Chapter 11
Nanotechnology: An Efficient Technique of Contaminated Water Treatment

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11.1 Introduction

For the existence of life and good health, water is an ultimate need. The whole planet is suffering from water scarcity, and this issue grieved more due to the alarming pollution. From the data of world health organization, it is suggested due to the microbial contamination and lots of health issues are arising worldwide (Heymann 2007). Every year around two million people lose life due to infections originated from infected water. Although many techniques are used for treating water like disinfection and radiation, the water contamination is not fully cured. The heavy metals like zinc, cadmium, lead and mercury contaminate the water bodies, thereby releasing toxic substances in the water which is fatal for the living environment (Verma and Dwivedi 2013; Baby et al. 2010). The advanced industrialization and growing urbanization are burdened the natural sanity with harmful chemicals and wide range of pollution. Water pollution is one of the alarming issues that the world is facing. The rapid population outbreak in the coming year needs a massive supply of clean drinking water, domestic purpose, commercial, agricultural, etc., demand to support the growing human race as reported by Pendergast and Hoek (2011). In the year 2014, the World Health Organization reported that by the year 2025, fifty per cent of world's population will face the problem of water scarcity (Guarino 2017). In developing countries, more than half of the industrial wastewater is released to the environment without proper treatment. The available technology for wastewater treatment and the production of pristine and safe water is not sufficient to meet pace with a rapid increase of water pollution and demand for pure water supply in

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developed as developing countries. Hence, it is needed to adopt such water treatment technology which is equally economical and highly efficient. Nanotechnology is one such technique which has attracted researchers in the last decades due to better performance in water treatment in comparison with existing conventional methods (Qu et al. 2013). The materials having dimension lesser than hundred nanometre are defined as nanomaterials as reported by Tesh and Scott (2014). This range of materials has extraordinary chemical and physical characteristics in comparison with their bulkier structure. The property of large surface area of nanomaterials generally has allowed larger density of active centres per unit mass. Additionally, nanomaterial displays higher surface free energy which results in upgradation in the reactivity of the surface. Till now, from the literature survey it is evident that nanomaterial is capable enough to treat wastewater particularly in the field of sensing, disinfection, catalytic oxidation, adsorption, etc., as reported by Das et al. (2015), Ayati et al. (2014) and Ali 2012). In Tesh and Scott (2014), Karn et al. (2011) reported that zero-valent iron nanoparticles by injection are one of the most frequently applied nanotechnologies for groundwater treatment in America. Initially, nanoparticles tend to accumulate on the water system causing reduction in the pressure and severe activity as reported by Lofrano et al. (2016). Further, the most difficult tasks remain the separation of the degraded or exhausted nanoparticles from the treated water for further use. Moreover, the nature and behaviour of nanomaterials during the treatment of wastewater are yet to be understood clearly. The consequences of the remaining nanomaterials after the treatment of wastewater are the topic of concern for the environment and human health which can act as an obstacle in the application of this technique as reported by Dale et al. (2015). In order to fill up this loophole to bring out the desirable impact of this technique, it is necessary to find a better material which can reduce the release of nanomaterial in treated water while retaining its reactivity. In these contexts, nanocomposites have been identified as potential candidate for the desired approach. It is designed by using different support materials like membranes or polymers on which desired nanomaterials are loaded. The nanocomposites can be defined as material having multiphase where the dimension of the constituent is one hundred nanometre as reported by Tesh and Scott (2014). This chapter throws light on the advanced applications of nanotechnology in wastewater treatment. The various types of nanomaterials like carbon nanotubes, graphene-based, metal and metal oxide-based, zeolites, nanocomposites, metal–organic frameworks are discussed focussing on their structures and performances in the removal of water contaminants. Moreover, few bioremediation techniques for purification of water are also discussed. The toxicity of the nanomaterial after treatment of wastewater on the environment also needs to be tackled carefully to ensure the safety of the environment which is also mentioned in this chapter.

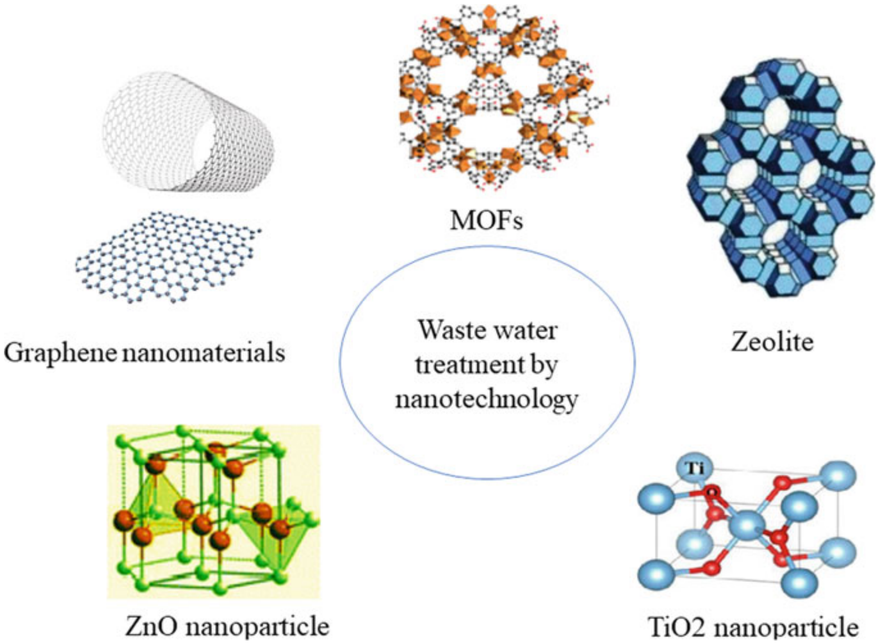

Fig. 11.1 Nanomaterials used for wastewater remediation

11.1.1 Water Nanotechnology

With the advancement of nanotechnology, its utilization has gained attraction in the field of wastewater treatment. In this part, a brief summarization of the various techniques of nanotechnology for treating wastewater is discussed like adsorption, oxidation and sensing. In Fig. 11.1, nanomaterials used for wastewater treatment are displayed.

11.1.2 Adsorption

Separation procedure based on membranes or adsorbents is the most frequently used technique for wastewater polishing. Traditional adsorbents generally face difficulties like low selectivity and loading capacity. Adsorbents based on nanomaterials such as carbon nanotubes, metal or metal oxide have the property of high surface areas, reactivity and special affinity towards different contaminants. In Ali (2012) and Khajeh et al. (2013) respectively, reported regarding the adsorption performance of nanomaterial-based adsorbents that their rate of adsorption for specific contaminants is higher in magnitude in comparison with the traditional adsorbents.

11.1.3 Catalysis

Photocatalytic or catalytic oxidation refers to the method in which microbial pathogens and trace contaminants are removed from the water in the advanced manner. Reddy et al. (2016) reported that this method is significant for pre-treatment as it enhances the rate of biodegradation of non-biodegradable and hazardous contaminants (Reddy et al. 2016). The high ratio of surface to volume of the nanocatalysts noticeably display upgraded the performance of catalysis in comparison with the corresponding bulkier counterparts. In addition, the crystal structure and the bandgap of the nano-semiconductors displayed size dependency. Moreover by immobilizing the nanomaterial over different supporting groups, there was an enhancement in the stability of the nanocatalyst and the resulting nanocomposite was found to be consistent with the photoreactors, according to Petronella et al. (2017).

11.1.4 Disinfection

In order to minimize the growth of diseases caused due to water contamination, the process of disinfection is vital step. There are certain criteria for an idealized disinfectant like it should be able to deal with wide range of microbes within a short span of time, absence or minimum production of fatal by-products, minimum toxic impact on human health and environment, economical and easy to handle, on-corrosive and can be disposed safely. Higzay et al. (2010) reported many nanomaterials exhibiting antimicrobial characteristics like chitosan nanoparticles; Rai et al. 2009 reported, Hebeish et al. (2013) reported photocatalytic TiO_2; Martynková and Valášková (2014) reported carbon nanomaterials. The above-mentioned nanoparticles were capable of killing or destroying microbes by the toxic metal ions released from them and can also destroy cell membrane by coming in contact, etc. In contrast to traditional disinfectants, the nanomaterial-based disinfectants achieved the task with more sustainably which led to the release of lesser by-products as reported by Li et al. (2008).

11.2 Sensing

Traditional methods of monitoring and sensing face obstacles in the case of less concentration of pollutant at microlevel in complex cases of water pollution. Urgent and instant detection of desired harmful and toxic pathogenic substances especially during water-based accidents are the demand of the time. Some nanomaterials such as noble metals like silver or gold, quantum dots, carbon nanotubes have extraordinary magnetic, optical and electrochemical characteristics; hence, when they are combined with sensing devices, they can selectively assist in the detection of trace pollutants (Li et al. 2008).

11.2.1 Nanomaterials Applied in Water Treatment

11.2.1.1 Zeolites

These are defined as crystalline, inorganic porous material bearing highly ordered structure and generally comprises of oxygen, aluminium and silicon according to (Camblor et al. 1998). The unique characteristics of zeolites which make it suitable for various applications like ion exchange, separation and catalysis are high surface area, chemical and mechanical resistance as reported by Song et al. (2005). These characteristics are the reason behind its application in the treatment of wastewater. The traditional method of synthesis of zeolites of the range from 1 to 10 micrometre, while nanoscaled zeolites consist of five-to-hundred nanometre with uniform and discrete crystals as reported by Ding and Zheng (2007), Camblor et al. (1998), Xu et al. (2004).

11.2.2 Carbon-Based Nanomaterials

11.2.2.1 Graphene Nanomaterials

Graphene is defined as consisting of single layer of graphite structure having the structure similar to honeycomb. It has unique electrical and thermal conductivity. One of the oxidative forms of graphene which consists of oxygen-based functional moieties like epoxy, carbonyl, hydroxyl is graphene oxide. Its attractive properties have captured the attention for application related to various environmental problems. Graphene possesses excellent number of pi-bonds. Graphene and graphene oxide bear large surface area. According to Sun et al. (2010), generally in the adsorption process induced by graphene-based nanomaterials, there are five interactions which are possible and they are electrostatic and covalent interaction, hydrogen bonding, pi–pi interaction and hydrophilic effect. These materials are identified to be suitable for treatments of wastewater using adsorption process to eliminate the contaminants from the water. Graphene oxide and reduced graphene oxide, which is the modified form of graphene oxide, are reported to be capable of eliminating heavy metals from the contaminated water like arsenic (trivalent and pentavalent), mercury (divalent), cadmium (divalent), copper (divalent), lead (divalent). The graphene-based nanomaterial is also capable of adsorbing anionic contaminants. Li et al. (2011) reported that graphene is capable of adsorbing fluoride very efficiently with a load capacity of around thirty-five milligram per gram at 25 °C at pH seven (Li et al. 2011). In Vasudevan and Lakshmi (2012) reported their research on the adsorption of phosphate using graphene-based nanomaterials. Graphene oxide along with its composites also displayed the promising capacity of dye removal and for ionic dyes generally depends on covalent bonding and electrostatic interaction. Graphene oxide demonstrated better adsorption efficiency for cationic dyes in comparison with anionic dyes because of strong electrostatic repulsion. But graphene and their corresponding composites are reported by Luo et al. (2012) to be displaying better adsorption of anionic dyes due to their covalent bonding and ion exchange property. By the process of hybridization and modification of the surface, the efficiency of reusability, separation, and removal of graphene nanomaterials can be enhanced, thereby making it a better and significant candidate for application for the decontamination of polluted water. But, few challenges which stand as hurdle in their way are their high cost, safety and reusability.

11.2.3 Carbon Nanotubes

The carbon nanotubes display antimicrobial property, and this is exhibited by two pathways: physical and chemical (Lelimousin and Sansom 2013). In physical method, inhibition of the passage of microbes occurs by using filters, and in chemical method, its activity is performed via reaction with pathogenic substances (Upadhyayula et al. 2009). From the literature survey, it is reported that carbon nanotubes are capable of destroying cells of bacteria through interacting with them physically or by incurring stress by oxidation which results in the degradation of the cell (Kotchey et al. 2012). The chemical pathway of carbon nanotube antimicrobial action requires the contact of targeted pathogenic substances and carbon nanotubes. But, the chemical way of application is limited due to the issue of obtaining uniform dispersion and stable carbon nanotube in water. The physical approach is quite effective and efficient for microbe filtration like virus and bacteria. Single-walled carbon nanotubes are identified to be effective in filtering almost all the pathogenic substances. Their dimension ranges from two to five nanometres which is very small (Manshian et al. 2013).

11.3 Metal and Metal Oxide-Based Nanomaterials

Metal and metal oxide nanomaterials recently gained attraction due to their efficient performance in economical removal of contaminants. In Hua et al. (2012) reported that examples of metal and metal oxide are cerium oxides, magnesium oxides, titanium oxides, manganese oxides, aluminium oxides, ferric oxides, nano-sized zero-valent iron, etc.

From the literature survey, it is reported that these metal and metal oxide-based nanomaterials displayed significant performance in the sorption process of number of metallic contaminants like reported by Kanel et al. (2006), Cd reported by Boparai et al. (2011) and Engates and Shipley (2011), Cr reported by Hu et al. (2005) and Yu et al. (2014), U reported by Crane et al. (2011) with very high selectivity and capacity (Crane et al. 2011).

11.3.1 Zero-Valent Iron Nanomaterial

In Wang and Zhang (1997) reported that zero-valent iron nanomaterial is first-generation nanotechnology for environmental remediation especially for treatment if groundwater. From the laboratory results, it was reported that zero-valent iron nanomaterial is efficient in the transformation a wide range of contaminants such as heavy metal arsenic (trivalent), lead(divalent), copper(divalent), Nickel(divalent), chromium(hexavalent) as reported by Ponder et al. (2000), Kanel et al. (2006)) and Li and Zhang (2006), nitrate and perchlorate (inorganic ions) as reported by Choe et al. (2000) and Cao et al. (2005) and much more. Alternatively, these particles can also be attached on some supporting solid matrix like zeolite or activated carbon in order to upgrade its efficiency in its application for wastewater treatment as reported Zhang (2003). Choe et al. (2000) reported the use of zero-valent iron nanomaterial in the reduction of nitrate into nitrogen gas (Choe et al. 2000). The data and result discussed above confirm that nano-sized zero-valent material is a promising candidate for groundwater and industrial effluent remediation.

11.3.2 Iron Oxide Nanomaterial

Selecting a suitable technique and materials for treating and wastewater is a very crucial job and is achieved by considering many conditions. Some of these factors are economical, eco-friendly, efficiency and flexibility of the treatment technique; reusability was reported by Zhang and Fang (2010), Xu et al. (2012) and Oller et al. (2011). The property of magnetism is extraordinary which assists in purifying water by affecting the physical characteristics of contaminants present in wastewater. According to Ambashta and Sillanpää (2010) and Mahdavian and Mirrahimi (2010) reported that the integration of magnetic separation and adsorption has extensive application for cleaning environment and treatment of water. The nano-sized-based iron oxide material is identified as potential candidate wastewater treatment in industrial sector because of their cost-effectiveness, better stability, strong adsorption and ease of separation as reported as Hu et al. (2005), Carabante et al. (2009) and Fan et al. (2011). According to White et al. (2009), Girginova et al. (2010) and Girginova et al. (2010) reported that these iron oxide-based nanomaterials are utilized for the removal of contaminants in both field and laboratory-scale test. Currently, there are two categories of applying iron oxide nanomaterials for treating wastewater: one involves the utilization of these materials as a type of immobilizing carrier and nanosorbent for enhancing the efficiency of removal and other group includes using it as photocatalyst in order to degrade these contaminants into lesser toxic form.

11.3.3 Titanium Oxides Nanomaterial

Titanium dioxide displays photocatalysis when ultraviolet radiation is present. Titanium dioxide possesses antibacterial property because of the release of reduced oxygen species like peroxide and hydroxyl free radicals produced in the presence of ultraviolet radiation via the series of reduction and oxidation reaction occurring in a cell. The unique property of using titanium dioxide nanomaterial as disinfectant is their characteristic of displaying photocatalysis also in the presence of visible sunlight (Sakthivel and Kisch 2003). This nature can be upgraded by mixing titanium dioxide with different metals. It is a very efficient and perfect option for the treatment of water due to its stability in water, cost-effectiveness and non-toxicity while ingestion. It is used as thin-film coating on the surface of reactor and in UV reactor as slurry (Reddy et al. 2015).

11.4 Zinc Oxide Nanoparticles

Like titanium dioxide, zinc oxide nanoparticles demonstrate better ultraviolet absorption and also efficient photocatalysis. During photocatalysis, zinc oxide nanomaterial produces hydrogen peroxide in the cells as a result of which cell components are subjected to oxidation. Moreover, they are also capable of inhibiting the growth of bacteria by penetrating into the envelope of the cell, thereby disorganizing the membrane of bacteria. But, if zinc oxide nanomaterials enter the natural water sources, they can be dangerous for the aquatic organisms. These materials get dissolved easily, and this limits its use in drinking water Szabó et al. (2003).

11.4.1 Nanocomposites in Water Treatment

11.4.1.1 Nanocomposite Membrane

The membrane processes which are available commercially for the purification of water are ultrafiltration, nanofiltration, microfiltration, reverse osmosis, electrodeionization and electrodialysis (Frenkel 2008). Few other processes which are used in limited number include pervaporation, membrane distillation and forward osmosis. The membrane process of nano- and ultrafiltration is found to be efficiently separating emulsion and oil. But, the ultrafiltration technique fails in the removal of contaminants of large size because they do not contain any charge. As we know that seawater due to its salinity is very corrosive and hence requires the utilization of stainless steel and austenitic, and as a result, excessive energy consumption, high cost and maintenance are required. To ease this problem, various nanofiltration membranes are present as an alternative to ultrafiltration and osmosis. The advantage of using nanofiltration over existing conventional reverse osmosis processes is that there is less energy consumption and less pressure (Van der Bruggen and Vandecasteele 2003). There are wide range of application of nanofiltration membranes like the elimination of viruses, microbes, heavy metals and pesticides and also seawater desalination (Van der Bruggen et al. 2001). From the literature survey, it is reported that the technical of viral nanofiltration is very effective and efficient in separating all the biological contaminants. Nanomaterials like alumina fibres and nanotubes are used for building materials which possess controlled dimensions, density and shape in order to filter specific components (Mera et al. 2010). Ceramics and polymer are the main categories of membrane materials which exhibit unique benefits for the fabrication of membrane with multifunctionalities (Mera et al. 2009). The unique thermal and chemical stability of ceramic membranes adds extra benefits like enabling it to perform even in extreme condition of temperature and pH and also in the presence of oxidizing surrounding (Rossi et al. 2014). Ozone oxidizes carbon–carbon double bonds of organic molecules and electron-rich species. Some polymeric materials like sulfonated polyethersulfone, cross-linked poly(furfuryl alcohol), thin-film composite, cellulose acetates are reported to be used for desalination.

11.4.2 Magnetic Nanocomposites

Magnetic nanomaterial and nanocatalyst are capable of purifying different types of inorganic and organic contaminants dispersed in water (Shipley et al. 2009). In general, metals and enzymes are applied as catalyst but their catalytic performance enhances by modifying it into nanoscale. At nanoscale, the materials are longer lasting, more reactive and also display better selectivity. Investigation is performed on magnetic nanoparticles because of their application in the removal of many chemical owing to their high surface area and property of binding with chemical even in the absence of auxiliary adsorbent material. Magnetite (Fe_3O_4) nanoparticles displayed efficient adsorption behaviour for removing arsenic. These nanoparticles can be later easily being removed from treated water at lower magnetic field (Fuhrer et al. 2011). The smaller size of these nanoparticles causes enhancement in surface area, surface energy and fraction of atoms on the surface. By using microwave synthesis method using sodium hydroxide and ferrous sulphate in the presence of solvent mixture containing water and ethylene glycol, magnetite magnetic microsphere can be synthesized. Other iron-containing minerals which are applied in wastewater treatment by the adsorption process are maghemite, lepidocrocite, hematite, goethite, ferrihydrite, feroxyhyte and akaganeite. On surface modification, magnetic nanomaterials display selectivity towards different contaminants and effectively remove heavy metals like As and other pollutants from water.

11.4.3 Metal–Organic Framework for Heavy Metal Removal from Water

Rapid pollution of ground and surface water due to heavy metal contamination is a crucial issue worldwide. It not only affects the purity of the environment but also have adverse impact on human health. Excessive abundance of these harmful metals causes the risk to human life by initiating much dreadful disease like cancer and also affects other species by accumulating in the food chain. It is very essential to eliminate these elements from surrounding especially from water bodies up to permissible level. Metal–organic frameworks or MOFs are defined as category of porous adsorbent material made up of metal clusters and organic linkers. These frameworks are connected in 3D lattices. Metal–organic frameworks exhibit a number of benefits in the field of adsorption. The unique characteristics of porous structure and high surface area enabling it to be applied for many fields like drug delivery, catalysis, gas storage and separation (Kuppler et al. 2009). The property of porosity and large surface area supports the contaminants in accessing the adsorption site and gets diffused into the framework. The crystallinity aids MOF with highly ordered pores, and shape and size of these pores can be controlled by selecting suitable ligands and metal ions (Yaghi et al. 2003). MOFs can be effectively used in the removal of pollutants from water, and this is a very popular area of research nowadays. Table 11.1 displays some important MOFs and their role in heavy metal removal.

11.4.4 Removal of Nanoparticles After Water Treatment

Using nanoparticles for various environmental applications causes the release of these particles and accumulation in the environment. In order to assess the amount of risk that can be incurred on the environment, knowledge regarding its persistence, toxicity, bioavailability and mobility is required. The rapid utilization of nanoparticles for various industrial applications and the purification of water especially drinking water arise a threat that these nanomaterial will remain in the environment and will cause damage and hence needs to be eliminated by suitable pathways. Conventional pathways for the elimination of suspended matter in the wastewater popularly include filtration and sedimentation. But, the size of the nanoparticles is very small, and hence, the sedimentation technique is not suitable for removal unless they aggregate and form larger size. Techniques like flocculation can be also not suitable for eliminating nanoparticles from the water, and hence, some novel process is required. Techniques like reverse osmosis and nanofiltration which are also applied for removal of pathogenic substances from wastewater can be also applied for removing nanoparticles. These hindrances are based on the fact that these nanomaterials are mobile in the presence of porous medium due to their minute size, thereby they get dispersed over a large area and remain persistent in the environment for a longer time.

Table 11.1 Examples of metal–organic framework applied in heavy metal removal

S. No.	Heavy metal	Metal–organic framework	Method	References
1	Arsenic	ZIF-8	Adsorption	Bahrani et al. (2019)
		UiO-66	Adsorption	Audu et al. (2016)
		FE-BTC	Adsorption	Kobielska et al. (2018)
2	Cadmium	PCN-100	Adsorption	Saleem et al. (2016)
		HKUST-1	Ion exchange	Yang et al. (2016)
		AMOF-1	Adsorption	Fang et al. (2010)
3	Chromium	ZIF-67	Adsorption/ion exchange	Aboutorabi et al. (2016)
		Cu-BTC	Adsorption	Li et al. (2017)
		Chitosan-MOF	Adsorption	Maleki et al. (2015)
4	Lead	MOF-5	Adsorption	Rivera et al. (2016)
		TMU-5	Adsorption	Rahimi and Mohaghegh (2016)
		MnO_2-MOF	Adsorption	Qin et al. (2011)
5	Mercury	PCN-100	Adsorption	Saleem et al. (2016)
		Bio-MOF	Adsorption	Mon et al. (2016)
		LMOF-263	Adsorption	Rudd et al. (2016)
6	Nickel	Chitosan-MOF	Adsorption	Maleki et al. (2015)
7	Cobalt	TMU-5	Adsorption	Rahimi and Mohaghegh (2016)
8	Copper	ZIF-8	Adsorption/ion exchange	Zhang et al. (2016)
		MOF-5	Adsorption	Bakhtiari and Azizian (2015)
		TMU-5	Adsorption	Rahimi and Mohaghegh (2016)

(continued)

Table 11.1 (continued)

S. No.	Heavy metal	Metal–organic framework	Method	References
9	Zinc	Cu-terephthalate-MOF	Adsorption/ion exchange	Zou et al. (2013)
10	Iron	Cu-terephthalate-MOF	Adsorption/ion exchange	Zou et al. (2013)

According to Wiesner et al. 2006, it was assumed that due to the smaller size nanoparticles should not be so much mobile because their higher diffusion will cause more number of contacts with the porous media surface like sand filters or groundwater aquifers used in water treatment (Auffan et al. 2009). Even though nanotechnology has positive impact on health due to its application on the purification of water but also has adverse impact on human health and environment if they remain suspended in the treated water as reported by Bergamaschi et al. (2006), Elder et al. (2007), Aschberger et al. (2011), Fratoddi et al. (2015), Sharifi et al. (2012), Bystrzejewska-Piotrowska et al. (2009), Baun et al. (2008), Farré et al. (2009) and (Aschberger et al. 2011). Waste produced during the synthesis and use of these nanoparticles will cause harmful effects on the environment, and hence, there are chances that human beings can be affected by ingestion, inhalation, skin contact and absorption in the digestive tract. Recently, there are no sufficient data available regarding that all the nanomaterials have a toxic effect on organism or environment or all the nanomaterials have antimicrobial activity, as reported by (Elder et al. 2007). Hence, more research and development are needed to find out facts regarding toxicity of nanomaterials. In Table 11.2, some of the examples of toxicity of nanomaterials are displayed.

11.5 Bioremediation Methods of Water Contaminants

Bioremediation refers to the utilization of microorganisms for degradation or reduction of the quantity of poisonous waste in a contaminated system. The various treatment techniques in this context include clean-up of contaminated system like stream, sludge, soil and water. Due to the extensive urbanization, industrialization and farming as well as various other activities of human have caused the degradation of land leading to pollution and decrease in the productivity of the crops. The technique of bioremediation is an efficient method for treating and recovering the ecosystem in a greener manner (Divya et al. 2015).

Table 11.2 Examples of the toxic effects of nanomaterials

Nanomaterial	Dose and exposure route	Species	Effects	References
TiO_2 particles, nanoscale rods or dots	1 or 5 mg; Intratracheal instillation	Rats	TiO_2 rods or dots produced transient inflammatory and cell injury effects and were not different from the effects of larger-sized TiO_2 particles	Warheit et al. (2006)
SWCNT	2-mg implant; Subcutaneous implantation	Mice	Activation of the histocompatibility complex in CD4*/CD8 + T-cells.	Koyama et al. (2006)
Ultrafine TiO_2	0.5, 2 or 10 mg/ml; Aerosol inhalation	Mice, rats, hamsters	Pulmonary particles overload and inflammation in rats and mice exposed to 10 mg/ml. Inflammation included an increased number of macrophages and neutrophils, progressive fibrosis in rats, elevated protein and lactate dehydrogenase levels	Bermudez et al. (2004)
SWCNT	0.1 or 0.5 mg; Intratracheal instillation	Mice	56% mortality in 0.5 mg dose, weight loss, kung lesions in 0.5 mg group, necrosis, macrophages and granulomas, interstitial and peribronchial inflammation	Lam et al. (2004)

(continued)

Table 11.2 (continued)

Nanomaterial	Dose and exposure route	Species	Effects	References
Intact or ground MWCNT	0.5, 2 or 5 mg; Intratracheal instillation	Rats	Intact MWCNT-induced collagen-rich granulomas and surrounding alveolitis	Muller et al. (2005)
MWCNT	12.5 mg; Intratracheal instillation	Guinea pigs	Pneumonitis and pulmonary lesions	Grubek-Jaworska et al. (2006)

SWCNT Single-walled carbon nanotubes; *MWCNT* Multi-walled carbon nanotube

11.5.1 Bioremediation of Industrial Effluents

In this twenty-first century, the effluents releasing from industries are the principal source of toxic and poisonous contaminants in our surrounding as reported by Mohana et al. (2008) and Gowri et al. (2014). Worldwide outburst of urbanization and industrialization has caused extreme increase in the level of organic contaminants in the ecosystem as reported by Chaudhari et al. (2009). Cyanobacteria displayed promising efficiency in the treatment of wastewater and industrial discharge treatment, detoxification of effluents of fuel, feed, food, fertilizer and chemical industries, bioremediation of terrestrial and aquatic habitats. In Dubey et al. (2011) reported some of the species of cyanobacteria like *cyanothece* sp., *Nodularia* sp., *Synechococcus* sp., which displayed efficient biosorption and biodegradation efficiency for effluents released from industries. Microbes used in municipal sewage activated sludge treatment include Pseudomonas, *Zooglea* sp. *Acinebacter*, *Alcaligenes* and *Flavobacterium* as reported by Adamse et al. (1984). According to Mahmood et al. (2013) it was reported that most suitable microbes responsible for textile effluent bioremediation includes *Micrococcus* sp., *Pseudomonas* sp., *Bacillus mycoides*, *Bacillus cereus* and *Bacillus subtilis* Mahmood et al. (2013). In Kamika and Momba (2012) reported bacteria like *Bacillus licheniformis* and *Pseudomonas putida* for the domestic water as well as moderately heavy metal concentrated water bioremediation Bahrani et al. (2019) Audu et al. (2016), Kobielska et al. (2018) and Saleem et al. (2016).

11.6 Conclusion

Nanotechnology has gained attention recently from researcher community. Apart from water treatment, nanomaterial has other application in the field of environment.

Most of the nanotechnology for the wastewater treatment is performed only at laboratory scale, and most of the technique is not possible to establish in comparison with the traditional technique because of high cost. As a result, it is not easy to predict the future scenario of this technology. Another challenge remains in incorporating the nanotechnology in the already prevailing water purification system. Reverse osmosis and nanofiltration (membrane processes) have gained attraction for the purification of water for public consumption and also in industries due to their flexibility, and easy maintenance and operation. Moreover, the toxicity of the nanomaterial on the environment is a matter of concern and hence needs care in the selection of material and designing for purification of water. There is not much information regarding the toxicity of this material on the environment. Hence, it can be concluded that, nanotechnology has both sides of a coin, i.e. positive in the direction of effective water purification and negative in the direction of imparting risk to the environment, when it remains persistent for a longer time. On a final note, it can be assumed that nanoparticles are ideal and promising candidates for the purification of water, and hence, there is a future scope if sufficient research and development will be done to eliminate the negative face of this technology.

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