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EFFECTIVENESS OF NANOMATERIAL IN ENVIRONMENTAL POLLUTION

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Abstract:
Environmental contamination is without a doubt one of the most serious issues confronting civilization today. New technologies for the cleanup of toxins in the air, water, and soil are continually being developed. Particulate matter, heavy metals, pesticides, herbicides, fertilizers, oil spills, poisonous gases, industrial effluents, sewage, and organic compounds are just a few of the numerous contaminants to be concerned about. Because different materials can be used in environmental rehabilitation, a wide range of methodologies can be used for this purpose.

Keywords:
Contamination, civilization, particulate matter, rehabilitation

Details:
Environmental contamination is without a doubt one of the most serious issues confronting civilization today. New technologies for the cleanup of toxins in the air, water, and soil are continually being developed. Particulate matter, heavy metals, pesticides, herbicides, fertilisers, oil spills, poisonous gases, industrial effluents, sewage, and organic compounds are just a few of the numerous contaminants to be concerned about. Because different materials can be used in environmental rehabilitation, a wide range of methodologies can be used for this purpose. Due to the complexity of the mixture of diverse compounds, high volatility, and low reactivity, the capture and degradation of environmental pollutants can be difficult. Recent studies have focused on the use of nanomaterials for the development of new environmental remediation methods.
Nanotechnology has gained a lot of attention in the past few decades due to the unique physical properties of nanoscale materials. Because of their larger surface-to-volume ratio, nanomaterials have greater reactivity and, consequently, greater effectiveness when compared to their bulkier counterparts. Furthermore, as compared to standard techniques, nanomaterials have the ability to exploit unique surface chemistry, allowing them to be functionalized or grafted with functional groups that can target specific molecules of interest (pollutants) for efficient remediation. Furthermore, intentional adjustment of nanomaterial physical parameters (such as size, shape, porosity, and chemical composition) might bestow additional favourable qualities that directly improve the material's effectiveness for pollutant remediation. The complex surface modification chemistry of the nanomaterial, together with its customizable physical properties, provides considerable advantages over current approaches for dealing with environmental contaminants. Methods constructed as a combination of several different materials (hybrids or composites), gaining certain desirable features from each of their components, may be more efficient, selective, and stable than methods based on a single nanoplatform. When compared to using nanoparticles alone, attaching nanoparticles to a scaffold, for example, can be an alternative technique to boost the material's stability. Material selectivity and efficiency can be increased by functionalizing it with specific compounds responsible for targeting contaminating molecules of interest.
It is critical that the materials used to clean up pollution do not become another contaminant once they have been used. As a result, biodegradable materials are particularly appealing for this application. The use of biodegradable materials may not only increase consumer confidence and acceptance of a particular technology because there is no material waste to be disposed of after treatment, but it may also offer a greener and safer alternative for pollutant environmental remediation. Furthermore, new methods that focus on target-specific capture of pollutants are particularly appealing since they can overcome low efficiency caused by off-targeting. As a result, various studies have focused on using nanotechnology principles and combining them with chemical and physical modification of the surface of the materials

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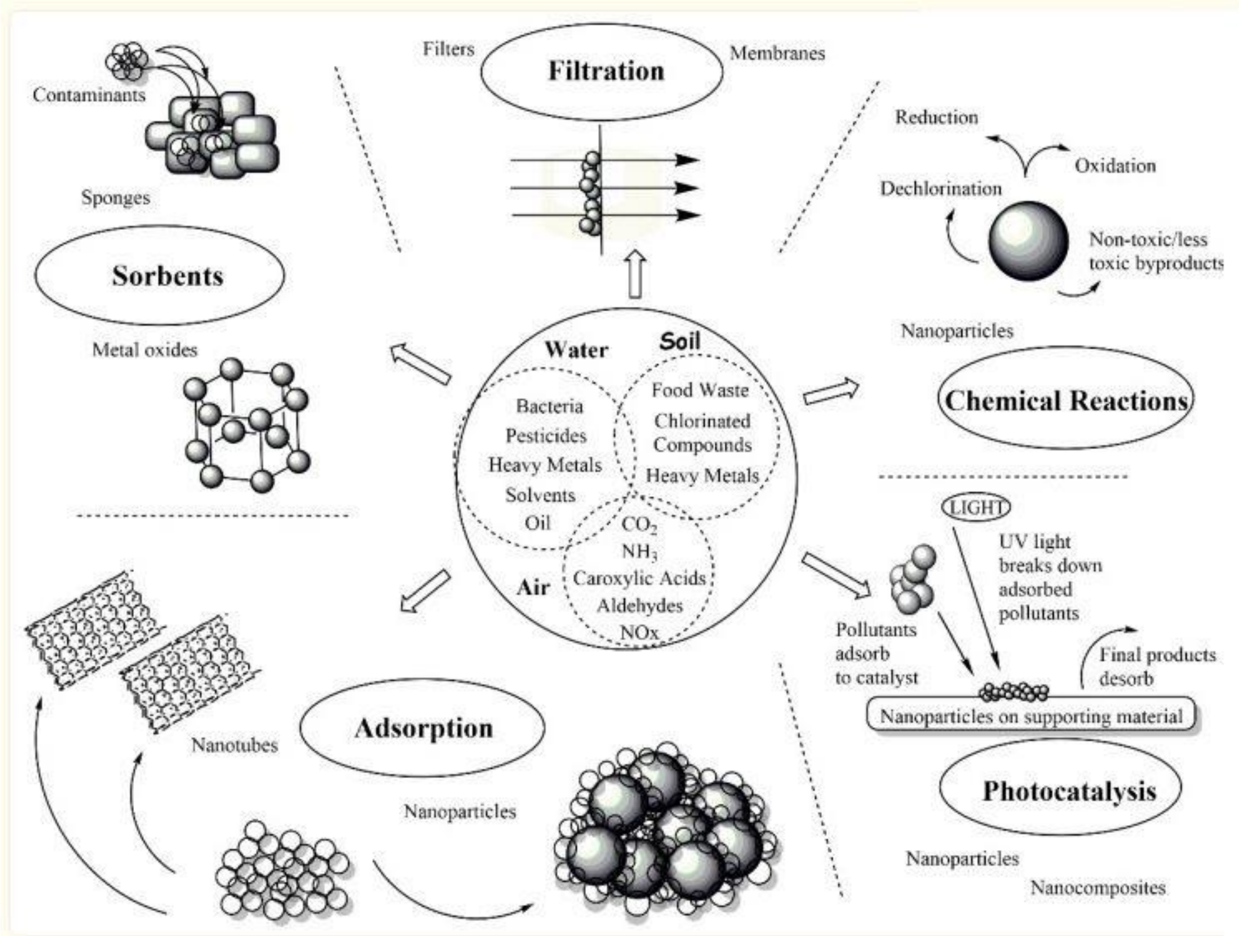
in an effort to obtain engineered materials that can overcome many of the challenges associated with contaminant remediation. Some of the key challenges that must be considered when developing new nanomaterials for environmental remediation are target-specific capture, cost effectiveness, simple synthesis, green chemistry, non-toxicity, biodegradability, recyclability, and the potential for recovery after use (regeneration). Despite the potential benefits of the nanomaterials outlined above, several are intrinsically unstable under normal settings, necessitating the use of special nanoscale formulation processes. Additional processes are required to avoid agglomeration, improve monodispersity, and improve stability. Another concern that may limit their utilisation is the potential toxicity of metallic nanoparticles used in the remediation process, as well as their byproducts and recovery expenses from the remediation site. This is why developing good nanomaterial candidates capable of solving environmental challenges necessitates a thorough grasp of material platforms, fabrication processes, and performance optimisation.
A broad overview of some of the most recent achievements in the production of functional nanomaterials and nanocomposites for the environmental rehabilitation of various contaminants Absorption, adsorption, chemical reactions, photocatalysis, and filtering are just a few of the many ways a pollutant can be removed, as seen in Figure 1.



A variety of different materials can be used for the approaches described in Figure 1.
Three main types of nanomaterials described in the literature:

1. inorganic,
2. carbon-based, and
3. polymer-based materials.

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Each of these classes and their applications will be discussed in the following sections.

2. Inorganic Nanomaterials

2.1 Metal-and Metal Oxide-Based Nanomaterials

Various metal-based nanomaterials have been described for the remediation of a wide range of contaminants, although the great majority of research have focused on the removal of heavy metals and chlorinated organic pollutants from water. Metal and metal oxide nanoparticles are highly efficient adsorbents with quick kinetics and great adsorption capacity. Because nanoparticles are very adaptable to both in situ and ex situ uses in aqueous environments, they are widely used for environmental cleanup. Table 1 summarises some of the various metal-based materials studied for various environmental remediation applications.

Material	Application
Ag NPs/Ag ions	Water disinfectant—*E. coli*
TiO_2 NPs	Water disinfectant, soil—MS-2 phage, *E. coli*, hepatitis B virus, aromatic hydrocarbons, biological nitrogen, phenanthrene
Metal-doped TiO_2	Water contaminants—2-chlorophenol, endotoxin, *E. coli*, Rhodamine B, *Staphylococcus aureus*
Titanate nanotubes	Gaseous—Nitric oxide
Binary mixed oxide	Water—Methylene blue dye
Iron-based	Water—Heavy metals, chlorinated organic solvents
Bimetallic NPs	Water, soil—Chlorinated and brominated contaminants

Table-1

Metal-based nanomaterials and applications in environmental remediation of contaminants

Silver nanoparticles (AgNPs) are widely used as water disinfectants due to their substantial antibacterial, antifungal, and antiviral activity. AgNPs of diameters less than 10 nm, for example, were discovered to be highly hazardous to Escherichia coli and Pseudomonas aeruginosa. They can also block viruses from binding to host cells by binding to the virus's glycoproteins preferentially. Smaller particle sizes (11-23 nm) have reduced bactericidal action. Furthermore, triangular AgNPs outperformed Ag nanorods and Ag nanospheres in antibacterial activity, highlighting the importance of particle shape in eliciting desirable effects.

Titanium oxides are another frequently researched metal-based substance for environmental cleanup. Because of their low cost, nontoxicity, semiconducting, photocatalytic, electronic, gas sensing, and energy conversion capabilities, TiO2 NPs have been widely explored for waste treatment, air purification, self-cleaning of surfaces, and as a photocatalyst in water treatment applications. Because TiO2 NPs are light activated, they are often researched for their capacity to remove organic pollutants from diverse media. TiO2 nanoparticles have the ability to produce highly reactive oxidants such as hydroxyl radicals, which operate as a disinfectant for microorganisms such as fungi, bacteria, viruses, and algae.

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Park and Lee used a sol-gel electrospinning approach to create TiO_2 nanofibers (control) and Ag-doped TiO_2 nanofibers. These materials were then tested as photocatalyst candidates for the photocatalytic degradation of 2-chlorophenol in the presence of UV light.

Titanates (i.e., inorganic titanium oxide compounds) have also been reported for contaminant removal in addition to titanium oxide materials. Chen et al., for example, described the hydrothermal production of basic, acidic, and neutral titanate nanotubes (TNTs). The neutral Mn/TNTs had the highest surface area, the best active species dispersion, and the most active redox performance of the series. Thus, the neutral Mn/TNTs demonstrated the highest catalytic reduction activity, while the basic Mn/TNTs demonstrated insignificant activity.

Rasalingam et al. described the synthesis of TiO_2-SiO_2 binary mixed oxide materials with bamboo as a silica source and titanium isopropoxide or titanium butoxide. These mixed oxide materials have improved their ability to remove a wide range of contaminants.

2.2. Silica Nanomaterials

Mesoporous silica materials have acquired popularity for a variety of applications, including adsorption and catalysis, due to their versatility. Mesoporous silica materials provide several advantages for environmental cleanup applications, including high surface area, easy surface modification, huge pore volumes, and controllable pore size.

Material	Application
Amine-modified xerogels	Gaseous—CO_2, H_2S
Amine-modified aluminosilicates and porous silica	Gaseous—CO_2, aldehydes, ketones
Carboxylic acid-functionalized mesoporous silica	Wastewater—Cationic dyes, heavy metals
Amino-functionalized mesoporous silica	Wastewater—Heavy metals
Thiol-functionalized mesoporous silica	Wastewater—Heavy metals

Table-2

Silica nanomaterials and applications in environmental remediation of contaminants

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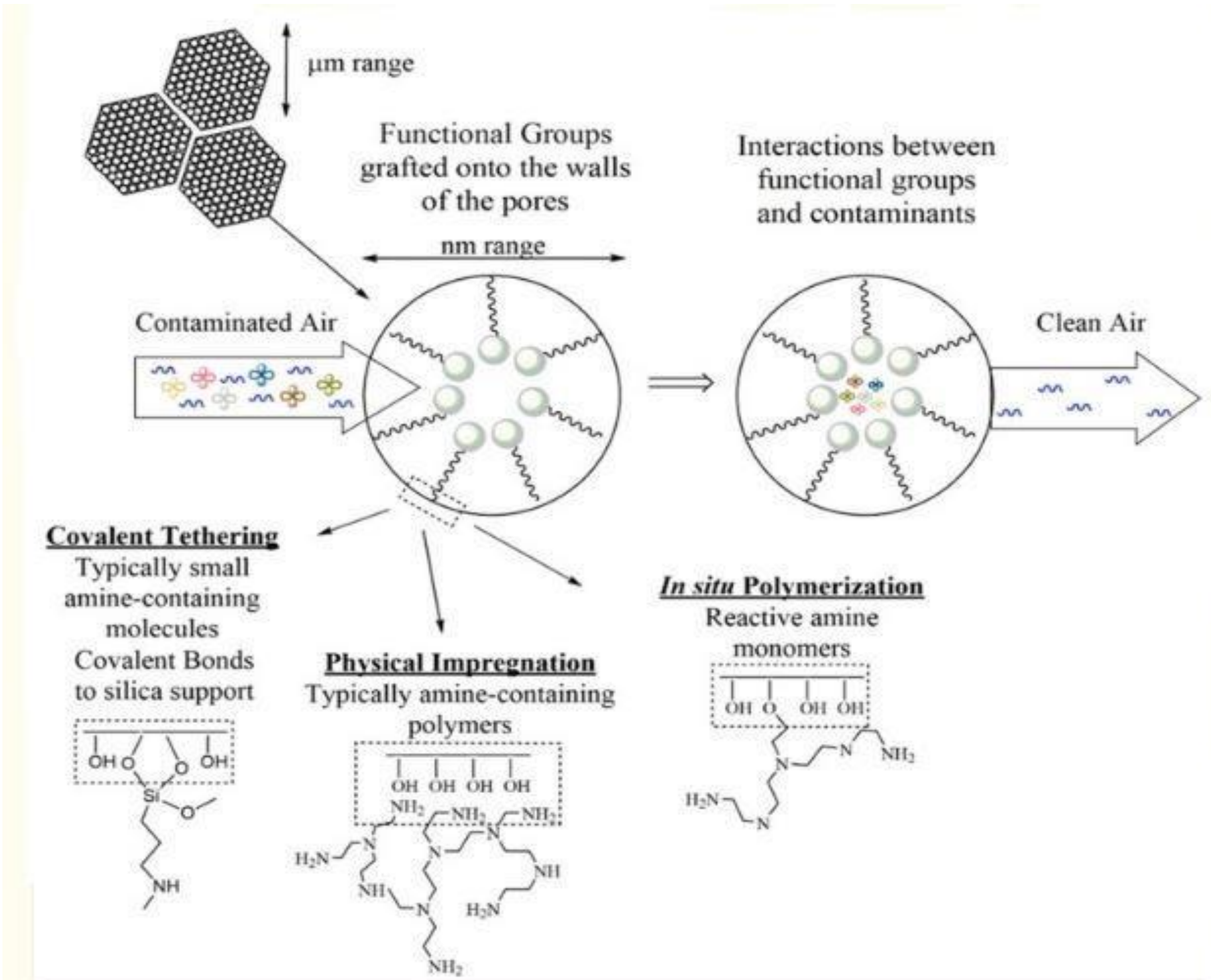

Figure-2
An example of mesoporous silica materials used for environmental remediation of contaminants.

3. Carbon- Based Nanomaterials

When compared to metal-based nanomaterials, the distinctive physical, chemical, and electrical properties of carbonaceous materials are attributed to the structural composition of elemental carbon and its malleable hybridization states. Mutable hybridization states can produce fullerene C60, fullerene C540, single-walled nanotubes, multi-walled nanotubes, and graphene, among others. Surface treatments, activation, or functionalization of the virgin carbon material is first required, according to a number of studies establishing the feasibility of carbon nanotubes and graphene for environmental remediation applications. Many investigations have been conducted on multi-walled and single-walled carbon nanotubes (MWCNTs and SWCNTs). These materials' adsorption capabilities make them particularly helpful for removing organic and inorganic contaminants from air and huge quantities of aqueous solution. Photocatalytic techniques are also used to remediate pollutants using carbon-based nanomaterials. Figure 4 depicts the photocatalytic approach to environmental pollutant cleanup. Photons with energies larger than or equal to the band gap of the nanotubes enhance the formation of valence band holes (h+) and conduction band electrons (e^-) when exposed to UV light. The holes cause the production of hydroxyl radicals, which participate in the oxidation of

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chlorinated organic molecules. The electrons combine to generate superoxide radicals, which aid in the elimination of heavy metal pollutants. Several studies on the usage of graphene to create photocatalytic nanocomposites have been published. Due to an increase in conductivity, graphene composites containing TiO_2 NPs exhibit higher photocatalytic activity when compared to bare TiO_2 NPs.

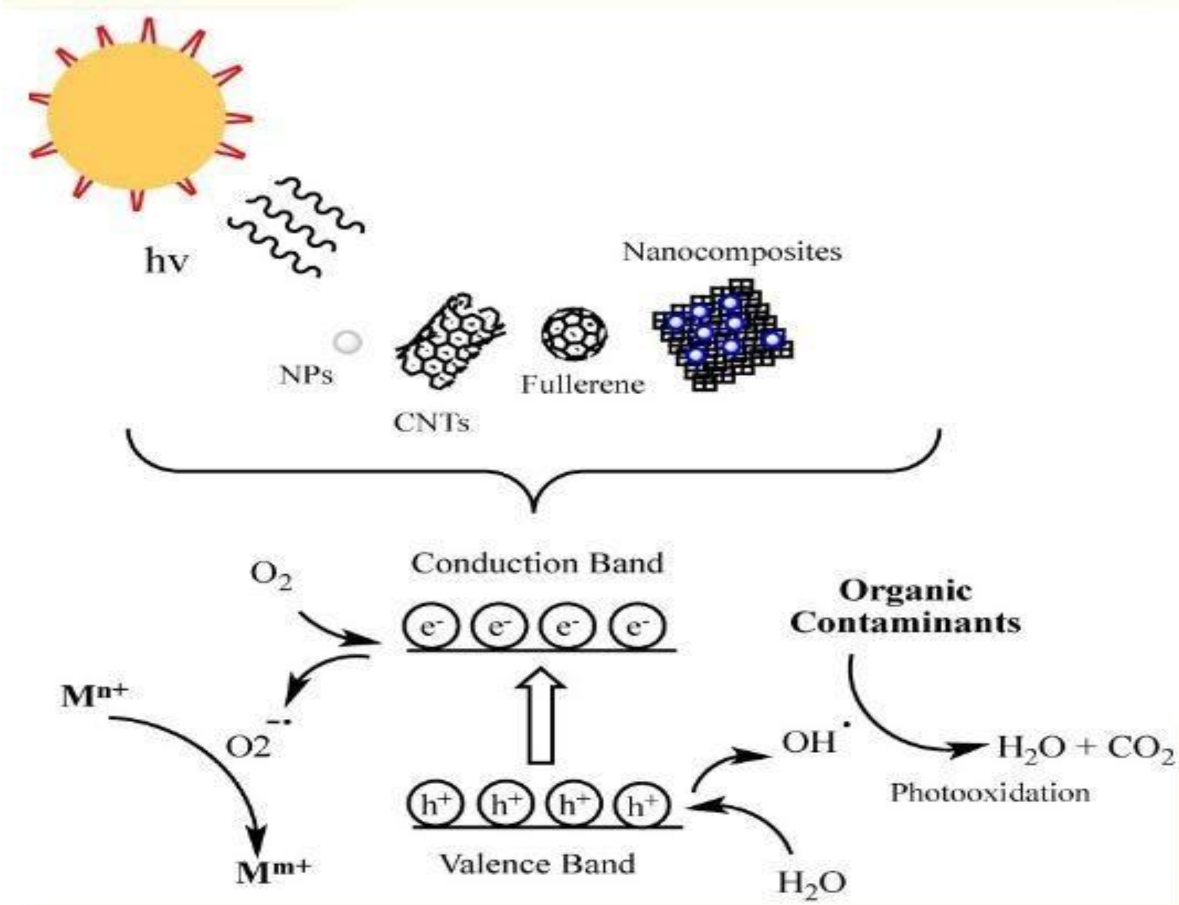

Figure-3
Photocatalytic degradation mechanisms of metal and organic contaminants

3.1. Graphene Materials

Both pristine graphene or its modified form have been investigated for environmental remediation applications. Table 3 summarizes some of the different types and its applications in environmental remediation.

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Material	Application
Pristine graphene	Water—Fluoride
Graphene oxide	Water/Gaseous—SO_x, H_2, NH_3, heavy metals, pesticides, pharmaceuticals
ZnO-graphene/CdS-graphene	Water—Heavy metals
TiO_2-graphene	Gaseous—Benzene

Table-3
Graphene materials and their use in environmental remediation

3.2 Carbon Nanotube (CNTs)

Specifically, efforts have been made to open the closed ends of virgin carbon nanotubes in order to improve their adsorption capabilities. SWCNTs are typically organised in a hexagonal pattern (one nanotube surrounded by six others), resulting in bundles of aligned tubes with a heterogeneous, porous structure. Adsorption can occur in four different available sites for a typical open-ended CNT bundle, which are of two types: those with lower adsorption energy, localised on the external surfaces of the external CNTs composing the bundle, and those with higher adsorption energy, localised either between two neighbouring tubes or within an individual tube. Because the exterior sites are directly exposed to the adsorbing substance, adsorption on external sites approaches equilibrium considerably faster than adsorption on internal sites. MWCNTs are rarely found in bundles, unless specialised methods of preparation are applied to create such arrangements. In their nitrogen adsorption research, Yang et al. proved that distinct types of pores (i.e., inner and aggregated) form a multi-stage adsorption process. Aggregated pores were found to be more significantly responsible for these materials' adsorption capabilities than the less accessible interior pores.
In conclusion, Without alteration, virgin carbon-based nanomaterials are frequently inert towards environmental pollutants. To boost their efficiency, they are usually modified or coated with additional reactive materials that have the required functional groups or charges. As a result, these hybrid materials combine numerous properties into a single template in order to achieve the necessary performance.

4. Polymer- Based Nanomaterials

Although the high surface area-to-volume ratio of nanoparticles contributes to better reactivity and improved performance, aggregation, non-specificity, and low stability can limit the utilisation of these nanotechnologies due to a lack of functionality. Another method for improving the stability of nanoscale materials is to use a host material, which serves as a matrix or support for other types of materials (e.g., NPs).
Table 4 summarises several polymer-based nanoparticles utilised for environmental pollutant treatment.

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Material	Application
Amphiphilic polyurethane NPs	Soil—Polynuclear aromatic hydrocarbons
PAMAM dendrimers	Wastewater—Heavy metals
Amine-modified PDLLA-PEG	Gaseous—VOCs
Polyamine-modified Cellulose	Gaseous—VOCs
Polymer nanocomposites (PNCs)	Water—Metal ions, dyes, microorganisms

Table-4
Polymer-based materials for environmental remediation of contaminants

Type of Nanoparticles	Removal Target
Ag-doped TiO_2	2,4,6-Trichlorophenol
Ag-doped TiO_2 nanofibers	Methylene blue dye
Cu/Fe/Ag-doped TiO_2	Nitrate (NO_3^-)
Silica nanoparticles prepared by mixing salicylic acid and hyper-branched poly (propylene imine)	Removal of polycyclic aromatic hydrocarbons (PAH), such as pyrene and phenanthrene, and Pb^{2+}, Hg^{2+}, Cd^{2+}, $Cr_2O_7^{2-}$ from contaminated aqueous solutions
PAMAM dendrimer composite membrane consisting of chitosan and a dendrimer	Separation of CO_2 from a feed gas mixture of CO_2 and N_2 on porous substrates
Fe^0 coated with carboxymethyl cellulose polymer matrix	Hexavalent chromium (Cr^{6+}) from aqueous solutions
Gold coated with chitosan polymer	Zn^{2+}, Cu^{2+} form aqueous solutions
Poly (methacrylic acid)-grafted chitosan/bentonite	Th^{4+}
Carbon nanotubes/Al_2O_3 nanocomposite	Fluoride
Multiwall carbon nanotube (MWCTs)	Zn^{2+}

Table-5
Lists of some examples of additional nanomaterials for environmental application

5. Conclusions

Inorganic, carbonaceous, and polymeric nanoparticles are examples of materials that can be successfully used in a wide range of environmental remediation applications. Choosing the best nanomaterial to mitigate a specific pollutant in a specific environmental context necessitates a thorough examination of the contaminant to be removed, accessibility to the remediation site, the amount of material required to implement efficient remediation, and whether it is advantageous to recover the remediation nanomaterial (recycling). Because each material has its own set of benefits and drawbacks in terms of application, we have provided an overview of various nanomaterials that have been used in the area of environmental restoration.

Numerous studies have been conducted to study the use of nanotechnology, issues about the use of nanotechnology for environmental restoration have yet to be addressed. Furthermore, while many studies show efficacy in laboratory settings, more research is needed to fully understand how nanotechnology can significantly affect environmental contaminant remediation in real-world scenarios (e.g., the remediation of contaminated water, soil, and air from industrial processes). Furthermore, while the methods by which the various nanotechnologies are used are well understood, what happens to these materials after they have been used for pollutant capture or degradation is unknown. Despite the fact that the recyclability of some materials has been detailed, it appears that at some time the efficacy of these materials will be compromised. Therefore, research is necessary to elucidate the fate of these materials after

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introduction to the environment for remediation purposes in order to avoid the possibility of these materials becoming themselves a source of environmental contamination.

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