Bioactive Nanoparticles: A Next Generation Smart Nanomaterials for Pollution Abatement and Ecological Sustainability

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Abstract

The level of environmental pollution is increasing rapidly with increased urbanization and rapid industrialization across the globe. To abate pollution, there is utmost necessity to develop technology that can monitor, detect and clean contaminants from the air, water and soil with higher efficiency. Recently nanotechnology has emerged as a highly effective and reliable technique that offers a wide range of capabilities to improve the quality of existing environment. Due to its large surface area, the nanoparticles adsorb large amount of pollutants at a much faster rate. Nanomaterials can reach to inaccessible areas making in-situ remediation of pollutants effective. Coating of nanomaterials with various ligands provides opportunities to develop sensor with high selectivity and specificity toward pollutants. However, nanomaterials used for pollution abatement can itself cause environmental pollution. There are limited studies exploring the fate of nanomaterials after their end use. Nanotoxicological studies conducted so far indicate damaging impact of nanomaterials in ecological functioning and maintenance of ecosystem integrity. Bioactive nanoparticles on the other hand are biodegradable, have shorter life span and minimal negative impact on environment. Although application of bioactive nanomaterials in environmental pollution abatement is in its infancy, it is gradually gaining wider acceptance in pollution management because of its promising potential.

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15.1 Introduction

Ever increasing industrialization and urbanization has filled the world with number of toxic chemicals such as carbon monoxide (CO), chlorofluorocarbons (CFCs), heavy metals, hydrocarbons, nitrogen oxides, organic compounds, sulfur dioxide and particulates. Water bodies are polluted with fertilizers, herbicides, pesticides and by-products of number of industries across the globe. Contaminants are mostly found mixed in the air, water and soil (Ang et al. 2005). Environmental pollution is one of the most challenging problem, the modern world is confronting now. As reported by The World Health Organization, every year 270,000 children loss their life due to lack of clean water and acute air pollution. In low income countries having poor technology and resources to deal with emission of VOCs such as polycyclic Aromatic Hydrocarbons (PAHs), people are getting exposed to number of carcinogenic/mutagenic contaminants in air above their acceptable level causing increased mortality from cancer in the community (Montero-Montoya et al. 2018).

Conventional methods such as adsorption, biological remediation, chemical oxidation, ion exchange, chemical precipitation, electrochemical treatment, membrane filtration, reverse osmosis, coagulation, extraction and irradiation are used primarily for remediating environmental pollutions (Ouyang et al. 2019). However, these methods have their own disadvantages such as the use of large amounts of reagents for precipitation methods, high operational costs for ion exchange methods, low adsorption capacity and selectivity for adsorption methods. In this context, nanotechnology offers a wide range of capabilities and technologies to improve the quality of existing environment by enhancing the performance of pollution control technologies and reducing their cost of operation. Though the implication of nanomaterials in pollution remediation is still in its infancy, people across the globe have begun to recognise the promising potential of nanotechnology. Because of the nano scale size of the nanomaterials and high surface area to volume ratio, it can be used for detection of sensitive environmental pollutants (Willner and Vikesland 2018).

As an alternative to conventional materials, nanomaterials can provide new opportunities to cope with these challenges. Nanomaterials can be used for the preparation of excellent adsorbents, catalysts, and sensors due to their unique properties, including large surface area to volume ratio, high reactivity, reduced size, strong sorption, active surface sites, specific interaction with contaminants, etc. With the use of nanomaterials, polymer nanocomposites can be obtained with improved sorption, removal and filtration properties when they are used in environmental applications. In environmental remediation applications, iron oxides, titanium dioxide, cadmium sulphide, etc. are used as nanomaterials and PVP, PMMA, CMC, PANI, PHB, alginate, etc. are used as polymers to prepare nanocomposites

(Guerra et al. 2018). These materials can be blended using mainly two methods as direct compounding and in situ synthesis. The existing technologies used for pollution remediation though are effective but the cost of their implementation in different sectors is prohibitively high. It is realized now that there is a dare necessity for development of technology capable of monitoring, detecting and cleaning the contaminants from the air, water and soil in ecofriendly, cost effective and sustainable manner.

The number of new nanomaterials with specific desired characteristics is now designed, synthesized and produced in large-scale industrially. Currently, it has been observed that the conventional engineering environmental nanomaterials (EENM) lose their functionalities when subjected to changing environmental condition making them non-functional (Chang et al. 2018). To overcome such problems, smart environmental bio-nanomaterials (SEBN) having capacity to self adjust under changing environmental conditions are now been designed and synthesized. When the concentration of pollutants is above the MPL, state-of-the-art nanomaterials could be used, such as bio-inspired self-healing nanomaterials without external stimuli, not energy input, among others. However, there is also growing awareness of the need to understand and characterize the properties of ENMs as they change from the time of synthesis to their final state during application and possible release in the environment (Karakoti et al. 2012). Nanomaterials generally do not retain the same properties from their point of synthesis to their state of application and both the particle processing and storage histories often are poorly documented.

15.2 Nanomaterials as Environmental Pollutants

In the last one decade, the application of nanomaterials in the field of medicines, cosmetics, electronic devices and number of consumer products has seen a spectacular rise resulting in the generation of emerging class of environmental pollutants. As it is not known with certainty how nanomaterials after their end use behave in the environmental compartments like air, water and soil, appropriateness of the existing regulations for chemical environmental pollutants is debatable (Gupta and Xie 2018). Significant progress in understanding the roles of various factors influencing the fate and transport of nanomaterials in environmental compartments have been made in the last few years. Researches demonstrate that the nanomaterials behave differently in aquatic environment as a dissolved chemicals compared to their solid or colloidal counterpart. However, there are not enough investigations made to understand the structure and activity relation of different classes of nanomaterials in different condition. How one nanomaterial interacts with other nanomaterial present in the same environmental compartment with respect to their toxicity on organism living within is still an unanswered question requiring further investigations. There is necessity of establishing predictive models for nanomaterials in environment to suitably access and manage the risk associated with exposure to various nanomaterials singly or in combination.

Nanomaterials are known to undergo significant settling under normal gravitational condition in various environmental media. Analytical techniques show that they also exhibit reduced diffusivity compared to other dissolved species. In the absence of gravitational and inertial impaction, air/water, air/soil and water/soil inter medium transport of nanomaterials is known to be governed by diffusive processes. Eco-toxicity by nanoparticles is a major concern in present scenario and gains the interest of scientists and researchers. These nano-materials may drift-off from the manufactured site to alternate places like water bodies and agricultural fields through physical and natural processes. Pollution by nanomaterial's in air, water and soil cause adverse effects on terrestrial and aquatic eco-system. It also cause severe damage to micro and macro habitat through dermal contact, inhalation or by pore penetrations (Hoet et al. 2004). The industrial waste approximately of nano range is common nano-sized material which causes a major exploitation of physcio-chemical properties of living creature and existence of nature. The nature of nanoparticles depends upon techniques used during synthesis procedure, chemical and physical synthesized nano material is highly toxic as compared to biologically synthesized material (Das et al. 2017). It has been observed that atmospheric nanomaterials can have residence time of about twenty days and their aggregate may not cause any effect on human respiratory system. Similarly exposure assessment to nanomaterials in water may not always bring identical result as nanomaterials particle stabilize in aquatic system (Ray et al. 2009). Nevertheless there is very few research to establish the environmental pollution by nanomaterials barring a handful of modeling studies that have investigated ENM release to the environment. The major source of release of nanomaterials to environmental compartments is mostly sewage sludge, wastewater, and waste incineration of products containing ENM. However, there is lack of proper evidence on release of ENM during their production and application in various fields. No quantitative information is available till now linking occupational exposure and emission flow of ENM into environment.

15.2.1 Monitoring of Nanowastes in Environment

The traditional methodologies used for quantification of nanomaterials during their manufacturing cannot be applied adequately while analysing nanomaterials in environmental sample. There are no available standard methods for analysis of nanomaterials in environmental sample especially their fate, transport and toxicological effect on living being. The existing methods for detection and quantification of nanomaterials cannot differentiate the fraction of the nanomaterials which are generated and released to environment through natural processes from the manufactured nanomaterials that are released to the environmental compartment because of their application in different sectors by human being (Laux et al. 2018). The traditional analytical techniques proved inadequate for analysing the physico-chemical forms of ENMs. The effects of the surrounding medium on most of the nanomaterials in environmental compartment that influence their properties make analysis inaccurate and difficult to understand because of the artefact effect (Lin et al.

2014). Now it is high time to develop appropriate technique for extraction, cleanup, separation, and sample storage inducing minimal artefacts, increase sensitivity and add specificity of analytical techniques.

15.3 Bio-nanomaterials as a Degradable Smart Option in Pollution Abatement

Last few years has seen rapid growth in the use of nanomaterials in different fields. Today, because of widespread applications of nanomaterials, several thousand tons of nanomaterials are manufactured daily which enters to environmental compartments after their end use (Buzea et al. 2007). However, most of these nanomaterials are non-biodegradable, toxic and are conservative in nature and hence tend to accumulate in environment (Sharifi et al. 2012) Unlike metallic and carbon based nanomaterials, bio-nanomaterials have shorter life, biodegradable in nature and easy to prepare (Mishra et al. 2018). Therefore bio-nanomaterials can be used as a safer alternative to the existing nanomaterials based technologies without compromising with their performance.

15.3.1 Bioactive Nanoparticles for Water Pollution

There are several techniques popularly used at present to remediate water pollution in different sectors. Technology like Electro coagulation, though effective in removing fluoride and other contaminants from water, sometime leaching of the coagulants into the treated water during treatment process make the water toxic (Kabdaşlı et al. 2012; Tetteh and Rathilal 2020). Moreover, it leads to the generation of toxic sludge which are very difficult to manage. Ion exchange techniques used for water treatment is highly expensive and its sensitivity to *p*H make it difficult to operate. The most effective water treatment technique at present is membrane based processes which are highly efficient in removing contaminants. But its drawback is that it is prohibitively costly and energy intensive and sometime causes ionic imbalance in drinking water. In addition, it releases huge volume of water with higher concentration of initial contaminants. On the other hand, adsorption based processes are less efficient in removal of contaminants, lack reusability and require high energy input (Guillossou et al. 2020). The effort to overcome the disadvantages of existing water treatment techniques is underway across the globe. Scientists believe that nnanotechnology has the potential to address all of these drawbacks and can be a magical instrument to deal with the current and upcoming water crisis. Focussed researches are being undertaken all over the world to develop novel nanomaterials with high affinity, capacity, and selectivity toward contaminants (Table 15.1).

Current research intends to enhance the removal efficiency of bio-based materials used in water treatments processes by impregnating them with various nanomaterials. Activated bio char impregnated with metal oxide nanomaterials like Fe_2O_4, Al_2O_3, and ZrO_2 have been reported to be highly effective as an

Table 15.1 List of the selected nanomaterials used popularly for pollution abatement

Nanomaterial	Type of pollutant removed	Origin of removed pollutant material	References
Graphene oxide(GO)	Removes cationic, anionic, and/or amphiphilic and detection of chlorophenol	Water	Scalese et al. (2016) and Yi et al. (2019)
Chitosan and alginate coated with silver nanoparticles	Highly efficient in removal of fluoride and chromium	Water	Kumar et al. (2017)
Bioactive carbon nanotubes CNT	Helps in removal of chlorophenol and excessive fluoride, NO_X, SO_2 and CO_2	Water and air	Khin et al. (2012)
Nanocellulose	Removes heavy metals and commercial dyes	Water	Suman et al. (2015)
Bioactive silver nanoparticles	The Ag nanoparticles removes hazardous dyes like Safranine O, Methyl red, Methyl orange and Methylene blue	Industrial waste management	Jyoti and Singh (2016)
Bioactive graphene, fullerene, and nanotubes	Acts as an adsorbent for polyaromatic hydrocarbons PAHs	Soil and water	Wang et al. (2014)
Bioactive TiO_2	Integrated with air pollution devices also have a potential to remove benzene, toluene, ethylbenzene and xylene (BTEX)	Air and water	Patel et al. (2020)
Bioactive ZnO	Acts as a photocatalyst and remediate chlorocatechol	Air	El Golli et al. (2021)
Single walled (SWNTs) and multi walled nano-tubes MWNTs	Acts as a sensor for NO_2 and NH_3	Air	Pandhi et al. (2020)
Zero-valent (nZVI)	This may highly remove Cu^{2+}, chlorinated hydrocarbons, $CrO2^{-2}$ and $NO3^{-}$	Water and soil	Zhao et al. (2016)
Manganese oxide conjugated with gold nanoparticles	Japanese technology which are used to efficiently remove VOCs, nitrogen and sulfur oxides at room temperature	Air	Sinha and Suzuki (2007)
SeNps	It helps in removal of bacteria (A. faecalis SeO_3) also acts as an friendly candidate for bioremediation	Soil and water	Sakr et al. (2018)

adsorbent in removing contaminants from water compared to bio char alone (Pathak et al. 2003). Several studies reported enhanced removal efficiency of cellulose by trapping MnO_2 nanoparticles in the cellulose matrix (Maliyekkal et al. 2010). Impregnation of aluminium ions with activated carbon fibers and carbon nanofibers have been reported to elevate their fluoride removal efficiency manifold (Gupta et al. 2009). Doping of ferric oxide nanoparticles to carbon nanotubes improved the pollutant removal from water with higher efficiency. Magnetic alginate beads had very high defluoridation capacities (Gao et al. 2014). This material is not leachable and due to high magnetic sensitivity, the materials can be separated easily from the aqueous solution. The major advantages of these adsorbents are that their effectiveness remains intact over a wide range of *p*Hs. However, the major drawback of such adsorbents is that there is possibility of release of nanomaterials to treated water and their synthesis is energy intensive in nature.

Recently multipurpose bionanomaterials-based scaffold are designed to deal with water pollution effectively. Alginate and chitosan are mixed to prepare the scaffold and aluminium ion is added to it. The surface of the scaffold is coated with silver nanoparticles. The scaffold effectively removed fluoride, chromium and several reactive dyes mixed with water with remarkable efficiency. Regeneration of the scaffold after use depends upon whether the pollutants in water form covalent linkage with scaffold or not. Pollutants forming covalent bonds with scaffold make it difficult to regenerate and hence limit its reusability. For Cr (VI) and dye, the scaffold can be regenerated easily but fluoride form covalent bond with scaffold making it difficult to regenerate (Kumar et al. 2017).

Cleansing of polluted ground water can be achieved easily using nanotechnology because application of nanoparticles into the underground source of water is cheaper compared to pumping water for treatment. Nanosized fibre can be used as elctrode for efficient deionisation of water with very little investment and energy input (NRC 2006). In a recent study, starch-based nanocomposites (starch/SnO2) were used for removal of Hg2+ from an aqueous medium, and the removal percentage reached up to 97% (Thines et al. 2017). Nanofibre filter which has ability to filter out virus from drinking water has already been developed (Gupta et al. 2007). Ion exchange resins made up of bionanomaterials with nanosized pore on the surface to trap and exchange ions have already developed and in use for separation, purification and decontamination of water (Zhang and Liu 2020). These resins are widely used for softening of hard water. They also remove toxic heavy metals from water and replace them with sodium and potassium.

15.3.2 Bio-nanomaterials as a Degradable Smart Option in Air Pollution

Around 4.2 million people lost their life and 103.1 million people became disable because of exposure to particulate matter $PM_{2.5}$ world wide in 2015 as per WHO report (Oberdorster et al. 2007). Pollutants like volatile organic compounds are the most common contaminant in both indoor and outdoor air. VOCs like Polycyclic aromatic hydrocarbons (PAHs) which are released to air from combustion processes are highly toxic, mutagenic and carcinogenic in nature. Therefore, appropriate technical advancement must be achieved rapidly and efficiently to reduce these contaminants in air to a safer level and in a cost-effective manner (Gómez et al.

2012). Applications of nanocatalyst that can speed up the chemical reactions transforming harmful pollutants into harmless gases are gaining popularity in pollution control. Currently nanofiber catalyst made of manganese oxide is used popularly to remove VOCs from industrial smokestacks (Kuleyin 2007). Nanostructured membranes having pore size small enough to separate methane or carbon dioxides are used near the automobile exhaust. Researchers are now developing carbon nanotubes (CNT) to trap GHGs emitted from mining and thermal power industries. These nanotubes can trap GHGs much faster than any other conventional methods. Therefore, CNTs can purify large volume of air effictively within small time. Studies conducted in Japan in 2006 demonstrated a technique to convert soot filtered out of diesel fuel emissions into single walled CNT filter through laser vaporisation process (Uchida et al. 2006). This technique resulted in no waste because essentially the waste generated out of filtration process became the filter.

Wide range of toxic chemical pollutants are removed from air and water using polyamide nanofilter fabricated with MgO, TiO2 and other oxides (Ibrahim et al. 2016). The decontamination of toxic nerve gases such as paragon from air has been achieved with higher efficiency using electrospun nanofibres. Environmental remediation using polymer-supported metal and metal oxides mostly silver, iron, aluminum, titanium and magnesium are more widely used because of their high reactivity and ability catalyze degradation of air pollutants (Yang et al. 2019). Semiconductor metal oxides such as titanium dioxide (TiO2), zinc oxide (ZnO), tin dioxide (SnO2), and copper oxide (CuO), are promising materials for photocatalytic degradation of pollutants (Uddin et al. 2020).

15.4 Challenges in Synthesis of Bioactive Nanomaterials

Recent research has shown that green method for synthesis of nanomaterials is highly effective and low cost in nature. It has been observed that severe stress on environment is exerted when nanomaterials are synthesized using physical and chemical methods due to release of toxic metabolite in larger quantities. However, Bio based synthesis of nanomaterials are easy and less troublesome where metal salts is synthesized with desired plant extract and the process get completed within minutes to hours at room temperature. Bio nanomaterials of silver and gold metals synthesized using green synthesis process has been reported to be more stable and secure compared to their metallic counterpart. Large scale production of bio-nanomaterials using green synthesis protocol can be easily achieved and are cost effective (Singh et al. 2018). Nanomaterials synthesized using conventional methods where large number of toxic and harmful chemicals is used which make the composition of nanomaterials synthesized uncertian and could pose greater risk on human health and environment. Green methods of synthesis are significantly attractive because of their potential to reduce the toxicity of NPs. Accordingly, the use of vitamins, amino acids, plants extracts is being greatly popularized nowadays (Gour and Jain 2019).

In the recent decades, several research activities are being undertaken to prepare bio-composites by blending/reinforcing bio-nanomaterials in a wide variety of polymer matrices (Rossi et al. 2014; Uddin et al. 2012). The applications of nano-composites based on entirely renewable polymerase versatile (Yang et al. 2015). Unlike other nanomaterials, bionanomaterials can be synthesized easily using plant and animal resources (Mir et al. 2017). The synthesis of nano crystallites involves mechanical stirring and acid hydrolysis process Acid hydrolysis removes lower order regions. The resulting water insoluble high crystalline regime further gets converted to stable suspension via mechanical shearing (Rossi et al. 2014). There are significant challenges which need to be addressed are as follows:

(i) It is difficult to develop effective separation route suitable for extraction of nano-reinforcements from renewable resources,
(ii) It is hard to Find proper compatibility between nano-reinforcement and the polymer matrix and
(iii) It is essential to process the bio-nanocompsites using suitable techniques

Further commercialisation of bionanomaterials require the entire process to be cost effective and less dependent on high energy supplementation. Though at present nano-reinforcement in the polymer matrix is the widely used method for improving the properties bioolymers, the techniques itself is in the developmental phase and is not full proof. Bionanofiller have several advantages over number of commercially available nanofillers such as nanoclay, inorganicfillers, activated carbon, graphene and carbon nanotubes. Bionanofiller are renewable and biodegradable while nanofillers are not. Preparation of PVA composite films is done using solution casting method. The thermal stability and crystallisation propoerties of chitosan matrix remain unaffected when chitin is incorporated in the chitosan matrix (Grząbka-Zasadzińska et al. 2017). The tensile strength of the nanocomposite has been observed to increase with increase in chitin whiskers.

15.4.1 Green Synthesis from Enzymes and Vitamins

Enzymes because of their well defined structure and purity are best option for utilization in green synthesis of nanomaterials. Silver bionanomaterials are synthesized by combining them with enzymes involved in growth process of organisms. For synthesis of bimetallic nanomaterials Fe/Pd particles, enzymes were inserted into the lipid bilayer through electrostatic interactions (Gao et al. 2008). Extracellular amylase is utilized to generate Au NPs. It has been reported that large size silver nanomaterials were obtained when reduced with decreasing amount of beet juice. To get bimetallic nanomaterials, Green tea extracts is suitably used which produces nanomaterials Fe/Pd due to the fact that the extracts of green tea can act as both reductive as well as capping agent (Krishna et al. 2012). Use of natural agents in the field of nanosynthesis is big advancement toward green nanotechnology Vitamin B_2 has been used as reducing and capping agent in synthesis of Ag and palladium nanosphere and nanowires. Chitosan is popularly used as stabilizing agent because of its ability to bind strongly with metal ions along with Ascorbic acid as capping and reducing agent (Lu et al. 2010).

15.4.2 Green Synthesis Using Bacteria, Yeasts, Algae, Fungi and Actinomycetes

Psychrophilic bacteria *Pseudomonas antarctica, , Pseudomonas meridiana, Arthrobacter kerguelensis, Arthrobacter gangotriensis, Pseudomonas proteolytica, Bacillus indicus* and *Bacillus cecembensis* have been demonstrated to synthesize AgNPs which are highly stable and smaller in size (Shivaji et al. 2011). Silver nanocrystals of different compositions were successfully synthesized by *Pseudomonas stutzeri* AG259 (Klaus et al. 1999). Number of different species of yeast and fungi are used for synthesis of bionanomatterials. *F. oxysporum* metabolically transform Silver nitrate into well dispersed Ag oxide nanoparticles (Salem et al. 2015). *Alternaria alternata* are popularly used for synthesis of nano-platinum with partcile size varying from 2 to 30 nm (Sarkar et al. 2012). The fungus *Trichoderma viride* synthesize silver nanoparticles from silver nitrate through extracellular biosynthesis process (Elamawi et al. 2018). Very stable silver nanoparticles with size range of 5–15 nm have been reported to be synthesized using *Fusarium oxysporum* (Ahmad et al. 2003). Cyanobacterial Species like *L. majuscule, S. subsalsa, R. hieroglyphics, C. vulgaris, C. prolifera, P. pavonica, S. Platensis* and *S. fluitans* can be used as cost effective materials for bio recovery of metal and green synthesis of metal gold NPs (Bakir et al. 2018; Uma Suganya et al. 2015).

15.4.3 Green Synthesis Using Plants and Phytochemicals

The pomegranate was found to have the ability to produce more uniform size and shape NPs of Au and Ag in the range of 20–500 nm. *F. herba* isolate was used to reduce the platinum compound, the closeness of hydrogen and carbonyl in polyphenolic compound mainly goes about as fixing expert for metal particles (Dobrucka 2016). Formation of NPs could be completed in salt solution within short duration of time depending on the nature of plant extracts; the main reason being the concentration of the extracts, metal salt, pH and contact. It has been discovered that decrease of $AgNO_3$ to AgNPs by dihydroquercetin, quercetin and rutin prompted the development of an intensive surface plasmon resonance (SPR) band, which suggests reduction of this constituent (Veisi et al. 2018). Kou and Varma reported a simple, green and fast (complete within 5 min) approach for the construction of Ag NPs by MW irradiation using beet juice as a reducing reagent.

15.5 Future Prospective of Bioactive Nanomaterials in Pollution Abatement

The pollution of environments today has reached to its peak causing serious harm to the living beings on the earth. Toxic gases emitted from manufacturing industries and several sectors are now reaching to levels that directly deteriorate the quality of air. Relentless and unsustainable uses of numerous hazardous chemicals in agricultural sector are making the water bodies unsuitable for human use and are damaging the soil microbes that maintain the soil health. Increased cases of oil spillage from industries, warships, and leakage during transportation are major concerns that pollute the environment (Mohamed 2017). Under such condition, nanotechnology can prove itself a boon in pollution remediation. Nanomaterials can be used to develop an excellent environmental pollution cleaning system because of its unique structural characteristics. However the main concern in synthesis of nanomaterials requires the use of reagents, volatile organic and inorganic chemicals that are toxic in nature (Palit 2017). Although nanotechnology water treatment is far better and more efficient than conventional water treatment systems, the environmental fate of used nanomaterials, their transport in environmental compartments and their interaction with living beings are not well understood.

In the last few years, efforts to replace the toxic chemicals used in preparation of nanomaterials by safer and biologically conducive materials are underway. Regulatory bodies have already put stern regulations that ensure reduction of use of toxic chemicals during synthesis of nanomaterials so that their levels remain within safe limits in the environmental compartments. The greener route of synthesis of nanomaterials could be one of the options to get rid of these hazardous chemicals used in synthesis of nanomaterials. The biogenic method involves natural substances contain in plants, bacteria, algae, fungi, yeast, actinomycetes that act as reducing, capping and stabilizing agents for nanomaterials. Hence the biogenic method is both ecologically sustainable and economically viable. The manufacture of metallic nanomaterials using natural vitamins, polyphenols, proteins, amino acids and natural surfactants is slowly becoming more appropriate (Dhillon et al. 2012). As bionanomaterials have potential to clean and prevent environmental pollution and greener route of their production do not involve any toxic chemicals, nanotechnology involving bionanomaterials could be the next generation technology dealing with pollution abatement in near future.

15.6 Conclusion

Demand for clean and safe environment is growing worldwide with increased incidences of pollution related health issues in the community and development of awareness in public. Recent reports shows that there is a strong association between environmental chemicals and heavy metals pollutants in air, water and soil and rapid increase in the cases of cancer, lungs and kidney related diseases across the globe. Rapid progress in the nanotechnology-based pollution abatement techniques has generated a ray of hope for creating a world free of pollutants. Advancement of research and innovations in the field of nanotechnology could lead to the development of highly effective environmental pollution treatment techniques in the near future. Treatment of environmental pollution using bioactive nanomaterials not only ensure clean environment but also has the potential to overcome the hurdles of high cost and technical capacity for present and future generations. Large scale production of nanomaterials should only be done using greener route. Biogenic production of nanomaterials should be scaled up, commercialized and proper evaluation of their toxicity to environment and health should be performed in natural environmental condition in order to develop a clean and pollution free environment.

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