Microbial Nanobiotechnology in Environmental Pollution Management: Prospects and Challenges

2

M. B. Alao, C. O. Bamigboye, and E. A. Adebayo

Abstract

Environmental pollution is a major concern all over the world as various substances are added to nature by human activities and subsequently resulting in adverse effects on man, animals, plant and the ecosystem. In the time past, pollution has been managed conventionally by physical and chemical methods, but the pollutants persist in the environment, mostly in different forms, thus necessitating the need for a green technological approach. Environmental biotechnology is greatly accepted as it is safe and cheap and remediates all pollutants. Microbial nanobiotechnology is a viable option in pollution management in the world today as it is of high efficiency with no known toxic end products. The microorganisms producing the eco-friendly, nano-sized materials are generally regarded as safe. Diverse nanoparticles of environmental importance have been extensively synthesized intracellularly and extracellularly by bacteria, fungi, algae, yeasts, etc. Microbial nanoparticles of gold, silver and other metals have found applications in waste management, and they are of different shapes ranging from spherical, triangular, rectangular to pentagonal. Currently, in addition to remediating polluted environments, microbial nanobiotechnology is of great promise in pollution biosensory activity and prevention.

This chapter also assesses the prospects, challenges, sustainability and risks related to the application of microbial nanobiotechnology in pollution management.

M. B. Alao · C. O. Bamigboye · E. A. Adebayo (✉)
Microbiology Unit, Department of Pure and Applied Biology, Ladoke Akintola University of Technology, Ogbomoso, Nigeria
e-mail: eaadebayo@lautech.edu.ng

S. Arora et al. (eds.), *Biotechnological Innovations for Environmental Bioremediation*, https://doi.org/10.1007/978-981-16-9001-3_2

Keywords

Pollution management · Biotechnology · Nanotechnology · Risk assessment · Environment

2.1 Environmental Pollution

Broadly, pollution can be described as the discharge or introduction of waste substances or energy into the environment through human activities in amounts which are harmful to man, crops or animals. Environmental pollution can be defined as an activity, either by individuals or corporations that can lead to the release of contaminants into the environment, thereby compromising the health status of other persons living in the area, with a clearly established causal link. Urbanization and continuous upsurge in human population has led to equal increase in industrialization and a consequential pollution of the environment. Environmental pollution is predominant in both the developing and developed countries of the world. However, extended pollution of the environment often occur in the developing countries due to poor waste management, industrial emissions, mining activities and poor sanitation.

2.1.1 Types of Environmental Pollution

2.1.1.1 Air Pollution

This is caused by the release of toxic gases, fumes, dust, smoke, etc. Broadly, air pollution may be natural or of anthropogenic origin. Before the advent of civilization, the atmosphere was polluted to some extent from natural sources. A given sample of air may contain a host of natural contaminants such as smoke, dust, fungal spores and disease-causing bacteria. In 1909, about 1500 died in Scotland because of polluted air. It was as a result of this that the word ‘smog’ was coined as an abbreviation of smoke and fog. Atmospheric pollution progresses, most especially with the release of chlorofluorocarbon which has an effect in ozone depletion. Generally, air pollutants fall into one of four categories: particulate matter, heavy metals, persistent organic pollutants and gaseous pollutants. Particulate matters consist of varied and complex mixtures of particles suspended in the air with varied composition and size (coarse, fine and ultrafine) produced from anthropogenic and natural sources. Sources of pollution by particulate matter include activities in construction site, vehicles, industries, incinerators, dust, etc. Heavy metals are embedded in the earth’s crust, and they are not degradable and cannot be destroyed. They can be introduced into the environment via manufacturing facilities and discharge of waste water.

2.1.1.2 Water Pollution

Water pollution is one of the dangerous pollution that can negatively impact the ecosystem, man, animals and plants and can also interfere with the use into which a given water is applied. Some water pollutants include pathogens (Bamigboye et al. 2020), heavy metals (Cr, Ni, Cu, Hg, Zn, Cd, Pb, etc.), petroleum products and some organic chemicals. Others include industrial waste, radioisotopes, oil spills, sewage leakages, herbicides, pesticides, animal wastes, fertilizers and contaminants from mining activities. It is notable that both groundwater and underground water can be polluted. Most freshwater resources (groundwater, lakes and rivers) are used in domestic, agricultural and industrial activities. Pollutants, especially chemicals, may be introduced into this resource during the course of these activities. For example, run-off from agricultural fields can increase the nutrient level in receiving rivers leading to the depletion of oxygen, production of toxic alga blooms and increased biomass. Agricultural activities can be a major source for introducing pesticides and other agrochemical products including persistent organic pollutants into waterbodies.

Some water pollutants are referred to as ‘persistent organic pollutants’ (POPs). They are described as POPs if they are toxic to animals, humans and other living organisms, bioaccumulate and resist biological, chemical and photochemical transformation processes and finally if they can be transported to far distances. They include polychlorinated dioxins, polycyclic aromatic hydrocarbons, dichlorodiphenyltrichloroethane and other emerging chemicals. These emerging chemicals might have been present in the environment but not yet detected or recognized as toxic. POPs are of concern because they can biomagnify and bioaccumulate in aquatic food webs. This dangerous trend has been demonstrated in marine mammals, fishes and human tissues and breast milk resulting from the consumption of the latter.

Also, water can be polluted substantially by leachates from landfills and hazardous waste sites. A lot of wastes are generated and discarded yearly throughout the world. They often contain infectious, radioactive and hazardous wastes, some of which end up polluting the river or underground waterbodies. Oil and chemical spills are also a cause for alarm especially in oil-producing regions leading to the pollution of drinking water in these regions. In addition, mining activities lead to the production of some heavy metals that may contaminate underground water.

2.1.1.3 Soil Pollution

Soil is an important natural resource and rich in nutrients. It enhances the functioning of the ecosystem by supporting primary productivity and enhancing the flow of nutrients in the ecosystem (Milosavljevic et al. 2020). However, soil is continuously been polluted through mining, oil drilling, use of chemicals and fertilizers in agriculture, road transport, inappropriate waste disposal and industrial activities. Some pollutants introduced through these and other anthropogenic activities include heavy metals, hydrocarbons, solid waste, electronic wastes and microplastics. Previous studies have established that e-waste sites in many countries including Nigeria, Ghana, China and India are laden with organic contaminants and heavy metals, especially the vegetation, dust and soil of analysed sites. The presence of heavy metals in soil is commonly attributed to anthropogenic activities; therefore, polluted soil samples are mostly found around industrial area. Heavy metals are of concern globally since they are not biodegradable and they persist in the environment, bioaccumulate and remain toxic over a long period of time (Ma et al. 2020).

Environmental protection agency reported that Cd, Hg, Cu, As, Cr, Pb and Ni are toxic to the ecosystem; therefore, the contamination of soil by heavy metals poses a threat to environmental security and human health (Taati et al. 2020). Significant soil contamination with Cd was reported for Russia, the United States, Europe, India and Australia. Soils in Mexico and Italy were also significantly contaminated with Zn, Pb and Cu. An in-depth study of agricultural and urban soils in China also demonstrated gross pollution with heavy metals (Yuan et al. 2020).

Electronic wastes are often generated in large quantities throughout the world, with an expected increase of 3–4% per year, and about 44,700 kt of e-waste generated in 2016 worldwide (Baldé et al. 2017).

2.1.2 Effects of Pollution

One disturbing aspect of air pollution is that it may directly modify the intensity of sunlight, flower formation, rainfall and temperature, all of which are basic to the survival of all organisms. In addition, relatively slight rainfall or temperature change may disrupt the balance of ecosystem by eliminating plant and animal species. Moreover, air pollution may increase the earth average temperature. The atmospheric gases, including particulate matters, water vapour, carbon (IV) oxide, low level ozone and chlorofluorocarbon, are transparent to incoming solar radiation but absorb outgoing heat radiation from the earth surface. These gases reradiate the heat back to the earth. Due to the mass consumption of fuel as well as industrialization, the concentration of carbon (IV) oxide and other gases in the atmosphere increases. The increased concentration of these gases causes more heat to be radiated into the atmosphere, thereby increasing the earth temperature. This effect is beneficial because it creates extra warmth which prevent earth temperature from going below freezing point. When water is polluted by pathogens (bacteria, fungi, viruses and/or parasites), waterborne diseases are inevitable. These include diarrhoea, respiratory infections, ascariasis, typhoid and giardiasis, and damage to some body organs may also occur. Continuous exposure to heavy metals, oil spill, etc. can lead to loss of aquatic life, reduced plant diversity and cancer development.

Cardiovascular diseases have been linked with air pollution-mediated mortality and morbidity. This mostly stems from exposure to particulate matter resulting into cardiac arrhythmias and sudden death. In addition, vehicle emissions can trigger infarctions and myocardial ischaemia within hours after been exposed. Increase in the risks of hospitalizations and development of stroke has also been associated with automobile traffic emissions. Some studies have established that inhalation of some types of particles may result into increase in platelet reactivity, altered coagulation factors and increase in blood viscosity and fibrinogen. Microplastics have notable effects on soil organisms and can easily accumulate by causing alterations in the chemical contents and soil characteristics. In another study, microplastics were found to reduce the growth rate in *Lumbricus terrestris*, with no reduction in number of juvenile and final weight of adult earthworms (Chae and An 2018). Microorganisms are also affected by the presence of heavy metals in soil, and their activity, diversity, community structure and biomass are negatively influenced (Ma et al. 2020).

With regard to plants, negative effects have also been recorded. Pollutants may cause premature senescence, leaf injury, reduced yield and growth as well as photosynthetic activity. Leaves of *Albizia lebbeck* showed reduced leaf area and increase in breadth and length of leaflets. Stomata closure as a result from air pollution can inhibit fixation of carbon and may reduce the availability of CO_2 in leaves. Decrease in chlorophyll concentration in plants found in polluted sites has also been reported. It has been demonstrated that a significant reduction in soluble sugar is associated with most plants found at polluted sites. Other common effects on plants include depletion of cellular lipids, peroxidation of polyunsaturated fatty acids and pigment destruction. Pollution of soil with high concentrations of heavy metals can also have deleterious effects on human health. Cadmium can cause bone loss, lung cancer, adenocarcinoma and renal dysfunction. Also, lead can adversely affect the biosynthesis of haemoglobin, decrease the learning power, damage the kidney and cause behavioural disorder in children, lung cancer and central nervous system disorder. Exposure to arsenite can lead to the development of skin lesions, kidney and bladder cancer and hyperkeratosis (Taati et al. 2020).

2.2 Microbial Nanobiotechnology in Pollution Management

Nanotechnology, using different particles of sizes within the nanometre, is becoming an option in the technology of remediating polluted environments (Tripathi et al. 2018; Isa et al. 2019). Nanotechnology can be characterized as fabricating compounds of sizes 1–100 nm, and specific phenomena allow novel applications. It is a new environmental remediation technique and referred to as nanoremediation by many, and this technique has certainly established a new area of technology and science. When environmental clean-up includes the use of living organism-formed nanoparticles or nanomaterials, it is called nanobioremediation (Yadav et al. 2017). It has been used in the treatment of polluted water, air and soil in addition to being proven to be a modern and efficient ecological friendly technique for cleaning up residual pollution in a number of environments. The benefits of nanotechnology in environmental remediation include sensing, identification, prevention and remediation of pollution, at low cost, less time-consumption resulting in effective pollution etc. Nanoremediation is more adaptive and selective than traditional approaches and can be used in air, water and soil environments as sensors to track toxic compounds, organic contaminant and heavy metals.

Nanotechnology promises to provide the means for the design of nanomaterials, materials controlled by defined molecular structures and dynamics with tailor-made biological and physicochemical characteristics. Importance of nanotechnology in developing new products and devices has been identified, with a major effect on various areas, from sensor technology to biological medicine. Contrary to conventional physiochemical techniques, microbial nanobiotechnology, which is the biological synthesis of materials of nanosizes by microbes, has recently attracted attention as a modern, promising method to the production of greener nanoparticles. Green chemistry concepts of the discovery, making and use of chemical substance and methods to minimize or eradicate the application and production of harmful compounds combined with white biotechnology that uses plants, bacteria, moulds, enzymes and yeasts to produce compounds is greatly contributing to developing high sustainable nanomanufacturing industrial process. Microorganism-driven production of nanomaterials is an emerging biotechnology which presents an environmental friendly option to nanosynthesis of physiochemical methods (Khan et al. 2018) with microbial strains of bacteria, moulds, microalgae and yeasts. Hulkoti and Taranath (2014) reported the microbial-mediated biological synthesis of metallic (alloys), metal oxides or non-metallic nanoparticles.

Teow and Mohammad (2017) suggested complementing physical and chemical techniques of pollution control with nano-based technologies could offer new opportunities to advance the science of pollution management, especially as most presently available techniques have offered their best in ensuring adequate environment quality, particularly in the presence of emerging and persistent contaminants. Nanomaterial shows essential specific characteristics including heavy sorption, increased reactivity as well as rapid dissolution in addition to non-continuous characteristics like quantum contaminant effects, plasmon resonance of surface localization and super magnetism. Various nanomaterials applied in the treatment of environmental pollutants include nanometal oxides, nanometal and nano-adsorbents, in addition to photocatalytic and membrane techniques (Baruah et al. 2015).

2.2.1 Microorganisms Important in Nanobiotechnological Management of Pollution

Generally, any microorganism considered for nanobiotechnological functions must be of generally regarded as safe (GRAS) status in all fronts without any sort of controversy. Different microorganisms are known to biologically synthesize diverse nanoparticle via the NADPH-dependent reductase enzyme which reduces salts of metals to nanoparticle by electron shuttle activity of enzyme reducing metals.

2.2.1.1 Bacteria

In the last decade, important inorganic nanomaterials (primarily of silver, selenium and gold) synthesized by bacteria are applied in the production of sensor devices and third-generation biosensors. Biological chemical processes that drive the bacteria biological synthesis of nanoparticles have been suggested and are presently being researched. Quite a handful of biochemical processes has been identified as part of cellular detoxification in microorganism resistance pathway that involve changes in inorganic ion solubility through reduction by enzymes and precipitating toxic soluble compounds to non-toxic nanocompounds that are insoluble. Cellular transporters as well as oxidoreductase enzymes (e.g. cysteine desulfhydrase, NADH-dependent nitrate reductase and NADPH-dependent sulphite reductase flavoprotein subunit alpha) are primarily important in intra- and extracellular biological catalytic secretion (with and probable excretion). Biomolecules-mediated physicochemical processes such as stabilization, biosorption, growth, nucleation and complexation have also been described. Some genera of bacteria have demonstrated the capability to biologically synthesize unusual organic nanostructures in addition to inorganic nanomaterials. Nanocellulolytic compounds from bacteria are mainly 3-D network of nanofibril cellulose secreted by aerobic acetic bacteria and *Gluconacetobacter*. These compounds of bacteria origin exhibit increased purity, crystallinity and mechanical balance compared to nanofibrillated and nanocrystalline cellulose (Golmohammadi et al. 2017). These celluloses of bacteria origin are therefore referred to as nanomaterials which are important in biosensor platforms like nanocomposites as well as aid in immobilizing biological elements as reported by Pourreza et al. (2015). Recently, discovery of chip-like biosensory device of bacteria origin in measuring the level of toxin was reported.

2.2.1.2 Fungi

Fungi can secrete metal ions through physicochemical and biological pathways, like metabolite and polymer extracellular binding, specific polypeptide binding and accumulation depending on metabolism. In addition, even in thin solid substrate fermentation methods, fungi can easily be scaled up, and this is an important attribute of using them in nanoparticle synthesis. It is also feasible to achieve vast enzyme output as fungi are very effective secretors of extracellular enzyme. Low cost and abundant biological components are other benefits of fungi-mediated green pathway in synthesizing metal nanoparticle as diverse fungal species grow rapidly and not difficult to cultivate and store. Several studies on the importance of fungi in nanotechnology are well documented due to fungi production of important compounds in large quantities. In downstream activities, the extracellular secretion of enzymes also has an additional value. Furthermore, the intracellular metal absorption and high wall-binding are other properties of fungi that have made them preferred for nanobiotechnological functions. Fungi can secrete metal nanoparticles and nanostructure through extracellular or intracellular reduction of the enzyme and the biomimetic mineralization process. Compared to bacteria and other microorganisms, fungi are excellent protein secretors, resulting in higher nanoparticle yield. Therefore, rapid and ecological friendly biosynthesis of metal nanoparticles is possible using these dissimilar properties of fungi.

2.2.1.3 Microalgae

Microalgae are one-celled photosynthetic microbes that are of interest in nanobiotechnology. In biological production of noble metal nanoparticle, microalgae like *Desmodesmus*, *Scenedesmus* and *Tetraselmis kochinensis* are well documented. For most microalgae, pathways described for nanoparticle biological secretion are nucleation phenomena, dimension control and nanoparticle structure stabilization, driven via reducing agent activities and cytoplasmic membrane enzyme in cell wall, biomolecules such as phenolic compounds, proteins, polysaccharides and polyphenols. For the future creation of new nanomaterials, the mechanisms behind biological mineralization including in vivo inorganic mineral formation have been researched to a great extent. Likely use of optical chemosensing of dissolved ammonia has been demonstrated by microalgae silver nanoparticles (Chetia et al. 2017).

2.2.2 Secretion and Importance of Microbial Nanoparticle in Pollution Management

In degradation of multiple pollutants, various metal-based nanomaterials have been identified, but most studies have been devoted to removing from water chlorinated organic contaminants and heavy metals. Metal oxides and metal nanomaterials exhibit benefits such as high adsorption capability and fast kinetics as highly efficient adsorbents (Santhosh et al. 2016). There are special mechanical, magnetic, catalytic and optical characteristics of metal nanoparticles, differentiating them from other metals. In this light, in the removal of radionuclides and heavy metals, nanoscale metal oxide is identified as promising alternative. Nanoscale metal oxides such as nano-TiO_2 and nanosilver are applied in water disinfection, biofoul prevention and organic compound remediation. Nanosilver has low human toxicity but high bactericidal properties and minimal longevity, while nano-TiO_2 is of increased chemical stability in addition to longer durability, but active ultraviolet is required for effectiveness. In treating groundwater pollution, particularly for arsenic removal, magnetic nanoparticles (magnetite Fe_3O_4) are used and retrieve with magnetic field, but stabilization is required. The fact that there is elevated reactivity, nano-zerovalent iron has a brief half-life and also needs stabilization, thus restricting its usage for certain purposes. The application of various microbial nanoparticles in environmental pollution management is presented in Table 2.1.

2.2.2.1 Gold Nanoparticle

The fact that gold nanoparticles (AuNPs) are highly stable, are biologically compatible with diverse compounds and possess high oxidation resistance, they are of great interest in pollution control. More so, these special characteristics have made gold nanoparticles important in several industrial processes like in optics, electronics, sensors and coatings. The development of accurately named shape and size methods for the controlled production of gold nanoparticles is a major problem, and several chemical techniques are documented in literature, focusing on manipulating the physical characteristics of the nanoparticle. Several technologies are still at embryonic stage, and difficulties with the stability of nanoparticle preparations, crystal growth regulation and particle aggregation are often encountered. As a novel approach to the production of metal nanoparticle, roles of microorganisms in synthesizing nanosized materials have recently been well documented. Although recent efforts have been made towards nanomaterial biosynthesis, the relationship between metals and microbes has been established, and the capability of microbes to

Table 2.1 Nanoparticles and their applications in environmental pollution management

Nanoparticles	Applications	References
Immobilized nanocellulose composites of *Arthrobacter globiformis* D47	Degradation of diuron herbicide	Liu et al. (2018)
Nanoscale zerovalent iron of ag, Ti, au and Mn from *Sphingomonas* sp.	Removal of decarbominated diphenyl ether, pathogens and chlorinated hydrocarbons	Kim et al. (2012)
Thin-film composite polyamide of *Cynomorium coccineum* L. extract	Degradation of cyanide compounds	Sebeia et al. (2019)
Binary mixed oxide water	Break down of methylene blue dye	Rasalingam et al. (2014)
Iron oxide nanopowder of soil microorganisms	Removal of azo dye direct red 23	Kos et al. (2014)
Ag NPs/ag ions	Water disinfection	Xiu et al. (2012)
Zinc sulphide (ZnS) of enzymatic degradation by bacterially overexpressed organophosphorus hydrolase	Degradation of P-nitrophenol and acid Orange 7	Torres-Martínez et al. (2001)
Titanate nanotubes	Gaseous—Nitric oxide decontamination	Chen et al. (2013)
Enzyme organophosphate hydrolase of paper Unzipped, single-walled and multi-walled carbon nanotube	Degradation of organophosphates and heavy metals in soil and water	Mechrez et al. (2014)
TiO_2 NPs	Water and soil disinfection targeting MS-2 phage, *E. coli*, hepatitis B virus, aromatic hydrocarbons, biological nitrogen, phenanthrene	Da Silva et al. (2016)
Iron-based water	Heavy metal and chlorinated organic solvent degradation	Guo et al. (2017)
Metal-doped TiO_2	Water decontamination of 2-chlorophenol, endotoxin, *E. coli*, rhodamine B, *Staphylococcus aureus*	Younas et al. (2014), Sreeja and Vidya (2016)
Bimetallic NPs water, soil	Brominated and chlorinated pollutant removal	Xie et al. (2014)

accumulate or extract metal is used in industrial technological techniques like bioremediation and bioleaching.

Metallic nanoparticles and inorganic nanostructures with characteristics related to chemically secreted compounds are created by several microbes, while strict control is exercised over the particle's composition, shape and size. Examples include the production nanoscale, semiconducting CdS crystals in *Schizosaccharomyces pombe*, secretion of magnetic nanoparticle by *magnetotactic* bacteria and the formation of palladium nanoparticle using sulphate-reducing bacteria in the presence of an exogenous electron donor. A number of organisms have been successfully demonstrated in the ability of plants, bacteria, algae, fungi, yeasts and actinomycetes to absorb gold ions from solution. For example, *Bacillus* sp., fungal species like *Fusarium* and *Verticillium*, actinomycete like *Thermomonospora* and *Rhodococcus* and lactic acid bacteria have been reported to produce gold nanoparticles. Production of nanostructures like nanowire and the development of nanoparticle by biological models like viruses, DNA, S layers and proteins are also of interest.

2.2.2.2 Silver Nanoparticle

Secretion of silver nanoparticles (AgNPs) by microorganisms is owed to their protection principle (resistance pathway), and the formed nanoparticles are very useful. The bacterial cell's resistance to ions of silver in the environs is important for the synthesis of nanoparticle. In nature, ions of silver are extremely noxious to bacteria. Their cellular machinery thus aids to transform reactive ions of silver into stable silver atoms. Furthermore, pH as well as temperature plays essential part in their growth. Nanoparticle size is 50 nm at room temperature; at higher temperatures, i.e. 60 °C, the size decreases to 15 nm. This means the size decreases with temperature increase. In alkaline environment, the microorganism's secretion of nanoparticles is more similar to acidic environment. Above the pH of 10, however, death of cell is observed. *Pseudomonas stutzeri* AG259 was initially isolated from the silver mine and it is the first evidence for the secretion of silver nanoparticles. A secretion of nanoparticles by *E. coli* depends on $AgNO_3$ concentration. Silver helps to cause the organism to produce nanoparticle at lower concentration, whereas at higher concentration, it induces cell death. In the purification of microbial waste, such as water disinfection, silver nanoparticles are often used. In addition, in increasing the overall performance of the resulting nanocomposite, AgNP has been combined with many components, like metal oxides and polymers.

2.2.2.3 Titanium Oxide Nanoparticles

Titanium oxides are another commonly studied metal-based substance for environmental nanotechnology bioremediation. Because of their properties ranging from photocatalytic, known cheap cost, semiconducting, gas sensing, non-toxicity, electronic and energy converting abilities, titanium oxide nanoparticles (TiO_2 NPs) have been widely researched in air purification, waste management, surface cleansing and photocatalysis in environmental pollution management. TiO_2 NPs are light-activated and are also commonly investigated for their capability to extract organic pollutants from different media. For microbes such as algae, fungi, viruses and bacteria, TiO_2 NPs generate highly reactive oxidants such as hydroxyl radicals acting as disinfectant. The material is usually doped with another transition metal ion to improve efficiency, since TiO_2 shows very restricted photocatalytic ability. In addition, magnetic metallic nano-adsorbents are specifically desirable because they are easy to preserve and isolate from treated environment. In the literature, nanoparticles of iron oxides and iron are generally researched for the remediation of various heavy metals, like Cu^{2+}, Ni^{2+}, Co^{2+} and Cd^{2+} and remediation of organic chlorinated solvents.

2.3 Principles of Nanotechnology in Pollution Management

The principles of nanotechnology in pollution management are presented in Fig. 2.1. Major nanotechnological mechanisms of pollution management including adsorption, filtration and photocatalysis are discussed in this section.

2.3.1 Adsorption

Adsorption is widely applied in the remediation of inorganic and organic pollutants from the environment as it is economically feasible. Adsorption includes the application of various materials such as zeolites, clay and alumina silicates to extract metals from solutions. The nanomaterial's large aspect ratio and surface area makes it one of the latest superior performance adsorbents (Yano et al. 2018). One of the common applications is in multiwall carbon nanotubes as they have greater potential for sorption of metal ions (3–4 times) than granular and powder activated carbon (Yano et al. 2018). Compared to nano-adsorbents, the conventional adsorbents available are less effective because nano-adsorbents have major advantages due to their large unique surface area and associated sorption sites, tunable pore size, short

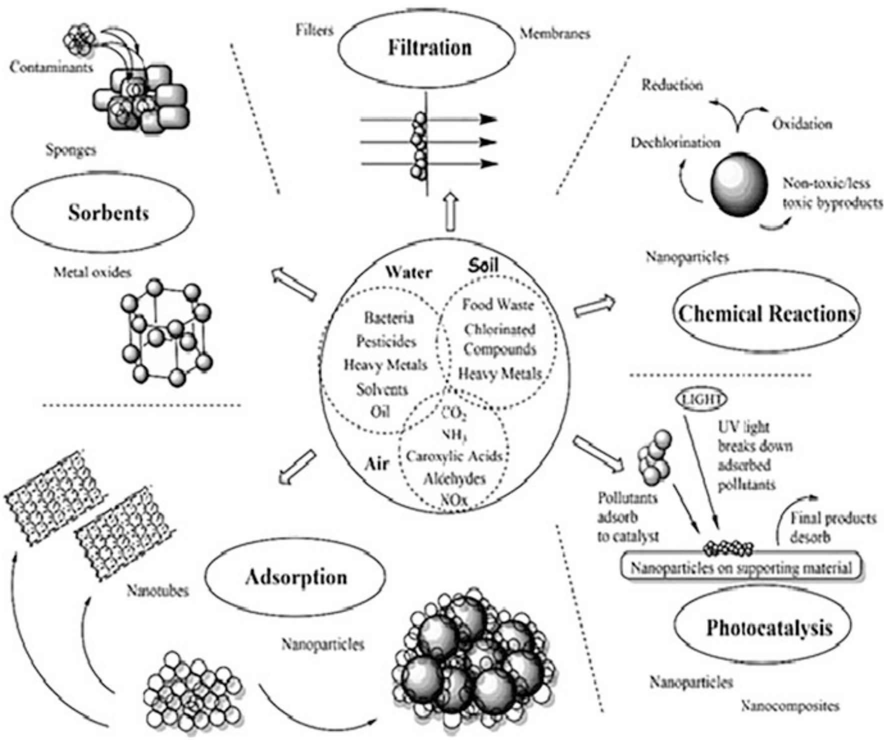

Fig. 2.1 Principles of nanotechnology in environmental pollution management (Guerra et al. 2018)

intra-articular diffusion distance and surface chemistry, in addition to their high adsorption rates for inorganic compounds like heavy metals and micro-pollutants. Four kinds of nano-adsorbents, namely, zeolites, metal-based nano-adsorbents, polymeric nano-adsorbents and carbon-based nanomaterials, appear to be the subject of recent research.

Owing to diverse contaminant-carbon nanotube interactions and large surface area, carbon nanotubes (CNTs) are reported to be highly effective in the adsorption of organic matter and can therefore help in the breakdown of diverse organic contaminants. Compared to activated carbon, CNTs are effective in the adsorption pathway of several organic compounds, and their high adsorption is linked to large surface area and varied interactions between contaminants and CNT. Its external surfaces are the available surface area for adsorption on individual CNTs. It is easy to assess the adsorption potential of the carbon nanostructure by its textural characteristics as reported by Gupta and Saleh (2013), while photeric and other functional groups as well as oxygen can be added to carbonaceous nanomaterial surfaces, which provide new chemical adsorption sites. CNTs form loose bundles in the aqueous solution owing to the hydrophobicity of the graphitic surface, thus decreasing the adsorption effectiveness, whereas the production of aggregates requires interstitial spaces that increase the adsorption location, thereby increasing the adsorption effectiveness of different organic molecules.

Although activated carbon and CNT bundles have about the same basic surface area, there are micropores on activated carbon that are not available to many organic molecules. Because of more open sorption sites, CNTs have large pores that improve the adsorption of many molecules, so they have higher adsorption ability. Owing to diverse existing pollutants-CNT relationships, like hydrogen bonding, hydrophobic effect, covalent bonding, pep interactions and electrostatic interactions, CNTs strongly adsorb several polar organic compounds. The CNT surface rich in p electrons permits pep interactions with organic molecules. Organic compound having functional groups of –COOH, –OH and $–NH_2$ forms a hydrogen bond with the electron-donating graphitic CNT surface. Via non-covalent bonding like hydrophobic interactions, hydrogen bonding, electrostatic forces, π–π stacking and van der Waals forces, strong interactions between organic molecules and CNT occur. Adsorption of positively charged organic compounds like certain antibiotics at sufficient pH is facilitated by electrostatic attraction. In addition, the system's stability and selectivity can also be improved, as CNT enables one or more functional groups to be added to further improve the system's efficiency.

Via functionalization or purification pathways, compound functional groups are attached to CNT surface. Owing to the condition of preparation, the carbon nanotubes may be multi-walled carbon nanotubes (MWCNT) or single-walled, while the CNT is of interest in the treatment of environmental pollution due to high stability and surface area. CNTs assist in the remediation of heavy metals (Cd^{2+}, Pb^{2+}, Zn^{2+} and Cu^{2+}) in the environment via the adsorption process. In addition to adsorption, CNT cab aid other adsorptive materials, CNT can be used. Metal oxides (Fe, Ti and alumina) are an affordable and efficient technique in toxic metal adsorption. The dissolved metal ions in question adsorb substantially. Due to the presence of large active sites, nanoparticles clean the polluted sites with greater adsorption, and the ability of adsorption increases with size reduction.

In photocatalytic remediation, in the presence of catalyst and light, the pollutants can be quickly degraded into products of low molecular weight that are eventually transformed into CO^2, H_2O and anions (NO^{3-}, PO^{3-} and Cl^-). Different types of photocatalysts are applicable, but TiO_2 is the most frequently researched due to its biological stability, inexpensiveness and photostability (Guesh et al. 2016). Ultraviolet radiation is needed to separate charge due to the energy gap, and TiO2 generates reactive oxygen species (ROS) on irradiation with UV light that can fully degrade pollutants in short reaction time. In addition, TiO_2 NPs demonstrate no selectivity and are therefore suitable for the remediation of several forms of pollutants, like organic chlorinated compounds, aromatic polycyclic hydrocarbons, colorants, phenols, pesticide, arsenic, cyanide and heavy metals (Chen et al. 2016; Nguyen et al. 2016).

Adsorbents that have the capacity to extract both organic and heavy metals from the water are dendrimers. Their inner shells may be hydrophobic for organic compound sorption, while the outer branches may be adapted for heavy metal adsorption (e.g. hydroxyl- or amine-terminated). The adsorbent adsorption of metals and organic pollutants is based on complexation, electrostatic interactions, hydrophobic effect and bonding of hydrogen. In order to recover metal ions from aqueous solutions, the dendrimer ultrafiltration system was developed. The metal-laden dendrimers are recovered by the ultrafiltration technique and the dendrimers are regenerated by reducing the pH to 4.

2.3.2 Nanofiltration

Nanofiltration (NF) is a modern method of membrane filtration for waste water treatment based on the properties of charge repulsion and high permeation rate (Sharma and Sharma 2012). Nanofiltration is a method of separation with a cut-off between reverse osmosis and ultrafiltration. Centrifugal pumps are most commonly applied inside the nanomembrane for the pressure and circulation of waste water. The plant has large modules, with various membrane configurations (Sharma and Sharma 2012). The normal length of the module ranges from 0.9 to 5.5 m in nanofiltration, and the diameter varies from 100 to 300 mm. Considering the membrane pore size and the specific material to be extracted, membrane separation processes serve as an obstacle for various pollutants (Kusworo et al. 2018). Nanofiltration membranes have been effectively applied to eliminate hardness, heavy metals, colour and odour. Together with a charge-based repulsion mechanism, nanofiltration membranes have high selectivity but need considerable operating energy and are vulnerable to fouling. Alternatively, nanocomposite membranes are a fouling resistant filtration option for membrane filtration that has thermal or mechanical robustness and is widely used in reverse osmosis water treatment in removing micro-pollutants (Bhati and Rai 2017).

2.3.3 Photocatalysis

Photocatalysis is an oxidization mechanism in which photocatalytic oxidation degrades organic pollutants. This is done by combining a catalyst-coated filter with ultraviolet light rays. In advanced oxidation processes, nanocatalysts can efficiently be applied in chemical oxidation of inorganic and organic contaminants in the environment. These techniques are on the basis of creating highly reactive radicals, readily able to react with pollutant molecules. Owing to the expensive nature of supplying necessary energy (ozonators, UV lamps and ultrasonicators, etc.), the implementation of this method is often limited. The most substantial oxidation mechanism is photocatalysis. This is a change in the chemical reaction caused by the adsorption of a photon whose energy is greater than the energy required to resolve the interstitial force of a semiconductor's two electron shells (conductive and valentine). The electron (negatively charged particle) is moved from the valentine shell to the empty conduction shell when the photon illuminates the catalytic surface and leaves a void with a positive charge behind it. This electron–hole (e–h) pair produces highly reactive radicals that bind and thus remediate pollution molecules. There are, however, many technological problems that need to be addressed in order to allow wider practical implementation of this method, such as more effectively separating nanocatalysts after treatment and enhancement of selective properties during chemical reactions and optimization of catalysts in the utilization of available light energy.

2.4 Current Advances in Nanotechnological Management of Pollution

2.4.1 Pollution Bioremediation

A role in microbial bioremediation has been played by nanotechnology. The biggest challenge in biological degradation has been improving the solubility or bioavailability and consequently the rate of degradation. Surfactant micelles are recently applied in enhancing the solubility of the pollutants, but these appear to interfere with microorganism liposomes and are often broken down upon contact with soil, thus reducing the effectiveness of biological remediation. A promising move in this direction has been shown by recent developments in nanotechnology. An improvement in the solubilization degree of the model remediation compound phenanthrene (PHEN) using amphiphilic polyurethane (APU) nanoparticles has been reported. These particles, made of precursor chains of polyurethane acrylate anionmer (UAA) or poly(ethylene) glycol (PMUA), have hydrophobic interiors that demonstrate high PHEN affinity. By forming a nanoparticle suspension that competes with NAPLs, they improve PAH desorption and mobility. The affinity of nanoparticles to hydrophobic pollutant is improved by adjusting the hydrophobic portion of the precursor chain as opposed to surfactants, and mobility can be improved by regulating the charge density of the modified nanoparticles. Magnetite nanoparticles' form is another advantage provided by nanoparticles in biological remediation. Magnetite nanoparticles are produced in inert conditions by the co-precipitation of ferrous and ferric salts. In terms of simpler separation, reusability and cost-effectiveness, this technology imparts great industrial applicability. The use of magnetite nanoparticles by coating them with dibenzothiophene-desulfurizing bacterial strains of *P. delafieldii* and *R. erythropolis* LSSE8-1 has been documented, while biological desulfurization behaviour was observed. Cells coated with magnetite nanoparticles modified with ammonium oleate displayed repeated biological desulfurization behaviour and could be collected with an external magnet on the flask surface. In summary, magnetite nanoparticle usage has demonstrated increased desulfurization activity.

Nano-adsorbent used in powdery form in slurry reactors is highly effective as reported by Vijayageetha et al. (2018), but an extra system must be attached for the nanoparticles to be recovered. Nano-adsorbents may be applied in fixed or fluidized adsorbers by filling beads or granules with the nano-adsorbents. Fixed-bed reactors are typically associated with limits on head loss and mass transfer, but no future separation process is necessary (Miklos et al. 2018). As nano-adsorbents display good efficiency and are also inexpensive compared to other adsorbents, nano-adsorbents are commonly used in the breakdown of arsenic (Vijayageetha et al. 2018). ArsenXnp is a polymer and nanoparticles of iron oxide (Vijayageetha et al. 2018), while ADSORBSIA is a medium of nanocrystalline titanium dioxide and they are both utilized in extracting arsenic from water (Vijayageetha et al. 2018). In drinking water treatment systems, both small and medium scale, ArsenXnp and ADSORBSIA are used and proved to be cost-effective (Miklos et al. 2018; Vijayageetha et al. 2018).

Earlier studies have validated the effective breakdown of Hg and bulky dye molecule by graphite oxide-coated sand granules (Rhodamine B) with the breakdown nearly analogous to the activated carbon effectiveness. Nanoparticles of zerovalent type can easily eliminate the different metallic contaminants present in waste water and industrial effluent. In remediation of several halogenated hydrocarbons, organic compounds and radionuclides, nanoparticles have also been used. For Cr(VI) and Pb(II), the degradation degree of nanoscale zerovalent iron is 30 times higher compared to iron powder. Nano-adsorbent iron oxide is important in degrading arsenic forms (As(V) and As(III)), and the degradation rate is 5–10 times higher than that of the micron scale.

2.4.2 Pollution Biosensory

In many ways, nanotechnology plays a crucial role in solving pollution problems. Firstly, the ability to coat nanoparticles with a wide variety of biological and chemical ligands helps to give the sensor specificity. The capping of nanoparticles with different ligands such as proteins, DNA, enzymes, etc. has been documented by diverse scientists. The binding is extremely precise between these ligands and analytes. Secondly, through changing the shape and size of the nanoparticle, the volume to surface ratio of the nanoparticles can be managed, thereby imparting influence over the quality of contact with the analyte molecule. Thirdly, the capability to create nanoparticles of different metals aids to enhance conductivity and thus sensitivity. For sensing biological species, inorganic and organic pollutants, sensors based on nanoparticles have been utilized. The application of semiconductor nanostructures of porous silicon for organic contaminant detection has been proposed by scientists. Porous silicon shows photoluminescence phenomenon, and in the presence of inorganic or organic molecules, this luminescence is quenched. The concentration of pesticides as small as 1 ppm could be detected using this technology.

Both the transfer of energy to the triple substrate of the organic substrate and that of electron from the silicon nanocrystal conduction band to the quencher's vacant orbital are due to the reduction of photoluminescence by organic contaminant. For the sensing of different gases such as NH_3, NO_2 or O_3, carbon nanotube-based sensors have been applied. The electrical resistance of the nanotubes changes so dramatically when they are in contact with these gases that they are observed. The detection using nanoparticles of diverse heavy metals, like Pb, CD and Hg, is either fluorescence or calorimetric dependent. In the detection of heavy metal ions like mercury, cadmium and lead, functionalized gold nanoparticles with 11-mercaptoundecanoic acid and chitosan have been used. Mercaptoundecanoic acid and chitosan are chelating agents made of metal. The binding of these metal chelators to heavy metals makes nanoparticles being aggregated, causing a change in the absorption of wavelengths and eventually a resultant change in colour from red to blue. While it is not peculiar to a particular ion, the detection of heavy metal ions in general has been very sensitive. Different sensors such as that for Pb have been developed based on similar concepts. The gold nanoparticles were coated with lead-based DNA enzymes for this sensor.

Enzyme-induced aggregation of nanoparticles occurs in the absence of lead, while in the presence of lead, the activated enzyme cleaves the substrate and prevents aggregation. This resulted in a change of wavelength absorption. Selective mercury detection by Au nanoparticles coated with rhodamine B, which is a very fluorescent compound, has been reported. Owing to its binding with Au nanoparticles, its fluorescence is quenched. In the solution, the presence of Hg results in the release of rhodamine and thereby restores the fluorescence, with the intensity relating to the amount of Hg present in the solution. The mercury specificity was given by changing the surface of the nanoparticle with thiol ligands and adding to the solution a chelating agent. The nanosensor thus developed was highly selective and sensitive and can detect very low mercury concentrations (2 ppb) compared to the other available fluorescent chemosensors.

The detection time was also reduced to less than 10 min. Microorganisms (mainly bacteria) or their by-products that may be harmful to human health are biological pollutants. The largest bacteria contaminants belong to the family of *Enterobacteriaceae*. The application of mannose-encapsulated gold nanoparticles to detect *E. coli* was suggested, since mannose has an affinity for *E. coli* pilli type I. It was found that encapsulated mannose nanoparticles had a greater affinity for *E. coli* as opposed to free mannose. Instead of a particular sensor for a specific microbe, Yonzon et al. (2005) built a universal device for bacteria detection based on silver nanoparticles. Maltose showed affinity for carbohydrate binding protein concanavalin A, when functionalized with silver nanoparticles. Concanavalin A was also shown to show a greater tolerance for maltose compared to galactose. In addition to detection, the removal of bacteria from the media by amine functionalized magnetic nanoparticles has been suggested. The positive charge on the surface of the nanoparticles revealed that the bacterial negative charged surface had an electrostatic interaction. The efficiency was 88.5% for removing bacterial from water samples. Ho et al. (2004) coated IgG with gold nanoparticles and examined the association of IgG with protein for pathogenic microorganism sensing. This interaction was efficacious for sensing *S. aureus* and *S. saprophyticus* with related experiments carried out in order to identify other pathogenic microorganisms. The IgG antibody was coated on the surface of magnetic nanoparticles with a view to purifying water. By adding an external magnet, the trapped microorganisms have been extracted, and for the identification of microorganisms, quantum dots (QD) are often used as a fluorescent labelling method.

Zhu et al. (2004) reported that antibody-to-QD conjugation could be used for the detection of pathogens like *Giardia* and *Cryptosporidium*, while for *Salmonella typhimurium* and mutant *E. coli* strains, similar findings were also published. The simultaneous detection of four distinct toxins was proposed by Goldman et al. (2004). Using quantum dot shells and antibodies as probes, the cholera toxin, ricin, shiga-like toxin 1 and staphylococcal enterotoxin B were detected. As compared to organic dyes, quantum dots demonstrate superior photostability and multiplexing analysis. In addition to these biological pollutants, because of their potential as bioterrorism tools, the detection of *Bacillus* specifically is becoming important. The *B. anthracis* virulence is encoded by an exotoxin capsule and a tripartite. As a biomarker, the sensor for bacillus spores utilizes calcium dipicolinic acid (CaDPA). In the spores, CaDPA is strictly present and has no molecule that interferes. The deposition of spores on the surface of AgFON (silver film over nanoparticles) has been reported to have resulted in a CaDPA-unique SERS spectrum. At less than the life-threatening dose, the device was able to detect spore concentrations. A surface aided fluorescent sensing device for the detection of anthrax spores was developed by Yilmaz et al. (2010). Using ultraviolet light, the binding of DPA to the receptor was observed. The emission of blue light resulted from DPA-bonded receptors, although no bonding resulted in red light. For calculating the concentration of spores, the ratio of red to blue light might be used. The sensors thus produced were more sensitive and reliable than the current available techniques and can be reused. A nanosensor based on bacillus-generated exotoxin detection was developed by Zhang et al. (2011). Three genes, namely, Cya, Pag and Lef, are encoded by the exotoxin. The developed sensor was based on the toxin Pag gene encoding detection. This was made up of two nanoparticles, viz. magnetite and gold. A target DNA-specific first probe and tracer labelled barcode DNA were coated on gold nanoparticles. The magnetite nanoparticles were coated with the target DNA-specific second probe. A sandwich structure consisting of gold nanoparticle and magnetite was formed in the presence of the target. To separate the complex from the mixture, a magnetic field was applied, and the presence of the target DNA was detected using a nuclear tracer.

Nanoparticles are applied in the detection, concentration and identification of trace organic or inorganic contaminants. As they deliver high adsorption ability and recovery rate, with fast kinetics, CNTs are of promises in environmental analysis of organic contaminants or trace metals. With quick adsorption kinetics, the pre-concentration factors for metal ions have been demonstrated to range from 20 to 300. In order to pre-concentrate a number of organic compounds, CNTs were also extensively tested, most of which were carried out in real water samples. Adsorption to CNTs of charged species results in changes in conductance, providing the basis for the association between the concentration of analytes and current variations. Other nanomaterials have also been used, such as nano-Au and QDs. In a colorimetric assay, modified nano-Au was used to detect pesticides with high sensitivity and selectivity at ppb levels. Furthermore, modified nano-Au was shown to detect Hg^{2+} and CH_3Hg rapidly. The detection limits of PAHs were reduced by QD adjusted TiO_2 nanotubes to the level of pica-mole per litre based on fluorescence resonance energy transfer. A CoTe-based nanosensor of QDs immobilized on a glassy carbon electrode surface detect in water bisphenol A even at a concentration of 10 nM within 5 s.

2.4.3 Pollution Prevention

Metal oxide nanocatalysts, primarily gold nanocatalysts, have positive results in the prevention or reduction of source contamination. Pollution prevention is accomplished either by applications of pollution control, like air cleaning, or as low light-off autocatalysts and hydrogen stream purification used for fuel cells. During 2001, 27 patents were issued on gold catalysts for various activities in the field of pollution control and have since shown an upward trend. The aim of the patents for pollution prevention by gold nanocatalyst was divided by subject, based on World Gold Council analysis, with chemical processing having the highest share of 46%, followed by pollution control (29%), manufacturing or regeneration of catalysts (15%) and fuel cells (10%). The key attribute that regulates the widespread use of gold nanocatalysts is its high rate of operation under mild conditions, thereby minimizing the operating costs of chemical plants. Gold nanocatalysts also have low activation energy and moisture improved behaviour. Oxidation of carbon monoxide is achieved in diverse temperature ranging between 90 and 400 K.

Au nanoparticles have hemispherical shapes and reaction sites serve as the perimeter interfaces around the particles. On the edge and phase sites of Au surfaces, CO gets adsorbed and oxygen adsorbs on the support surfaces. In the interface field, both then react. CO is oxidized more readily than hydrogen by using Au, MgO or MnOx at 20 °C. In a prototype air purification unit that extracts CO from the air at room temperature, the gold nanocatalyst Mintek, South Africa, is commercially used. It is intended for use in restaurants, hospitals, offices and hotels. In oxidizing carbon monoxide, gold nanocatalysts are often used to extract it from the hydrogen feed applied in fuel cells, making the fuel cells more effective. Nanoparticles of titanium dioxide have photocatalytic properties and have therefore been used to create self-cleaning surfaces that minimize current emissions. When exposed to UV radiation, it is also a strong oxidizing agent. This helps the degradation into less toxic species of VOCs, nitrous oxides and other contaminants. An aluminosilicate molecular sieve, otherwise known as a zeolite, is another widely used structure in separation and catalysis. It is a porous crystalline solid that is well described. To oxidize hydrocarbons, such as toluene and benzaldehyde, nanosized zeolites (10–100 nm) have been developed. There are two main reasons why these zeolites make oxidation eco-friendly. Firstly, as the reaction is caused by visible light, there is a decrease in the consumption of energy. Secondly, pathways of low-energy reaction are followed that help to reduce unnecessary secondary photoreactions and thus increase the target product's yield.

2.5 Risk Assessment and Sustainability of Nanotechnology in Pollution Management

Nano-science research has documented that non-absorbents, nanocatalysts, bioactive nanoparticles, nanopowder, nanotubes, magnetic nanoparticles and nanoparticles are typically used to address many of the environmental problems after remediation. Nanotechnology has many benefits that help to improve the existing remediation methods, and this provides a new approach that is better than the current ones, due to the high surface area to volume ratio of the nanoparticles that enables them to absorb maximum quantities of contaminants, and their incredibly small size often enables quantum effects to come into play. Because of their increased surface area per unit mass, nanoparticles are more reactive than bulk ones (Isa et al. 2019). Nano-science has been used in a number of scientific, environmental, industrial and medical applications.

Nanotechnologies are expected to make a significant contribution to minimizing the impact of pollution using nanoparticles and nanomaterials in the environment, and are considered to be integrated into various materials to enhance distinct properties (National Research Programme (NRP) 2017). It is a promising step to control pollution from their source or restrict the process to a certain extent, so the strategies used by nanoparticles to control pollution in the following ways:

1. Some nanoparticles such as zerovalent ions act as a reduction agent by donating electrons to pollutants, thus reducing them to a less toxic material.
2. Without subsequent release, nanoparticles can be designed with specificity and affinity for a particular contaminant, which helps to absorb the contaminants.
3. There are internal voids in nanomaterials like dendrimers that allow them to trap minute substances (Triano et al. 2015).
4. To degrade organic and inorganic pollutants, low quantities of energy may be used (Isa et al. 2019).

5. The bacterial cell wall is destroyed by some nanoparticles which interfere with DNA synthesis (Raj Kumar and Gopinath 2016).
6. Nanomaterials prevent hazardous intermediates and products from forming and prevent pollutants from being released at production sites (Pandey et al. 2016).

By replacing currently used hazardous materials, nanotechnology aids the development of environmentally friendly materials. In the fabrication of computer monitors, the use of carbon nanotubes as a replacement for cathode ray tubes (with lead as one component) was suggested. By removing the use of harmful heavy metals and dramatically reducing material and energy requirements, while providing improved efficiency, CRT monitors using carbon nanotubes prevent pollution. In photovoltaic cells, the efficiency of nanoporous silicon was studied. Its porous structure contributes to quantum confinement and an increase in the bandgap, while higher internal quantum efficiency benefits from increased light absorption. Organic solar cells were produced using TiO_2 nanoparticles coated with an organic dye to transform light into energy by a method similar to photosynthesis in search of an alternative to Si photovoltaics. Although the conversion efficiency is only 10%, using simple technology, this type of cell can be produced from cheap, low-purity materials. By using nanostructured electrode materials such as lithium cobalt oxide, iron fluoride, cobalt chloride, rubidium oxide and nickel phosphide, the ALISTORE European Network of Excellence in Advanced Lithium Energy Storage Systems has been working on increasing the power output of rechargeable lithium batteries from the current 200 to 300 Wh/kg. To have actual control over the form, size and location of nanoscale metals used in a catalyst, nanofabrication methods are followed. The ones used in cars include platinum group metals (PGM). Investigators indicated that a nanofabrication-based automotive catalyst would cause a highly reduced loading level of PGM. This will decrease the quantity of energy consumed, enhance environmental sustainability and contribute to the sustainable use of resources.

As it can be regenerated, the adsorbent used is economical. The decrease in pH is useful in reversing metal adsorption on CNTs and the recovery rate is nearly 100% at pH below 2. It was found that the nano-adsorbent can be regenerated and reused many times without affecting the adsorption power of the adsorbent. The key advantage of carbon nanotubes is that the iron oxide adsorbent can be conveniently isolated by applying a magnetic field. Because of the low cost and high stability, nano-alumina particles are used to remove metals such as Pb, Cr, Cu, Cd and Hg from waste water. Nanoparticles known for specific properties can easily eliminate metals and other contaminants from waste water. The removal of different chemical species from waste water is simple due to the large number of active sites in nanoparticles. The challenge of extracting heavy metals from waste water is that there is no technology available that can extract metals from waste water effectively, but the use of nanotechnology offers a strong solution for waste water management.

Due to its lower operating pressure and high flow rate, nanofiltration is also cost-effective compared to reverse osmosis (Sharma and Sharma 2012). As monovalent ions are partly permeable and show absolute impermeability against bivalent salts

(Sharma and Sharma 2012), nanofiltering membranes help to extract hardness from the water to a large extent. Total dissolved solids (TDS) and hardness can be reduced by nanofiltration in addition to colour, odour and heavy metal ion removal. The high efficiency of membrane filtration helps to remove from the water the various forms of contaminants and can also achieve the optimal standards for water purification (Zekić et al. 2018). Nanofiltration is a process of treatment of the high-pressure membrane, but less energy is consumed compared to reverse osmosis because of low drive pressure (Zekić et al. 2018).

The advantages of photocatalysis are high availability, limited toxicity, cost-effectiveness and established characteristics of the material (Bai et al. 2017). Due to its supermagnetic ultraviolet photocatalytic activity, low human toxicity, high stability and low cost, TiO_2 nanoparticles are commonly used as a photocatalyst. Furthermore, when combined with other nanoparticles, the efficacy of TiO_2 as a photocatalyst is strongly increased. The emphasized value of bifunctional property is polymeric nano-adsorbents used in the removal of organics and heavy metals, whereby the inner shell branches have the ability to adsorb organics, while the outer shell adsorbs heavy metals (Yang 2019). Zeolites are a modern, flexible, low-cost nanomaterial that can be used for the treatment of waste water and desalination of water (Sutisna et al. 2017). Zeolites have a charged, permeable and thick polyamide active layer that provides a high surface area characterized by hydrophilic pores that form possible pathways for water flow in combination with their porous structure (Yurekli 2016).

2.6 Challenges and Recommendations

2.6.1 Challenges

The key drawbacks to nanoparticle direct use relate to the human and environmental hazards that accompany their use, which have not yet been fully established. An additional hindering factor may be the disposal of the spent adsorbents. The expense of both planning and deploying these innovations is another significant factor to consider. While many of the base nanoparticles are relatively inexpensive to acquire or prepare, the changes necessary to maximize the adsorption potential of the target contaminants, as in the case of many of the studies alluded to above, add to the complexity and economic feasibility of pilot-scale, and probably large-scale, applications. Therefore, in addition to the based studies on large-scale applications, the need for comparative testing between different adsorbents is important to allow for faster development of the technology for potential applications (Zhou et al. 2016).

Overall, magnetic nano-adsorbents have shown strong potential for fast removal of hydrocarbon wastes. However, the fact that the performance of such applications depends on a variety of factors affecting the rate of removal, such as the ease of synthesizing the nanocomposite, the ease of implementation and the cost of the material, may have the effect of restricting the widespread use of such nanocomposites. It should be noted that there is a large gap in knowledge in the existing literature on the optimum conditions to which the various adsorbents, or their combinations, are ideally suited. Each adsorbent has its own particular collection of tailored treatment conditions to maintain high pollutant removal rates; however, their changed types or the combined use of multiple adsorbents could also have a significant impact on the efficacy of the removal of target contaminants under various operating conditions.

Even, when pilot-scale experiments and field implementations need to be scaled up for the systems, the lack of knowledge related to optimized operating conditions could easily lead to incorrect results and eventual failure of the treatment method. It can also lift maintenance costs while making various components of the device unfeasible. Equally significant, it is necessary to use naturally polluted environment instead of synthesized environment that does not represent the diverse components present in natural environments when designing a study dealing with the removal of persistent contaminants using nanomaterials. High production costs and possible health risks are included in the drawbacks of carbon nanotubes, and the complex multistage production process for polymeric nano-adsorbents is also a disadvantage.

It is known that nanoparticles are released into the environment (Wilson 2018), and through a variety of known and unknown sources, these nanoparticles can enter the environment. Research aimed at developing an approach that understands how nanoparticles spread into the environment and their possible toxicity due to their activity has shown that nanoparticles may interact with the biological system when inhaled due to their small size, solubility and wide surface area (USEPA 2017), which may end up binding to proteins in the blood, thus suppressing the immune system. Most nanoparticles require authentication of their effectiveness and safety in the field due to the negative impact exerted by nanoparticles, as they have been successfully demonstrated on the laboratory scale, and this may probably be the reason why few nanotechnological applications for environmental clean-up have been commercialized for the time being. At this time, many risks associated with nanoparticles are not identified, but as more is learned about their transformative behaviour, the number of potential hazardous ones may increase over time.

2.6.2 Recommendations

The need to develop analytical tools for environmental measuring and monitoring of manufactured nanoparticles cannot be overemphasized, because there are currently not many standard methods for easily detecting and monitoring nanoparticles in the environment. In environmental systems, for measuring nanoparticles, there are only a few quantitative analytical techniques, and most of these are time-consuming and need expensive equipment and expertise. The occurrence and fate of nanoparticles after they are released into the environment show a gap in information and awareness, since there is no legislative obligation to track environmental nanoparticles, or other particles. In different environments, certain models and extrapolations seek to measure the quantity of nanoparticles. These models, however, are based on estimates of nanoparticles released into the environment and have not been calibrated using specific field measurements.

In addition, more research is required to assess the impacts of nanoparticle on the full ecosystem. Findings from ecotoxicological studies indicate that, under certain environmental conditions, animals are influenced by certain nanoparticles. The tests, however, were performed using elevated pristine nanoparticle concentrations. The authors suggested future studies to evaluate the exposure to nanoparticles that are functionalized since several nanoparticles created are functionalized, which changes their behaviour. Significant processes that have not been extensively studied are changes by environmental factors such as oxidants, light and microorganisms, resulting in biological or chemical modifications or breakdown of the functionalized surface or surface coated with natural compounds. Moreover, contained in a matrix, most nanoparticles are released and not as single nanoparticles. The study of nanoparticle forms in which organisms in the environment and man may be exposed to them is significant.

Furthermore, it is advisable to develop engineering applications with nanobiotechnology for onsite bioremediation. For remediation, there is a need to create smarter nanomaterials. New coatings or functional classes, for instance, may increase nanoparticle mobility. The capability to carry out multiple functions like catalysing multiple pollutant reactions on the same particle or interacting with hydrophilic and hydrophobic contaminants could be more advanced in nanomaterials.

2.7 Concluding Remarks

Nanotechnology provides an important alternative solution to current environmental pollution remediation, and superior performance is attributable to the novel properties of nanoparticles. The most recent techniques used in the remediation of polluted environment were discussed in this chapter. Such approaches are deemed to be the most successful and cost-effective till date.

References

Bai H, Zhou J, Zhang H, Tang G (2017) Enhanced adsorbability and photocatalytic activity of TiO_2-graphene composite for polycyclic aromatic hydrocarbons removal in aqueous phase. Colloids Surf B Biointerfaces 150:68–77. https://doi.org/10.1016/j.colsurfb.2016.11.017

Baldé CP, Forti V, Gray V, Kuehr R, Stegmann P (2017) The global E-waste monitor–2017. United Nations University (UNU), International Telecommunication Union (ITU) & Int Solid Waste Assoc (ISWA), Bonn

Bamigboye CO, Amao AJ, Ayodele TA, Adebayo AS, Ogunleke JD, Abass TB, Oyedare TA, Adetutu TJ, Adeeyo AO, Oyedemi AA (2020) An appraisal of the drinking water quality of groundwater sources in Ogbomoso, Oyo State, Nigeria. Groundw Sustain Dev 11:100453

Baruah S, Najam KM, Dutta J (2015) Perspectives and applications of nanotechnology in water treatment. Environ Chem Lett 14:1–14. https://doi.org/10.1007/s10311-015-0542-2

Bhati M, Rai R (2017) Nanotechnology and water purification: Indian know-how and challenges. Environ Sci Pollut Res Int 24:23423–23435. https://doi.org/10.1007/s11356-017-0066-3

Chae Y, An Y-J (2018) Current research trends on plastic pollution and ecological impacts on the soil ecosystem: a review. Environ Poll 240:387–395

Chen X, Cen C, Tang Z, Zeng W, Chen D, Fang P, Chen Z (2013) The key role of pH value in the synthesis of titanate nanotubes-loaded manganese oxides as a superior catalyst for the selective catalytic reduction of NO with NH_3. J Nanomater 2013:871528

Chen ZP, Li Y, Guo M (2016) One-pot synthesis of Mn-doped TiO_2 grown on graphene and the mechanism for removal of Cr(VI) and Cr(III). J Hazard Mater 310:188–198

Chetia L, Kalita D, Ahmed GA (2017) Synthesis of Ag nanoparticles using diatom cells for ammonia sensing. Sens Bio Sens Res 16:55–61

Da Silva MB, Abrantes N, Nogueira V, Gonçalves F, Pereira R (2016) TiO_2 nanoparticles for the remediation of eutrophic shallow freshwater systems: efficiency and impacts on aquatic biota under a microcosm experiment. Aquat Toxicol 178:58–71

Goldman ER, Clapp AR, Anderson GP, Uyeda HT, Mauro JM, Medintz IL, Mattoussi H (2004) Multiplexed toxin analysis using four colors of quantum dot fluororeagents. Anal Chem 76:684. https://doi.org/10.1021/ac035083r

Golmohammadi H, Morales-Narvaez E, Naghdi T, Merkoci A (2017) Nanocellulose in sensing and biosensing. Chem Mater 29:5426–5446

Guerra FD, Attia MF, Whitehead DC, Alexis F (2018) Nanotechnology for environmental remediation. Mater Appl Mol 23:1760. https://doi.org/10.3390/molecules23071760

Guesh K, Mayoral A, Alvarez CMCY, Diaz I (2016) Enhanced photocatalytic activity of TiO2 supported on zeolites tested in real wastewaters from the textile industry of Ethiopia. Micropor Mesopor Mater 225:88–97

Guo M, Weng X, Wang T, Chen Z (2017) Biosynthesized iron-based nanoparticles used as a heterogeneous catalyst for the removal of 2,4-dichlorophenol. Sep Purif Technol 175:222–228

Gupta VK, Saleh TA (2013) Sorption of pollutants by porous carbon, carbon nanotubes and fullerene—an overview. Environ Sci Pollut Res 20:2828–2843

Ho KC, Tsai PJ, Lin YS, Chen YC (2004) Using biofunctionalized nanoparticles to probe pathogenic bacteria. Anal Chem 76(24):7162–7168. https://doi.org/10.1021/ac048688b

Hulkoti NI, Taranath TC (2014) Biosynthesis of nanoparticles using microbes—a review. Colloids Surf B Biointerfaces 121:474–483

Isa B, Adam HB, Usman YM, Abdulrahaman F (2019) Potentials of nanoparticles for soil and water remediation (a review). Int J Info Eng Technol 10(3):19–28

Khan T, Abbas S, Fariq A, Yasmin A (2018) Microbes: nature's cell factories of nanoparticles synthesis. In: Exploring the realms of nature for nanosynthesis. Springer, Cham, pp 25–50

Kim YM, Murugesan K, Chang YY, Kim EJ, Chang YS (2012) Degradation of polybrominated diphenyl ethers by a sequential treatment with nanoscale zero valent iron and aerobic biodegradation. J Chem Technol Biotechnol 240:525–532

Kos L, Sójka-Ledakowicz J, Michalska K, Perkowski J (2014) Decomposition of azo dye C.I. Direct Yellow 86 by the Fenton process in the presence of nanoparticles of iron oxides. Fibres Text East Eur 5:114–120

Kusworo TD, Qudratun DP, Indriyanti IR (2018) Enhancement of separation performance of nano hybrid PES—TiO_2 membrane using three combination effects of ultraviolet irradiation, ethanol-acetone immersion, and thermal annealing process for CO_2 removal. J Environ Chem Eng 6: 2865–2873. https://doi.org/10.1016/j.jece.2018.04.023

Liu J, Morales-Narváez E, Vicent T, Merkoçi A, Zhong GH (2018) Microorganism-decorated nanocellulose for efficient diuron removal. Chem Eng J 354:1083–1091

Ma Y, Wang Y, Chen Q, Li Y, Guo D, Nie X, Peng X (2020) Assessment of heavy metal pollution and the effect on bacterial community in acidic and neutral soils. Ecol Indic 117:106626

Mechrez G, Krepker MA, Harel Y, Lellouche JP, Segal E (2014) Biocatalytic carbon nanotube paper: a "one-pot" route for fabrication of enzyme-immobilized membranes for organophosphate bioremediation. J Mater Chem B 2:915–922

Miklos DB, Zemy C, Jekel M, Linden KG, Drewes JE, Hübner U (2018) Evaluation of advanced oxidation processes for water and wastewater treatment—a critical review. Water Res 139:118–131

Milosavljevic JS, Serbula SM, Cokesa DM, Milanovic DB, Radojevic AA, Kalinovic TS, Kalinovic JV (2020) Soil enzyme activities under the impact of long-term pollution from mining-metallurgical copper production. Eur J Soil Biol 101:103232

National Research Programme (NRP) (2017) Opportunities and risks of nanomaterials. Engineered nanomaterials: impact & safety aspects. Swiss National Science Foundation

Nguyen AT, Hsieh CT, Juang RS (2016) Substituent effects on photodegradation of phenols in binary mixtures by hybrid H_2O_2 and TiO_2 suspensions under UV irradiation. J Taiwan Inst Chem Eng 62:68–75

Pandey S, Kumari M, Singh SP, Bhattacharya A, Mishra S, Chauhan PS, Mishra A (2016) Bioremediation via nanoparticles: an innovative microbial approach, p 25. https://doi.org/10.4018/978-1-4666-8682-3.ch019

Pourreza N, Golmohammadi H, Naghdi T, Yousefi H (2015) Green in-situ synthesized silver nanoparticles embedded in bacterial cellulose nanopaper as a bionanocomposite plasmonic sensor. Biosens Bioelectron 74:353–359

Raj Kumar S, Gopinath P (2016) Nano-bioremediation applications of nanotechnology for bioremediatio, pp 27–48. https://doi.org/10.1201/9781315374536-3

Rasalingam S, Peng R, Koodali RT (2014) Removal of hazardous pollutants from wastewaters: applications of TiO_2-SiO_2 mixed oxide materials. J Nanomater 2014:617405

Santhosh C, Velmurugan V, Jacob G, Jeong SK, Grace AN, Bhatnagar A (2016) Role of nanomaterials in water treatment applications: a review. Chem Eng J 306:1116–1137

Sebeia N, Jabli M, Ghith A, Saleh TA (2019) Eco-friendly synthesis of *Cynomorium coccineum* extract for controlled production of copper nanoparticles for sorption of methylene blue dye. Arab J Chem 13:4263–4274

Sharma V, Sharma A (2012) Nanotechnology: An emerging future trend in wastewater treatment with its innovative products and processes. Int J Enhanced Res Sci Technol Eng 1:121–128

Sreeja S, Vidya SK (2016) Microbial disinfection of water with endotoxin degradation by photocatalysis using Ag-TiO_2 core shell nanoparticles. Environ Sci Pollut Res 23:18154–18164

Sutisna WE, Rokhmat M, Rahman DY, Murniati R, Khairurrijal AM (2017) Batik wastewater treatment using TiO_2 nanoparticles coated on the surface of plastic sheet. Procedia Eng 170:78–83. https://doi.org/10.1016/j.proeng.2017.03.015

Taati A, Salehi MH, Mohammadi J, Mohajer R, Díez S (2020) Pollution assessment and spatial distribution of trace elements in soils of Arak industrial area, Iran: implications for human health. Environ Res 187:109577

Teow YH, Mohammad AW (2017) New generation nanomaterials for water desalination: a review. Desalination 451:2–17. https://doi.org/10.1016/j.desal.2017.11.041

Torres-Martínez CL, Kho R, Mian OI, Mehra RK (2001) Efficient photocatalytic degradation of environmental pollutants with mass-produced ZnS nanocrystals. J Colloid Interface Sci 240: 525–532

Triano RM, Paccagnini ML, Balija AM (2015) Effect of dendrimeric composition on the removal of pyrene from water. Springer Plus 4:511. https://doi.org/10.1186/s40064-015-1295-x

Tripathi S, Sanjeevi R, Anuradha J, Singh CD, Ashok KR (2018) Nano-bioremediation: nanotechnology and bioremediation. IGI Global, pp 202–219. https://doi.org/10.4018/978-1-5225-4162-2.ch012

USEPA (2017) Technical fact sheet—nanomaterials. EPA 505-F-17-002, pp 1–9

Vijayageetha VA, Annamalai V, Pandiarajan A (2018) A study on the nanotechnology in water and waste water treatment. IOSR J Appl Physics 10(4):28–31

Wilson N (2018) Nanoparticles: environmental problems or problem solvers? Bioscience 68(4):241

Xie Y, Fang Z, Cheng W, Tsang PE, Zhao D (2014) Remediation of polybrominated diphenyl ethers in soil using Ni/Fe bimetallic nanoparticles: influencing factors, kinetics and mechanism. Sci Total Environ 485–486:363–370

Xiu Z, Zhang Q, Puppala HL, Colvin VL, Alvarez PJJ (2012) Negligible particle-specific antibacterial activity of silver nanoparticles. Nano Lett 12:4271–4275

Yadav KK, Singh JK, Gupta N, Kumar V (2017) A review of nanobioremediation technologies for environmental cleanup: a novel biological approach. J Mat Env Sci (JMES) 8(2):740–757

Yang J (2019) Nanomaterials for the removal of heavy metals from wastewater. Nanomaterials 9: 424. https://doi.org/10.3390/nano9030424

Yano H, Omura H, Honma Y, Okumura H, Sano H, Nakatsubo F (2018) Designing cellulose nanofiber surface for high density polyethylene reinforcement. Cellulose 25(6):3351–3362

Yilmaz MD, Hsu SH, Reinhoudt DN, Velders AH, Huskens J (2010) Ratiometric fluorescent detection of an anthrax biomarker at molecular printboards. Angew Chem Int Ed 49:5938–5941. https://doi.org/10.1002/ange.201000540

Younas H, Qazi IA, Hashmi I, Ali Awan M, Mahmood A, Qayyum HA (2014) Visible light photocatalytic water disinfection and its kinetics using Ag-doped titania nanoparticles. Environ Sci Pol 21:740–752

Yonzon CR, Stuart DA, Zhang X, McFarland AD, Haynes CL, Van Duyne RP (2005) Towards advanced chemical and biological nanosensors—an overview. Talanta 67:438–448. https://doi.org/10.1016/j.talanta.2005.06.039

Yuan X, Xue N, Han Z (2020) A meta-analysis of heavy metals pollution in farmland and urban soils in China over the past 20 years. J Environ Sci 101:217–226

Yurekli Y (2016) Removal of heavy metals in wastewater by using zeolite nano-particles impregnated polysulfone membranes. J Hazard Mater 309:53–64. https://doi.org/10.1016/j.jhazmat.2016.01.064

Zekić E, Vuković Z, Halkijević I (2018) Application of nanotechnology in wastewater treatment. Građevinar 70(4):315–323

Zhang D, Anderson MJ, Huarng MC, Alocilja EC (2011) Nanoparticle-based biobarcoded DNA sensor for the rapid detection of pagA gene of bacillus anthracis. IEEE Trans Nanotechnol 23(21):4756–4764. https://doi.org/10.1109/TNANO.2011.2165965

Zhou Q, Li J, Wang M, Zhao D (2016) Iron-based magnetic nanomaterials and their environmental applications. Crit Rev Environ Sci Technol 46:783–826. https://doi.org/10.1080/10643389.2016.1160815

Zhu L, Ang S, Liu WT (2004) Quantum dots as a novel immunofluorescent detection system for Cryptosporidium parvum and Giardia lamblia. Appl Environ Microbiol 70:597–598. https://doi.org/10.1128/AEM.70.1.597-598.2004

M. B. Alao is a winner of several awards in microbiology with vast knowledge in microbial genetics, antimicrobial resistance, nanobiotechnology, mushroom technology and bioremediation. He holds a Master's Degree in Microbiology, and he is presently a Ph.D. researcher at the University of Birmingham, UK, focusing on chemogenomics.

C. O. Bamigboye (B.Tech., M.Tech., Ph.D.) is a Lecturer in Microbiology Unit of the Department of Pure and Applied Biology in Ladoke Akintola University of Technology, Ogbomoso. She won the prestigious OWSD postgraduate fellowship in 2014, and has some published papers to her credit. Email: coadegunlola@lautech.edu.ng, Phone number: +2347031068220. https://scholar.google.com/citations?user=gwsZ4fAAAAAJ&hl=en&oi=ao

E. A. Adebayo is an Association Professor (Reader), in Industrial Microbiology and Biotechnology/Nanotechnology, and lecturer in the Department of Pure and Applied Biology, Ladoke Akintola University of Technology, Ogbomoso, Nigeria. Some of the awards he won are Tugbileye Prize and the Mr and Mrs Tunji Ige Adedoyin Prize for the Best Graduating Student in Biology, CSIR-TWAS (2009) Postgraduate Fellowship Award, LAUTECH Senate grant (2013), TETFund International conference grant (2013) and CONACYT-TWAS (2013) Postdoctoral Fellowship in Mexico and TETFund Institution-based Research grant (2018). He had published many articles in reputable national and international journals and books. He also had 31 registered accessions of microbes with NCBI (USA).