water, and only 2.5% is clean water. Water is utilized for domestic purpose and numerous industrial activities being discharged enormous quantity of untreated wastewater into water bodies. Besides, farming activities consume a range of fertilizers, pesticides and insecticides which reach water bodies through run-off.

In general, the microorganisms, inorganic and organic materials, cause water contamination. The inorganic pollutants consist of metals like Pb, Hg, Cd, Cr, etc., and the organic pollutants consist of agricultural pesticides, pharmaceuticals, textile wastes such as dyes, personal care products, household wastes like detergents,

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phenolic compounds and halogenated and aromatic compounds. Discharge of these pollutants in the lakes, rivers and/or drinking water resources leads to serious environmental issues like water pollution, water scarcity and health risks (Saleh 2015). According to the World Health Organization (WHO), up to 12 million people are affected by consumption of polluted water every year.

In present decades, water treatment techniques have turn into a considerable attention worldwide in increasing fast growth of industries and ecological contamination (Geise et al. 2010; Sharma et al. 2019; Yahya et al. 2018). Removal of pollutants from water is most important for the developing countries and some of the techniques are employed for the water treatment. Among, various wastewater treatment technologies, nanotechnology acquire several advantages owing to its unique physicochemical properties. Oxidation, adsorption and degradation are the nanotechniques used for the removal of contaminants which persist in the polluted water. Chemical oxidation and advanced oxidation are efficient processes for the removal of organic contaminants in water. The oxidants used in the chemical oxidation process are ozone, chlorine, chlorite, hydrogen peroxide, etc. Fenton process is one of the advanced oxidation process (AOP) which degrades the organic contaminants from water by redox reactions, dehydrogenation and electrophilic addition. AOP does not eliminate the byproducts completely during the treatment which leads to health risk to humans (Feng et al. 2013; Celiz et al. 2009).

Adsorption is a critically significant method to remediate pollutants from the polluted water, and it is an economic method. The efficiency of the adsorption depends on the nature of adsorbate, adsorbent and condition of the operation. The mechanism of adsorption generally attributes to electrostatic, π–π and Van der Waals interactions. Activated carbon, carbon nanomaterials, metal organic frameworks, clays and zeolites are used as the adsorbent (Yu et al. 2016). This remediation mechanism can be applied in water treatment nanotechnology to eliminate a number of contaminants. Hence, this chapter highlights sources of wastewater, properties of various nanomaterials, mechanism of nanoremediation and efficiency of nanomaterials used for target pollutants in wastewater.

21.2 Sources of Wastewater

Organic contaminants in waster ecosystem cause serious issues in the environment. In addition to the organic contaminants, heavy metals in water also lead to the health issue to the living organism. The pharmaceutical products are also identified in surface and groundwater ecosystem. The personal care products and endocrine disrupting compounds are high volatile and high polar in nature. Due to this intractable and persistent nature in the environment, these compounds does not undergo the degradation process (Archer et al. 2017; Tijani et al. 2019; Snyder et al. 2003).

The world population is increasing day by day, and so the world faces the lack of food. Pesticides play a significant part in the production of crops and vegetables, and it includes fungicides, herbicides, insecticides, etc. To control the pest in farming, more than a million tons of pesticides have been prepared each year. Usage of pesticides in farming leads to fast transfer of pesticide residue to the water bodies and penetrated into food chain. In farming countries, water pollution due to pesticides are incredibly frequent, and it is hazardous to human beings. Consumption of water affected by pesticide causes organ damage, cancer, reproduction effects, nervous system damage and also birth defects. The famous pesticides are organophosphate, organochlorine, *N*-methyl carbamate, arsenic-containing fungicides, chlorophenoxy, nitrophenol, pentachlorophenol, rodenticides and fumigants (Milne 2018).

Organic dyes are the most common organic pollutants obtained from textile, plastic, construction, leather, food industries, cosmetics and paper industries. It was anticipated that above 15% of dyes (approximately 400 ton/day) were liberated into the water body during the dyeing process (Garcia et al. 2007; Vanhulle et al. 2008). These are synthetic organic compounds which have the mutagenic and carcinogenic effects (Tang et al. 2016). The azo dyes, for instance, methylene blue and rhodamine B, are commonly used in the recent decades. These organic dyes are nondegradable naturally (Chen et al. 2011; Mirzazadeh and Lashanizadegan 2018; Han et al. 2015). Methylene blue causes eye and skin irritation and also respiratory tract irritation upon contact during the consumption (Jain et al. 2007; Kumar and Kumaran 2005). In addition, usage of detergents has increased in our daily life, and it affects the water ecosystem. These detergents are classified as cationic detergents like quaternary ammonium cations; anionic detergents like linear alkylbenzene sulfonates; and non-ionic and zwitterionic detergents. The general industrial chemicals like aromatic compounds and bisphenol A cause many health issues during consumption (Sui et al. 2011).

The water contaminated with heavy metals shows high density and atomic weight as high as five times than pure water, and these metals naturally occur via different sources. Heavy metal sources including soils, rocks and volcanic explosion and other anthropogenic sources including mining actions contaminates the water bodies. Arsenic (As), chromium (Cr), lead (Pb), mercury (Hg), cadmium (Cd), copper (Cu) and nickel (Ni) are some of the common metals which cause heavy metal contamination in water. Amongst all the heavy metals, arsenic and chromium are the principal reasons of water contamination by both natural and anthropogenic sources. According to the World Health Organization (WHO), arsenic is classified as group 1 human carcinogenic substance. Consumption of arsenic-polluted water leads to various types of skin diseases such as hyperpigmentation, hyperkeratosis and cancers like kidney, skin, lung and bladder (Khare 2016; Singh et al. 2015; Halem et al. 2009).

21.3 Mechanism

Elimination of contaminants present in wastewater can be done by photocatalysis, and the catalyst used for the degradation process in photocatalysis is known as photocatalyst which alters rate of the reaction only. After the completion of degradation process, the catalyst can be recovered and reused. During the photocatalytic activity, the following reactions are taking place in the remediation of contaminants in the water body:

- The contaminants transferred are adsorbed on the surface of the catalyst.
- The photonic activation and decomposition of the adsorbed contaminants.
- Desorption of the reaction product.
- Reaction products are eliminated from the surface of the catalyst.

$$e^{-} + O_2 \rightarrow O_2^{\cdot -}$$
$$O_2^{\cdot -} + 2H^{+} + 2e^{-} \rightarrow OH^{\cdot} + OH^{-}$$
$$h^{+} + H_2O \rightarrow OH^{\cdot} + OH^{+} / OH^{\cdot}$$
$$OH^{\cdot} + OC \rightarrow CO_2(g) + H_2O(l) + \text{Other}$$
$$e^{-} + OC \rightarrow OC^{-} \rightarrow \text{Degradation products}$$
$$h^{+} + OC \rightarrow OC^{+} \rightarrow \text{Degradation products}$$

where OC organic contaminants.

The photocatalytic degradation of pollutants present in water can be carried out with the use of photons, electrons and catalyst (Fig. 21.1). The photocatalytic degradation of materials such as dyes, heavy metals, organic pollutants, microplastics, etc., engages the photons, catalyst and electrons. These were engaged the individual energy stage in the atom. Depending upon the atoms, every individual energy state was divided into several energy levels. The energy bands are formed depends on close energy state. Atom filled with electrons by donation of the energy and

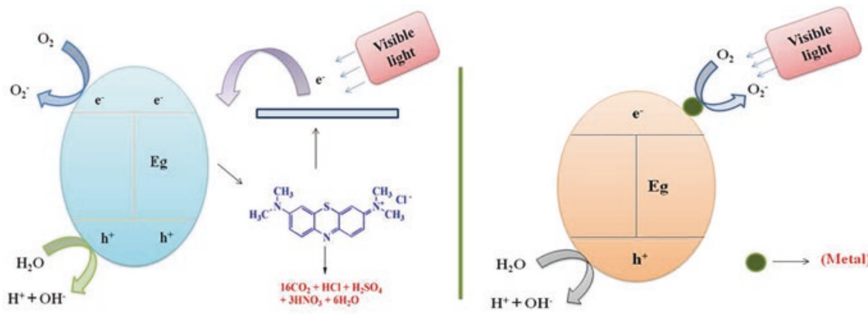

Fig. 21.1 Photocatalytic mechanism of nanomaterials

conductivity band was created. This action can be done by photocatalyst, and then the different factors were contributed in the important parts of photocatalytic activity. The electrons are energized to conductance band from valence band in the presence of sunlight. The assortment of the photogenerated n-type and p-type from nanoparticles prohibited beneath sunlight gives enhanced time of charge transporters and additional proficient redox properties (Nivetha et al. 2019).

21.4 Remediation

Nowadays, wastewater obtained from industrial sources are treated by different processes, and they have the capability to remediate the contaminants. There are numerous methods that have been adopted for the wastewater treatment such as phytoremediation, bioremediation, etc. But these methods have some disadvantages like inefficiency, regeneration, waste products, weak selectivity, etc. To overcome these demerits, alternate method must be needed. Hence, nanotechnologies play a pivotal role in wastewater treatment processes. Adsorption and degradation process is considered as the most significant process in the water purification. The degradation efficiency of contaminants relies on several factors like source of irradiation, adsorbent dosage, contact time, effect of pH, temperature and nature and type of the

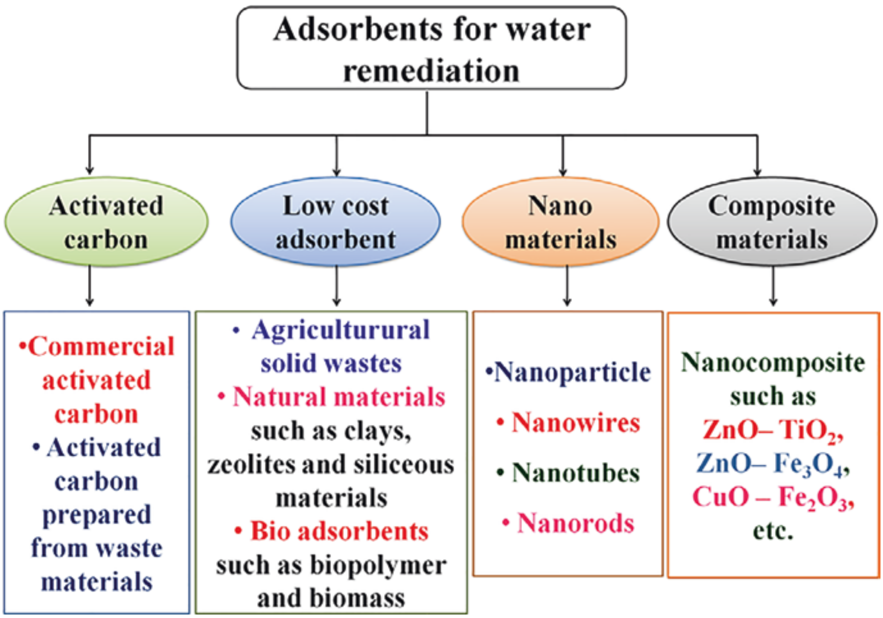

Fig. 21.2 Nano-adsorbents for wastewater remediation

catalyst used in the wastewater remediation. Some of the important nano-based materials are depicted in Fig. 21.2 for wastewater remediation.

21.4.1 Magnetic Nanomaterials

The application of various nanomaterials and its degradation efficiency in pollutant remediation were depicted in Tables 21.1 and 21.2.

21.4.1.1 Zero-Valent Iron Nanoparticles

Zero-valent iron (ZVI) nanoparticles have been widely considered and applied for the wastewater treatment (Fig. 21.3). Owing to the ease of oxidation, high reactivity, non-hazardous nature, economic, plenty, synthesize easily, bioavailabilities and large surface area, it is used in wastewater treatment processes (Zhu and Chen 2019; Zhang 2003). The ZVI is used to eliminate the organic pollutants, polychlorinated biphenyl, organic chlorinated solvent and heavy metals present in wastewater. It is used as catalyst in the degradation and oxidation of organic pollutants transferred to hydrogen peroxide in presence of dissolved oxygen. From ZVI, two electrons are transported repeatedly to reduce the hydrogen peroxide into the water. In addition, the hydroxyl radicals are produced, and it has the ability to oxidize the organic pollutants during the permutation of hydrogen peroxide and Fe^{2+} (Fenton reaction). It has the standard redox potential value 0.440 V and shows that it can eliminate the halogenated compounds via reductive dehalogenation (Fu et al. 2014; He and Zhao 2007). It quickly removes hazardous non-aqueous phase liquids like halogenated partially volatile compound, halogenated volatile material and non-halogenated partially volatile materials to non-hazardous materials in polluted water.

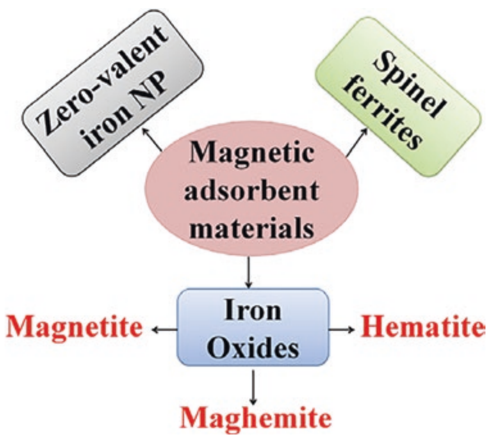

Fig. 21.3 Iron-based nanomaterials for wastewater remediation

Table 21.1 Degradation efficiency of various nanomaterials in pollutant removal

S. no	Material	Pollutants	Degradation efficiency and time	Reference
1	ZVI NPs	Amoxicillin	86.5% & 25 min	Zha et al. (2014)
2	ZVI NPs	Methylene blue	72.1% & 30 min	Hamdy et al. (2018)
3	ZVI NPs	Pb(II)	95% & 1 h	Ahmed et al. (2017)
4	ZVI NPs	Cd(II) Cu(II) Pb(II) Ni(II)	71.4% 100% 99.9% 96.6%	Danila et al. (2018)
5	ZVI/kaolinite	Acid black 1	98% & 2 h	Kakavandi et al. (2019)
6	ZVI/peroxymonosulfate	Tetracycline	88.5% & 5 min	Cao et al. (2019)
7	Cu	Safranin Carbol fuchsin Malachite green Methylene blue	92% 94% 97% 85%	Dlamini et al. (2019)
8	CuO-Fe_2O_3	Rhodamine B	100% & 1 h	Alp et al. (2019)
9	ZnO	Ag(I) Pb(II) Cr(VI)	97.92% 85.18% 43.34%	Le et al. (2019)
10	ZnO	Cd Cu Fe Pb	99.03% & 1 h 97.39% & 1 h 100% & 1 h 97.64% & 1 h	El-Dafrawy et al. (2017)
11	ZnO	Crystal violet dye	90% & 2 h	Franco et al. (2019)
12	ZnO	Dibenzothiophene	97% & 3 h	Khalafi et al. (2019)
13	ZnO MWCNT ZnO/ MWCNT	Reactive blue 203	85.4% & 20 min 19% & 20 min 99.1% & 20 min	Bagheri et al. (2020)
14	$TiO_2/CoFe_2O_4$	4-nitrophenol	94% & 35 min	Ibrahim et al. (2019)
15	$Fe_3O_4/TiO_2/SiO_2$	Methylene blue	98% & 2 h	Abbas et al. (2016)
16	$Fe_2O_3/BiVO_4$	Methylene blue and rhodamine B	100% 20 min	Wen et al. (2019)
17	$MgFe_2O_4$-TiO_2@GO	Methylene blue	100% & 5 h	Kaur and Kaur (2019)

(continued)

Table 21.1 (continued)

S. no	Material	Pollutants	Degradation efficiency and time	Reference
18	Cu Fe_2O_4/graphene oxide	Acid orange 7	95% & 50 min	Ayazi et al. (2016)
19	$ZnFe_2O_4$/AgI	*E. coli*	100% & 1 h 20 min	Xu et al. (2018)
20	TiO_2-CdS/reduced graphene oxide	Methylene blue	97.5% & 20 min	Kassaee et al. 2011
21	Reduced graphene oxide/ TiO_2	Methylene blue	92% & 2 h	Kireeti et al. (2016)
22	TiO_2/graphene oxide	Phenol	99.3% & 8 h	Pizarro et al. (2015)
23	Ag–TiO_2	Chloramphenicol	100% & 30 min	Shokri et al. (2013)
24	Fe–TiO_2	Metronidazole	97% & 2 h	Malakootian et al. (2019)
25	Zr–TiO_2	Bisphenol A	100% & 1 h 20 min	Gao et al. (2010)
26	Cu–TiO_2	Naproxen sodium	87% & 6 h	Hinojosa-Reyes et al. (2019)
27	Multiwalled carbon nanotubes (MWCNT)	Phenol, anti-inflammatory and nonsteroidal drugs, polychlorinated biphenyls	80–99%	Hu et al. (2015)
28	CNT	As(V)	80%	Peng et al. (2005)

In aqueous solution, zero-valent iron nanoparticles undergo oxidation readily either by oxygen or react with subsurface component which is occurring naturally leading to low reactivity and surface passivation. The reaction circumstances like pH, strength of ions, initial concentration of pollutant, method of synthesis, stabilizing agent used during the synthesis, medium for oxidation either air or water, and time play a crucial role in the degradation of organic contaminants. ZVI nanoparticles have some disadvantages as follows:

(i) Passivation – Owing to the less active iron hydroxides formation on ZVI nanoparticles surface during the reaction
(ii) Aggregation – Owing to the Van der Walls and magnetic force and also formation of less active small particles
(iii) Poor retrievability
(iv) Potential health and environmental risk – Because of bioaccumulation (Lu and Astruc 2020)

Table 21.2 Various nanomaterials and its adsorption capacity in pollutant removal

S. no	Material	Pollutant	Adsorption capacity (mg/g)	Reference
1	EDTA-GO	Pb(II)	479 ± 46	Clemonne et al. (2012)
2	MWCNT	Magnetic carbon Methylene blue	149 399	Ma et al. (2012)
3	MWCNT	Pb(II) Cd(II)	97.08 10.86	Li et al. (2003)
4	Chitosan	Pb(II)	398	Qi et al. (2004)
5	Graphene sand composite	Cr(VI)	2859.38	Dubey et al. (2015)
6	Nitrogen-doped magnetic CNT	Cr(III)	638.56	Shin et al. (2011)
7	MnO_2-MWCNT	Cr(III)	99.01	Tian et al. (2014)
8	TiO_2	Cd(II)	29.28	Sharaf El-Deen and Zhang (2016)
9	TiO_2	Cd Cu Ni Pb	120.1 50.2 39.3 21.7	Mahdavi et al. (2013)

21.4.1.2 Iron Oxide

Iron oxide nanoparticles have existed in different structures like maghemite, hematite and magnetite (Fig. 21.3). These iron oxide nanoparticles acquire polymorphism which includes temperature-induced phase transition (Cornell and Schwertmann 2003). Owing to the strong magnetic property, porosity and precise surface area, iron nanoparticles displayed tremendous properties in adsorption process (Huang and Chen 2009; Nizamuddin et al. 2019).

Hematite (α-Fe_2O_3) is an n-type semiconductor, and it has the band gap value of 2.1–2.2 eV, and it has paramagnetic phase at Curie temperature (T_c = 682.85 °C). According to JCPDS file No. 33-0664, it has trigonal crystal structure which belongs to R-3c space group and unit cell parameter $a = b = 4.9865$ Å, $c = 13.5016$ Å (Rozenberg et al. 2002). Crystallinity, particle size, cation doping, exchange interactions and subparticle structure influence the magnetic properties of the hematite. Not only the size and shape of hematite but also the nature of the dopant plays a vital role to increase the adsorption properties and lead to the efficient catalyst in the wastewater treatment (Tadic et al. 2019). Owing to poor conductivity and low efficiency of separation, its photocatalytic activity is controlled (Zhang et al. 2017). During visible light irradiation, it absorbs approximately 43% of light which helps to degrade the effluent from the polluted water under light source (Santhosh et al. 2019). Kang et al. (2019) reported that hematite-based material can enhance the degradation efficiency of rhodamine B in the presence of photocatalyst. Chen et al. (2019) reported the admirable degradation kinetics of antibiotics such as ciprofloxacin, norfloxacin, sulfadiazine and tetracycline under solar light irradiation in the presence of $AgBr/Ag_3PO_4$@natural hematite as a photocatalyst. The rate constants of antibiotics are 0.16, 0.19, 0.34 and 0.10 min^{-1} for ciprofloxacin, norfloxacin, sulfadiazine and tetracycline, respectively.

Magnetite (Fe_3O_4) is nothing but a combination of ferrous and ferric ions, different to all other metal oxides. Magnetite divulges both p-type and n-type semiconductor with low band gap energy of 0.1 eV. According to JCPDS file No. 19-0629, it has a cubic inverse spinel structure which belongs to Fd3m space group (Okube et al. 2012). Owing to high surface energy, it is not stable in the aqueous environment. Surface functionalization generates the stability of the magnetite, and it increases the efficiency of elimination of pollutant. It can be used as adsorbent to remove the heavy metals from the polluted water compared with other adsorbents. Fan et al. (2019) tried to eliminate the lead from lead-containing solution using carboxymethyl-cellulose-immobilized magnetite nanoparticles, and it shows that the utmost adsorption capability of lead ion was attained at 152 mg/g.

Maghemite (γ-Fe_2O_3) has an analogous crystal arrangement to magnetite, and it has cubic structure. Because of high magnetization saturation, it is broadly employed as an appropriate adsorbent in wastewater treatment (Wu et al. 2015; Leone et al. 2018). It reveals ferromagnetic nature and more stable in aqueous environment. It is more superior adsorbent for heavy metal than magnetite due to small size and high specific surface area (Martinez-Boubeta and Simeonidis 2019). Rajput et al. (2017) reported the removal efficiency was found at 59.2 and 25 for lead (II) and copper (II), respectively, in the presence of maghemite.

21.4.1.3 Spinel Ferrites

Spinel ferrites have the general formula MFe_2O_4, where M represents the divalent metal ions with ionic radius ranging between 0.6 and 1 Å. Examples for divalent ions are Cu, Ni, Mg, Mn, Co, Zn, Cd, etc. (Ashour et al. 2014). These are magnetic semiconductors which are widely used in the field of water treatment. Depends on nature, sharing of cations and synthesis method, the properties and application of spinel ferrites varies (Fig. 21.3). The attractive band gap makes the spinel ferrite a more efficient catalyst in heavy metal removal and increases the ability of photodegradation. Owing to biocompatibility, magnetic behaviour and chemical stability, spinel ferrites and its composites are utilized in wastewater treatment. Aromatic nitro compounds are identified as common pollutant in agricultural and industrial wastewater owing to their stability and solubility in water which can be efficiently degraded by photocatalytic activity of spinel ferrites.

21.4.2 Transition Metal Oxide NPs

21.4.2.1 Titania

Titanium oxide (TiO_2) is a semiconductor material which acts as photocatalyst under ultraviolet light. The electron present on the surface of substrates is transported to the conduction band. The various effluents present in the water can be degraded using titania because of its stability, abundance and less hazardous (Shakeel et al. 2016). Owing to the intrinsic properties like wide band gap (3.2 eV) and low quantum yield, the use of titania in water treatment was limited under visible light (Upadhyay et al. 2014; Qin et al. 2015). To induce the solar efficiency the nanomaterials are undergoing modification. During contact of catalyst with light sources, it produces electron and hole pairs. The electrons and hole pairs move around to the surface of the catalyst, and the redox reaction occurs for absorbing the pollutant (Fujishima et al. 2008; Di Paola et al. 2012). Transition metal or non-metal supporting is one of the tactics to decrease the band gap of titania which stimulates the photocatalyst under different light sources or direct sunlight radiation. Titania thin films and titania-decorated alumina showed high efficiency in the remediation of creatinine and methylene blue dye. Titania nanoparticles have the ability to degrade the highly hazardous materials such as antibiotic and chemotherapeutic doxorubicin present in water. Titania nanorods, nanobelts, nanowires, nanotubes, nanomembranes and nanofibers have been used to remediate the wastewater. Titania doped with other metals such as silver, iron, copper, zirconium, etc. improved electrical, catalytic and optical properties.

21.4.2.2 Copper Oxide

Copper oxide nanoparticles have been employed for the wastewater treatment owing to its incredible optical, superconductive, electrical, magnetic and thermal properties and also its low cost, low toxicity and abundance. The monovalent copper oxide nanoparticle is a p-type semiconductor with the narrow band gap of 2.0–2.5 eV. Copper oxide nanoparticles have the affinity to adsorb molecular oxygen to proliferate photogenerated electrons. Yadav et al. (2021) tried to remove the organic dyes such as Congo red (CR), methylene blue (MB), methyl orange (MO) and methyl red (MR) from the water using copper oxide nanoparticles. The increasing order of degradation efficiency was found to be MO > MB > CR > MR. Husein et al. (2019) synthesized copper nano-adsorbent for the removal of pharmaceutical pollutants from real wastewater samples. Ibuprofen, naproxen and diclofenac were identified as pollutants in real water samples. The removal capacities were calculated as 36.0, 33.9 and 33.9 mg/g for ibuprofen, naproxen and diclofenac. Dlamini et al. (2019) collected three different samples such as coal mine water, domestic wastewater and Mzingazi river water. Copper nanoparticle showed 85 and 76% removal efficiency of phosphate and sulphate from coal mine water, respectively.

The removal efficiency was found at 80, 89, 63, 62 and 64% for phosphate, total nitrogen, nitrate, aluminium and sulphate, respectively, in domestic water sample. The removal efficiency was found at 92 and 52% for phosphate and total nitrogen in Mzingazi river water, respectively.

21.4.2.3 Zinc Oxide

Zinc oxide nanoparticles are a semiconductor material which acts as better photocatalyst in the removal of organic dyes. It is an n-type semiconductor with the band gap value of 3.37 eV. Owing to the non-hazardous nature, effective adsorption properties, good thermal, mechanical and chemical properties and zinc oxide nanoparticles can be employed for the elimination of organic and inorganic nanomaterials (Mustapha et al. 2020). It has the admirable UV and visible light adsorption and reflective properties, and it has high surface activity due to its large number of active adsorption sites. The wavelength and intensity of light source is more important, owing to the essential characteristic of the material in photocatalytic reaction. The catalyst used for the wastewater treatment not only eliminates the chemicals but also eliminates the microbial contaminants present in water. Photocatalytic inactivation of microbes was a tedious process, and the process differs with concentration, physiological state and kind of microbes. The morphology, nature and concentration of the catalyst influence the rate of microbial inactivation. Anusa et al. (2017) removed the heavy metals such as Cu(II), Pb(II) and Cd(II) using zinc oxide nanoparticles at different pH from simulated industrial wastewater. The removal efficiency of Cu(II) at pH = 2, 4, 6 and 8 was 99.15, 99.25, 100 and 100%. The removal efficiency of Pb(II) at pH = 2 was 63.61 and at pH = 4, 6 and 8 was 77.47%. The removal efficiency of Cd(II) at pH = 2, 4, 6 and 8 was 87.05, 96.50, 98.05 and 97.85%.

21.4.3 Carbon-Based Nanoparticles

21.4.3.1 Carbon Nanotubes (CNTs)

Currently, carbon-enriched materials such as carbon nanotubes, graphene oxides, activated carbon, carbon fibres and biochar are used as adsorbents in water purification. CNTs have π–π conjugative structure with hexagonal arrays, and every carbon atom has sp^2 hybridization. It is hydrophobic in nature (Gupta et al. 2013). Carbon has the capability to form carbon to carbon long chains due to its binding ability in both straight and complex branching which facilitates double or triple bond formation and collection of atoms in different geometrical arrangements (Mubarak et al. 2014). Because of non-hazardous and high adsorption property, carbon-based nanomaterials have been broadly used for the elimination of heavy metals present in water. Electrostatic communication, ligand replacement, surface complex formation and adsorption–precipitation within metal ion and functional groups present in surface of carbon nanotubes (CNTs) are the steps followed in the mechanism of elimination of heavy metals in water. Due to the higher surface area to volume ratio of CNTs, the absorption property will be increased (Ruthiraan et al. 2015).

Multiwalled carbon nanotubes (MWCNTs) were synthesized by chemical vapour deposition, and the synthesized MWCNTs which has been found in between the width 60 and 70 nm range revealed the 100% efficiency in the removal of Cd(II) at pH = 10 and 12 with 0.5 mg/mL from 100 ppm metallic solution. The pH plays a vital role in the elimination of heavy metals. The heavy metals can be removed easily in the acidic condition. In the case of basic pH, the metals form precipitate because of the hydroxide formation. The MWCNTs shows the higher efficiency in the elimination of heavy metals in water, but its efficiency depends upon the pH of the reaction (Bhanjana et al. 2017).

Carbon microspheres can be utilized for the elimination of chromium, nickel and copper. Magnetic carbon nanomaterials have been employed for the elimination of heavy metals. MWCNTs-incorporated ZVI nanoparticles have been used in the removal of arsenic in the pH ranging between 6 and 7. During the oxidation in water, ZVI forms Fe^{2+} and Fe^{3+} hydroxides and leads to the formation of arsenic complexes, and these complexes can easily be eliminated from the water because the precipitation is taking place (Alijani and Shariatinia 2017).

21.4.3.2 Graphene Nanomaterials

Graphene have been obtained from graphite, and it acquires good electrical and mechanical properties and also it shows better thermal conductivity with honeycomb network structure (Aghigh et al. 2015; Chatterjee et al. 2015). It exists in various forms such as graphene oxide and reduced graphene oxide which are used for the removal of heavy metals (Gao et al. 2011). Graphene oxide (GO) is an oxidative product of graphene, and reduced graphene oxide (r-GO) is a reduction product of graphene oxide. GO have different oxygen functional group, while r-GO can be changed by functional groups, for instance, hydroxyl, amine and carboxylic acid group with more structural imperfection than graphene. To enhance the adsorption nature of GO, different kinds of functional groups are added to modify the GO. Due to the high surface area with fine chemical constancy, GO and r-GO are used for the wastewater remediation. The mechanism of heavy metal elimination from water using graphene-based nanomaterials depends on the electrostatic interactions and surface metal hydroxide. Based upon the surface area and surface charge, the interaction is taking place. Surface area is directly proportional to adsorption ability which is straightly with respect to particularly tunable morphology of the GO-supported nanomaterials. GO-supported metal oxides increase the ability of elimination of heavy metals in the water because of the increase of metal oxide's electronegative charge over the GO (Ghorbani et al. 2020).

21.4.4 Nanomembranes

Filtration and membranes are extremely efficient methodologies for purification water and remediation of wastewater. The remediation includes elimination of heavy metals, inorganic ions, organic pollutants such as dyes, pesticides, pharmaceutical products, etc. and bio-based products like microorganisms (Zhang et al. 2018). Reverse osmosis is the process which is used to purify the water and desalination of seawater till now. In between ultrafiltration and reverse osmosis, there is a process called nano-filtration, using membranes that have been employed for the wastewater treatment and desalination of seawater. Nanomembrane filtration is a very efficient method for wastewater treatment. It can be divided into inorganic and organic membranes in which zeolite, silicon dioxide and 2D graphene-based nanomaterials are inorganic membranes and organic polymer-based nanomaterials belong to organic nanomembranes (Liu et al. 2014; Pedrosa et al. 2019; Huang et al. 2014). The organic polymer membranes consist of natural polymer such as chitosan, cellulose acetate and synthetic polymeric membrane such as polyacrylonitrile, polyurethane, polyamidoamine, polysulfone, polyethersulfone, polyvinyl alcohol and polyamide. The efficiency of membranes mainly depends on the structure and weight of the molecule, pore size and volume, polarity, hydrophilicity and hydrophobicity (Cyna et al. 2002; Ahmad et al. 2008; Bonne et al. 2000; Tepus et al. 2009).

21.5 Conclusion and Future Prospect

The universe is in need of advanced water treatment technologies to get freshwater for drinking and agricultural purposes. Nanotechnology mutiny will play a crucial part in resolving the difficulty of increasing demands of freshwater and disseminated water recycle. Nanomaterials are attractive material which is used for water treatment because of its fascinating physicochemical properties. Engineering nanomaterials like nanoadsorbents, photocatalysts, nanomembranes, etc. provide the prospective for new water treatment technologies, and it can be adapted to precise applications in the removal of pollutants from contaminated water. Owing to their distinctive properties such as high reaction rate, high surface area-to-volume ratio, increased surface associated behaviour (antimicrobial properties and catalysis), high conductivity and self-assembling property on substrate, nanomaterials show high efficiency in the removal of pollutants. Nanomaterials can act as catalyst to purify the water under ultraviolet light source and freely existing sun irradiation. Nanomaterials can be used to eliminate harmful organic pollutants, microplastics and microbes via catalysis using ultraviolet and solar irradiation. A nanomembrane (semi porous membranes) is used to convert hard water into soft water by blocking monovalent and bivalent ions present in water body. In future, nanotechnology plays a fascinating role in water treatment, water monitoring, etc. that can effectively stop an extensive assortment of contaminant present in water together with affordability and ease of operation. There is no debate that nanotechnologies play a vital role in the field of wastewater treatment because of its unique nature.

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