Chapter 18
Prospects and Challenges of Bio-Nanomaterials for Wastewater Treatment

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Abstract Water is a precious and limited resource on earth which play pivotal role in life, agriculture, industries and ecological processes. Toxic chemical substances released from industrial processes, agricultural activities, gray water and sewage are the major water pollutants. Due to increasing human population, industrial and agricultural operations, the magnitude of water pollution has been increased significantly. Release of untreated or partially treated effluent in the environment is the major source of water pollution. Pollution of drinking water sources and natural water bodies have negative effects on human health, living organisms and ecological systems. The existing physical and chemical methods of wastewater treatment are neither eco-friendly nor cost-effective, under such circumstances pollutants removal from contaminated water warrant alternative and eco-friendly technologies. Bioremediation is an alternative to these technologies where plants, microorganisms and organic materials are used for treatment and removal of toxic chemicals and metal ions from polluted water. With the emergence of nanoscience and its concept of thinking big and working small, nanotechnology-based treatment methods have proved to be the most effective and eco-friendly approach to combat water pollution. Development of nano-based bioremediation technologies gives rise to a novel, much rapid and efficient remediation technology termed as nanobioremediation. Nanobiremediation utilizes microorganisms and plants to synthesize bio-nanomaterials which have potential to clean wastewater generated from large-scale industrial processes. It is advantageous over other treatment methods because of pollutants removal without posing any toxic effects to the microorganisms and also enhances microbial activity in the contaminated environment. Although much research has been carried out on application of bioremediation for wastewater treatment, however, a little is known about bio-based

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nanomaterials in wastewater treatment. This chapter aims to comprehend the recent advances and application of bio-nanomaterials for wastewater treatment and scope of environmental pollution control.

Keywords Bio-nanomaterials · Water pollution · Nanobioremediation

18.1 Introduction

Water is an essential resource for survival and development of living beings on earth. Availability of clean and safe water can boost the economy of any country, but due to the rapid industrialization, population growth, extensive agricultural practices and urbanization have led to the spread of enormous amounts of pollutants in water which ultimately deteriorate the quality of water. Pollution is one of the major causes of the declining quality of the environment in today's world. Water pollution is the serious issue of global concern for living being health, threat to biodiversity and aquatic ecosystem. Wastewater contains many hazardous pollutants which originate from sewage, agricultural and industrial processes. Treatment of wastewater using physical, chemical and biological methods is essential to protect living organisms and the environment. Wastewater treatment is a process of separation of pollutants from polluted water using different processes before releasing it in the environment. Various techniques such as electrochemical, advanced oxidation processes and valorization have been used for wastewater treatment (Gupta and Shukla 2020). These techniques have higher operational cost and generate several byproducts of environmental concern. Use of efficient, eco-friendly and economically viable technologies can help to achieve the goal of environmental sustainability (Chauhan et al. 2020). The development of nanotechnology and nanoscience has opened new avenues for the remediation of water pollutants. Bioremediation of water pollutants using bionanoparticles is one of the eco-friendly and economically feasible approach. Nanotechnology is among the fastest growing areas of scientific research and technology development across the world. Nanoparticles have found applications in bioremediation of heavy metal pollution, solid waste, hydrocarbons and uranium contamination, groundwater and wastewater remediation (Chauhan et al. 2020). Nanoparticles have unique capabilities to remove toxic substances from wastewater and also provide a healthy substrate for microbial activity which accelerate the process of environment clean-up (Sherry et al. 2017).

Nanoparticles used for bioremediation are biologically synthesized from plant extracts, fungi and bacteria. Traditionally, nanoparticles produced by chemical and physical methods are very costly. Therefore, the need of a cost-effective pathways for biosynthesis of nanoparticles arose. Synthesis of nanoparticles by using plant extracts and microorganisms is a cost-effective and alternative method than the conventional methods. Nanoparticles are highly reactive particles because of high surface to volume ratio. Nanoparticles can be either used as activated nanoparticles or as a carrier, due to smaller size and high surface to volume ratio. Due to quantum effect nanomaterials require less activation energy to make the chemical reactions feasible and faster. Nanoparticles also exhibit surface plasmon resonance which is helpful for the detection of toxic material (Sherry et al. 2017; Rizwan et al. 2014). Small size of nanoparticles makes them most appropriate purification agents. Biologically synthesized iron nanoparticles have been used in remediation of wastewater due to their redox potential, magnetic susceptibility and non-toxic nature (Bolade et al. 2020). The different types of bio-nanomaterials such as zinc, iron, silver, gold, copper, etc. synthesized from plants, animals and microbes have been used at the nanoscale for clean-up technology as well as wastewater treatment.

18.2 Nanobioremediation

Integration of bio-based nanomaterials for removal of pollutants from wastewater is known as nanobioremediation. The rapid urbanization, industrialization and modern agricultural practices (excess use of fertilizers and pesticides) cause environmental pollution and adverse effect the living organisms. The remediation of wastewater pollutants using nanoparticles is more efficient than other methods due to smaller size, high surface area to volume ratio and higher activity of nanoparticles (Baruah et al. 2019). Green synthesis of nanomaterials from microorganisms and plant extracts has proved a path toward the eco-friendly approach for remediation of pollutants. Nanobioremediation approach includes a wider range of potential applications with low cost and minimum negative impacts on the environment (Rizwan et al. 2014) for treatment of groundwater and wastewater (Yogalakshmi et al. 2020), heavy metals, hydrocarbons (Gisi et al. 2017) and polluted soil sediments (Bharagava et al. 2020).

Presently, nanomaterials have been used for removal of toxic pollutants from contaminated sites in the environment. The basic principle of nanobioremediation is defined as the degradation of organic wastes using nanocatalysts as a medium which allows them to penetrate deep inside the contaminants and facilitate microbes to act on such substances without affecting the surrounding (Yadav et al. 2017). Nanomaterials bring the pollutants (complex organic compounds) to a level where the pollutants can be degraded easily into environmentally innocuous by products (Pandey 2018). In this process, a proper interaction between nanoparticles and microorganism is essential for nanobioremediation of toxic pollutants. Tan et al. (2018) reported that interactions among nanomaterials, microbes and contaminants depend on size and shape of nanomaterials, surface coating, chemical nature of the nanomaterials, contaminant, media, pH, reaction temperature and type of organism used in synthesis. Stability of nanomaterials is major issue for synthesis of nanoparticles. Microorganisms have the potential to reduce the size of metal ions at nanoscale and produce nanoparticles/materials because of extracellular enzymes. Bacteria have special affinity for metals and this unique metal binding property makes them useful for nanobioremediation. Apart from bacteria, yeast and fungi are also being used for biosynthesis of nanoparticles. The purpose of using fungal cells is to harness the fungal proteins for large amount of nanoparticle synthesis. Biosynthesis of nanoparticles is generally done by the following bottom-up approach which is the result of redox reaction. The phyto-chemicals with antioxidants or microbial enzymes are usually responsible for reduction of metal compounds into their respective nanoparticles size.

18.3 Green Synthesis of Nanoparticles

Green synthesis of bio-nanomaterials involves plants (Philip 2010) and microorganisms (Ahmad et al. 2003; Roh et al. 2001; Mukherjee et al. 2001) which is an eco-friendly and non-toxic way of nanosynthesis with a wide range of shapes, size, compositions and physicochemical properties (Mohanpuria et al. 2008). Because of its cost-effectiveness, eco-friendly nature, controlled toxicity and rapid reaction speed, etc. green synthesis of nanomaterials is the most advantageous approach over other conventional methods. For large quantities, plants mediated nanoparticle synthesis is a more valuable and straightforward approach in comparison with the microbial mediated synthesis as the employment of microorganisms for nanoparticle synthesis requires complex procedures like isolation, purification and handling of cultures (Iravani 2011; Thakkar et al. 2010). However, the faster growth rate makes microorganisms more advantageous over other biological entities.

Synthesis of nanoparticles from plant resources required green reducing agents (Salehi et al. 2016; Nikalje 2015) which are obtained from phytochemical extracts (Boisselier and Astruc 2009). Phytoextracts from plants like *Sinapis arvensis*, *Abelmoschus esculentus*, *Aloe vera*, *Punica granatum*, *Cinnamomum camphora* and *Melia azedarach* can be utilized for the biosynthesis of Silver, Gold, Iron, Copper, Zinc and Palladium nanoparticles (Lam et al. 2018; Chaturvedi and Verma 2015; Kumar et al. 2011; Dashora and Sharma 2018; Laokul and Maensiri 2009). Plant extracts possess a combination of biomolecules including; amino acids, proteins, enzymes, alkaloids, polysaccharides, saponins, tannins, terpenoids, phenolics, vitamins and flavonoids (Marshall et al. 2007; Castro et al. 2011) that can be incorporated during nanoparticle synthesis (Table 18.1). These bioactive polyphenols have been extracted from leaves, stems, roots, flowers, fruits, fruit peels, seeds, gums and waste of vegetation (Yew et al. 2020). Extracellular enzymes secreted by microorganisms can be utilized for microbe mediated bionanomaterial synthesis (Tripathi et al. 2015; Calderon and Fullana, 2015). The bottom-up approach of nanobiomaterial synthesis from various bioresources is given in Fig. 18.1.

Silver nanoparticles can be biosynthesized from the phytoextracts of various plants like *Sinapis arvensis*, *Lantana camara, Trigonella foenumgraecum, Artemisia nilagirica, Nerium oleander* (Lam et al. 2018), etc. while gold nanoparticles are synthesized from the plant extracts of *Abelmoschus esculentus, Angelica, hypericum, Eucalyptus* and *Mentha*, (Chaturvedi et al. 2015). Copper nanoparticles are synthesized from leaf extracts of *Ocimum tenuiflorum, Nerium oleander, Ricinus communis,* etc. Zinc nanoparticles and Palladium nanoparticles have been biologically synthesized using plant extracts from *Camellia sinensis* and *Coffea arabica*, *Cinnamomum camphora, Melia azedarach, Delonix regia and Evolvulus alsinoides* (Pandey 2018).

Table 18.1 Green synthesis of nanoparticles using plant extract for wastewater treatment

Nanoparticles	Plant extract	Application of nanoparticles	References
Nano-zerovalent copper	Test a extract of *Anacardium occidentale*	Removal of uranium from wastewater	Chandra and Khan (2020)
Magnetite NPs	Crude latex of *Jatropha curcas* and leaf extract of *Cinnamomum tamala*	Removal of methylene blue dye, Cu(II) and Co(II) from aqueous solution	Das et al. (2020)
Zinc oxide NPs	Aloe vera and Cassava starch	Removal of copper ion	Primo et al. (2020)
Nano-zerovalent copper	Aqueous fruit extract of ripened *Duranta erecta*	Reduction of azo dyes (congo red and methyl orange)	Ismail et al. (2019)
Copper nanoparticles	*Eichhornia crassipes* (water hyacinth) extract	Detection of hazardous H_2O_2	Roy et al. (2019)
Copper nanoparticles	Leaf extract of *Camelia sinensis*	degradation of dyes	Ahmed et al. (2019)
Copper nanoparticles	Extract of *Cynomorium coccineum*	Adsorption of methylene blue dye	Sebeia et al. (2019)
Copper nanoparticles	Leaf extract of *Nerium oleander*	Interaction with organic dyes	Sebeia et al. (2019)
TiO_2 Nanoparticles	*Jatropha curcas* leaf extract	Photocatalytic treatment of tannery wastewater	Goutam et al. (2018)
Silver nanoparticles	Leaf extract of *Ficus Benjamina*	Removal of Cd(II) from contaminated solution	Al-Qahtani (2017)
Silver nanoparticles	*Piliostigma thonningii* aqueous leaf extract	Heavy metal removal activity in laboratory simulated wastewater	Shittu and Ihebunna (2017)
Fe Nanoparticles	Green tea (*Camellia sinensis*) and pomegranate (*Punica granatum*) leaf extract	Organic carbon removal from textile wastewater	Ozkan et al. (2017)
Au Nanoparticles	*Lagerstroemia speciosa* plant leaf extract	Photocatalytic reduction of organic pollutants	Choudhary et al. (2017)
Silver nanoparticles (AgNPs)	*Penciillium Citreonigum* Dierck and *Scopulaniopsos brumptii Salvanet-Duval*	AgNPs showed an excellent antibacterial property on gram-positive and gram-negative bacterial strains	Moustafa (2017)

(continued)

Similarly bacteria, yeast, fungi, algae and actinomycetes are used for the green synthesis of different nanoparticles. Microorganisms have the potential to reduce size of metal ions which lead to the synthesis of nanoscale materials. Pandey (2018) reported that microorganisms secrete extracellular enzymes which are being used for the synthesis of relatively pure nanoparticles while Koul et al. (2018) reported that

Table 18.1 (continued)

Nanoparticles	Plant extract	Application of nanoparticles	References
Silver nanoparticles	Testa extract of *Anacardium occidentale*	Reductive degradation of carcinogenic azo dyes like congo red and methyl orange	Edison et al. (2016)
Silver nanoparticles	*Ocimum sanctum* and *Artemisia annua* leaf extract	Reduction in pH, odor, color, dissolved oxygen (DO) and biochemical oxygen demand (BOD)	Sardar and Khatoon (2016)
Iron oxide NPs	Tangerine peel extract	Removal of cadmium ions from contaminated solution	Ehrampoush et al. (2015)

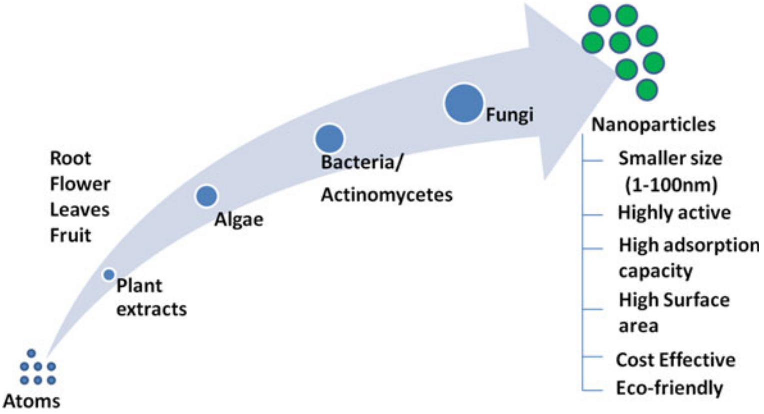

Fig. 18.1 Bottom-up approach for green synthesis of nanoparticles

bacteria have been most commonly used for the production of iron nanoparticles. In a study by Bharde et al. (2005) *Actinobacteria* sp. was used to produce spherical iron nanoparticles under aerobic environment. Greigite (Fe_3S_4) and maghemite ($\gamma-Fe_2O_3$) nanoparticles were also synthesized using the same bacterial spp. Thermophilic bacterium *Thermoanaerobacter* has also been used for the production of magnetite nanoparticles. Sahayaraj (2012) reported that microbes belonging to the *Streptomyces, Verticillium, Lactobacillus, Fusarium, Aspergillus, Pseudomonas, Corynebacterium, Aeromonas, Bacillus*, *Desulfovibrio, Plectonema* and *Rhodopseudomonas* genus have been used for the green synthesis of nanoparticles. Apart from bacteria, many fungi are also being used for the synthesis of nanoparticles and because of the secretion of a large amount of protein they proved to be better at producing a larger amount of nanoparticles as compared to bacteria (Raliya et al. 2013; Gurunathan et al. 2015; Yadav et al. 2018).

18.4 Nanoparticles for Water Disinfection and Purification

Nanotechnology has potential applications in wastewater treatment (Athirah et al. 2019). Noman et al. (2019) observed inactivation of antibiotic-resistant *Escherichia coli* (Gram-negative) and *Staphylococcus aureus* (Gram-positive) bacterial presence in graywater using Zn/Cu nanoparticles biosynthesized from a novel fungal strain. *Aspergillus iizukae* EAN605. Similarly, Ag nanoparticles biosynthesized using *Penciillium citreonigum Dierck* and *Scopulaiopsos brumptii Salvanet* have been found effective against *E. coli, Staphylococcus sps.* and *Pseudomonas sps.* removal from wastewater (Moustafa 2017) with complete decontamination at 676.0 mg/L NP concentration and 120 minute contact time. The nano-silver coated foam has been reported to remove both the gram-positive and gram-negative bacteria from contaminated water. Several researchers have synthesized Ag NPs from bacteria (Saifuddin et al. 2009), yeast (Pimprikar et al. 2009), fungi (Rai et al. 2016), plants and plant extracts (Anandalakshmi et al. 2016) for water disinfection (Table 18.2).

18.5 Nanoparticles as Sensors and Detectors for Water Pollutants

Organic and inorganic contaminants present in wastewater, like heavy metals, aromatic compounds, organophosphates, toxins and dyes, which are highly toxic and carcinogenic needs prior detection due to the toxicity posed by these pollutants even at trace levels. Detection of these pollutants with simple and sensitive metal ion sensors needs further advancement as these are non-biodegradable and can accumulate in the food chain, which poses a severe threat to the environment and human health. In general, a simple colorimetric sensor is preferable, and it can be made more advanced by the application of green chemistry which uses biogenic synthetic protocols based on non-toxic, multifunctional reactants derived from natural sources. For example, biomolecules, unicellular microorganism and higher plants, for a highly sensitive and selective detection of pollutants (Joshi and Kumar, 2018). In a study, fruit extracts of *Citrus limon* and *Citrus limetta* were used for biosynthesis of silver (Ag) and gold (Au) nanoparticles and used for Hg+ detection at pH range from 3.2 to 8.5. (Ravi et al. 2013). Ha et al. (2014) synthesized Au NPs from *Xanthoceras Sorbifolia* for sensing of Cr^{3+} ion with a detection limit of 3 μM. Plant extract of *Allium sativum* was used to synthesize Ag NPs for the detection of polyaromatic hydrocarbon (PAH) such as phenanthrene, pyrene and anthracene (Abbasi et al. 2014). For the detection of NH_3 (1 ppb) biosynthesized Au NPs from *Cyamopsistetrago Aloba* were used (Pandey et al. 2013). Biosynthesized Ag NPs from pods of *Phaseolus vulgaris* was used in photodegradation of mordant black and Congo red (Sunkar et al. 2013). All these tested bionanosensors provide a promising approach for the selective and sensitive detection of various pollutants in the contaminated water.

Table 18.2 Use of nanomaterials in wastewater treatment

Nanomaterials	Water pollutants	Organism and biological systems used	Effect	References
Microorganism-immobilized nanocellulose composites [Bacteria-decorated nanocellulose (BDN)]	Diuron herbicide	*Arthrobacter globiformis* D47	>90% pollutant removal in 48 hours	Liu et al. (2018)
Unzipped carbon nanotube (CNT), single-walled CNT and multi-walled CNT	Organophosphates and heavy metals	Enzyme organophosphate hydrolase	22% removal of heavy metals	Fosso-Kankeu et al. (2014)
Iron oxide nanopowder (nano-Fenton process) (<50 nm)	Azo dye C.I. Direct Yellow 86	–	81–99% decolorization of wastewater	Kos et al. (2014)
Nanoscale zerovalent iron (nZVI) and palladized nZVI	Polybrominated diphenyl ethers (PBDEs)	*Sphingomonas* sp.	67% of deca-BDE was transformed to the lower BDEs	Kim et al. (2012)
Glutathione (GSH) or cysteine-capped ZnS nanocrystals (3–5 nm)	p-nitrophenol (pNP) and Acid Orange 7	Enzymatic degradation by bacteria	80% of the AO7 was degraded within 15 minutes	Torres-Martínez et al. (2001)

18.6 Recent Advances in Bio-Nanomaterial and Wastewater Treatment

Nanotechnology offers some of the promising techniques for wastewater treatment which includes photocatalysis, nanofiltration and nanosorbents (Bora and Dutta 2014). Nanocatalyst, nanoadsorbents and nanomembranes are mostly being used for wastewater treatment. A variety of nanoparticles have been successfully reported for water and wastewater treatment such as zerovalent metal nanoparticles (Ag nanoparticles, Fe nanoparticles, Zn nanoparticles), metal oxide nanoparticles (TiO_2 nanoparticles, iron oxide nanoparticles, ZnO nanoparticles), carbon nanotubes and nanocomposites (Mueller and Nowack, 2009). Goutam et al. (2018) reported that photocatalytic treatment/degradation of tannery wastewater using green synthesized TiO_2 nanoparticles revealed promising results. Nano-based photocatalysis employed by Devatha et al. (2016), Wang et al. (2014), Ghaly et al. (2011) and Bordes et al. (2015) has also reported the potential of nanoscience in wastewater treatment. Nanosorbents have been widely used for the removal of microbes, organic dyes and heavy metal pollutants from water and wastewater. Studies have been conducted on the use of nanoparticles as nanoadsorbent in the wastewater treatment for iron oxide as nanoadsorbent for the removal of various pollutants from wastewater, Fe-La composite oxide for the removal of As (III) from wastewater (Nassar 2012; Zhang et al. 2014). For the treatment of textile dye, Banerjee et al. (2014) synthesized silver nanocomposites using leaf extract of *Ocimum tenuiflorum* (Black Tulsi). Cadmium removal from wastewater by iron oxide nanoparticles synthesized using peel extract of tangerine was reported by Ehrampoush et al. (2015). Rosales et al. (2017) reported the degradation of textile dye by zerovalent iron nanoparticles synthesized from two different extracts, green tea (*Camellia sinensis*) and Rooibos (*Aspalathus linearis*). Similarly, *Jatropha curcas* leaf extract was successfully utilized for the synthesis of titanium dioxide (TiO_2) nanoparticles for photocatalysis of treated wood waste (Goutam et al. 2018). Biosynthesized iron oxide nanoparticles using *Padina pavonica Thivy* and *Sargassum acinarium* were successfully entrapped in calcium alginates beads and used for Pb adsorption (El-Kassas et al. 2016). Many researchers across the globe are working on eco-friendly techniques such as green synthesis of nanoparticles for proving solution to the problem of wastewater.

High reactivity, larger surface area, better disposal capability, eco-friendly and non-toxic nature are some of the advantages of bio-nanomaterials for wastewater treatment. These properties can be utilized for adsorption and reduction of various harmful pollutants in the water. Examples of bio-based nanoparticles used for water remediation include Fe NPs, Ag NPs, TiO_2 NPs, Silver nanocomposite hydrogel (SNC), ZnO, CuO, Co_3O_4, Nickel oxide and Cr_2O_3, Nano-zerovalent iron (nZVI), etc. (Goutam et al. 2018; Ozkan et al. 2017; Shittu and Ihebunna 2017; Devi et al. 2016; Shanker et al. 2016; Hoag et al. 2009). In a study, iron nanoparticles (FeNPs) were synthesized via a green method using loquat *(Eriobotrya japonica)* leaves aqueous extract as a renewable reducing agent which showed more than 90% Cr (VI) adsorption at a wide range of initial Cr (VI) concentrations (50–500 mg/L) (Onal et al. 2019). Mehrotra et al. (2017) employed protein capped zerovalent iron NPs synthesized using yeast, for complete degradation of organophosphorus insecticide (Dichlorvos). At an optimum experimental condition with 2000 mg /L nanoparticles dosage, 1000 μl H_2O_2, 99.9% degradation was observed within 60 min of reaction. *E. coli*-mediated biogenic synthesis of gold NPs served as an efficient, eco-friendly and cost-effective bionanocomposite for the complete degradation of 4-nitrophenol.112 R. In a study, *Tilia* leaf extract was used for the synthesis of copper nanoadsorbent for remediation of aquatic systems contaminated with Ibuprofen, Naproxen and Diclofenac (Dalal et al. 2019).

18.7 Advantages and Limitations of Bio-Nanomaterials

Though nanoparticles have shown potential in treating contaminated sites with higher effectiveness. However, there are several problems associated with the use of nanomaterials for environmental clean-up. The major limitations are loss of reactivity with time, transportation and their effect on microorganisms (Mohammed et al. 2017; Lunge et al. 2014). Studies suggest that Iron nanoparticles exhibit, a loss in reactivity level after a certain period of time, a blocking effect in the soil by clogging the pores of soil and restricting the passage of fluids. The use of stabilizers, such as lactate, enhances the mobility of iron nanoparticle in turn facilitating their improved transport in soil (Warner et al. 2011). Various studies under controlled conditions have been executed on the consequence of nanoparticles on microorganisms and the results thus found were conflicting (Bai et al. 2011). Some of the studies have shown inhibitory effects on microorganisms like *Staphylococcus aureus* and *Escherichia coli* (Simeonidis et al. 2015; Qu et al. 2013 and Demming 2011). Few other studies have shown the stimulating effect of nanoparticles as electron donors on microorganisms such as bacteria and methanogens (Dong et al. 2015). A few nanoparticles with certain concentrations are hazardous, toxic and can thus damage human health and the environment (Cornelis et al. 2014). Carbon nanotubes in the form of asbestos can cause lung cancer when inhaled in insufficient quantities through treated water (Buzea et al. 2007).

Moreover, the synthesis of nanoparticles utilizes conventional methods which include physical and chemical methods. The physical methods of nanoparticle synthesis comprise high energy irradiation, lithography or laser ablation, while chemical synthesis utilizes photochemical reduction, electrochemistry and chemical reduction methods. These conventional methods require huge amount of energy for the successful operation of physical methods whereas synthesis of nanoparticles through chemical methods poses detrimental effects on the environment due to the use of toxic chemicals in the synthesis process and the formation of lethal byproducts. However, with the application of biological methods or green synthesis approach for the synthesis of nanoparticles, these limitations can be effectively overcome.

Biologically synthesized nanoparticles have been lucratively applied in the treatment of wastewater with minimal effluent discharge. Bionanoremediation is a sustainable approach to nanoremediation as the nanoparticles are non-toxic in nature, eco-friendly and can be synthesized by a simple green chemistry approach using plants and microbes. Thus, the eco-friendly approach of biologically driven nanotechnology restricts the risk of producing toxic intermediates and end-products. Undoubtedly biologically synthesized nanomaterials have proved more beneficial for human health and environment prospects; however, it is also very important to consider the challenges associated with them (Ali et al. 2017).

Long-term exposure of bio-nanomaterials should be evaluated before application. In spite of the basic amalgamation strategy, the use of solution extract volume, temperature, solvent type, pH, strength of forerunner and functional groups from plant metabolites ought to be optimized to avoid any alteration in the magnetic behavior and saturation magnetization value of the bio-nanomaterials. To maintain the stability of bio-nanomaterials for efficient treatment of wastewater, efforts are required to formulate the nanoparticle morphology and saturation magnetization value. For selective and wide range of pollutant removal, bio-nanomaterials should be synthesized with multiple functional groups by manipulating the plant metabolites and synthesis method. In addition, the properties of the synthesized nanoparticles must be studied systematically in comparison with their chemical counterparts. For commercial application cost–benefit analysis should be performed as there is no information on this aspect. Until date, the biological synthesis of metallic nanoparticles has been mostly carried out at laboratory scale. The industrial scale optimization is required for large-scale production.

18.8 Future scope of Nano-Biomaterials for Water Pollution Control

Distribution of water on the Earth's surface is enormously irregular with only 3% fresh water available in rivers, glaciers, groundwater and in the atmosphere while the remaining 97% is found in the ocean. Providing clean and affordable water for human consumption is a huge challenge in the present scenario when the population is increasing at a faster rate. Besides, water supply is worsened by developmental activities, global climate change and water quality deterioration due to environmental pollution. Currently, many conventional and non-conventional wastewater treatment technologies are available to remove pollutants from various types of wastewaters, but high operating cost, high energy requirement, reduced efficiency and non-eco-friendly nature limit the extensive use of these methods (Bora and Dutta 2014). On contrary, nanotechnology offers a great potential for the development of next-generation water and wastewater treatment technologies and could replace the conventional methods (Goutam et al. 2018). Nanoparticles (NPs) are increasingly applied for wastewater treatment and purification due to their high reactivity and degree of functionalization, large surface area, size-dependent properties, etc. Nanotechnology finds major application in the water pollution management like detection of water pollutants, wastewater treatment and purification.

18.9 Conclusion

Water is a distinctive feature that makes the earth a habitable and superior place than other planets. The continuous decrease in freshwater sources due to never-ending water demand has led the water insufficient to fulfill the human water requirements like drinking, sanitation, developmental activities, etc. Moreover, the contamination of water bodies with pollutants, have made the situation worse, under such circumstances novel ways of water treatment needs to be explored in order to recycle water and to eliminate high load of contaminants from water reservoirs. Conventional water treatment methods include use of chemicals which generate by products and require further disposal mechanisms. However, the biological methods utilizing microorganisms and plants for wastewater treatment are eco-friendly and non-toxic in nature but have a slow operating rate. Nanotechnology is advantageous over chemical methods of treatment because of its faster reaction rate. Nanomaterials possess unique properties like high reactivity and sensitivity, accumulation on substrates to form films, high surface to volume ratio, high adsorption rate, etc. which makes them much more suitable for wastewater treatment. Due to these properties, nanomaterials proved effective against various organic and inorganic pollutants, heavy metals and harmful microorganisms present in contaminated water. Moreover, the conventional methods for nanoparticles synthesis have certain problems like higher energy requirements for the successful operation of physical methods whereas synthesis of nanoparticles through chemical methods pose detrimental effects on the environment due to the use of toxic chemicals in the synthesis process and formation of lethal byproducts. Existing wastewater treatment technologies are capable of removing organic and inorganic pollutants from wastewater, but these methods are energy-intensive and uneconomical due to their inability to fully decontaminate wastewater as well as to be retained again for further remediation. Biologically synthesized nanoparticles have been lucratively applied in the treatment of wastewater with minimal effluent discharge. These nanoparticles act as an adsorbent for the remediation of water pollutants evidently due to their physicochemical properties, nanosize, controlled growth and surface alteration. The carbohydrates, proteins and enzymes present in these biological entities act as a surfactant and capping agents which reduces the use of harmful chemical surfactants. Nanobioremediation is a sustainable approach to nanoremediation as the nanoparticles are non-toxic in nature, eco-friendly and can be synthesized by a simple green chemistry approach using plants and microbes. The bio-based nanoparticles offer a promising alternative to conventional nanoparticles in wastewater treatment, as these are biocompatible, economical, eco-friendly and energy-intensive. Thus, Nanobioremediation or bio-based synthesized nanoparticles can become an essential component of wastewater treatment systems in the future. Further research is necessary on this direction to commercialize the use of bio-based nanoparticles for pollutant removal from wastewater.

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