Nanotechnology in Environmental Soil Science

14

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Abstract

Nano-materials play an important role regarding the fate, mobility, and toxicity of soil pollutants and are essential part of different biotic and abiotic remediation strategies. Efficiency and fate of nano-materials is strongly dictated by their properties and interactions with soil constituents. Investigations into the remediation applications and fate of nano-particles in soil remain scarce and are mostly limited to laboratory studies. Once entered in the soil system, nano-materials may affect the soil quality and plant growth. The fate of NMs is highlighted in soil-plant system with a critical evaluation of potential threats to the soil ecosystem. The environmental application and risk assessment of manufactured nano-particles (MNPs) in soil greatly depend on our understanding of the interactions between MNPs and soil components. Because of the complexity of the soil system and the very early stage of MNP research in soil, our understanding of MNP behavior in this system is very limited. Manufactured nano-particles are applied deliberately for soil remediation and are also released unintentionally through various other pathways to soil. Currently, the remediation of polluted soils using nanoscale zerovalent iron (nZVI), carbon nanotubes, and nano-fibers has become an emerging area with a huge potential to improve the performance of traditional remediation technologies. However, environmental concerns have also emerged regarding human and environmental health when nanotechnologies are released to ecosystems. The goal of this article is to highlight the environmental benefits and risks that arise when nanotechnologies are used to remediate polluted soils. Cutting-edge knowledge regarding the use of nano-particles to

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decontaminate soils has to move forward, but environmental quality, human health, and social welfare should also be ensured.

Keywords

Engineering nano-particles · Environmental concerns · Remediation · Soil pollution · Ecological risk

14.1 Introduction

Current promulgation of industrialization and urbanization activities entailing transportation, manufacturing, construction, petroleum refining, mining, etc., exhaust the natural resources and generate huge amounts of hazardous wastes which leads to soil, water, and air pollution. This masquerades several issues pertinent to soil-plant ecosystem and the environmental security that toughen the application challenges of conventional treatment technologies. Based on the current advancement in nanotechnology and its pivotal role to cover the vital requirement to examine and treat the rising hazardous wastes with lower cost, less energy, with higher efficiency, emphasis may be given for its wide spread application in our country. Fundamentally, the key points to briefly delineate the advantages of nanotechnology over conventional treatment technologies are (a) soil (application of nano-materials as amendment for phyto-remediation processes), (b) water (nano-composite treatment to decontaminate water), (c) air (treatment of greenhouse gases, volatile organic compounds, and bioaerosols via adsorption, photocatalytic degradation with nano-materials). Moreover, possibility of accumulation of some pollutants in food chains, like bioaccumulation of heavy metals and persistent organic pollutants (POPs) in biota and fishes, which causes major risks to human and wildlife.

Hence, an urgent requirement demands for the development of sustainable, efficient, and low-cost technologies to examine and properly treat toxic environmental contaminants. One of the most promising routes to revolutionize the environmental remediation techniques is “nanotechnology” which can be defined as a group of emerging technologies that work on nanometer scale (i.e., between 1 and 100 nm range) to produce materials, devices, and systems with fundamentally new properties and functions by controlling the size and the shape of matters (Ramsden 2009). The global momentum of nanotechnology has been well recognized due to its potential applications in many fields of pollution treatment (Brame et al. 2011) is offering leapfrogging prospects in the improvement and transformation of conventional remediation technologies. The noble properties such as thermal, optical, mechanical, electromagnetic, structural, and morphological properties provide the nano-materials with advantageous features for many applications where they can be explored as nano-adsorbents, nano-sensors, nano-membrane, and disinfectants. Considering the remarkable advances in nanotechnology, necessary steps may be taken urgently in our country to develop green, robust, and economic approaches for environmental remediation with the applications of nano-materials in, soil, water, and air and provides an expansive view on favorability of nanotechnology over the conventional technologies.

14.2 Soil Pollution and Nano-Remediation

The presence of hazardous compounds in the natural soil environment is the main source of soil pollution. Anthropogenic activities like mining, manufacturing, landfill sites, particularly those that are accepting industrial wastes (e.g., paint residues, batteries, electrical wastes, etc.) and application of municipal or industrial sludge to agricultural fields direct to heavy metal pollution in soils. Heavy metals can be considered one of the challenging soil pollutants because they are non-degradable substances and they will stay in the contaminated environment once they are introduced to it, the only exceptions are mercury and selenium, since they can be transformed and volatilized by microorganisms. When large areas of soil are polluted, treatments can be done in situ (on-site) or ex situ (removed and treated off-site), however, the traditional treatment methods for contaminated soil are cost-prohibitive and extremely difficult (Natural Resources Conservation Service 2000). As a result, the best way to protect the environment is by preventing the contamination of heavy metals or by hindering the spreading of heavy metals in soil by immobilization technique (Ma et al. 1993). Due to the fact that activity of heavy metals in soil is governed by sorption–desorption reactions with other constituents of soil, a wide range of amendment agents have been used to manipulate the bioavailability of heavy metals and to impede their diffusion in soil by inducing various sorption processes: adsorption to mineral surfaces, formation of stable complexes with organic ligands, surface precipitation and ion exchange. There are two types of amendment agents (Robinson et al. 2009): (1) Mobilizing agents, which increase the bioavailability and mobility of heavy metals and enhance their removal through plant intake and soil washing (i.e., phytoextraction process) and (2) immobilizing amendment agents that decrease the bioavailability and mobility of heavy metals and reduce their transfer to food chain by preventing their leaching to the groundwater (i.e., phytostabilization).

In recent years, nanoscale particles have gained a great interest for heavy metal immobilization in soil and groundwater. Two essential requirements should be met when using nano-particles as amendment agents including the following (An and Zhao 2012): (1) they must be deliverable to the contaminated zones and, (2) when removing the external injection pressure, the delivered nano-particles should remain within the confined domain (i.e., under natural groundwater conditions), where the delivered nano-particles will work as an immobile sink for capturing soluble metals. However, the rapid tendency of nano-particles to aggregate into micro- to millimeter scale aggregates results in losing their distinctive characteristics such as high specific surface area and soil deliverability. For the purpose of overcoming these problems, organic polymers such as starch and carboxymethyl cellulose (CMC) (He and Zhao 2007) are often attached on the nano-particles as stabilizers in order to prevent nano-particle agglomeration through steric and/or electrostatic stabilization mechanisms and to improve the physical stability and mobility in soil and greater specific surface area.

Liang and Zhao (2014) investigated the effectiveness of starch-stabilized magnetite nano-particles for in situ enhanced sorption and immobilization of arsenate As

(V), the results indicated that water-leachable As(V) was greatly reduced as well as the toxicity characteristic leaching procedure (TCLP) leachability of As(V) was decreased. Phosphate compounds can be used as effective agents for in situ immobilization of heavy metals in contaminated soils, as demonstrated by immobilization of lead (Pb) where phosphate was commonly applied to soil either in its soluble forms such as phosphoric acid or solid forms such as synthetic apatite, natural phosphate rocks and even fishbone (with apatite being the effective composition). Therefore, a new type of apatite nano-particles was synthesized using CMC as a stabilizer in order to increase the dispersion rate of phosphate and immobilize lead in soil. It was suggested that the carboxyl and hydroxyl groups in cellulose molecules played an important role in inhibiting further agglomeration of nano-particles; moreover, in producing a stable lead phosphate compound, that is widely recognized as pyromorphite (Liu and Zhao 2013).

Zerovalent iron (ZVI) nano-particles are also used widely for in situ reductive immobilization of heavy metals in soil. The main drawback of ZVI nano-particles that are prepared using traditional methods is their ability to agglomerate rapidly or react quickly with the surrounding media (e.g., dissolved oxygen or water), resulting in losing in their reactivity and mobility in soil. The agglomerated ZVI particles are often in the range of micron scale; therefore, they are not transportable or deliverable in soils and thus, they are not applicable for in situ treatments. Accordingly, various ZVI particle-stabilizing strategies have been reported including modification of nZVI with several types of organic coatings, such as starch, polyvinylpyrrolidone (PVP), and sodium CMC. Cetylpyridinium chloride has also been used to control ZVI nano-particle agglomeration (Chen et al. 2004). Another problem that is limiting the engineering applications of iron-based materials is the cost factor due to the large amount of chemical reagents such as ferrous sulfate and ferrous chloride that are consumed during the material conventional preparation technologies. With intention to reduce the cost, Wang et al. (2014) successfully prepared CMC-stabilized nanoscale zerovalent iron from steel pickling waste liquor to remove Cr(VI) from contaminated soil and the results revealed that TCLP leachability of Cr(VI) reduced by 100%. However, the immobilization technique to remediate the contaminated soil imposes many problems. Firstly, despite both soluble and solid phosphates being reported as highly effective for heavy metal in situ stabilization on the laboratory scale, adding large amounts (e.g., 3% PO_4–3 dosage) of very soluble phosphoric acid or phosphate salts into the subsurface is limited not only by the cost of materials but also by the secondary contamination problems that arise due to the high solubility of phosphate which may lead to the contamination of groundwater and surface waters in the affected area by excessive nutrient input (eutrophication) (Park et al. 2011).

Secondly, Xu and Zhao (2007) stated that the CMC stabilizer is vulnerable to hydrolysis and, once it decomposes, its particle-stabilizing ability ceases and the fine residual precipitates end up in the soil phase. Finally the ecotoxicity of the immobilized chromium by CMC-stabilized ZVI nano-particles prepared from steel pickling waste. The results suggested that such remediation exerted an inhibitory effect on plant growth, which might be related to specific physicochemical properties of nZVI. There are several possible mechanisms by which fresh nZVI could enhance Fe uptake into plants; one possibility is that they penetrate the seed coat and are assimilated by the seed embryo. Another expected way for nZVI to enter the plant is via root epidermal cells by endocytosis (Slomberg and Schoenfisch 2012). Moreover, it was confirmed that carbon nanotubes are also able to penetrate the seed coat while supporting and allowing water uptake inside the seeds (Khodakovskaya et al. 2009).

14.3 Water Pollution and Nano-Remediation

Globally convenient access to clean and affordable water is one of the major challenges that needs immediate solution. Population growth, global climate change, and water pollution are the highest challenges that increase the struggles faced by water supply systems. In both developing and industrialized countries, water scarcity is exacerbated by human activities that play the greatest role in contaminating the natural water resources by releasing energy, chemicals, and other pollutants that deteriorate the water quality for other users. In addition, nature itself can be one of the contamination sources such as water storm runoff, animal wastes, etc. The United States Environmental Protection Agency (EPA) classifies water pollution into the following six categories: (1) plant nutrients, (2) biodegradable waste, (3) heat, (4) sediment, (5) hazardous and toxic chemicals, and (6) radioactive pollutants. Thus, water pollutants include organic pollutants, pathogens, industrial discharge containing heavy metals and different anions, etc. that are added to the water and cannot be naturally broken down and they tend to change the properties of the water body. Essentially, the wastewater treatment involves physical, chemical, and biological technologies and it usually occurs in four stages: (1) preliminary, (2) primary, (3) secondary, and (4) tertiary advanced treatment. The technologies that are generally used for water purification are coagulation and flocculation, sedimentation, dissolved air flotation, filtration, steam distillation, ion exchange, deionization, reverse osmosis, and disinfection. Materials usually used in these technologies are sediment filters, activated carbon, coagulants, ion exchangers, ceramics, activated alumina, organic polymers, and many hybrid materials (Hotze and Lowry 2011).

However, the conventional water treatment procedures might be costly and could release secondary toxic contaminants into the environment (Gaya and Abdullah 2008). Nanotechnology enables extremely efficient, flexible, and multifunctional processes that can provide a promising route, in order to retrofit aging infrastructure and to develop high performance, inexpensive treatment solutions which depend less on large infrastructures. The current advancements in nanotechnology spot the light on great opportunities to develop the next generation of water supply systems and expose the possibilities to expand the water supplies by affording new and cost-effective treatment capabilities that can overcome the major challenges faced by the current treatment technologies.

14.4 Sensing and Monitoring Systems

A major challenge for environmental remediation management is monitoring the emission of toxic substance like organic and inorganic pollutants, pathogens, and hazardous atmospheric pollutants, coupled with accurately assessing the extent and composition of these contaminants. Therefore, various analytical techniques have been employed in environmental pollution detection and monitoring, for instance, surface plasmon resonance (SPR) (Salah et al. 2012), high-performance liquid chromatography (HPLC) (Shintani 2014), gas chromatography–mass spectrometry (GC-MS) (Tranchida et al. 2015), supercritical fluid chromatography (SFC) (Ishibashi et al. 2015), capillary electrophoresis (CE) (Sánchez-Hernández et al. 2014), flow injection analysis (FIA) (Gerez et al. 2014), etc. Nevertheless, these techniques are inappropriate for routine environmental detection because of their high cost and time consumption in addition to their complicated requirements. The growing advances in nano-science and nanotechnology are having a remarkable influence on the field of environmental monitoring and sensing, where a large number of nano-particles have been introduced for detection and remediation of a wide range of contaminants in both gaseous and aqueous mediums. Many investigations have been carried out to develop high selectivity and sensitivity nano-sensors for monitoring different types of gases in the ambient air (Zhou et al. 2015) in order to prevent potential explosion or poisoning, particularly for odorless, colorless, and tasteless hazardous gases such as hydrogen and for poisonous and irritant gases such as nitrogen dioxide (NO_2) (Beheshtian et al. 2012).

Similarly, the application of nano-material-based sensors is widely studied for water quality monitoring by the detection of organism fecal pollution (Savichtcheva and Okabe 2006) such as fecal coliforms, total coliforms, *E. coli,* enterococci bacteriophages, and disease causing viruses and parasites (Theron et al. 2010) and detection of different types of trace contaminants (such as pesticides, phenolic compounds, inorganic anions, heavy metals). As any other chemical sensors, nano-particle-based sensors usually consist of two components: the receptor, which enhances the detection sensitivity and the transducer, a chemical or physical sense component (nano-material), that works with electrochemical, thermal, optical, and other detection principles (Su et al. 2012). The operating mechanism involves a charge transfer that occurs between pollutant molecules and the receptors, resulting in an electrical and/or optical signal that is related to the molecule type and number. Not to mention that in the case of bionanosensors, recognitions agents (e.g., antibodies (Volkert and Haes 2014), carbohydrates (Chen et al. 2011), aptamers (Li et al. 2009), and antimicrobial peptides (AMPs) (Cui et al. 2012) are presented as a third components and specifically provide the selectivity by interacting with antigens or other epitopes on the pathogens surface.

Moreover, to obtain nano-sensors with high sensitivity and fast response time, nanostructures such as nanorods, nanobelts, and nanowires were functionalized. For instance, tungsten oxide nanowires (WO_3-NWs) were functionalized with palladium for hydrogen gas detection and with copper oxide for high-performance hydrogen sulfide sensor (Park et al. 2014). As a matter of fact, nano-material-based sensors have shown great potential in the chemical and biological detection researches due to their physical, chemical, optical, catalytic, magnetic, and electronic properties as well as their high selectivity and sensitivity. Some examples of widely used nanomaterials in sensors technology include quantum dots (QDs) which can be benefited from their fluorescence properties to detect heavy metals, toxic gases, cyanotoxins, and pathogens (Feng et al. 2014). Metal nano-particles such as silver and gold nanoparticles rely on the changes in their color for pollutant detection (Salah et al. 2012). Furthermore, CNMs are facilitating the electron transfer between electrodes and electro-active species (Su et al. 2012) and they have been employed for monitoring of different pollutants and toxins. For instance, SWCNT and MWCNT were effectively used to develop electrochemical systems for monitoring of MC-LR in water below its WHO provisional concentration limit (Han et al. 2013). The specificity of MWCNT biosensor was improved by adding monoclonal antibodies specific to MC-LR in the incubation solutions and the performance of MWCNT array biosensor was enhanced by electrochemical functionalization of MWCNT in alkaline solution to enrich its surface with oxygen containing functional groups that permit the immobilization of MC-LR onto MWCNT array electrodes.

14.5 Environmental Risk From Nanotechnology

Among the applications of NMs, the use of nZVI is becoming one of the most prominent examples of a rapidly emerging technology with considerable potential benefits, many uncertainties and misconceptions regarding the fundamental features of this technology have made it difficult to engineer applications for optimal performance. For example, currently there are three basic fundamental uncertainties associated with the application of nZVI, such as (1) high concentrations of nZVI aggregate to produce micron size clusters which does not exhibit "true" nano-size effects; (2) the mobility of bare or uncoated nZVI will be less than the few meters under almost all relevant conditions; and (3) the potential risk to human or ecological health remains largely unknown (Tratnyek and Johnson 2006). These uncertainties highlight that our understanding of the basic processes involved in this technology is still evolving and incomplete. The major environmental concern is that the tiny nano-particles could end up in environmental bodies infesting drinking water sources harming the health of humans and animals (Oberdörster et al. 2006). Nano-particles present potential risks in terms of (1) dispersal—ability to disperse in the environment including potential long range transport; (2) ecotoxicity—ability to cause adverse effects to organisms in the environment; (3) persistency—ability to remain in the environment; (4) bioaccumulation—ability to bioaccumulate or bioconcentrate in higher order organisms; and (5) reversibility—ability for the removal or to reverse their original introduction from environment. Although nanotechnology is likely to represent a beneficial replacement of current practices for site remediation, research into health and environmental effects of nano-particles is urgently required.

Currently, standard methods to readily detect and monitor NMs in the environment are not up-to-date. For example, Kuhlbusch et al. (2011) stated that, a major drawback to the current state-of-the-art measurement devices is their lack of differentiation of background particles from NMs. Additionally, the majority of the devices available today are able to discriminate particles according to size, but not according to density. Little is known about the rates of aggregation and deposition of specific engineered NMs, due largely to complex nature of the system and the lack of instrumentation for measuring NMs at such small sizes and concentrations. As current research does not provide strong data to evaluate the fate and transport of NMs once incorporated in water, air, or soil it hinders the process of NMs risk assessment in the environment, further indicating the need for additional research in this field. In order to understand the risk of NMs in the environment both the dose–response effect of NMs and the exposure pathways determining how NMs enter an organism must be considered. Toxicity studies should not only focus on human and wildlife but also lower organisms as they make up the basis of food chains. Earlier research has shown that nano-particles can have adverse effects on pure cultures of bacteria like *Escherichia coli*, *Pseudomonas fluorescens,* and *Bacillus subtilis* var. niger where oxidation of the nZVI led to the production of reactive oxygen species in living cells (Diao and Yao 2009).

In addition, Fe2+ can enter cells creating oxidative stress which can damage their membranes leading to the leakage of intracellular materials and eventually cell death. Adverse nZVI effects were also observed in plant species. For example, Ma et al. (Ma et al. 2013) evaluated the phytotoxicity and accumulation of bare nZVI by two commonly encountered plant species, cattail (*Typha latifolia* L.), and hybrid poplars (Populous deltoids $\times$ Populous nigra) where nZVI exhibited a strong toxic effect on Typha at higher concentrations ($>$200 mg L^{-1}). nZVI also significantly reduced the transpiration and growth of hybrid poplars at higher concentrations with the upward transport to shoots minimal for both plant species. A lower population growth of earthworms, phyto-, and zooplanktons was also observed in the presence of NMs like nZVI (Keller et al. 2012). A number of studies have indicated toxicity of NMs to soil microorganisms such as CuO and Fe_3O_4 were found to cause changes in soil microbial communities caused by toxicity at 1% and 5% w/w dry soil (Ben-Moshe et al. 2013). In contrast, Fajardo et al. (Fajardo et al. 2012) reported that exposure of nZVI (34 micro g g^{-1}) and C60 (100 micro g g^{-1}) had little impact on microbial cellular viability and biological activity within the indigenous microbial population in the soils even at high concentrations.

This suggests that the toxicity may be strongly related with the bioavailability and solubility. Even if current production and subsequent release of NMs were estimated to increase to 100-fold, only three NMs are considered a major concern: Ag, nZVI, and ZnO. Of these, ZnO is the greatest concern since it exhibits toxic effects to all species tested. Hence, NMs release and its effects on the environment should be monitored closely, with special care given to the use of nZVI in soil and groundwater remediation as toxicity is observed at $>$0.5–1 mg L^{-1} (El-Temash and Joner 2012) and typical remediation concentration can range as high as 1–10 g L^{-1} (Grieger et al.

2010). Unlike larger particles, NMs can be taken up by cell mitochondria and the cell nucleus (Porter et al. 2007).

DNA mutations and major structural damage to mitochondria resulting in a cell death, has been demonstrated (Nel et al. 2006). These concerns over safety may limit the widespread applications of NMs for environmental remediation. Hence, to make this technology more beneficial than harmful, monitoring and intervention measures need to be implemented sooner than later. It is simple, environmentally friendly, and inexpensive thereby representing a technology which degrades contaminants sustainably which reduces the risk of the release of further toxic products and by-products into the environment mitigating the risk to aquatic and human health.

14.6 Strategies and Regulatory Measures

Strategies like green and microbial synthesis of nano-particles, or with the help of advanced engineering, viz. development of biomarkers to monitor nano-particles, combined the use of permeable iron barriers and nano-particles, etc. may be followed to improve the situation. Moreover, legal or regulatory measures require to formulating to examine stringently and control the utilization of nano-particles in the soil ecosystem. A pivotal issue crop ups from the widespread use of nanotechnology is how to control the development and deployment of nano-remediation technologies to exploit enviable outcomes and keep adverse outcomes at bay. United Kingdom made most important progress to identify nano-particles as new chemicals, which are controlled under existing chemical regulatory statutes (Bowman and Hodge 2007). However, developing nations should try to firmly follow nanotechnology regulations. For example, it is very difficult for the countries like India to cope up nanotechnology risks that may influence its huge population due to constraint of the resources, expertise, and political mandate (Barpujari 2011). Due to the lack of current legislations on nano-particles, a serious risk may pose for raw-material production, distribution, use and disposal processes. A comprehensive approach including advanced research, public education, media coverage, and integrated legislation will be vital to supervise the complexity of nanotechnology to thwart any detrimental effect due to nano-particles exposure. Update of current OECD test guidelines will lead to the development of new regulations along with guidance for appropriate and valid testing of the environmental fate and ecotoxicity endpoints for nano-particles. These assessments require to be amended in a timely manner with the progression of nanotechnology and must be tracked firmly to give meaningful, reproducible, and precise ecotoxicological information to prevent detrimental effect of nano-particles.

14.7 Recommendations

In India research work on nanotechnology particularly in the field of natural resource management still is in infancy. Endeavors to support research in nanotechnology in India started early in the millennium. But still there is a lot of scope for its expansion. The amount India invests on nanotechnology research is still very meager in comparison to other countries like Japan, USA, France, and China. The investment also from the private sector to nanotechnology research has been nominal. Research from academic institutions has pointed out that nanotechnology recorded a great impact on Indian market, like arsenic decontamination of water, water based self-cleaning technology for use in textile industry, etc. Indeed, it is really a worry, despite such mammoth potential the private sector is not endowing enough in nano-science research. Funding should be raised for long-term research programs with high-impact outcome. All over India, different research centers/institutes must work jointly so that the united efforts can direct to better results. A well-equipped central facility should plan and instigate the research activities. The administrative matters should be streamlined for new initiatives. Moreover, incentives for people skilled in the field should enhance, to magnetize highly talented personnel to join these research services.

14.8 Future Studies and Thrust

There are some future prospects and researchable issue in soil pertinent to nanotechnology are (1) development of Nano-sensor to monitor soil quality, (2) development of Nano-magnets for soil contaminant retrieval, (3) development of Nano-membrane for water treatment and purification, (4) establishment of baseline information on safety, toxicity, and adaption of NPs in soil and adequate life. Research needs to be undertaken for the assessment of the human and environmental risks associated with the application of this technology. Hence, there is a huge potential to dedicate systematic research knowledge on to developing large scale greener processes, which can further boost the application of nano-remediation at a commercial scale.

14.9 Epilogue

Nanotechnologies and nano-sciences have been very useful for delivering some materials, products, or services with better characteristics compared to their respective bulk material. Also, these areas have also provided some nano-sized materials to the environment. However, nanotechnologies have also been used to dissipate soil pollution. It is well known that some strategies to remediate polluted soils through nanotechnology might be accomplished, but some questions have to be answered prior the spread of nano-remediation, i.e., nano-particle toxicity has to be assessed while the standardization of techniques should be set by scientists and decision-makers worldwide. The cutting-edge knowledge regarding the use of nano-particles to decontaminate soils has to move forward, but environmental quality, soil, and animal health should also be ensured. Otherwise, these patents regarding modern nano-materials might jeopardize sustainability. Environmental damage due to increasing population and industrialization is a serious cause for concern. The advent of nano-remediation, using smarter engineered NMs can deliver cost effective and time saving in situ clean up procedures for large scale contaminated sites. Moreover, it can eliminate the need for treatment of the contaminated material by reducing the contaminant concentration to zero. With a rapid advancement of this technique, proper evaluation needs to be done to prevent any potential environmental or ecological hazards. The promising and innovative technology, together with the proposed improved understanding of nano-particles in both basic and field demonstrations in well characterized environments provides the prospect for exploiting nanoscale technology for environmental applications. The exacerbated human activities are convulsing the ecosystem balance by feeding the environment with large amounts of anthropogenic hazardous toxicants that pollute soil, water, and atmosphere and consequently threaten human public health. An attempt to adopt a compatible treatment technology for cleaning up all the wastes that are left behind the industrial revolution, this account simply compared with the application of propitious nanotechnology to conventional technologies in environmental remediation. It has been shown that nanotechnology exhibits remarkable features for advanced, robust, and multifunctional treatment processes that can enhance pollution monitoring, treatment performance, as well as overcome all the aforementioned barriers. In brief, nanotechnology has the potential to improve the environmental remediation system by preventing the formation of secondary by-products, decomposing some of toxic pollutants by zero waste operations, and prohibiting further soil contamination by converting the pollutants from labile to non-labile phases. Finally, nanotechnology will pave the way for versatile and vibrant systems which involve the cutting-edge techniques in sensing and monitoring of varieties of harmful chemicals and toxins in different environmental media.

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