Chapter

Nanoparticles: Novel Approach to Mitigate Environmental Pollutants

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Abstract

Pollution is one of the biggest challenges of current times. For control of environmental pollutants, degradation of these contaminants is need of times. Degradation of pollutants can be achieved by various physical and chemical or by physicochemical approaches. Since these methods are in efficient, hence development of biological methods began. Bioremediation is the approach of using bacteria, fungi, plants, algae, etc. to degrade wide range of environmental pollutants. Nano-bioremediation is one of such method which has received lot of attention in past few years. Nano-sized particles have large surface area relative to their volumes and thus have enhanced chemical and biological reactivity. Nano-bioremediation aims at reducing the contaminant concentrations to low risk-based levels and alleviating environmental impacts simultaneously. It brings the benefits to both nanotechnology and bioremediation together to achieve remediation which is more efficient, less time taking and eco-friendly.

Keywords: Environmental Pollution, Bioremediation, Biodegradation, Nanoparticles, Nano-bioremediation

1. Introduction

Problem of Environmental pollution is not limited only to developed countries but the challenges of waste management are also being faced by developing countries which is gradually growing day by day. The situation of effective management of environmental contaminants is grim in developing countries. Automation of most of the industries, establishment of new industries, ineffective disposal mechanisms adopted by these and similar establishments have led the world to face serious problems of municipal solid waste management, air, water and land pollution, various types of dangerous organic and inorganic pollutants that have entered into water, soil, and air by these industrial and urban waste. The developments and technical progress have led to increased harmful effects by accumulated pollutants into the surroundings. The major kinds of pollution, usually classified on the basis of environment, are air pollution, water pollution, and land pollution (**Figure 1**). Modern society is also concerned about specific types of pollutants, such as noise pollution, light pollution, and plastic pollution. Pollution of all kinds has negative effects on the environment, wildlife and impacts human health and well-being.

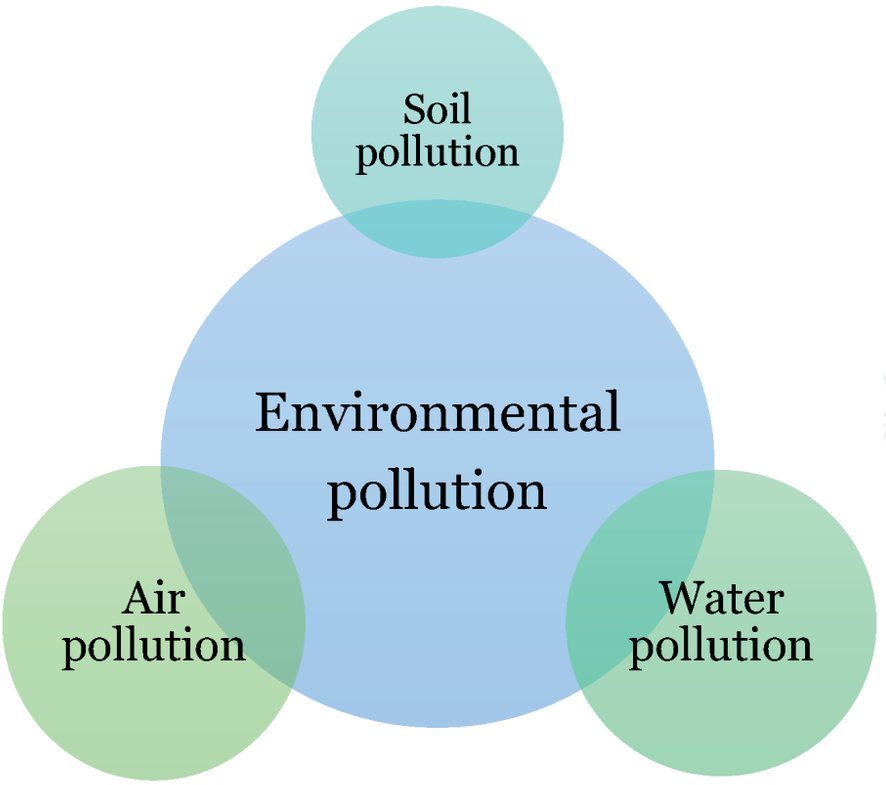

Figure 1.
Major environmental pollution.

Pollution is causing a lot of harm to human and animal health, plants and trees as well as the wider environment and has been harshly affecting the entire ecosystem and disrupting the marine life in lakes and streams causing depletion of the natural flora and fauna [1, 2].

Air pollution is increasing day by day due to release of smoke and toxic gases from various industries, transportation mediums, and various other human activities such as burning of wood, coal for fuels, etc., natural events such as forest fires. Air pollution is very common in large cities. Air pollutants cause significant damage to human health, vegetation, and cultural heritage [3].

Soil pollution is mainly caused by the disposal of municipal and industrial wastes as well as contaminated slurries from treatment plants at the waste disposal sites. Disposal and dumping of excessive use of single-use plastics, accumulation of chemicals such as pesticides, DDT, fertilizers, industrial use chemicals, raw materials for various manufacturing and production units, human activities such as deforestation, etc. have led to increased land pollution [4].

The problem of water pollution has grown with the increased amount of industries being set up and release of untreated industrial effluent in the water bodies such as ponds, lakes, riverine systems situated in the nearby vicinity of these industries. These industrial discharges include many toxic substances such as chemicals, heavy metals, metals and non-metals, floods runoffs, pesticides, fertilizers and acid rains, etc. [5]. In addition, greenhouse gas emissions such as methane and carbon dioxide continue to drive global warming and pose a great threat to biodiversity and public health [6].

The deposition of increased amount of toxicants and contaminants in our environment, have led to development and evolution of various technologies to reduce these pollutants and make our environment a better place to live. The developed technologies include use of various chemical, physical, physiochemical technologies to degrade environmental pollutants. In the last half decade bioremediation

approaches has gained a lot of attention as the other technologies are either not much effective, are cost intensive and also leaves other accumulants into the environment [7].

Remediation of pollutants using nanotechnology based approaches is the recent advancements for the development of more effective, cost effective technologies for mitigating different type's pollutants form all kinds of environments [1]. Nanotechnology products, processes, and applications are expected to contribute significantly to the environment and eliminate protection by saving raw materials, energy and water as well as by reducing greenhouse gases and hazardous wastes (**Figure 2**). By the use of nanomaterials, therefore, promises certain environmental benefits and sustainability effects [1].

The word "nano" meaning "dwarf" in the Greek language refers to dimensions of the orders of magnitude 10^{-9}. Nanotechnology is the field of applied science, focuses on the design, synthesis, characterizations, and application of materials and devices on the nanoscale. It is also known as the study of phenomena and the manipulation of materials in the nanoscale. Nanotechnology can detect the presence of pathogens or toxic agents in air, water and soil are of great importance for human health and protection of the environment by offering equipment that has extremely sensitive and fast measurement with sensor equipment. Nanomaterials are less bulky, easy to operate, and having low cost [5, 8].

In addition to this, nanomaterials help to improve the quality and performance of many consumer products. Therefore, nanotechnology is very useful in solving environmental pollution [8].

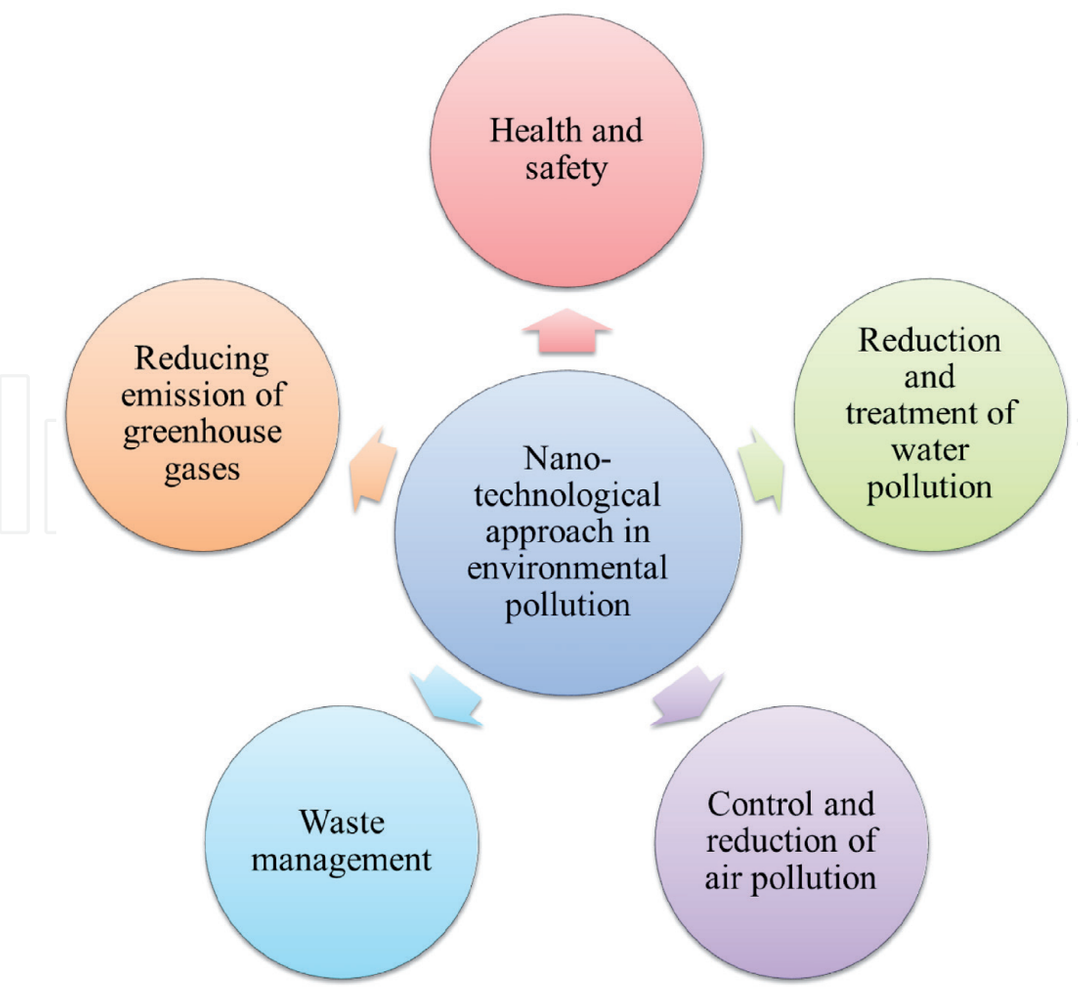

Figure 2.
Significance of nanoparticles in remediation of environmental pollution.

Accumulation of harmful air pollutants such as NOx, SOx, CO, etc., is increasing day by day. Nanotechnology is one of the current methods used in the world for controlling air pollutants using nanosensors, nanocatalysts, nanocomposites, nano filters, and nano-biomaterials [9].

Toxic gases in the air can be cleaned with help of nanotechnology but the most important thing is its continued control. Molecular level detection of toxic gases is done with the help of nanosensors such as nanocontact sensors and cantilever sensors. Nano contact sensors have been developed which can detect heavy metal ions and radioactive elements and cantilever sensors have been developed to sense VOCs, heavy metals, and pesticides. Nanocatalyst materials can be used as an environmental catalyst in the purification of automobile exhaust gases and air filtration. It is widely used in purification of water. Carbon nanotubes (CNT) have hollow ring structures composed of carbon atoms. CNT is divided into two parts, the first one is single-wall nanotubes and the second is multi-wall nanotubes which can be used to trace pollution and collect information on environmental pollutants [7].

As we know many toxic and non-biodegradable materials such as xenobiotics, heavy metals, leads, inorganic compounds cannot be eliminated by the biological and physicochemical method at environmental standards from wastes [1]. Nano-filters, nano-photocatalyst, and nanoporous catalysts are used for waste management. Nano filters can remove 60–70% of Chemical Oxygen Demand (COD) and 50% of ammonium in the leachate, anions, cations, arsenic, uranium, chromium, and pathogens from the wastewater. Nano-filter technology can be widely used in the separation and purification of gases and pollutant vapors in various industries and preventing their release into the environments. It is used in water treatments in homes, offices, and industries. Nano-photocatalyst is a nanotechnology that can absorb heavy metals from wastewater. Nanoporous catalysts can be used to convert the wastes into ethanol [10]. Another nonporous material, manganese oxide has great adsorption of toxic due to its large surface area and molybdenum disulphide (MoS_2) is used for energy-efficient desalination of water which filters five time more than conventional ones. To clean oil spills in the water bodies, a nanofabric paper towel has been developed which are woven from tiny wires of potassium manganese oxide that can absorb oil 20 times its weight [2, 8, 11].

Another use of nanotechnology is in human health and safety. It is used in many cosmetics, dyes, textiles, foods, medicines, medical equipments, and many other materials. Therefore with the help of nanotechnology, we can protect the sustainability of human health and environment. It also helps in waste management and monitoring pollutants. It also helps in reducing the emission of greenhouse gases and the discharge of hazardous chemicals in water bodies [2].

Nanoparticles can also harm human health and the environment. Due to the quick absorbance of nanoparticles through the skin, mucous and respiratory tract, causing new and unknown toxins that can threaten human health. Due to the lack of knowledge of the effect of nanomaterials in the environment and human society, we do not have a sufficient defense mechanism against them. Therefore, possible risks and its impact on organisms and environment should be considered [11].

2. Nano-remediation of soil pollution

2.1 Soil pollution

After air and water, soil is the third main components of an environment. Soil plays very important role in many activities like in plant growth (the prime activity of soil), gives anchorage to plants, supports many forms of life, provides proper

environment to microbes for decaying the dead materials into simpler component which further goes in biological cycle perform by the living organism [4].

Soil pollution can be defined as the reduction in the productivity of soil due to presence of soil pollutants. Soil pollutants reduce the productivity of soil because it shows an adverse effect on the physical, chemical and biological properties of soil. Soil pollution occur due to pesticides, carcasses, tins-cans, fertilizers, organic manual, chemicals, bottles, plastics, paper, leather goods, discarded food, clothes and radioactive wastes (**Figure 3**) [12].

Sometimes soil pollution can be the reason of water pollution as well as air pollution, these chemicals leaches into groundwater and reaches to the water stream like lake, pond, sea and also the some volatile compound release harmful gases in the atmosphere respectively [13].

2.2 Causes of soil pollution

There are many causes of soil pollution and some are as follows:

2.2.1 Types of contaminants

Organic and inorganic are the two major groups of chemicals which cause soil pollution. Soil is polluted by many chemicals like simple inorganics ions to complex organic molecules.

2.2.2 Inorganic pollutants

In the environment due to industry, mining, transportation and urban activities inorganic pollutants are released. Inorganic pollutants can interact both extracellular and intracellular levels respectively and this make it high risk component for environment [14].

Figure 3.
Municipal solid waste pollution-municipal solid waste (MSW) on a beach. Such land pollution can contaminate the soil and water and is a health hazard to local communities.

Some elements known as Micronutrients are essentials for in small amount and become toxic when increase the concentration for example B, Cl, Cu, Fe, Mn, Mo and Zn. Metals like Cd, Cr, Cu, Hg, Ni, Pb, V and Zn, metalloids like As, Bo, and Sb, non- metals like Se, actinoids like U and halogens like I and F are the inorganic contaminants which causes soil pollution when exceed the certain threshold [15].

Some elements are toxic at all concentration for examples Hg, As and Tl and some form organomettalic compound which are highly toxic and lipophilic for example methylmercury and tributyl tin oxides [16].

2.2.3 Organic pollutants

Organic compounds in which carbon is the main elements in the structure with or without functional groups. Organic pollutants include several groups like pesticides, hydrocarbons, polycyclic aromatic hydrocarbon (PAHs), polychlorinated biphenyl (PCBs), polychlorinated dibenzo-p-dioxins (PCDDs) polychlorinated dibenzofurans (PCDF), polybrominated biphenyls (PBBs), polybrominated diphenyl ethers (PBDEs), surfactants, or pharmaceuticals. This group separately or together pollutes the soil for examples the groups of PCBs include 209 congeners [17, 18].

The compounds are used due to its wide range of physical properties like polarity, solubility, volatility etc. These compounds shows different behaviors in environment and toxicity in organism due to its physical properties even come in same group.

Some of the organic compounds can be degraded or bio transformed but many of them shows resistant to both chemical as well as biochemical transformation and have long half-lives for example polyhalogenated compounds. Due to its molecular stability it remains in soil for very long time and effect environment and can travel to long distance [19, 20].

2.3 Origin and sources of soil pollution

Soil contaminants can be naturally or anthropogenic. Natural activities like weathering of rocks and volcanic activities or forest fires can produces organic, inorganic or both types of pollutants respectively. Human can also cause soil pollution accidentally or deliberately. Mining, smelting, disposal of wastes, fossil fuel combustion, gaseous works, industries, sports shooting, and application of agrochemicals or sewage are the human activities which cause soil pollution. Nuclear accidents, flooding by rivers or seas, leaks from landfills, or accidental spills are the accidental pollution (**Figure 4**) [22]. Above all examples mining is one of the important sources of toxic elements.

2.4 Effects of soil pollution

Due to direct or indirect contact with contaminated soil, the health risks increases and causes many diseases. Ecological balance also disturb due to increase in pollution of soil as well as health of many living organisms is also under risk. Soil pollution affects the quality of soil which causes deaths of many organisms which are essential for the growth of plant (e.g., earthworm). Indirectly the soil pollution also affects the life of predators like birds which move to other places in search of food.

People who were living near polluted land are prone to health risk as polluted soil can cause poisoning directly and indirectly i.e. children playing near waste land come in direct contact and food which grow on polluted land cause disease indirectly like migraines, nausea, fatigue, skin disorders and even miscarriages are common symptoms seen in a people which are live near polluted land and drink polluted water [13].

Figure 4.
Anthropogenic sources of soil contamination with toxic metalloids [21].

2.5 Nano remediation of soil pollution

There is several ways to remediate soil pollution but here we are discussing about remediation of soil pollution by nanoparticles.

In advancement of research, engineered nanoparticles plays a very important role in removal of environmental pollution as they are cheaper and more reactive.

For the treatment of environmental pollution engineered nanoparticles also enhance in situ method. Examples of some engineered nanoparticles used in soil remediation are given below:

- Nanoscale calcium peroxide – used for degrading organic compounds like gasoline
- Nanoscale zero valent iron – utilized for destroying organic compounds that are halogenated
- Nanoscale metal oxides – used for metal adsorption

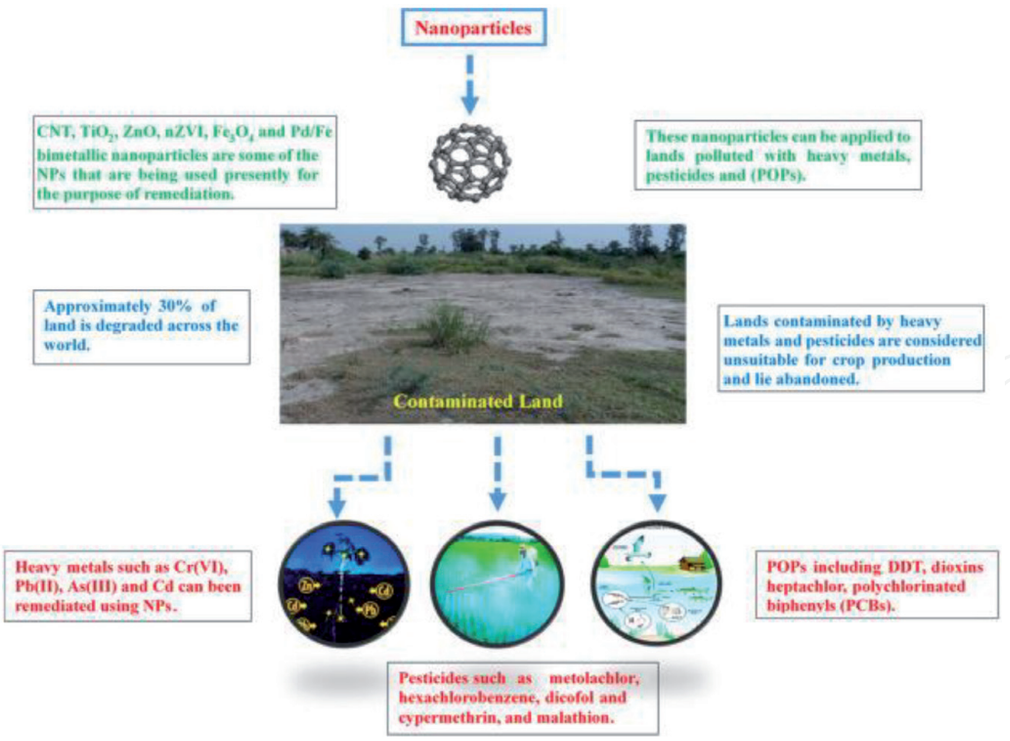

Figure 5.
The use of nanoparticles for remediation of soil contaminated with heavy metals, pesticides, and persistent organic pollutants (POPs) [23].

Other nanoparticles, such as carbon nanotubes, bio nanoparticles, polymeric nanoparticles, etc. used for the removal of aromatic and heavy metal contaminant (**Figure 5**) [24].

The above methods are considered as novel work but the effect of these engineered nanoparticles is yet to be studied [25].

From the above examples calcium peroxide is the best option because it releases peroxide very slowly which increases the attenuation time of the remediating reagent but due to its slow effective speed reaction, it shows some drawbacks. The speed of reaction of calcium peroxide nanoparticles can be increase by increase in surface to volume ratio [26].

2.6 Advantages of using nanoparticles

i. Large surface area – which helps in faster interaction.

ii. Presence of active sites – helps in increasing decontamination efficiency.

iii. Small size – helps in easy delivery at the contamination sites.

iv. Non-toxic at certain concentration.

v. Easily modified according to requirement.

vi. Pollutants can easily detected by use of nanomaterials.

vii. Low cost – the cost of remediation of soil pollutant is low.

viii. Effective and environmental friendly [27]

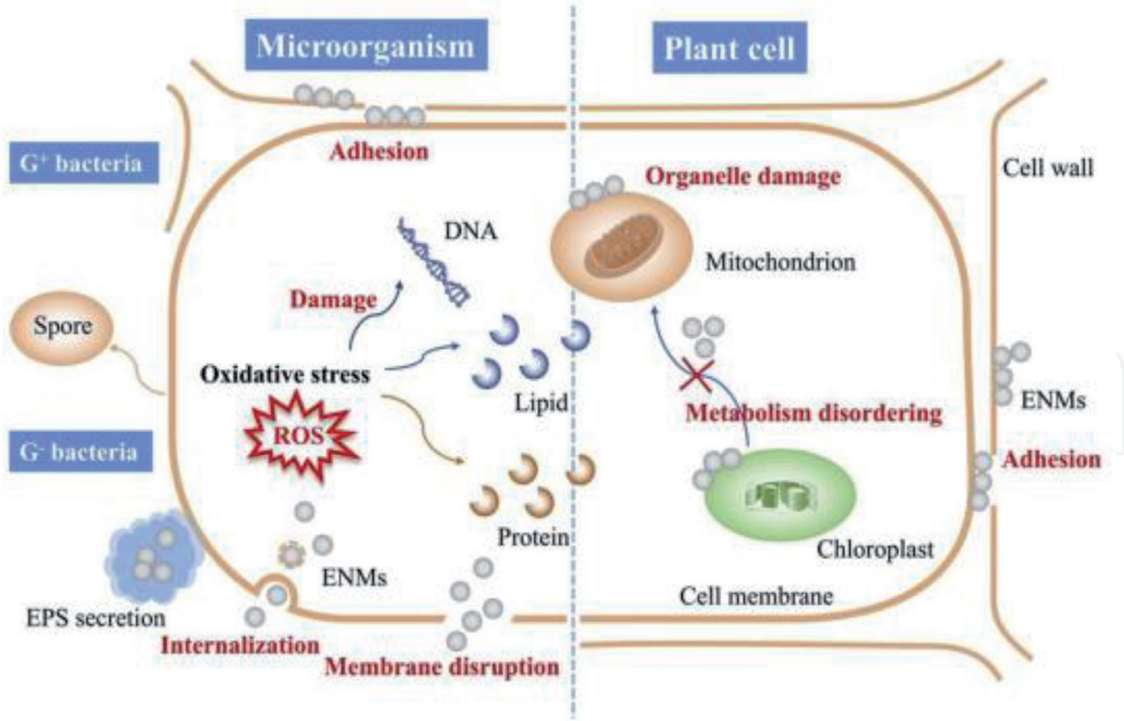

Figure 6.
Possible toxicity mechanisms of engineered nanomaterials (ENMs) at the cellular level (top left: Gram-positive (G + ve) bacteria; bottom left: Gram negative (G – ve) bacteria; right: Plant cells [29].

2.7 Disadvantages of using nanoparticles

i. Difference in function of natural and synthesized nanoparticles.

ii. Specific surface properties and chemistry for specific soil contaminants.

iii. Shows toxicity at certain size i.e. if size is less than 100 nm it shows pulmonary toxicity.

iv. Inhalation of nanoparticles can also cause damage inside body for examples FeO nanoparticles if inhaled, it release Fe(III) ion, also cause oxidative damage due to release of Fe (IV) ion.

v. Nanoparticles used in soil pollution degradation like Fe and magnetite responsible for oxidative stress response.

vi. Many studies shows adverse health effects in mammalian cells if expose to Fe oxide nanoparticles [28] (**Figure 6**).

3. Nanotechnology: an approach to improve water quality through nanoparticles

We need fresh water; it is a big task to have abundant fresh water for agriculture and industrial applications [30, 31]. More than one billion people in the world are facing challenges to have fresh water and in near future situation can be worst. It is estimated that the average supply of water to per person will drop by a factor of 1/3rd, which will result in premature death of millions of

people. Non-contaminated water is also not in reach to meet proper agricultural practices [32]. The need of great amount of fresh water is leading towards the contamination of ground water through the use of pesticides, fertilizers and other chemicals.

Novel, sustainable and cost-effective approach is needed to tackle these problems. Nanotechnological researches have enabled us to find the solution for remediation and purification of waste water. Water resources within reach are usually contaminated with pathogens, salts, metals(Cu, Pb, As, etc.), pesticides, herbicides, pharmaceuticals and personal care products (PPCPs) and radioactive elements due to natural occurrences or anthropological activities [33–35].

Although the conventional methods are effective in many ways, still this method are quite outdated and not much cost effective and requires more man power and specificity and also, conventional methods are not applied to lower concentrations of pollutants (**Table 1**).

Methods	Process applied	Remarks
Physical Treatment Methods		
Precipitation	Suitable ion is applied to precipitate the metal salts.	Efficiency is affected by low pH and sludge disposal process makes it expensive.
Ion-exchange	Solid-phase matrix material is used which has ability to exchange cations or anions.	This method cannot handle high metal concentration and is relatively expensive.
Electrowinning	Electric current is passed from an inert anode through a leach solution for the recovery and removal of heavy metals.	The migration of ions to the cathode surface creates a 'zone of depletion', which hinders the process.
Electrocoagulation	Electro-chemical based approach when electric current is used to remove metals from solution.	It is an intensive process and places a lot of strains on electrodes, resulting in wear and tear.
Cementation	A type of precipitation involving an electrochemical approach in which metals with greater oxidation capacity flows into the solution.	Efficiency is influenced by various factors, such as pH, surface area of absorbent and its surface energy, etc.
Membrane filtration	Separation of metals from water takes place by semi-permeable membrane with pressure gradient.	Water pretreatment and monitoring makes the process expensive.
Electrodialysis	Analogous to RO except for Driving force in which electric field is applied across semi-permeable membrane.	Efficiency is affected by porosity, pH, flow rate, conductivity, etc.
Chemical Treatment Methods		
Reduction	Reductants (H_2S, diothionites) are injected deeply to polluted regions.	Toxic intermediate formation takes place.
Chemical washing	Heavy metals are directly removed by means of strong extrants like acids.	Deterioration of soil quality, which is hazardous to surrounding.
Chelate flushing	Chelating agents are used for extracting huge quantity of heavy metals.	Chelates are expensive and carcinogenic.

Table 1.
Physical and chemical methods used for remediation.

The conventional methods which are used in removing pollutants and particulate matters are broadly categorized into three categories:

1. Physical treatment methods

2. Chemical treatment methods

3. Biological treatment methods

The most promising methods can be said to be the biological treatment methods which includes bioremediation through different organisms, biofiltration, biosorption, etc. These are basically useful for in-situ treatment but these are slow processes and take much time but cheap and cost-effective. Biological treatment methods are quite effective but in current scenario these cannot fulfill the human requirements as pollution is many folds so a quick and highly efficient method is needed which can be fulfilled by use of nanoparticles which are quite fascinating in present days.

3.1 Nanoremediation

Nanoremediation has played an efficient and effective solution for challenges of site remediation and for the process of environmental cleanup in a cost effective manner. As their sizes are too small and have unique surface coating, these can pass through the smallest spaces and can remain suspended in ground water and then can go farther at larger distribution.

3.2 Nano bioremediation of heavy metals

The major global concern is contamination of heavy metals because of their toxicity and threat to flora and fauna [36]. Anthropogenic activities are the main cause for pollution of heavy metals. There are 65 groups of heavy metals which can be distinguished on a number of criteria, like cationic- hydroxide formation, specific gravity >5 g/ml, complex formation, hard- soft acids and bases, eutrophication and environmental toxicity. Higher doses can cause birth defects, cancer, skin lesions, retardation, major organ damage such as liver and kidneys [37]. Industries of electroplating, cement, paint, etc. discharges heavy metals such as Cd, Cu, Pb, Hg, Ni, Zn and As which are highly toxic to living organisms. The waste water is directly discharged to water bodies without any prior treatment. These can cause serious mutations and Physiological damages to organisms of habitat [38].

If possible, we will be pleased to have uses of microbes in bioremediation of toxic heavy metals with interest of nanofabrication of environmentally useful submicron scale particles. In that condition, microbes can be utilized in an eco-friendly and effective remediation of heavy metals [39].

There are mainly three attributes of nanotechnology which are being used in nanobioremediation-

a. Use of clean and green nanoparticles

b. To remove hazardous materials from composite sites

c. Act as an environmental sensor [40, 41]

Nanobioremediation prefers in-situ treatment of contaminants because it's economical, highly efficient and can be applied on larger scale [42].

3.3 Nanoiron and its derivatives

The nano zero-valent iron (nZVI) is most widely used nanomaterial. These are helpful in removing aqueous contaminants by reductive dechlorination or by reducing to an insoluble form, in case of chlorinated solvents and in case of aqueous metal ions respectively. Iron will also go for 'redox' reaction with dissolved oxygen and water. Heavy metals such as As and Cr, pesticides, chlorinated solvents and nitrates can be removed from ground water and water bodies using nZVI. The zero valent iron can be used to remove highly toxic, mobile and predominant arsenic species [As(III) and As(V)] in anoxic ground water (**Figure 7**) [44].

3.4 Single-enzyme nanoparticles

Enzymes are biocatalysts, can enhance the process of bioremediation. Their usefulness in economical way is limited as compared to synthetic catalysts, as the enzymes lack stability and longer catalytic life. To increase the stability in an effective way, magnetic iron nanoparticles can be made and on applying magnetic field these can be separated out from reactants or products [45].

3.5 Dendrimers

The word "*dendrimers*" is a Greek word, where "*dendri*" means like a branch of tree and "*meros*" means part of tree. These are highly branched and

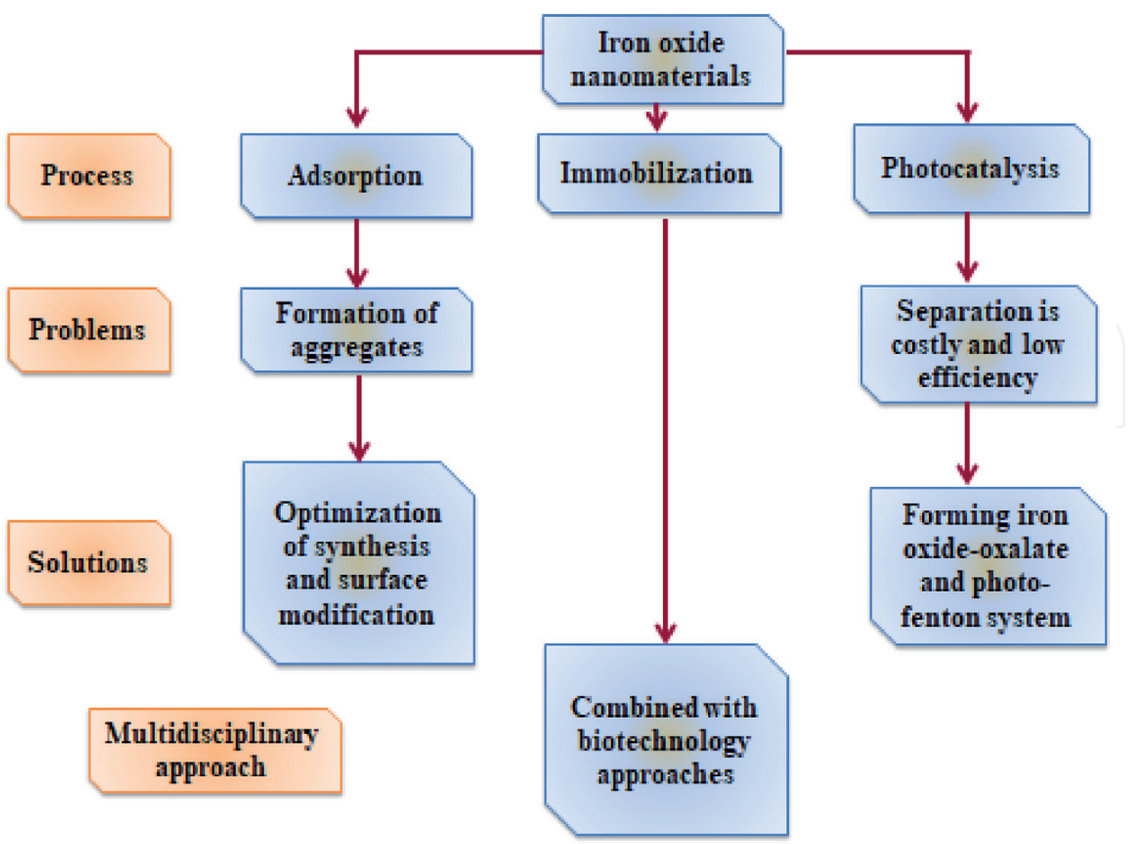

Figure 7.
Iron-oxide Nano-materials (NMs) for removal of heavy metals [43].

mono-disperse macromolecule of polymers [46–48]. These show a great potential in environmental applications. The composite, Dendrimers-NPs can be used to enhance catalytic activity due to less toxicity and more reactivity and more surface areas [49, 50].

3.6 Titanium dioxide (TiO_2) based nanoparticles (NPs)

Semiconducting, photolytic, energy-converting, electrical and gas sensing capabilities are found in TiO_2. Rutile, anatase and brookite are three polymorphs of TiO_2 crystals found in nature. These NPs are commonly available, affordable and non-toxic that's why these can be used to remove organic contaminants. The light energy is greater than band gap of semiconductor TiO_2 is necessary for the removal of different organic pollutants [51].

3.7 Bimetallic NPs

Halogenated Organic Compounds (HOCs) can be easily transformed to low or no toxic material by metals such as Zinc and Tin, which are more effective as compared to Iron. The complete dechlorination of many chlorinated aliphatic compounds to hydrocarbons can be achieved by superior catalytic ability of Palladized iron [52–54].

3.8 Photocatalytic NMs

Photocatalysis is used in the deterioration of organic contaminants in an effective manner, it is an advanced oxidation process (AOP). Even, trace amounts of pathogens and pollutants can be removed by oxidation process through photocatalysis. Catalyzation and other methods to modify NMs can improve the efficiency and remediation speed [55, 56].

3.9 Air pollution

Air pollution can be defined in many ways, one of the most used definitions of air pollution is the occurrence of chemical compounds in the atmospheric air that are toxic and present at concentration that may be injurious to animals, vegetation and humans. Air pollution decrease the quality of air due to presence of chemicals which are not present originally but resulting of human activity and it also change the lives on earth because of global warming and depletion of ozone layer [57].

3.10 Types of air pollutants

Air pollutants can be different types depending on the source, form and condition under which pollutants are generated.

3.10.1 Primary pollutants

Primary pollutants are the pollutants which are discharged directly in air.
For examples:
Particulate matter (PM10 and PM2.5); Carbon oxides (e.g. carbon monoxide); Oxides of sulfur; Ammonia; Light hydrocarbons; Volatile organic compounds; Metals (lead, mercury, cadmium) [58].

3.10.2 Secondary pollutants

Secondary pollutants are the pollutants which are formed when the chemical reaction occur between two gases present in the atmosphere.

For examples:

Sulfur dioxide, oxides of nitrogen, ammonia and non-methane volatile organic compound [58].

3.11 Causes of air pollution

Air pollution can be cause by naturally as well as man-made activities.

The examples of natural sources are emissions from plants, from the biomass of the ocean, volcanic gas and the re-suspension of dust in arid areas such as deserts.

The examples of man- made source are combustion engines (both diesel and petrol), household and industry solidfuel combustion for energy production (coal, lignite, heavy oil and biomass), other industrial activities (building, mining, manufacture of cement, smelting), agriculture, with the use of entrants, and the erosion of roads by vehicles and abrasion of brakes and tyres [59].

3.12 Other causes are

3.12.1 Urbanization and industrialization

Urbanization and Industrialization are one of the major cause of air pollution due to urbanization there is increase in use of automobiles and due to industrialization there is an increase in cutting of trees which increase the air pollution rapidly [59].

3.12.2 Burning of fossil fuels

Burning of fossil fuels is also the main cause of air pollution. Burning of fossil fuel can release a variety of primary and secondary pollutants as well as airborne oxide and also SO2, CO2, CO, hydrocarbons, organic compounds, chemicals, and nitrogen oxides (NOx). Due to burning of fossil fuel climates change and global warming is also increase due to release of major greenhouse gases (carbon dioxide, methane (CH4), nitrous oxide, and fluorinated gases) [59].

3.13 Effect of air pollution

The air pollution shows adverse effect on human health and causes many diseases like acute respiratory infection, pulmonary disease, cardiovascular disease etc.

3.13.1 Acute respiratory infection (ARI)

Acute respiratory infection is one of the common disease causes by air pollution. In this the pollutants can effects the lungs and show some symptoms like cough, sinusitis and ditis media [60].

3.13.2 Pulmonary disease

Pulmonary disease can cause due to inhalation of air pollutants which cause allergic disease and pulmonary disease such as asthma, atopic dermatitis and allergic rhinitis and lung cancer [60].

3.13.3 Cardiovascular disease (CVDs)

The pollutants like PM, PAHs, CO, heavy metal, and other organic pollutants are the main cause of cardiovascular disease [61].

Cardiovascular disease is severe when particulate matter increases and shows symptoms like ischemic stroke, myocardial infarction, cardiac arrhythmia, heart failure, and atrial fibrillation [62].

Particulate matter is one of the major factors which cause CVDs and induce the oxidative stress, systemic inflammation and increases the blood coagulability, and autonomic and vascular imbalance [60].

3.14 Nano-remediation of air pollution

Air pollution can be remediated in many ways and one of the best ways is use of nanoparticles like nanocatalyst, nano-membranes and photocatalyst semiconductor.

Nanocatalyst helps in gaseous exchange by increasing the surface area for the reaction of gases which increases the chemical reaction and help in conversion of harmful gases which are release from cars and industries into harmless gases. Nanofibre catalysts are one of the examples which are used in industries for the removal of organic compounds from the smoke stacks.

Nanostructured membrane is another way to separate methane or carbon dioxide from smoke due to having small pores. The best example is the Carbon nanotubes (CNTs) which are more efficient than other membrane for trapping greenhouse gases which is released by the mining and power generation. CNTs have major advantages as it can trap gases hundred times faster than other membranes [61].

The other approach for the remediation of air pollution is using of nanosize semiconductor photocatalyst. Photocatalyst are the catalyst that oxidized organic pollutants into nontoxic materials for examples titanium dioxide (TiO2), zinc oxide (ZnO), iron (III) oxide (Fe2O3) and tungsten oxide (WO3) and used in many ways [11].

Photocatalyst and semiconductor can use together to remediate air pollution by using the principle of semiconductor i.e. oxidizing of organic molecules by light. The process includes, at a sufficient light exposure the charge is moved from valence band to conduction band and causes the oxidation of surrounding substance. The semiconductor photocatalyst can be modified according to reactivity and selectivity [63].

4. Challenges of using NPs

There are several problems related in in-situ transport processes of nano-particles which depict the reactivity loss of zero valent ion-particles with time [64, 65]. Apart from this, several researchers have found that the in-situ application of nano-particles leads to clustering effect enhanced the deposition of nano-particles which blocks the pore of soil due to which difficulty faced to reach the targeted contaminated areas [66, 67]. Due to clogging effect of soil, filtration process becomes major issue in use of nZVI remediation. Besides this, NPs are denser than water molecules which lead to settle down of NPs in fluid medium, causing clogging effect [68].

Many studies have shown the effectiveness of nZVI application, but its effects to local microbes are still in early stages [69–72]. Lonf term effects and ethical issues related to use of NPs are hindrance to environmental agencies to implement NPs on

field scale. Hence, application of NPs primarily depends on regulatory affairs and policies of each country, that's why use of NPs is limited to European countries and nZVI extensively used in US [73–75].

There is a great concern related to use of NPs due to their negative effect on microbes. Number of studies has been done to address the toxicity of NPs with microbes. However, these studies have been performed on controlled laboratory conditions [76–81]. However, contrary results have also been reported with some studies showing inhibitory effects on microbes where as some of the studies have showing stimulatory effects of NPs [82].

Thus, till date the existing results are controversial and lacks proper studies on field level as these studies are based on type of NPs and tested microbes, pollutants and also, several studies have used specific culture media in controlled lab environment [83].

5. Future prospects

The field of nanotechnology has gained attention among the researchers due to its number of beneficial effects like large surface area, multiple uses, tolerance to harsh conditions, easy and efficient manipulations, greater efficiency and many more.

We are marching towards a greener approach in management of industrial effluents due to the integration of NPs with microbes and enzymes [14, 84]. The residues left are either biocompatible or they can be easily removed by using simple filtration or precipitation techniques.

Continuous studies and its merits provide a vision for new discoveries into products. It is possible to produce synthetic 'living-like' or 'nano-bots' type things which will remediate hazardous pollutants and heavy metals from environments. So, the application of these organisms/products on a large scale will be a stepping stone for industries and environment.

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