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Nanotechnology for Remediating Current Environmental Problems

Sandeep Bajpai[1], Alka Nivedan[2], Anand Kumar[3], Madhu Tripathi[4]

[1]Department of Zoology, BVBG Degree College, Gomtinagar, Lucknow-226010 (U.P) India
[2]Department of Botany, BVBG Degree College, Gomtinagar, Lucknow-226010 (U.P) India
[3]Department of Zoology, BSNV PG College, Charbagh, Lucknow-226001 (U.P) India
[4]Ex-Professor & Head, Department of Zoology, University of Lucknow, Lucknow-226007 (U.P) India

Abstract:

Nanotechnology can play important role in the field of environmental restoration and science. Environmental pollution has become one of the major problems of developing as well as developed countries at present time. Unchecked exploitation of resources, rapid industrialization, urbanization as well as excessive agricultural activities to meet the demands of the ever increasing population are the major cause for contamination of the land, water and atmosphere at all levels. Increasing pollution is not only resulting in the destruction of biodiversity, but it also causes degradation of human health. Recently, nanotechnology has emerged as an answer to these problems having significant role in environmental monitoring, pollution prevention and remediation methods. Nanotechnology has many advantages to improve present environmental technologies and help to create new technologies in comparison to the conventional one. Present article explores the role of different nanoparticles available for environmental remediation purposes and pollution monitoring.

Keywords: Environment, Pollution, Nanotechnology, Nanoremediation, Metal nanoparticles.

Introduction:

A nanopartical is a small particle ranging between 1 to 100 nanometer in size undetectable by the human eye. Nanoparticles exhibit significantly different physical and chemical properties to their larger material counterparts. Nanoparticles have the potential to deliver the environmental benefits both in terms of production processes and in products. Nanotechnology is the field of applied science focused on the synthesis, design, characterization and application of materials and devices on nanoscale (Urmil, 2016).This branch of knowledge is a sub classification of technology in colloidal science, chemistry, biology, physics and other scientific fields and involves the study of phenomena and manipulation of materials in the nanoscale (Mansoori and Soelaiman, 2005).Most of the Nanoparticles are made up of only a few hundred atoms. Owing to their very small size, Nanoparticles have extremely large surface area to volume ratio when compared to bulk materials such as powder, plate and sheet. This feature enables Nanoparticles to possess unexpected physical, optical and chemical properties as they are small enough to confine their electrons and produce quantum effects.

Advantages of nanomaterial are the non-conventional properties and new physiochemical characteristics, permitting them to develop their use in environmental monitoring, health, industry promote advanced materials and produce new products (Hussain *et al.*, 2015; Das *et al.*, 2015; Brigante *et al.*, 2016). There are various engineered nanomaterials like quantum wires, nanocomposites, carbon nanotubes, quantum dots, fullerenes and nanofibres (Georgakilas *et al.*, 2015; Tsekhmistrenko *et al.*, 2020). The manufactured nanomaterials have new chemical, physical, surface and optical electronic properties that help in solving the problems which cannot be solved by the traditional technologies thus they play significant role in the development of innovative methods for creating new products, chemicals and materials with high productivity and lower energy consumption (Srivastava *et al.*, 2015; Santosh *et al.*, 2016; Tsekhmistremko *et al.*, 2020).

Rapid industrialization, urbanization and modern expansion of anthropogenic activities have reduced natural resources and created hazardous and toxic wastes contaminating the environment including colloidal particles, toxic gases, organic compounds that are threatening the health and challenging environmental safety. Nanotechnology has provided new solutions for combating these environmental issues (Adeleye *et al.*, 2016) by reducing the emissions or preventing the formation of pollutants. The properties of nanomaterial caused by their high surface to volume ratio, that makes them more reactive than volume forms of the same material (Mukherjee, 2016). Intensive agriculture and land activities are not only contaminating water and soil resources but they are also releasing hazardous pollutants. Their remediation may further lead to the production of compounds that may have adverse health effects. Water discharges from pulp, petrochemical, dyeing and textile industries and the partial degradation of phenoxy contaminants in different remediation process produce phenolic components that may have adverse consequences upon the health and well being of plants and animal biota (Khan *et al*., 2014).

Nanotechnology offers solution to the problems of resource usage, energy consumption and waste generation. Nanoparticles specially metal based ones show properties which are largely different from the respective bulk forms due to their large surface area to volume ratio. The larger exposed area reflects in higher number of atoms that are being stationed at the surface and which are readily available for several reactions including catalysis (Khan *et al.*, 2014). Nanomaterials also find uses in the treatment and detecting existing environmental contaminants and preventing pollution. They can be used in the treatment of various contaminated media by chemically transforming contaminants or acting as super adsorbent for many compounds. They also play vital role in the development of rapid and precise environmental sensors that can be used in detection of pollutants at molecular levels and also for inactivating harmful bacteria (Stephens, 2010). For environmental remediation, nanomaterials are divided into inorganic, carbon and polymeric based forms.

Inorganic nanomaterials:

Several studies on the pollution removal are based on the removal of heavy metals and organochlorine compounds from water due to the fast kinetics and high absorption capacity of metal and metal oxide nanomaterials. Silver Nanoparticles are known for their significant antibacterial, antifungal and antiviral activity in aquatic environment. Silver ions Nanoparticles (AgNPs) are an effective disinfectant of water against *Escherichia coli* (Baia *et al.*, 2020) and the nanoparticles of titanium oxide destroys the *Escherichia coli,* hepatitis B virus in soil and remove aromatic hydrocarbons and phenanthrene (da Silva *et al*., 2016). Nanoparticles from titanium oxide (IV) are used in air purification, waste treatment, self cleaning of surfaces and as catalyst for water treatment as they are characterized by non-toxicity, low cost photo catalytic, electronic and ability to transform energy (Tsekhmistrenko *et al*., 2019). Adsorbants, mesoporoussilica materials in different modifications purify the gas phase from the contamination (Wang *et al.*, 2019; Brigante *et al*., 2016). Mesoporous silicon dioxide functionalized with carboxylic acid removes cationic dyes and heavy metals from waste water (Tsai *et al*., 2016).

Carbon nanomaterials:

Carbon nanomaterials- fullerenes, nanotubes, graphene are used extensively for the purification of pollutants (Azam *et al.*, 2017; Mortazavi *et al.*, 2019). The adsorption properties of single and multi-walled carbon nanotubes make them very useful and efficient for the removal of organic and inorganic contaminants from the air and large volumes of aqueous solutions (Chowdhury *et al*., 2015). The large adsorption capacity and efficiency of graphite allows it to actively adsorb fluorine (Song et al., 2016; Reddy and Yaakobovitz, 2019). Graphene oxide adsorbs gaseous and aqueous pollutants, volatile organic compounds, heavy metals, pesticides and pharmaceuticals (Hussain *et al*., 2015; Wang *et al.*, 2019).

Polymer nanomaterials:

Amphiphilic polyurethane removes multinuclear aromatic hydrocarbon from the soils and polyamidoamine dendrimers remove heavy metals from waste waters (Bhardwaj *et al.*, 2019; Arkas *et al*., 2019). Removal of metal ions, dyes and microorganisms from water by polymer nanocomposites had also been reported by Mittal *et al*. (2015) and Khare *et al*. (2016). Polymers are also used to identify and remove chemical contaminants (nitrate, arsenic, manganese, iron, heavy metals), gases (CO, SO_2), organic contaminants (aliphatic and aromatic hydrocarbons, pharmaceuticals, biological (bacteria, parasites, viruses). Polymeric bases (surfactants, emulsifiers, stabilizing agents) are used to enhance stability, overcome the limitations of pure nanoparticles.

Applications of Nanotechnology:

Widespread human activity is the major cause for environmental pollution at all levels (Das *et al.*, 2015). Vast industrialization and anthropogenic activities have changed the composition of atmosphere affecting the physical, chemical and biological factors introducing into air Chlorofluoro carbons (CFC), carbon monoxide (CO), heavy metals (As, Pb, Hg, Cr), hydrocarbons, oxides, SO_2, sand particles and biological substances. Created nanomaterials can be used in different industries because of significant monitoring characteristics, improved nanosensors and reduce pollution by replacing toxic materials with other safe materials (Zhang *et al*., 2016).

Air pollution remediation:

The benefits of nanotechnology in combating air pollution can be categorized into, recovery and treatment, detection and probing and pollution prevention (Yadav *et al.*, 2017). Certain uses of nanotechnology for the treatment and reduction of various air pollutants are degradation by nanocatalysis, adsorption by nanoabsorption materials, filteration and separation by nanofilters. The air quality problem can be solved or greatly improved with nanoscale adsorbents. Carbon nanostructures are adsorbent with high selectivity, affinity and capacity due to the average pore diameter, surface area, pore volume and surface area activity (Yadav *et al.*, 2017), also the addition of other functional groups with oxygen can provide new active sites for adsorption (Wang *et al.*, 2019). Nanofibres of silver, iron, gold and manganese oxide can be used to control the environment for the storage of volatile organic compounds from industrial smokey fuels and have therapeutic effects, remove carbon monoxide and decompose trichloroethylene (Singh and Tandon. 2014; Yadav *et al.*, 2017). To prevent air pollution, it is important to reduce pollution sources and eliminate waste generation. Use of eco friendly nanomaterials are biodegradable plastics, non-toxic nanocrystalline composite materials for replacing lithium-graphite electrodes in rechargeable batteries and carbon nanotubes can provide better functionality (Yadav *et al.*, 2017). Nanotechnology enhances air monitoring sensors by detecting many toxic compounds at ppm and ppb levels in different environmental systems (Zhou *et al.*, 2015). Nanotechnology had developed many new carbon nanomaterials that are used to capture CO_2 and nanocatalysts responsible for catalytic conversions of CO_2 and H_2O into fuels (Raj *et al.*, 2017) reduce industrial CO_2 emissions, reduce earths warming and produce additional energy sources.

Water pollution remediation:

Water pollution remediation is the process to remove, minimize or neutralize the water contaminants that can affect human health or ecosystems. Availability of pure water is one of the major requirements for human and for industries. Improvement of water quality is thus an important matter of concern globally. Advancement of nanotechnology can be used to improve water quality using reactive media for separation, filtration and disinfection (Cloete *et al.*, 2010). The nanosorbants, nanocatalysts, bioactive nanoparticles, nanostructured catalytic membranes and nanoparticle enhanced filtration have enormous applications in the field of water purification. They can also serve as high capacity recyclable ligands for toxic metal ions, radio nuclides, organic and inorganic solutes in aqueous solutions (Khan *et al.*, 2014). The advantages of using nanomaterials are their higher reactivity, larger surface contact and better disposal capability. There are many nanoparticles and nanomaterials that can be used for remediation of water such as Zeolites, carbon nanotubes etc (Sharma *et al.*, 2009), self-assembled monolayers on mesoporous supports, biopolymers, single-enzyme nanoparticles and nanoparticles of zero valent ions (ZVI) are important amongst others. The utilization of zero valent iron particles i.e. ZVI technology, for the decontamination of ground water reduces both the chlorinated hydrocarbons and metal toxicity. Their reductive ability has also been exploited for the remediarion of radio nucleotides like uranium (Arnold and Roberts, 2000). An electro exploding wire (EEW) technique has been proposed for the synthesis of iron particles that can be subsequently used for the removal of lead and cadmium ions from water (Alqudami and Alhemiary, 2012). The particles prepared by this technique have proved to be effective adsorbants having high adsorption capacities for the remediated metals at equilibrium. Solvothermal synthesis of magnetic nanocrystalline barium hexaferrite at 350ºC followed by annealing at 750ºC has been reported that produces nanoparticles of <200 nm capable of arsenic removal from polluted waters (Patel *et al.*, 2012).

Nanotechnologies that affect remediation by contaminant degradation rather than absorption are particularly attractive for organic contaminants (Urmil, 2016). A well established approach for remediation of organic contaminants is photo-oxidation catalyzed by metal oxide nanoparticles such as TiO_2. Another method is based on the injection of Fe^0 nanoparticles into the groundwater by the help of application wells, this technology is cost effective and environment friendly (Xu and Zhao, 2006). Iron nanoparticles coated with ferromagnetic carbon have a stronger ability to remove chromium from the waste water then simple iron nanoparticles (Zhang *et al.*, 2010). A common type of groundwater remediation methos used for cleaning up of contaminated groundwater is the 'permeable reactive barrier' (PRB). PRBs are the treatment zones composed of materials that degrade or immobilize contaminants as the groundwater passes through the barrier. They can be installed as permanent, semi-permanent or replaceable barriers within the flow path of a contaminant plume. The material chosen for the barrier is based on the contaminants of concern (Rajan, 2011). In addition to groundwater remediation, nanotechnology has also contributed towards reducing the presence of non-aqueous phase liquids (NAPL) by a material utilizing nano-sized oxide used in situ to clean up heating oil spills from the underground tanks. This approach provides the overall reduction in the contaminant level.

Soil pollution remediation:

Soil or land contamination is a challenging problem faced by our everincreasing population. Emerging nanotechnology solutions for bioremediation and phytoremediation have proved to be extremely beneficial in the treatment of these contaminants (Khan *et al.*, 2014; Watlington, 2005). The problem of soil contamination can be solved using nanoparticles which due to their large surface area are effective in transforming environmental contaminants not conductive to detoxification.The technical challenges such as the delivery of nanoparticles to the target area has to be resolved. Further, the release of large quantities of manufactured nanoparticles into the soil prior to extensive human and ecological toxicity testing is a matter of concern. So far, nano zero valent iron (nZVI) is the only application of nanomaterials in soil and ground water remediation that has been commercialized successfully. The use of nanoscale calcium peroxide for remediation is expected to be common in the coming years. Many nanomaterials have been tried for remediation applications and these were initially largely synthesized by physical and chemical methods (Ghorbani *et al.*, 2011).

Iron nanoparticles have been widely used in the chemical, electronics and other industries. Recently their applications have been extended to the treatment of toxic and hazardous wastes and also remediating soil. Iron is a strong reductant and nano iron has been accepted to have a core shell structure with Fe^0 as the core and oxide as the shell. In this form it can degrade dyes, reduce aromatic nitro compounds and also dehalogenate organic compounds along with removing metal ions. It has been observed that zero-valent iron Fe^0 nanoparticles are very effective in scavenging chromium from the soil with reduction of Cr (VI) being directly proportional to the concentration of metal particles (Singh *et al.*, 2011). Although iron is very effective in chromium remediation, its presence in powder and filling forms show reduced efficacy of remediation as compared to its nano form probably due to reduced surface area. Stability of these nanoparticles in suspensions has also been achieved by modifying them with lactate and such particles are very useful in remediating dehalogenating organic pollutants such as pentachlorophenol dinitrotoluene from various types of soil (Reddy, 2010). Nano zero-valent iron is also an emerging option for in-situ remediation of contaminated soil as it facilitates the removal of chlorinated organic contaminants such as PCB, TCE, PCE, TCA and pesticides etc along with the inorganic anions like perchlorate (Braun *et al.*, 1010).

Recently, an alternative method of green synthesis of nanomaterials has been attempted successfully by many researchers. The process involves use of plant extracts as well as from microorganisms such as bacteria and fungi. This route of synthesis is however largely restricted to metal nanoparticles and involves reduction process making use of intra and extra cellular enzymes secreted by the plants and microorganisms. Metal nanoparticles with desired shape and size can be obtained using the organisms ranging from simple bacteria to highly complex eukaryotes (Prashant *et al.*, 2008). Microbes can degrade toxic organics in the soil and iron nanoparticles can supplement their activity by increasing the microbial production as well as enhancing the activity of soil enzymes. The enhanced degradation of 2, 4-dichlorophenoxyacetic acid in soil especially in the presence of iron particles in nano range has been reported (Fang *et al.*, 2012). These special particles act by promoting the growth of soil microbes and increasing the enzyme activity of urease, catalase and alkaline phosphatase in treated soil as compared to the untreated soil (Khan *et al.*, 2014).There are various nanoparticles of CuO, Ag and ZnO that have good antimicrobial properties against pathogenic bacteria and can play significant role in pollution degradation, element cycling and plant growth.

Conclusion:

Nanoparticles are used to solve potential issues such as treatment of contaminated water, air and soil more effectively than through conventional methods. Nanoremediation has a great potential to clean up large contaminated sites in situ reducing the cleaning time and eliminating the need for removal of contaminants. Nanomaterials unlike traditional technologies can remove pollutants present in lower concentrations, their efficiency can be increased by particle modification and their cost can be reduced by the production on an industrial scale and the development of synthesis methods that look into account cheaper raw material and less energy. Nanoparticles and nanotubes can be applied as sensors for toxic substances particularly for the substances that are difficult to detect using conventional technology. Use of nanotechnology in the field of environment is not only limited to the conditions where environmental contamination has already occurred but it can also be applied to prevent the creation of pollution. Although nanotechnology offers a broad range of potential uses and rapid advances, this technology may also have unintended effects on human health and the environment which should also be taken into consideration and should be studied further for risk assessment.

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