NANOTECHNOLOGY IN ENVIRONMENTAL REMEDIATION: PERSPECTIVES AND PROSPECTS

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Nanotechnology in Environmental Remediation: Perspectives and Prospects

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FOREWORD

In recent years, the rapid growth in the domain of nanotechnology has opened up new horizons to address some of the most serious environmental issues. The fusion of nanotechnology and nanotechnological methods carries enormous potential to enhance the cost-effectiveness, potency, efficiency, and sustainability of efforts of environmental protection and pollution control for environmental remediation. This book, "Nanotechnology in Environmental Remediation: Perspectives and Prospects," exhibits a comprehensive analysis of the applications, recent advancements, and prospects of nanotechnology in the field of environmental remediation and protection.

The book starts with an insightful introduction to the origins of several contaminants and pollutants across distinct environmental zones. This deep and basic knowledge contributes to developing a better understanding of the necessity and scope of nanotechnological advancements related to environmental protection. The following chapters scrutinize the synthesis, characterizations, and properties of different types of nanomaterials for the remediation of the environment and also highlight the uniqueness and potency of nanomaterials.

Nanomaterials in the wastewater treatment section of the book will surely create awareness amongst the readers about the advanced materials that effectively remove impurities from wastewater, thereby improving water quality and availability. The application of nanotechnology and nanomaterials for the remediation of soil and air has also been thoroughly discussed, presenting unique solutions to tackle pollution in the environment.

A commendable feature of this book is to focus on several types of specialized nanomaterials, such as carbon nanomaterials, nanocomposites, metal oxides, polymers, and materials for the degradation of toxic organic pollutants. Each chapter of this book offers deep insights into the advantages, mechanisms, and effectiveness of these materials, supported by recent advanced research studies.

Further chapters show the utilization of different kinds of nanomaterials in environmental detection and remediation along with their applications, such as nanobiosensors and photocatalytic properties. These aforementioned technologies contribute to the early detection of several types of environmental pollutants, which proactively helps in environmental protection strategies.

The book also draws attention to its broader themes like the social and environmental implications of different nanomaterials, green nanotechnology, sustainability, and the risk of nanotechnological applications. These analyses are very necessary to certify that the utilization and growth of nanotechnologies are ethical, safe, and sustainable for the environment.

Ultimately, the book offers a wide range of perspectives regarding the future directions, challenges, and applications of nanotechnology in the remediation of the environment. This commendable section targets a boarder range of readers like scientists, researchers, practitioners, and policymakers to carry on their research in this innovative and dynamic field.

I appreciate the editors and contributors for their meticulous and comprehensive approach to this multifaceted field. Their collective expertise and thorough analyses make this book an extremely useful resource for scientists, researchers, professionals, students, and technologists interested in the deep analysis of nanotechnology and environmental science.

As we go through the issues of environmental degradation and search for sustainable solutions, "Nanotechnology in Environmental Remediation: Perspectives and Prospects" proves itself a beacon of knowledge that directs us toward a safer, cleaner, and better planet.

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PREFACE

As an emerging field, nanotechnology plays a potential role in environmental remediation. Due to the continuous increase in the level of toxic pollutants, advanced eco-friendly detection and remediation technologies are required. The book focuses on nanotechnology based approaches that offer easier, faster and economical processes in environmental monitoring and remediation. The aim of the book "***Nanotechnology in Environmental Remediation: Perspectives and Prospects***" is to provide comprehensive knowledge related to the use and applications of nanotechnology/nanomaterials for the remediation of environmental contaminants, along with other applications.

The book covers several aspects of nanotechnology in the remediation of air, water, and soil, along with prominent biological applications, and presents recent advances in these fields. Furthermore, the book provides a deep insight into the role of nanotechnology in the decontamination of the environment: tools, methods, and approaches for detection and remediation. It has also addressed the social and economic aspects related to nanotechnology and the toxicological footprint of advanced functional nanomaterials. The safety and sustainability aspects of the use of nanomaterials and future directions in multifaceted aspects of using nanomaterials have also been discussed which will facilitate in formulation of strategies of environmental restoration.

In chapter one, the author has given an overview of environmental nanotechnology by exploring the techniques utilized in the biogenic synthesis of nanoparticles along with their characterization. He has also highlighted how environmental nanotechnology has profoundly influenced all facets of the field, spanning from identification to remediation.

In chapter two, the author has presented an insight into the potential role of nanomaterials in the identification and treatment of wastewater effluents. She has also taken into account the opportunities and risks, highlighting the imperative need for the responsible and cautious application of nanomaterials.

The Authors in chapter three have demonstrated a broad range of prospective nanotechnologies that have been tried to treat and enhance the organoleptic properties of drinking water and wastewater, supplying a safe and harmless liquid to society and the environment in a responsible manner.

The Authors in chapter four have examined the recent advancements achieved in the elimination of contaminants from contaminated water utilizing diverse forms of carbon NMs as adsorptive agents, including graphene, carbon nanotubes, activated carbon, and fullerenes.

The Authors in chapter five have outlined the latest developments in synthetic techniques for the production of copolymer nanocomposites and highlighted their potential uses in environmental remediation. They have also highlighted how there will be a significant increase in the potential applications of copolymer nanocomposites as innovative adsorbents for environmental remediation in the future.

In chapter six, the authors have given a comprehensive insight into biochar-based nanocomposites with precise preparation techniques and their efficacy in eliminating pollutants. According to them, embracing biochar-based nanocomposites represents a crucial step toward promoting cleaner and healthier ecosystems, contributing to a more sustainable future.

In chapter seven, the author has given a detailed account of the mechanism of environmental remediation by biofabricated nano-based adsorbents while also addressing the remediation of persistent organic pollutants. He has also highlighted the long-term development of environmentally benign biofabricated nanomaterial-based adsorbents, along with basic mechanisms as well as societal applications.

The Authors in chapter eight have shed light on nano-bioremediation and phytonanotechnology for the remediation of various categories of pollutants. They have also highlighted why these methods deliver great efficiency at a low cost when applied widely.

The Authors in chapter nine have explored the synthesis of bionanomaterials from various sources, their characterization, and diverse applications in the remediation of different environmental matrices such as water, air, and soil. Furthermore, they have also examined the challenges that need to be addressed and presented prospects for bio-nanomaterials in the ongoing battle against environmental pollution.

In chapter ten, the authors have discussed the principles of green nanotechnology, potential applications of green synthesised nanoparticles in the remediation of air, water, and soil, along with their superiority over other conventional treatment techniques. The authors have also highlighted the limitations and associated challenges so that, with continued research and development, green nanotechnology can ensure a brighter future for generations to come.

The Authors in chapter eleven have presented a comprehensive understanding of the photocatalytic activity and potential of NMs, paving the way for sustainable environmental remediation strategies. They have also discussed how the integration of nanomaterials in sustainable environmental management holds great promise for achieving cleaner air, water, and soil while minimizing the ecological footprint and safeguarding human health for future generations.

The Authors in chapter twelve have given a deep insight into the impact of nanocomposite TiO2 photocatalyst in wastewater effluents. They have also tried to prove the idea of modulating the photocatalytic process and anticipated the potential for using this process to accomplish the utilization of wastewater effluent resources.

The Authors in chapter thirteen have given a comparative account of different types of nanomaterial based carbon-di-oxide sensors and their wide applications in various fields. Their discussion has highlighted the role of carbon dioxide nano-sensors in the agri-food sector, leading to more sustainable methods, less waste, and better use of available resources for environmental monitoring.

The Authors in chapter fourteen have specifically discussed the practical use of a range of nanomaterials for air pollution remediation applications. They have also discussed the pivotal role of nanomaterials as nano adsorbents, nanocatalysts, nanofilters, and nanosensors, showcasing the versatility and effectiveness of nanotechnological applications in this field.

The Authors in chapter fifteen have highlighted the importance of nanotechnology as an innovative technique for the remediation of degraded soil. They have emphasized that the promotion of efficient and sustainable use of nanomaterials can enhance the productivity and fertility of polluted soils to ensure a safe and healthy environment without degrading natural resources.

The Authors in chapter sixteen have highlighted the pivotal role of nanoparticles in the degradation of toxic organic materials by leveraging their unique properties, making nanomaterials a promising solution for addressing environmental pollution and promoting sustainable remediation practices.

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CHAPTER 1

Exploring Environmental Nanotechnology: Synthesis Techniques and Characterization Methods

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Abstract: Environmental nanotechnology deals with environmental issues and plays a crucial role in contemporary science and engineering. These cutting-edge nanomaterials (NMs) are being used for a variety of purposes, with a primary focus on environmental preservation. Understanding matter has been made possible by nanoscience and nanotechnologies, which have significant effects on all industries and economies, including food and agriculture, energy production efficiency, the automobile industry, cosmetics, medicine and pharmaceuticals, computers, weapons, and household appliances. The environmental sector leverages nanotechnology to develop sensors for the detection, monitoring, and analysis of toxic contaminants, contributing to the protection of the environment. The field of nanotechnology is improving the detection of hazardous water-borne compounds and creating new avenues for water purification, desalination, and decontamination. For the purpose of detecting pesticides, NM-based unit-molecular and array types of biosensors are being developed. Environmental applications of nanotechnology include developing solutions to present environmental challenges as well as preventative measures for future problems caused by interactions between energy, materials, and the environment. These applications additionally seek to evaluate and alleviate any possible dangers associated with nanotechnology. Different physicochemical and biological techniques can be used to synthesize nanoparticles (NPs) for a variety of uses. The utilization of microorganisms in the biogenic synthesis of NPs offers several advantages over alternative methods and is increasingly gaining attention. This chapter provides an overview of environmental nanotechnology and explores the techniques utilized in the biogenic synthesis of NPs, along with their characterization.

Keywords: Characterization, Environment, Nanomaterials, Environmental nanotechnology, Nanoparticles, Nanosensors, Pollutants, Synthesis.

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INTRODUCTION

The term ‘nanos’ signifies ‘extremely small’ and applies to both dwarfs and individuals of exceptionally short stature [1]. In the last decade, there has been an increasing utilization of the prefix ‘nano’ across various fields of expertise. Presently, it is a commonly employed term in a significant portion of contemporary research, leading to its more frequent appearance in scientific literature [1 - 5]. The fundamental characteristic distinguishing all NPs — with all materials possessing at least one dimension at the nanoscale— is their size, typically ranging from 1 to 100 nanometers (nm) [1]. Consequently, materials exhibiting at least one dimension within this range and possessing a spherical surface area per volume exceeding 60 m^2/cm^3 are classified as NMs. Nanoparticulate matter represents a distinct state of matter, which is different from all other states [1, 6 - 10].

Pinpointing the exact origins of human utilization of nanoscale entities is challenging. However, the use of NMs is not a recent phenomenon; humans have inadvertently employed them for various purposes over time [11]. As far back as approximately 4500 years ago, humans utilized asbestos nanofibers to reinforce ceramic mixes, albeit unknowingly [11, 12]. Ancient Egyptians, around 4000 years ago, incorporated PbS NPs into a traditional hair-dying recipe [11, 13, 14]. Another notable historical artefact is the Lycurgus Cup, crafted by the Romans in the fourth century AD. This cup exhibits a dichroic effect, appearing jade-like under direct light and translucent ruby under transmitted light, owing to the presence of Ag and Au NPs [11, 15]. In 1959, Richard Feynman, an American physicist and Nobel laureate, delivered what is considered the inaugural academic discourse on nanotechnology at the annual meeting of the American Chemical Society. Feynman's speech introduced the concept of nanotechnology [11, 16]. He emphasized that human's ability to manipulate matter is not constrained by natural laws but rather by a lack of tools and techniques. This notion laid the groundwork for modern nanotechnology, earning him the title of the father of this field [11, 17]. It is usually believed that Norio Taniguchi may have coined the term “nanotechnology” in 1974 [11, 16, 18]. Although nanotechnology was primarily a topic of discussion before the 1980s, its potential for future advancement was deeply embedded in the minds of scholars [11]. NPs have found extensive use in Ayurveda as well. Through scientific research, superhydrophobic surfaces have been developed for various applications, such as Lotusan self-cleaning paint (inspired by the lotus effect) and slippery liquid-infused porous surfaces (SLIPS) for refrigeration systems (inspired by nepenthes walls). Bhasma, a herbal-mineral metallic compound in Ayurveda, possesses nano dimensions typically ranging from 5 to 50 nm. Classical Indian alchemy, known as “Ayurveda Rasa Shastra,” produces items utilized in the treatment of numerous chronic diseases [19].

Nanotechnology and nanodevices have found diverse applications across fields, such as cancer treatment, nanoscale electronics, hydrogen fuel cells, and nanographene batteries, owing to their remarkable versatility in altering physicochemical properties. By utilizing smaller-sized materials, nanotechnology enables precise adjustments at the molecular and substance levels, thereby enhancing material mechanical qualities or facilitating access to previously inaccessible regions of the body. NMs find commercial applications in various sectors, such as paints, cosmetics, electronics, environmental remediation, sensors, and energy storage devices. The untapped potential of these NMs poses a significant risk to society due to their wide array of applications, which could lead to unforeseen impacts on the environment and health. There is a concern that the waste generated by these innovative materials may surpass current waste management capabilities, rendering them inadequate for proper disposal [20].

Current environmental research and engineering have been significantly influenced by environmental nanotechnology, often referred to as E-nano. The production of NPs for nanotechnology holds the potential for generating substantially less waste, minimizing hazardous chemical synthesis, enhancing catalysis, and accelerating advancements in clean and sustainable technologies. Nanotechnology is revolutionizing the detection of harmful water-borne compounds and opening up new avenues for water purification, desalination, and decontamination. In the realm of pesticide detection, NM-based biosensors, both unit-molecular and array types, are under development [21]. Advanced treatment methods for pesticide-contaminated soil and water include innovative approaches such as ultrasound-promoted remediation and other sophisticated oxidation processes, alongside conventional methods like incineration, phytoremediation, and photochemical processes. Their hydrophobic nature, high reactivity, varied shapes and sizes, large surface area, biological interactions, durability, deformability, tendency to aggregate, and sensitivity to light are just a few of the distinctive characteristics of these NMs. These attributes significantly influence their interactions with other environmental contaminants [22 - 24]. As a result, they could potentially expedite and enhance the spread of these pollutants through air, soil, and water media. Recent studies indicate that NMs have the capacity to swiftly traverse aquifers and soils, potentially aiding in the rapid dissemination of hazardous substances over vast distances by acting as carriers for other pollutants.

This chapter aims to showcase a summary of environmental nanotechnology and examines the methods employed in the biogenic creation of NPs, as well as their analysis.

CHAPTER 2

Aquatic Milieu and Nanotechnology: A Critical Review on Remediation of Pollutants

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Abstract: Access to sources of clean water is necessary for the existence of all living beings on Earth. In freshwater environments, a wide variety of species, from minuscule to mega, can be found. However, constant contamination of water bodies has changed the freshwater ecosystems. Every year, the problem of water pollution gets worse, which eventually affects the limited supply of freshwater resources. All the anthropogenic activities have caused long-term negative effects on the delicate structure of freshwater ecosystems. Wastewater can be treated in several ways before being released into recipient water bodies. However, these conventional techniques are unable to meet the necessary standards for wastewater treatment for a variety of reasons. Furthermore, there is reason for concern regarding the efficacy of these currently available conventional treatments. For environmental remediation, different skillful technologies such as physicochemical reactions, filtration, adsorption, and photocatalysis are employed to eliminate impurities from various environmental matrices. Materials based on nanotechnology have superior qualities and are especially useful for these kinds of procedures because of their low volume-to-surface area ratio, which frequently leads to increased reactivity. Based on the information presented in this chapter, it appears that using nanotechnology to treat wastewater could be advantageous, efficient, and environmentally friendly. It is selective but effective to clean only organic-based pollution. Additionally, due to their extraordinary adsorption behavior, Nanomaterials (NMs) are verified as disinfectants, pathogen identifiers, and antibacterial agents in environmental remediation.

Keywords: Disinfectant, Heavy metals, Industrial effluents, Nanoparticles, Nanotechnology, Remediation, Water pollution.

INTRODUCTION

Undoubtedly, environmental pollution is one of the biggest issues faced by the modern society. Continuous research endeavors are dedicated to developing innovative technologies for removing contaminants from air, water, and soil. The numerous dangerous contaminants include heavy metals, organic compounds, oil

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spills, pesticides, herbicides, fertilizers, hazardous gases, industrial effluents, sewage, and particulate matter. Many approaches can be used for environmental remediation because different kinds of materials are used in this process. Recent studies have emphasized the utilization of NMs in the advancement of environmental remediation technologies due to the challenges posed by the complex mixture of pollutants and their high volatility, making their clean-up and degradation challenging.

Water stress affects half of the world's population. Roughly 70% of the industrial effluent is released into waterways without being adequately treated. Incorporating NMs into current water and wastewater treatment processes could be a promising improvement. Owing to their lower cost, NMs offer tremendous potential for wastewater purification. The direct application of nanoparticles (NPs) in wastewater and water decontamination techniques is not without drawbacks. The activity of these NPs is greatly reduced as a result of these particles' propensity to aggregate in liquefied systems or beds. The impact of NPs on human health and the aquatic environment remains uncertain. It is, therefore, advisable to develop such a device or method that, during wastewater treatment, can reduce the release of NPs.

Freshwater makes up only 3% of the water on Earth, with the remaining 97% being salt water. Jose *et al*. reported that only 1 percent of the 3 percent is in the quantifiable form, and the other 2/3 is in the frozen form, and this scarcity is a terrible situation for developing nations. Pressure on the water bodies is increasing due to the unchecked population growth. Conventional techniques for treating wastewater are less efficient and not cost-effective [1]. According to Sharma and Sharma, 2013 [2], novel techniques such as nanotechnology are being continuously researched to enhance wastewater treatment techniques. NPs, thus, are defined as materials and particles with dimensions ranging from 1 to 100 nm.

After the scanning tunneling microscope (STM) was developed in the 1980s, nanotechnology saw a significant upsurge. Building block-sized particles are arranged in nanostructures and NMs, which have a nm size range. Materials at the nanoscale possess distinct qualities such as stability, morphological traits, and adsorption capacities that set them apart from macro-scale counterparts with similar structures, and these qualities increase their efficacy as wastewater treatment agents [3]. Nanotechnology offers significant advantages for the environment, notably in the cost-effective and efficient elimination of contaminants from wastewater [4]. Certain NMs have distinct modes of operation; some eliminate pollutants, while others isolate and segregate them. The numerous advantages of this technology, such as its high efficiency and cost-effective wastewater treatment, increase its dependability in addressing a wide range of global issues.

There are parallel endeavors beneath each investigative course in nanotechnology, and the gigantic sum of cash is streaming beneath its investigations and advancement plans. Thus, advancements may happen earlier than anticipated. The main objective of this review paper is to provide an overview of the interest and fascination that researchers and analysts have shown in utilizing nanotechnology for advanced water treatment. Additionally, it seeks to acknowledge the significant obstacles and potential directions for future advancements in the field of nanotechnology and its applications in water treatment.

NMS FOR WATER DISINFECTION

When it comes to pollution remediation, the materials used must not contribute to further environmental pollution. This is why the use of biodegradable materials is highly compelling in this field. By utilizing biodegradable materials, there is no waste left behind after the treatment process, which not only enhances consumer confidence and acceptance of the technology but also provides a safer and more environmentally friendly option for pollutant remediation. Additionally, these materials offer a solution to the problem of low efficiencies caused by off-targeting, making them particularly attractive in the development of new technologies that aim to capture contaminants. Therefore, much research is focused on applying nanotechnology principles and merging them with modification of material surfaces to create engineered materials capable of overcoming many of the challenges associated with the removal of contaminants. Some of the most important factors to reflect on while creating NMs are target-specific capture, cost-effectiveness, creation within the lab with green chemistry, nontoxic, ease of biodegradability, recyclability, and post-use recovery (possibility of regeneration). Despite the possible benefits of the previously listed NMs, some of them are inherently unstable and, therefore, require preparation [5].

Several NPs, like Ag, *etc*., have pronounced adsorption capability [6, 7]. Being passive oxidants, these NPs produce less harmful by-products. There are certain drawbacks to using nanotechnology to decontaminate wastewater [8]. For example, to remove contaminants, an NP must come in direct contact with the target organism, which lowers the particle's activity. Furthermore, the lack of NMs following the treatment process prevents wastewater from subsequently exhibiting antimicrobial activity [9]. Various environmental pollutant remedial approaches are shown in Fig. (**1**).

CHAPTER 3

Contemporary Execution of Nanomaterials in Wastewater Treatment

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Abstract: Water of high quality must be readily available to all living beings on the planet. With water resources becoming scarce, the primary need of the modern period is wastewater treatment. While there are other methods, such as adsorption, flocculation, and filtration, they are only employed in the initial stages of wastewater treatment. Nanomaterials (NMs) and recent advances in technology have garnered interest in wastewater treatment. The ability of nanoparticles (NPs) to catalyze reactions, adsorb substances, reactivity, and larger surface area makes them highly valuable in wastewater treatment. Diverse varieties of NMs are employed to eliminate distinct pollutants from wastewater to make it eco-friendly in use. Activated carbon, graphene, carbon nanotubes, metal oxide NPs (*e.g.*, TiO_2, ZnO, and iron oxides), zero-valent metal NPs (*e.g.*, Ag, Fe, and Zn), and nanocomposites, titanium oxide, and magnesium oxide are a few types of nanoadsorbents that are utilized in wastewater treatment to extract heavy metals. Both organic and inorganic contaminants can be eliminated from water using nanocatalysts, such as electrocatalysts and photocatalysts. Special destruction or removal of some organic contaminants with the use of semiconducting NPs, either alone or in conjunction with ozonation, the Fenton process, or sonolysis is being done. Additionally, the topic of how well nanotechnology works against different parameters to provide pure water in an environmentally responsible manner is covered. The advances gained in wastewater treatment through the use of NPs are the main concerns of this chapter.

Keywords: Contaminants, Metal NPs, Metal oxide NPs, Nanocatalysts, Nanocomposites, Nanotechnology, Wastewater treatment.

INTRODUCTION

Water pollution due to anthropogenic activities is a global problem in present times. Even though environmental factors are also responsible for the deteriorated quality of water, the term "pollution" typically suggests that human activities are

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the major cause of water pollution. The main cause of water pollution is the discharge of contaminated wastewater into the surface or groundwater, consequently affecting the environment and ecosystem badly. In this view, water pollution control and the treatment of wastewater is a matter of great concern. Unfortunately, only approximately 1% of the available water is fit for consumption by human beings. According to an estimation from the World Health Organization (WHO) in 2015, more than 1.1 billion people are facing potable water scarcity worldwide. This global scarcity of pure water is a consequence of rapid industrialization and a growing population [1]. Another major challenge is the purification of water and wastewater by the removal of organic and inorganic pollutants to bring it to a permissible level [2]. It becomes more challenging because the majority of the existing technologies have certain drawbacks, such as high energy requirements, incomplete removal of pollutants, and the creation of toxic sludge during the wastewater purification process [3, 4]. Nanotechnology is an emerging technique that works against different parameters to provide pure water in an environmentally friendly manner. Therefore, the authors have made an effort to cover the advances and potential of NMs in wastewater treatment in a comprehensive manner, along with other basic techniques.

BASIC TECHNIQUES FOR WASTEWATER TREATMENT

Wastewater treatment is an essential procedure to safeguard the environment and the public's health. Physical, chemical, biological, tertiary, and disinfection are the five fundamental principles of wastewater treatment [5].

Primary/Physical Treatment

Using physical procedures like filtration, sedimentation, and screening, solid particles are removed from wastewater as a part of physical treatment. To remove big solids, including plastics, sticks, rags, *etc*., from the wastewater, screens are used, followed by sedimentation, where the wastewater is allowed to settle in a basin so that smaller particles (such as sand and silt) settle down. The wastewater's tiny residual particles are subsequently eliminated by filtering.

Chemical Treatment

Utilizing chemicals to extract impurities from wastewater is known as chemical treatment. In order to eliminate contaminants by sedimentation or filtration, chemicals are added to the wastewater that causes them to be coagulated or precipitated during the process. For good results, physical and chemical treatments are frequently combined.

Biological Treatment

Biological treatment is done to remove organic matter in wastewater utilizing microorganisms like bacteria, algae, and fungi. Biological treatment mineralizes organic matter into simpler and more stable compounds. Although it is a natural process that occurs in an aqueous environment, in wastewater treatment plants, the process is artificially accelerated and controlled by regulating the growth conditions of microorganisms, including temperature and pH levels.

Tertiary Treatment

At the last phase of the treatment process, known as tertiary treatment, the water is given a thorough cleaning before being allowed to return to the environment. Dissolved solids and other contaminants that were not eliminated during the earlier treatment stages must be removed during this process. Reverse osmosis, activated carbon adsorption, and membrane filtration are a few examples of tertiary treatment procedures.

Disinfection

In order to guarantee that the wastewater is safe to be released into the environment, any pathogens, bacteria, or viruses must be eliminated during the final stage of wastewater treatment, known as disinfection. Ozone, chlorine, and UV light are a few examples of disinfection techniques.

The biological methods currently in use for wastewater purification have the disadvantage of being extremely slow processes and can occasionally make drinking water more toxic by releasing microorganisms [6]. Applying these biological systems to wastewater containing nonbiodegradable contaminants is also ineffective. Physical filtration techniques also produce toxic sludge that poses significant disposal challenges, and it is challenging to attain 100% purification using these techniques. The potential applications of NMs in wastewater treatment have been documented in many studies [7, 8]. The field of NMs plays a wide range of roles in the treatment of industrial and municipal wastewater. These include the use of nanoadsorbents [9, 10], semiconducting nanocatalysts [11, 12], electrocatalysts [13], antimicrobial materials [14], and nanomembranes [15]. To effectively degrade or remove organic pollutants, semiconducting NPs can be used alone or in conjunction with ozonation, the Fenton process, or sonolysis. Therefore, applications of NMs in wastewater treatment are listed and critically reviewed in this chapter. Additionally, the efficiency of nanotechnology in antimicrobial activity to generate pure water through a sustainable method is also discussed. The functions of NMs in adsorption methods—more especially,

CHAPTER 4

Carbon NMs in Environmental Remediation

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Abstract: Ecological concerns like polluted drinking water have impacted every facet of our existence. Ecological restoration hinges predominantly on employing diverse methods,` such as absorption, adsorption, chemical processes, light-induced catalysis, and purification of water, for the elimination of pollutants from distinct ecological mediums like terrain, aqua, and atmosphere. Nanoscience is a cutting-edge scientific discipline possessing the capacity to address numerous ecological hurdles through the manipulation of the dimensions and configuration of substances at a nanoscopic level. Carbon nanomaterials (NMs) are exceptional due to their harmless characteristics, large area, simplified decomposition, and notably beneficial ecological restoration. In this context, this chapter discusses the mechanistic pathways and uses of carbon materials for the light-catalyzed and adsorption elimination of contaminants present in polluted water. Carbon materials enable improved adsorption owing to robust bonding between contaminants and binding regions. In light-induced chemical reactions, increased efficacy is credited to the enhanced capture of radiance and diminished reassembly of light-activated charge carriers. The recent advancements achieved in the elimination of contaminants from contaminated water utilizing diverse forms of carbon NMs as adsorptive agents, including graphene, carbon nanotubes, activated carbon, and fullerenes, are examined.

Keywords: Adsorption, Carbon NMs, Environmental remediation, Pollutants, Water.

INTRODUCTION

Air contamination is defined as the existence of unwanted chemical species that obstruct the environment or induce harmful impacts on human species and other living forms. Rapid commercialization and the rise in human population have contributed to extensive urban development, resulting in a rapid escalation of environmental pollution [1]. Enhancing the quality of soil, water, and atmosphere is a significant hurdle in the contemporary world. Recognizing and mitigating air contaminants, along with their proactive prohibition, are crucial measures for

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safeguarding the surroundings. Nanotechnology is very crucial in achieving the goal of a green environment, and this technology has advanced significantly in the past 10 years, particularly in the field of nanoscale materials. The availability of uncontaminated water is diminishing because of commercialization, leading to a scarcity of pure water worldwide, particularly in emerging countries. Water can be contaminated by pollutants like organic substances, microbes, pathogens, coloring agents, and trace metals like Pb^{2+}, Cd^{2+}, Zn^{2+}, Ni^{2+}, Cr^{3+}, and Hg^{2+}. These contaminants do not decompose in the surroundings, and they even pose serious threats to living species and the environment. Trace metals can result in numerous harmful impacts, such as malignancy, renal impairment, liver inflammation, pregnancy loss, nephritic syndrome, blood deficiency, and brain disorder [2]. Pb^{2+} ions are typically discharged into the surroundings, often originating from the metallurgical sector, paper manufacturing industries, glass fabrication industries, and surface finishing industries [3]. Electrodeposition in battery design, solar cells, mining industries, and textile sectors are common sources of cadmium found in wastewater. Ni^{2+} ions can induce skin disorders upon contact with items such as jewelry, watches, zippers, and coins. Cr^{6+} ions can cause ailments such as liver impairment, renal inflammation, and abdominal discomfort. Additionally, Cr^{6+} ions are the predominant cause of mucosal lesions. Due to these severe negative consequences, the elimination of trace metals from aqueous media is critically important to safeguard humans from potential wellness problems. To eliminate heavy metals, various techniques can be employed, including charge transfer, bioaccumulation, flocculation, extraction, and reverse osmosis. Adsorption is regarded as the most commonly used approach due to its relatively cheap, high efficacy, and facile method of eliminating trace metals at low levels [4]. Fig. (**1**) illustrates various origins of trace metal ion pollution. Various NMs have been utilized for wastewater remediation, including organic and plant-based, particularly humic acid, which has found extensive use for wastewater treatment and the elimination of toxic metals. Material science plays a major role in various domains, including ecological studies and sustainability, the medical sector, supercapacitors/batteries, wastewater treatment facilities, catalyst development, power production, and storage of energy. Nano-sized materials offer unique characteristics for the treatment of polluted water, leveraging the expansive area of adsorbents and their capacity for chemical transformation and facile recyclability [5]. Nano-sized materials are increasingly utilized for the elimination of various contaminants, including inorganic contaminants, micro-organisms, and organic contaminants from polluted water. Different forms of carbon nanomaterial, *i.e.*, carbon nanotubes, graphene, fullerenes, graphene oxide, and activated carbons, have found extensive applications in detectors, storage of energy, electrical appliances, wastewater treatment, pharmaceuticals, and diagnostic evaluation due to their remarkable mechanical, physico-chemical, heat, and electrical properties. This chapter discusses the current achievements made in environmental remediation using carbon NMs as adsorptive agents, including graphene, carbon nanotubes, activated carbon, and fullerenes [6].

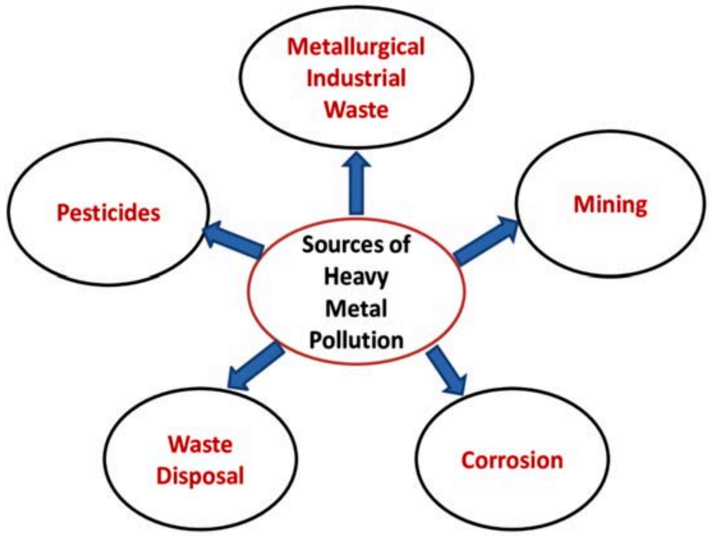

Fig. (1). Various origins of trace metal ion pollution [5].

TYPES OF CARBON NMS AND THEIR APPLICATIONS

Nanoparticles with all three dimensions below 100 nm are classified as zero-dimensional (0D) materials. Examples of such materials include quantum dots and fullerenes. Nanoparticles that have two dimensions smaller than 100 nm and one dimension larger than 100 nm are classified as one-dimensional (1D) materials [7]. Examples of such materials include carbon nanotubes. Nanoparticles with two dimensions larger than 100 nm are classified as two-dimensional (2D) materials. Examples of such materials include graphene. NMs characterized by all three dimensions, each exceeding 100 nm, are classified as three-dimensional (3D) NMs. Examples include certain NM composites and graphite.

Fullerenes and their application in wastewater treatment

Fullerenes were invented in the year 1985 from cosmic particles, and they exhibit an enclosed structure consisting of 5 and 6-membered rings. They are written by the chemical formula C20 + m, where m is an integral number. Fullerenes exhibit hydrophobicity, robust electron binding, large surface area, and surface irregularities. These distinctive chemical and physical characteristics render them suitable carbon NMs for different uses like electrical, medical biology semiconductors, electronics, biomedical sciences, photovoltaic cells, detectors,

CHAPTER 5

Environmental Remediation by Copolymer Nanocomposites

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Abstract: Environmental pollution due to human activities has become a serious problem around us, which has affected various living organisms worldwide. Therefore, there is an urgent need for new materials to remediate the polluted environment. Activated charcoal and copolymer were used to create a composite material. The material was spectrally characterized, and scanning electron microscopy (SEM) was used to examine the material's morphology. The composite material has effectively eliminated the chosen metal ions from the aqueous solution, according to the metal ion sorption data. This might be because of the composite's higher specific surface area and very porous nature. The cation exchange and synthesis of the 2-Amino-6-nitrobenzothiazole-adipamide-formaldehyde copolymer are described in this study. The condensation of 2-Amino-6-nitrobenzothiazole, adipamide, and formaldehyde with an acid catalyst in the presence of 1:1:2 molar proportions of the reacting monomers at 124°C produced the copolymer. The average molecular weight of this copolymer was determined by gel permeation chromatography, and the elemental analysis of the copolymer was used to determine its composition. The UV-visible, FTIR, and 1H NMR methods were used to characterize the newly synthesized copolymer and its nanocomposites. This copolymer nanocomposites ion-exchange properties for Cu^{2+}, Ni^{2+}, Zn^{2+}, Co^{2+}, and Pb^{2+} ions were examined using the batch equilibrium method in fluids with varying ionic strengths and a pH range of 2.0 to 6.0. The removal of these ions by copolymer nanocomposites followed the order of $Cu^{2+} > Ni^{2+} > Pb^{2+}$. According to the analysis ratio of distribution as a function of pH, this research could be used to treat industrial wastewater because resin uses more metal ions as the medium's pH rises. The emerging idea of environmental remediation using polymeric nanocomposites will be the focus of this chapter.

Keywords: Copolymer, Nanocomposites, Environment remediation, Batch equilibration method, Synthesis, Toxic metal ions.

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INTRODUCTION

Heavy hazardous metal ions tend to accumulate in living things. There has been a lot of focus in recent decades on removing residues of these ions from household, industrial, and nuclear wastes, which has detrimental consequences on the environment. As a result, an effort has been undertaken to create a new chelating copolymer and evaluate its ion-exchange properties. Electrical appliances, materials with great heat resistance, and ion exchangers are only a few of the research applications for copolymers. Heavy metal ions, including Pb^{2+}, Cd^{2+}, Zn^{2+}, Ni^{2+}, and $Hg^{2+,}$ have the most hazardous qualities of all water contaminants and can seriously harm both human and animal health.

Around the world, certain industries have experienced significant growth, including those related to mining, refining, battery production, paint manufacturing, chemicals, dyes, and pharmaceuticals. Among them, industries are widely contaminating the environment, particularly with regard to the elevated concentrations of heavy metals like cobalt, lead, cadmium, and mercury in the aquatic system and soil. These heavy metals are extremely dangerous and poisonous, and they may have an impact on biological processes and human health. Living systems in close proximity to industry typically absorb heavy metal toxicity in many ways, which can result in health risks and hazards such as cancers of the skin, lungs, and liver [1]. In addition to having renal effects, cadmium increases diarrhea. Lead and mercury have an adverse effect on brain function, memory, blood pressure, skin rashes, miscarriages in pregnant women, and other health issues [2]. Controlling or eliminating these heavy metals from wastewater and industrial effluents is the current environmental concern. Taking into account every factor, many traditional techniques, including chemical precipitation, electrochemical procedure, membrane filtration, biological treatment, coagulation, flocculation, and ion exchange processes, have been used to remove heavy metals. Batch separation ion-exchange analysis, with its better adsorption efficiency, selectivity, and reusability, is a powerful tool for sorting out such issues [3].

There have been several reports on the use of polymeric resins and composites in the ion-exchange process to remove heavy and hazardous metal ions from wastewater, industrial effluents, *etc*., utilising the ion-exchange technique. The chelating characteristics of a synthetic resin were successfully analysed utilising p-aminophenol, dithiooxamide, and formaldehyde terpolymer. The stated findings were dependent on physical parameters, including diffusion counter ion, particle size, and pore size [4].

The radiotracer approach has been used to study the polyaniline-polystyrene composite with the purpose of recovering Hg^{2+} metal ions. The findings demonstrated that a rise in temperature causes a rise in metal sorption. PGME copolymer was used in a batch equilibrium approach at 25–70°C to effectively adsorb the hexavalent chromium (VI) metal ion [5]. For the purpose of removing heavy metals, a unique comparison study was conducted between a synthetic terpolymer and its composite based on metals and heat deterioration. Both the terpolymer and the composite exhibit selectivity in the following order: $Zn^{2+} > Cu^{2+} > Co^{2+} > Pb^{2+} > Cd^{2+}$ and $Pb^{2+} > Cd^{2+} > Cu^{2+} > Co^{2+} > Zn^{2+}$, respectively [6].

To remove cadmium ions from the aqueous solution, a comparison of chitosan, commercial activated carbon, and chitosan/activated carbon composite was conducted. The most crucial element in the removal of heavy metal ions is the pH solution of the adsorbent [7].

Using a straightforward solution-evaporation technique, chitosan and charcoal were combined to create a chitosan/charcoal composite. Chromium from wastewater may be efficiently treated using the produced composite. The composite was used to adsorb chromium at different adsorbent doses, rates, and pH values. The maximum pH has an impact on the adsorption capacity [8]. Selective removal of heavy metal ions from an aqueous solution was achieved by combining magnesium and activated carbon from coconut shells. The generated magnesium and coconut shell-activated carbon composite successfully extracted Zn(II) and Cd(II) ions from the waste aqueous solution by utilizing the ion-exchange method [9].

There have been a lot of reports [10 - 12] on the sorption of various heavy metal ions by urea-based chelate polymers using the batch equilibrium method. These studies involved thiourea/urea with formaldehyde and o-aminophenol/o-cresol with formaldehyde. These polymers contain a variability of vigorous chelating functional groups. The >C=O group in urea is particularly significant due to its frequent presence in the separation of certain metal ions, including Fe^{3+}, Cu^{2+}, Ni^{2+}, Co^{2+}, Zn^{2+}, Cd^{2+}, and Pb^{2+} ions [13]. Gurnule and colleagues [14 - 17] investigated the chelation ion exchange characteristics of a number of copolymer/terpolymer resins. Additionally, they have investigated and documented the ion exchange characteristics of formaldehyde, biuret, and 4-hydroxyacetophenone terpolymer resins [18]. By employing the solution condensation process to synthesize semicarbazide with formaldehyde and 8-hydroxyquinoline5-sulfonic acid, a new terpolymer was created that functions as an efficient chelating ion exchanger. Its ion-exchange characteristics were assessed utilizing the batch equilibrium approach with various electrolyte

CHAPTER 6

Biochar-Based Nanocomposites for Environmental Remediation

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Abstract: Biochar (BC) stands out as a remarkable material in the domain of environmental remediation. Waste biomass, like municipal solid waste, manure, wood chips, and agricultural residues, undergo pyrolysis in a controlled oxygen environment, producing BC with a carbonaceous composition ranging from 65% to 90%. Using metal nanoparticles (MNPs) to reinforce BC significantly increases its novelty. The synergistic advantages of BC, coupled with the enhanced catalytic activity of NPs, enhance physicochemical characteristics such as thermal stability, ideal pore size, surface area, and versatile functionalization. These attributes contribute to effectively addressing emerging environmental pollution challenges and their remediation. There are three major hazards in industrial wastewater: dyes, heavy metals, and pharmaceutical compounds. Thus, BC-based Nanocomposites (BNCs) are being investigated as a potential solution for wastewater pollution treatment that uses both adsorption and photocatalytic degradation. As a result of these composites, four integrated objectives can be achieved: the removal of pollutants, waste management, carbon sequestration, and energy production. It stands as a superior choice to conventional methods, marked by cost-effectiveness, sustainability, and environmental friendliness. This chapter provides a comprehensive insight into BC-based composite with precise preparation techniques, efficacy in eliminating pollutants, and underlying adsorption processes.

Keywords: Agricultural waste, Biomass, Biochar, Environmental remediation, Nanocomposites.

INTRODUCTION

Environmental pollution is an increasing global concern that requires innovative solutions to mitigate its impacts. One promising approach is the production of BC-based NCs (BNCs) for environmental remediation. The carbon-rich material known as BC, which is produced by pyrolyzing biomass, has drawn interest due

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to its large porosity, surface area, and capacity to absorb contaminants. In BC production, biomass feedstock, such as lignocellulosic materials and agricultural residues, is pyrolyzed or gasified under controlled conditions without oxygen to provide combustion [1]. A diverse range of organic waste materials, including agricultural residues like cornstalks, cotton stalks, and wheat straws, garden waste such as leaves, grass, and wood, municipal waste like food waste, tire waste, and sludge, as well as different types of algae such as *Enteromorpha prolifera*, blue algae, and green algae, can be utilized as feedstock for BC production [2]. Its production can utilize a variety of thermochemical methods, including slow pyrolysis, fast pyrolysis, gasification, hydrothermal carbonization, torrefaction, and rectification, each offering distinct advantages and applications in sustainable biomass conversion [3]. Slow pyrolysis, conducted without oxygen, is a common method for producing BC, typically yielding about 35% [4] dry biomass and a minor amount of bio-oil [5]. While gasification is mostly utilized for the manufacture of syngas, which, as a result, produces heat and energy, fast pyrolysis is the favored method for producing biofuel [6]. Additionally, studies have shown that lignocellulosic materials yield a higher amount of BC compared to municipal solid waste [7]. Furthermore, its production stands out for its economic viability, environmental friendliness, and resource efficiency, requiring minimal energy input and achievable at temperatures below 700°C, making it a sustainable solution for waste utilization [8]. It is characterized by its significant specific surface area (SSA) and wide range of functional groups, such as hydroxyl, amino, and carboxyl groups. These properties contribute to its versatility and suitability for various applications across different industries [9]. There are multiple applications of BC across various industries, for example, wastewater treatment procedures, electrochemistry for energy storage devices, agriculture for soil amendment, catalysis for various chemical reactions, and so on, as illustrated in Fig. (**1**). Recent research has explored BC-based adsorbents for aqueous contaminant elimination, offering a synergistic approach to water pollution control and carbon sequestration [10].

The effectiveness of BC in water treatment is hindered by its restricted functionalities derived from the feedstock post-pyrolysis, which constrains its wider applications in this field. Furthermore, in aqueous solutions, powdered BC is difficult to separate because of its tiny particle size [11]. The development of “engineered BC” is an expanding area of research focused on enhancing BC's capabilities for multiple applications. The immobilization of materials at the nanoscale on BC is gaining significant scientific interest and attention. Functional NPs incorporated into BC can enhance its surface area, thermal stability, cation exchange capacity, and high-affinity adsorption sites. BC-based composite materials can be adapted to target many pollutant kinds, both positively and negatively charged. This involves selectively designing or producing composite materials by incorporating specific magnetic substances, functional materials, and NPs. Using these composite materials for environmental remediation can compensate for deficiencies found in pristine BCs in terms of functional groups [12, 13]. Engineered BC containing immobilized NPs has multiple potential applications, one of which is as a sorbent in environmental remediation.

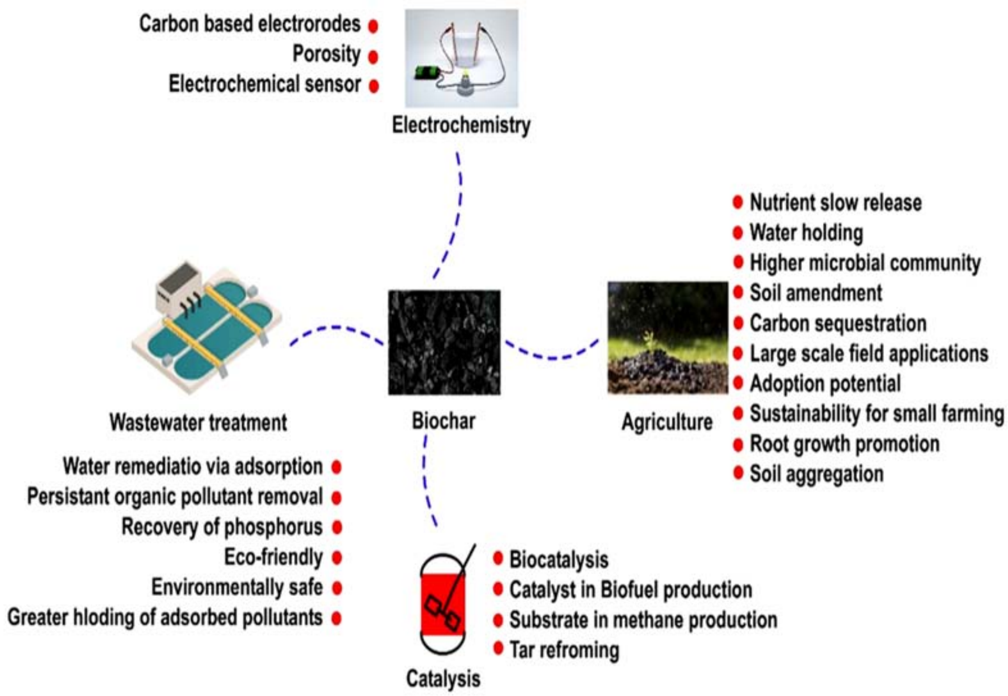

Fig. (1). Various Applications of BC [17].

Consequently, MNPs have been used as reductants, adsorbents, oxidants, and catalysts for the elimination of organic contaminants, diverse heavy metals, as well as other inorganic contaminants from aqueous solutions [14, 15]. However, MNPs tend to agglomerate and form larger particles due to their increased surface energy [16]. Activated carbon, BC, and silica porous supports have been employed to reduce the agglomeration of metal NPs. Thus, the immobilization of MNPs onto BC offers a novel approach to combine their advantages and overcome their drawbacks, creating a promising material called MNPs@BC for ecological restoration. Moreover, BC has demonstrated outstanding adsorption capabilities for various contaminants such as organic pollutants, dyes, heavy metals, pesticides, and volatile organic compounds (VOCs) in water. The chapter concludes with a concise summary and outlook on BC-based materials across

CHAPTER 7

Bionanomaterials: Harnessing Transformative Approaches for Environmental Remediation

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Abstract: Numerous biotic life forms on earth are being negatively impacted by the rising amounts of environmental pollutants caused by human activity. Heavy metals and certain organic pollutants are widely recognized as significant environmental contaminants globally because of their hazardous ability to persist in the environment. Contaminants present in various forms in the environment pose a challenge for eradication, as conventional technologies encounter difficulties in effectively eliminating them. Contemporary research primarily aims to devise cost-effective solutions for eliminating environmental contaminants. The latest investigation into minimizing environmental contaminants with minimal ecological impact involves leveraging the adsorption principles from traditional technologies alongside modified nanoscale adsorbents. In the past decade, the untapped prospective of biological resources enabling the biofabrication of nanomaterials (NMs) has spurred extensive investigation for benign pollution remediation. Processes such as surface active site interactions, electrostatic contact, photo and enzymatic catalysis, and other distinctive phenomena associated with biofabricated NMs play essential roles in detoxifying various contaminants.

In light of this context, the present chapter concentrates on the mechanism of environmental remediation by emerging biofabricated nano-based adsorbent while also addressing the remediation of persistent organic pollutants (POPs). Every category has been demonstrated with appropriate examples, basic mechanisms as well as societal applications. Last but not least, the long-term development of environmentally benign biofabricated NM-based adsorbents is highlighted.

Keywords: Adsorbents, Bioremediation, Biofabricated NMs, Heavy metals, Persistent organic pollutants, Wastewater treatment.

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INTRODUCTION

Researchers have shown a great deal of interest for the past few decades in materials with nanoscale dimensions owing to their exponential potential [1]. Nanotechnology has played a crucial role in fostering notable progress in bioengineering and medicine, influencing the development of biomaterials and the treatment of various ailments [2, 3]. Biological NMs encompass an interdisciplinary field, finding applications in materials science, quantum technology, biotechnology, chemistry, engineering, and physics [4]. Diverse nanoparticles (NPs) have been harnessed for specific applications, particularly contributing to the rapid expansion of research related to biomaterials [5]. This growth is propelled by the surface modification of biomaterials using NPs and the integration of NMs with medications, photosensitizers, and genes to create advanced delivery systems. The primary drivers for employing NMs include their exceptional biocompatibility, extensive surface area, and distinctive optical properties [6].

Biomaterials possess distinct physical features, dimensions, and improved stability and bio-efficacy due to their narrower size range of 1–100 nm. Science now has more options because of the skill of modifying materials at the nanoscale and using their characteristics for the benefit of society. Recent advances in bioanalytical instruments for accurate atom and molecular probing have brought this field of study to the forefront of scientific attention. Comprehending these distinct characteristics has facilitated the creation of novel and enhanced products worldwide through green process technology [7].

Through the reduction of industrial processes and materials to the nanoscale, nanobiotechnology has enabled the full utilization of surface and quantum phenomena. Biofabrication of NMs has become a popular area of study in nanobiotechnology in recent years because of the ease of production and the abundance of biological sources that include metabolites with a variety of properties [8]. In the search for safer alternatives to conventional NPs with potential hazards in biomedical applications, bio-nanomaterials (BioNMs) have emerged as an ideal choice. BioNMs are either created using biomolecules or can be employed to encapsulate or immobilize traditional NMs. Over the past fifteen years, attempts have been made to create NPs from biological resources, including plant extracts [9 - 11], bacteria [12], actinomycetes [13], basidiomycetes [14], and fungi [15]. These bioNMs exhibit enhanced biocompatibility, bioavailability, and bioreactivity, with minimal toxicity to humans, other living creatures, and the environment. Such special qualities make these bioNMs useful for a range of applications, including controlled drug delivery systems, electronics, tissue engineering, agriculture, biosensing, biolabeling, electronics, and agriculture [16].

Bioactive chemicals that serve as stabilizing agents for NPs, inhibiting their aggregation over time and providing them with further stabilization, would mediate the biocompatibility [17]. These bioactive substances can include carbohydrates, fats, carotenoids, proteins, vitamins, and other secondary metabolites with a variety of biological functions. These organisms function as bionanofactories, able to synthesize biochemicals necessary for the production of very stable NPs [18]. Due to their rich content of secondary metabolites, high effectiveness, widespread availability, and cost-effectiveness as reducing agents in environmentally friendly NP synthesis, plants are often referred to as chemical factories [19]. Biogenic NPs, synthesized using plants, are considered more biocompatible compared to chemical methods, thus rendering them more appropriate for a wide range of applications [20].

The objective of this chapter is to offer a thorough introduction to bioNMs, encompassing their definitions, origins, types, and characteristics. Additionally, the chapter presents advancements in the application of bio-NPs for environmental remediation.

WHAT ARE BIONMS

The terminology associated with NMs is rapidly evolving due to recent breakthroughs, leading to various definitions for these materials. Before delving into a detailed explanation of bioNMs, it is essential to outline the definitions of these terms. The science of the process by which NMs or NPs are created is known as nanoscience. In broad terms, nanoscience entails the exploration of matter at the nanoscale, with a specific emphasis on its size and structural characteristics that distinguish it from atoms, molecules, or bulk materials. NPs are commonly characterized as particles with at least one dimension spanning between 1 and 1000 nanometers. When particles reach a size between 1 and 100 nanometers, their properties alter significantly [21 - 23].

In the realm of nanotechnology, the term ‘bioNM’ is relatively recent compared to NPs. The key distinction between these two types of NMs lies in their origins: bioNMs are created using biological entities, while NMs are generated through physical and chemical methods. Consequently, bioNMs refer to materials at the nanoscale produced using biomolecules—such as enzymes, proteins, and amino acids—sourced from plants, animals, agricultural waste, or microorganisms. These biomolecules are derived from various sources, such as microorganisms, marine species, plants, agricultural wastes, insects, and certain mammals. BioNMs exhibit enhanced biocompatibility, bioavailability, and bioreactivity, with low or negligible toxicity towards humans, other species, and the environment. Additionally, the category of bioNMs encompasses NPs that have

CHAPTER 8

Nanobioremediation and Phytonanotechnology for Remediation of Various Categories of Pollutants

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Abstract: In the present scenario, the most serious threat to the environment and worldwide food safety is the anthropological incursion due to rapid development that has led to severe pollution. Pollutants such as dyes, heavy metals, pesticides, and polycyclic aromatic hydrocarbons can merge into nature in a number of different modes, both naturally and through human activities. These pollutants majorly contaminate soil, water, and air through solubilization, precipitation, and accumulation processes. Various traditional methods such as zeolite adsorption, photocatalysis, electro kinetics, electrochemical advanced oxidation processes, advanced oxidation process, electro-coagulation, ozonation, classical Fenton process, and biological processes are used to overcome the harmful effects of pollutants from the ecosystem, but they have some limitations due to the generation of hazardous compounds, high costs, ineffective clean-up methods, and significant capital needs. Hence, presently, more attention is on alternative methods such as nanobioremediation and phytonanotechnology due to their more effectiveness and eco-friendly nature to achieve better outcomes. A relatively new area of nanotechnology called phytonanotechnology combines nanotechnology and plant biotechnology and aims to produce nanoparticles (NPs) from natural sources by employing the main accessible synthesis methods, using fungal mycelial surfaces, plant bacterial culture, and secondary metabolite extracts. Therefore, it is very crucial to understand these remediation techniques that avoid the production of harmful by-products during the synthesis process. This chapter gives a detailed account of the great efficiency of these methods in environmental remediation.

Keywords: Bioremediation, Environment, Nanoparticles, Pollutant, Phytonanotechnology.

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INTRODUCTION

Urbanization, as well as the Industrial Revolution, has brought great economical and technological advancements worldwide. These advancements are responsible for increasing environmental pollution through the process of excessive resource extraction, product dissemination, and greater disposal of waste materials into the environment without diligence. Pollutants such as dyes, heavy metals, pesticides, and poly aromatic hydrocarbons (PAHs) contaminate soil, water, and air through solubilization, precipitation, and accumulation processes. Various traditional and advanced methods such as zeolite adsorption, photocatalysis, electro kinetics, electrochemical advanced oxidation processes, electrocoagulation, ozonation, classical Fenton process, and biological processes are used to mitigate the harmful effects of pollutants on the environment, but they have some limitations due to the generation of hazardous by-products, high costs, inefficiency, and significant capital needs. Hence, more attention is being paid to alternative methods such as nanobioremediation and phytonanotechnology due to their better efficiency and eco-friendly nature [1, 2]. Nanobioremediation is a largely accepted naturally occurring waste treatment method because it is more affordable than other remediation techniques for the remediation of pollutants from coastal regions, estuaries, and marine environments [3, 4].

It is an environment-friendly and highly efficient remediation technique that avoids the production of harmful by-products during the synthesis process [5, 6]. The main purpose of this chapter is to discuss the principles of bioremediation assisted by NPs and their interaction with different environmental matrices. The international regulatory frameworks that are applicable to these technologies and how they might contribute to sustainability are also discussed.

DIFFERENT CATEGORIES OF POLLUTANTS

The toxic substances that are released naturally or *via* anthropogenic activities that change the equilibrium of the environment, causing the contamination of soil, water, and air, are known as pollutants. Understanding different types of pollutants is crucial for addressing environmental issues and developing strategies for pollution prevention and remediation. A detailed account of various types of pollutants is discussed here [7].

Organic pollutants

Organic pollutants may be produced by plants or animals, or they can be synthetic chemicals created by human activities. Organic pollutants can have diverse chemical structures and properties. These organic pollutants can have adverse effects on human health, wildlife, and ecosystems. They may persist in the environment for extended periods, leading to long-term impacts. Efforts to manage and reduce the presence of organic pollutants often involve regulatory measures, pollution prevention strategies, and the development of cleaner technologies and practices. Various categories of organic pollutants, their sources, and their impacts are summarized in Table **1.**

Table 1. Different categories of organic pollutants and their impacts.

Categories of Organic Pollutants	Source	Impacts	Example
Polycyclic Aromatic Hydrocarbons (PAHs)	Combustion of fossil fuels, industrial processes, and incomplete combustion of organic matter.	Carcinogenic and mutagenic properties, bioaccumulation in the environment	Benzo-[α]-pyrene, naphthalene [8]
Volatile Organic Compounds (VOCs):	Evaporation of fuels, industrial processes, and use of certain products like paints and solvents.	Contribution to ground-level ozone formation, respiratory and neurological effects, and indoor air pollution.	Benzene, toluene, xylene, *etc* [9].
Pesticides	Agricultural activities, pest control.	Harmful to non-target organisms, bioaccumulation, and potential health risks to humans.	Organophosphates, organochlorines, and carbamates [10].
Chlorinated Solvents (CSs)	Industrial processes, dry cleaning, and use as cleaning agents.	Groundwater contamination, potential health risks	Trichloroethylene (TCE) and perchloroethylene (PCE) [11].
Pharmaceuticals and Personal Care Products (PPCPs)	Disposal of medications and personal care products	Potential ecological impacts, antibiotic resistance concerns	Antibiotics, hormones, personal care product ingredients [12].
Dioxins	Combustion of organic materials, certain industrial processes	Carcinogenic and toxic effects, bioaccumulation	Polychlorinated dibenzo--dioxins (PCDDs) [13].
Polybrominated Flame Retardants (PBDEs)	Flame retardants in electronics, textiles, and furniture	Persistent in the environment, potential endocrine-disrupting properties	Deca-bromo-diphenyl ether (DecaBDE) [14 - 16].
Herbicides	Agricultural and landscaping applications.	Runoff into water bodies, impact on aquatic ecosystems	Atrazine, glyphosate [17].
BTEX Compounds	Combustion of fossil fuels, industrial activities	Ground-level ozone formation, respiratory and neurological effects	Benzene, toluene, ethylbenzene, xylene

CHAPTER 9

Bionanomaterials and Environmental Remediation

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Abstract: Environmental pollution is one of the biggest threats to ecosystems and human health around the globe. Over the years, various methods have been implemented for environmental remediation. However, these methods have their limitations and urge the scientific community to find an effective alternate method. The emergence of nanomaterials (NMs) offers tremendous potential for addressing these pollution challenges and promoting sustainable development. Particularly, bioNMs possess unique characteristics such as high surface area, catalytic activity, and selectivity, which make them highly effective in removing contaminants and monitoring environmental conditions. This chapter explores the synthesis of bioNMs from various sources, characterization, their diverse applications in environmental remediation such as water and soil treatment, and air purification. Furthermore, it examines the challenges that need to be addressed and presents prospects for bioNMs in the ongoing battle against environmental pollution.

Keywords: Air pollution, Bionanomaterial, Environmental remediation, Green NMs, Soil pollution, Wastewater management.

INTRODUCTION

Environmental pollution is one of the most serious concerns around the globe. It is increasing gradually and causing a serious impact on living organisms, including humans. It is estimated that by 2030, nearly 3 million tons of waste will be produced globally [1]. According to WHO, every year, 2,70,000 children fall ill due to the toxic effects of environmental pollution [2]. In general, pollution is created by any unwanted change in the physicochemical and biological characteristics of any component of the environment. This includes the major components of water, soil, and air that can cause harmful effects on various forms of life and property [3]. Wastes are generated and discharged into the environment in a wide range of ways. For example, atmospheric pollutants like suspended

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organic particulates, nitrogen oxides, sulfur oxides, carbon oxides, and hydrocarbons, along with various organic pollutants like pesticides, insecticides, and heavy metals, can be found in soil and water. There are many effective remediation methods to clean it up. Bioremediation is one of the effective approaches to some extent, which involves breaking down the pollutants in the soil by microorganisms [4]. Phytoremediation involves planting species to extract contaminants from the soil, and landfill remediation involves techniques such as capping [5]. Thermal methods such as incineration and thermal desorption involve applying heat to contaminated materials to either volatilize or decompose the contaminants [6]. Chemical remediation involves the oxidation of pollutants into non-toxic forms using strong oxidants such as hydrogen peroxide, ozone gas, potassium permanganate, or persulfates [7]. Physical treatments such as air stripping, filtration, and sedimentation are used to physically separate contaminants from environmental media [7]. Most of the above-mentioned methods involved the removal of contaminants *via* processes like adsorption, absorption, chemical reactions, photocatalysis, and filtration. Here, NMs play a promising role due to their unique physical and chemical properties. Many NMs have been reported for environmental remediation [8]. Compared to classical methods of synthesizing NPs, utilizing biology for the synthesis of NMs, called bioNMs, has become an attractive area of research in recent years [9].

Among the various applications, bio-NMs are considered a promising candidate for environmental remediation due to their low toxicity towards living beings, enhanced biocompatibility, bioavailability, and bioreactivity. It paved the way for a sustainable, clean, and green environment, as they mimic the characteristics of NMs with advancements and remarkable performance, high efficiency, and monitoring of the adverse effects of pollutants. In general, bioNMs are synthesized by biological molecules like proteins, enzymes, nucleic acids, antibodies, secondary metabolites, and microorganisms such as bacteria, fungi, plant extract, *etc* [10]. Their smaller size, high surface area, more reactivity, and specific functionalities enhance environmental remediation ability. BioNMs express unique physical, chemical, structural, biological, and mechanical properties, which make them promising candidates for environmental applications.

SOURCES OF SYNTHESIS OF BIONMS

Synthesis of NMs using physical and chemical methods involves the usage of highly concentrated reductants and stabilizing agents that are highly harmful to the environment [11, 12]. Besides high yield, controlling the uniform size is a challenging task [13]. Over the years, various strategies have been employed to overcome the difficulties faced by traditional methods through the use of eco-friendly solvents, reagents, and methodologies. However, scalability limits their application. Hence, the development of a cost-effective and environmentally friendly yet scalable method is an urgent need. The biological synthesis of NPs is a single-step process that requires less energy, and it is eco-friendly in nature. Therefore, biosynthesis presents a promising alternative approach for the synthesis of nanomaterials. It uses eco-friendly resources such as plants, enzymes, nucleic acids, and microorganisms [13]. Various sources used for synthesizing bioNMs are given in Fig. (**1**).

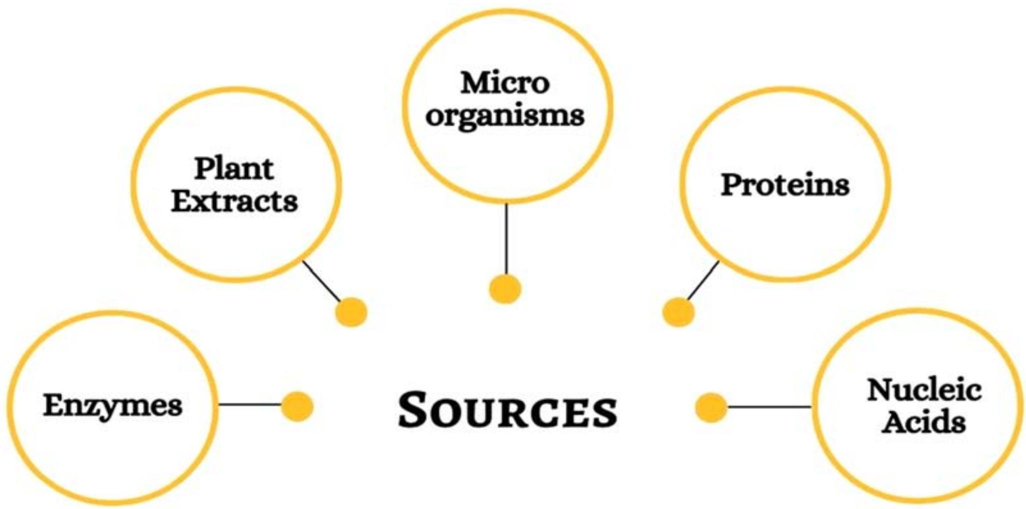

Fig. (1). Pictorial Representation of Source for Synthesis of BioNMs.

Plant Extracts

Plant-derived NPs have garnered huge interest because of their cost-effectiveness, environmental friendliness, and sustainability. In general, choosing the right plant and its components is the most crucial aspect of synthesizing bioNMs using plants. This is because different plants contain different levels of enzyme activity, phytochemicals, and biochemical processes.

BioNPs are prepared by treating the respective metal salts or oxides with plant extracts. After some time, the solution undergoes a visible color change that indicates the formation of NPs, as mentioned in Fig. (**2**). Plant extracts can be obtained using various parts of the plants, like seeds, roots, stems, leaves, flowers, and fruits. Various metal salts and the plant parts used for synthesizing bioNMs are given in Tables **1** and **2**, respectively. Plant extracts obtained from leaves, flowers, roots, *etc*., contain many bioactive compounds (secondary metabolites)

CHAPTER 10

Green Nanotechnology and Environmental Remediation: A Critical Review

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Abstract: Environmental pollution is a major challenge on a global basis. Traditional methods for cleaning up polluted environments are often associated with certain drawbacks such as high cost, inefficiency, and generation of hazardous by-products. Green nanotechnology has emerged as an innovative approach to synthesizing nanoparticles (NPs) from natural resources like plant extracts, microorganisms, or enzymes. Green-synthesized NPs hold immense potential for the remediation of different environmental matrices due to their unique properties and biodegradable nature.

Green nanotechnology provides sustainable and efficient solutions for environmental remediation and paves the way for a cleaner and healthier planet. In this chapter, the authors have highlighted the principles of green nanotechnology and potential applications of green synthesized NPs in the remediation of air, water, and soil, along with their superiority over other conventional treatment techniques. The authors have also highlighted its limitations and associated challenges so that with continued research and development, green nanotechnology can revolutionize the way we address environmental pollution, ensuring a brighter future for generations to come.

Keywords: Environmental footprint, Environmental remediation, Green nanotechnology, NPs, Natural resources.

INTRODUCTION

Green nanotechnology offers a revolutionary approach to environmental remediation by utilizing nanomaterials (NMs) synthesized through environmentally friendly methods. It can be defined as the design, development, and application of NMs with minimal environmental impact throughout their lifecycle [1]. It prioritizes the use of non-toxic, readily available, or renewable

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resources for the synthesis of NP. This minimizes reliance on harmful chemicals and reduces dependence on depleting resources [2]. Traditional techniques for NP synthesis often involve harsh chemicalsor high energy consumption. Green nanotechnology explores alternative methods like biosynthesis using plant extracts, microbes, or enzymes. These methods are more energy-efficient, produce less waste, and are generally safer for the environment [3, 4]. Ideally, green-synthesized NPs should be biodegradable or easily removable from the environment after performing their remediation function. This prevents long-term environmental contamination concerns associated with some traditional NMs [5].

ENVIRONMENTAL CHALLENGES AND CONVENTIONAL REMEDIATION METHODS

Human activities have significantly impacted the environment, leading to a multitude of challenges. These include:

Water Pollution

Industrial waste, agricultural runoff, and untreated sewage contaminate water bodies with heavy metals, organic pollutants, and pathogens [6].

Soil Contamination

Industrial spills, overuse of pesticides and fertilizers, and improper waste disposal pollute soil with heavy metals, persistent organic pollutants, and radioactive materials [7].

Air Pollution

Emissions from vehicles, industries, and burning fossil fuels release harmful gases like nitrogen oxides, sulfur oxides, and particulate matter, leading to respiratory problems and climate change [8].

Conventional remediation methods have been employed to address these challenges, but they often have several limitations. When the contaminated soil or sediment is removed and transported to landfills, it can be disruptive, expensive, and create a risk of secondary pollution [9]. High energy consumption is required when contaminated groundwater is pumped out, treated above ground, and then reinjected into the ground. This process potentially leaves residual contamination [10]. Chemicals that are used to immobilize or degrade pollutants may be toxic and leave harmful byproducts [11].

GREEN NANOTECHNOLOGY - A PROMISING SOLUTION FOR ENVIRONMENTAL REMEDIATION

Conventional remediation methods for environmental pollution often struggle with high costs, substantial energy consumption, and the generation of secondary waste. Green nanotechnology emerges as a promising alternative, offering a sustainable and potentially more effective approach. Its emergence is driven by several key factors, which are discussed below.

Growing Environmental Concerns

With rising global awareness of environmental issues, there is a strong push for sustainable solutions. Green nanotechnology aligns with this movement by minimizing environmental impact throughout the lifecycle of NMs used in remediation [1].

Limitations of Traditional Methods

Existing remediation techniques often have limitations. Chemical treatments can generate harmful by-products, while excavation and landfilling are disruptive and expensive [9, 10]. Green nanotechnology offers the potential to overcome these limitations by utilizing environmentally friendly synthesis methods and promoting targeted remediation strategies.

Unique Properties of NPs

NPs possess unique properties due to their extremely small size. This includes a significantly larger surface area compared to bulk materials, which allows them to interact more effectively with pollutants [5]. Green nanotechnology leverages these properties to design NPs specifically for environmental remediation applications.

Advancements in Biosynthesis

Research in green nanotechnology has led to significant advancements in eco-friendly synthesis methods. These methods utilize biological resources like plant extracts, microbes, or enzymes to synthesize NPs [2, 4]. It not only reduces reliance on harmful chemicals but also opens doors for potentially scalable and cost-effective production.

GREEN NANOTECHNOLOGY: A SUSTAINABLE APPROACH

Green nanotechnology represents a revolutionary approach to nanotechnology that prioritizes environmental sustainability. It can be defined as the design,

CHAPTER 11

Photocatalytic Activity and Potential of NMs in Environmental Remediation

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Abstract: Environmental pollution is a critical global concern that necessitates innovative and sustainable solutions. Among the emerging technologies, photocatalysis using nanomaterials (NMs) has gained significant attention for its potential in environmental remediation. Photoexcitation of wide-bandgap semiconductors like TiO_2, ZnO, SnO_2, CdS, and WO_3 in aqueous media leads to electron-hole pair generation, initiating subsequent photocatalytic processes. The photocatalytic activity is enhanced by the involvement of NMs like Metal oxide NMs, Metal NMs, Graphene-based NMs, and Quantum dots. This chapter explores the photocatalytic activity of various NMs and their applications in addressing environmental challenges. The synergistic effects of NMs in pollutant degradation, wastewater treatment, air purification, and soil remediation are discussed, highlighting the promising prospects for sustainable environmental management. The escalating threats posed by environmental pollution necessitate innovative and sustainable approaches to remediation. The size-dependent properties of NMs result in increased photocatalytic activity, rendering them highly effective in the degradation of diverse environmental pollutants. The interplay between NMs and photocatalysis is elucidated, emphasizing the promising avenues for addressing challenges associated with water, soil, and air quality. As we delve into the applications and mechanisms of NM-based photocatalysis, the chapter also addresses current limitations and future prospects. The insights presented herein contribute to a comprehensive understanding of the photocatalytic activity and potential of NMs, paving the way for sustainable environmental remediation strategies.

Keywords: Contaminants, CNTs, Degradation, Environmental pollution, Graphene oxide, Heavy metals, TiO_2, Photocatalysis, Phytoremediation.

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INTRODUCTION

Environmental pollution, a consequence of rapid industrialization, urbanization, and unchecked human activities, has emerged as a pervasive and urgent global challenge [1]. The release of pollutants into air, water, and soil ecosystems poses severe threats to biodiversity, human health, and the overall sustainability of our planet. Common pollutants include hazardous chemicals, heavy metals, greenhouse gases, and various contaminants from industrial and domestic sources. As the scale of pollution continues to escalate, traditional remediation methods struggle to keep pace with the magnitude and complexity of environmental degradation [2]. Conventional approaches, often resource-intensive and limited in efficacy, fall short of addressing the dynamic nature of pollutants and the intricate interplay of environmental systems. The need for innovative and sustainable remediation technologies has never been more pronounced.

In this context, the exploration and development of advanced remediation strategies have become imperative. The advent of innovative technologies capable of efficiently mitigating the impact of pollutants on ecosystems is crucial for safeguarding human health and preserving the delicate balance of nature. One such promising avenue is the application of photocatalysis using NMs, which has gained significant attention for its potential to revolutionize environmental remediation [3]. The urgency to address environmental pollution calls for a paradigm shift in our approach to remediation, emphasizing solutions that are not only effective but also sustainable in the long term [4]. Innovative remediation technologies, such as those incorporating NMs, offer the promise of enhancing pollutant removal while minimizing adverse environmental effects. By harnessing cutting-edge science and engineering, these technologies aim to provide efficient, cost-effective, and environmentally friendly solutions to combat the multifaceted challenges posed by pollution [5].

Photocatalysis, a process reliant on light-induced chemical reactions, stands out as a potent tool in environmental remediation [6]. The photocatalytic mechanism involves the excitation of electrons in semiconductor materials, typically NMs like titanium dioxide (TiO_2) or zinc oxide (ZnO), upon exposure to light [7]. This process generates electron-hole pairs that, in turn, initiate redox reactions capable of breaking down various pollutants. Photocatalysis plays a pivotal role in environmental cleanup through its applications in water purification, air decontamination, and soil remediation. In water treatment, photocatalysis proves effective in degrading organic pollutants and eliminating bacteria [8]. Similarly, in air purification, photocatalytic coatings facilitate the breakdown of airborne contaminants, addressing issues such as volatile organic compounds (VOCs) and nitrogen oxides. Furthermore, photocatalysis exhibits promise in remediating contaminated soil by transforming toxic substances into less harmful forms. Due to its ability to utilize sunlight or artificial light sources for pollutant degradation, photocatalysis emerges as a significant technology for sustainable and energy-efficient environmental remediation.

NMs play a vital role in enhancing photocatalytic activity for environmental remediation due to their unique properties. These materials, characterized by their nanoscale dimensions, offer increased surface area, enabling more active sites for pollutant adsorption and facilitating a higher number of photocatalytic reactions [9]. The quantum size effects of NMs allow for enhanced light absorption across a broader range of wavelengths, including visible light, making them efficient photocatalysts [10]. Additionally, NMs promote improved charge carrier separation, minimizing electron-hole pair recombination and enhancing overall efficiency [11]. The tunable bandgap of semiconducting NMs allows for the optimization of absorption properties, while surface modifications enable tailored chemical and electronic characteristics [12]. The diverse types of NMs, such as metal oxides and carbon-based structures, offer flexibility for specific environmental applications [13, 14]. Compatibility with renewable energy sources, particularly solar energy, aligns NMs with the goal of sustainable and energy-efficient environmental remediation technologies [15]. This collective synergy positions NMs as crucial components in the development of efficient, scalable, and sustainable solutions for mitigating environmental pollution.

NMS FOR PHOTOCATALYSIS

Photocatalysis is a process that utilizes light to initiate and drive chemical reactions. The crucial role of NMs in photocatalysis stems from their distinct physicochemical features, including reduced size, high surface area, quantum confinement effects, and tailorable electronic structures. This diverse toolbox of NMs finds application in various photocatalytic processes, ranging from water purification to air pollution remediation. Some of the NMs are reported in this chapter and are discussed below.

Metal Oxide NMs: Titanium Dioxide (TiO_2)

Titanium dioxide stands out as a highly effective material in photocatalysis, largely owing to its distinctive properties that facilitate the degradation of pollutants and the production of clean energy. With a wide bandgap, approximately 3.2 eV, TiO_2 exhibits significant photocatalytic activity under ultraviolet (UV) light, generating electron-hole pairs that initiate redox reactions and produce reactive oxygen species (ROS), including superoxide radicals ($O^{2\bullet-}$)

CHAPTER 12

Insights into the Impact of Nanocomposite TiO_2 Photocatalyst in Wastewater Effluents

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Abstract: Impurities of hazardous organic components are of growing concern for water, which is considered the primary operating parameter used in photodegradation investigations. Even in low quantities, the presence of hazardous chemicals in the water system can pose threats to living organisms' health and the environment. Traditional remediation methods are inefficient in eliminating the toxicity of hazardous chemicals containing wastewater effluents from the dye industry, the chemical industry, the pharma industry, and the cosmetic industry. Nanocomposites (NCs) of titanium dioxide (TiO_2) act as promising environmentally friendly photocatalysts for reducing water pollution. This chapter is focused on the discussion of the intermediate products that are produced during the photodegradation process using TiO_2 NCs and determining the impact of adding new elements on the TiO_2 energy gap. The pace at which photogenerated electron-hole pairs recombine, along with the suppression of the anatase-to-rutile phase transition is also discussed. The benefit of conducting comprehensive comparisons with a variety of photocatalytic reactions involving many substrates; utilizing a solar simulator to clarify the effectiveness of doped materials is also included in this chapter. The authors have tried to prove the idea of modulating the photocatalytic process and anticipated the potential for using this process to accomplish the utilization of wastewater effluent resources.

Keywords: Nanocomposite, Photocatalysts, Hazardous, Eliminating, Photodegradation, Utilization, Wastewater effluent.

INTRODUCTION

Titanium dioxide (TiO_2) is a semiconducting and inert metallic oxide that exhibits photocatalytic activity under solar radiation. Due to its unique characteristics, TiO_2 is commonly known as *'titania'* and has gained considerable attention in a vast range of environmental applications. Additionally, its relatively low cost and

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easy processing have made it a popular choice over the years. TiO_2 has been classified as chemically and biologically nonreactive material in animals and human beings [1]. TiO_2 has been formed from various minerals. There has been an exponential increase in the direct production of nano-sized TiO_2 during the last few years, with the annual production of TiO_2 powder estimated to be around 5 million tons worldwide in 2005, a 2.5% increase in 2009, and a 10% increase in 2015 [2]. TiO_2 in powdered form has characteristic properties such as opacity in many commercial products; such as paint texture, pharmaceuticals, paper texture, and cosmetics. It offers an advanced technological potential due to its high refractive index and light-scattering qualities. Nano-sized TiO_2 has been the basis for technological advancements that have made it possible to employ it in a variety of applications, including the plastics sector, confectionary, glass antifogging, and self-cleaning coatings. Furthermore, TiO_2 NPs and their NCs play a vital role in food and bakery products and pharmaceutical drugs [3]. Concerns have been raised regarding the increasing possible effects of TiO_2 powder (nano-sized) on humans and the environment due to its manufacturing process.

PROPERTIES AND POTENTIAL OF TIO_2 NPS

Physical and Chemical Characteristics of TiO_2 NPs

The nano range of TiO_2 particles is smaller than 100 nm with various shapes under modification, such as nano-powder, nano-film, nanowire, nano-tubes, nanorods, nano-sheet, *etc*. TiO_2 particles in micron and nano sizes have the same properties because of their larger specific surface area, but nano-powders have different physical characteristics. A recent study examined the size-related characteristics of metallic oxide NPs and discovered special features when their diameters were less than 30 nm, which improves their reactivity across interfaces [4]. NPs bind together to create soft aggregates with strong bonds. The zeta potential, which varies greatly for TiO_2 particles across a broad pH range (3.5-8.8), determines how soft agglomerates disperse [5]. In the range of physiological pH, TiO_2 is claimed to significantly impact its bioavailability due to its isoelectric nature. Regretfully, the majority of research on the interaction between TiO_2 NPs and biological systems has virtually ignored the size of the particles and their properties checked by zeta potential [6].

Naturally occurring crystalline TiO_2 comes in 3 forms: anatase, brookite, and rutile. Rutile is the most stable form out of the three crystalline forms. The average particle size of TiO_2 powder under visible light is 230 nm while 60 nm under UV light. The anatase form of TiO_2 exhibits*-*- greater photocatalytic activity than that of rutile and brookite forms. The TiO_2 NPs energy gap creates a band where an electron jumps from the valence level to the conduction level [7]. Photo-activation of nano-TiO_2 can occur when it is exposed to UV-A to C, visible, fluorescent, and X-ray radiation. Highly reactive photo radicals are produced as a result of photocatalytic activity, and these free radicals can react frequently with organic materials.

The cellular function of NPs possesses various characteristics that are important from a toxicological standpoint. Among these are their dimensions, surface area, chemistry and charge on the surface, crystallinity, shape, solubility, and state of agglomeration or aggregation. The surface of NPs can make them hydrophilic/lipophobic or hydrophobic/lipophilic as well as active or passive in catalytic activity. Active absorption by endocytosis and passive uptake by free diffusion are the two primary mechanisms of uptake of NPs in the cells. The "professional" phagocytes, such as macrophages, are known for their action-dependent endocytic function, known as phagocytosis [8]. Phagocysts are capable of phagocytosing particles that are smaller than 500 nm, which causes a persistent strain on other cells and tissues. According to studies, when rats are exposed to TiO_2 powders through inhalation, it efficiently removes 3-6 μm particles but 20 nm-sized particles are difficult to remove. Human keratinocytes have been shown to take up TiO_2 NPs endocytotically through *in vitro* investigations [9]. Reported experimental research has evaluated that the TiO_2 NPs of less than 200 nm size easily enter the human blood cells. However, particles of size greater than 200 nm couldn't enter; rather they accumulate on the surface of the human blood cells [10]. These findings demonstrated that the size and aggregation state of NPs affects their cellular uptake and subcellular localization, which ultimately determines their toxicity.

Increasing human population, urbanization, expansion of agricultural lands, climate change, and pollutants from industrial effluents create wide problems concerning harm to humans as well as the environment [11]. As a result, clean water resources are becoming scarce, making the water crisis an urgent issue that needs to be resolved. Furthermore, it is confirmed that there is widespread water pollution as a result of organic and inorganic contaminants and hazardous toxic elements (HTEs) traveling through different channels. A vast array of organic active moieties is included in organic contaminants, all of which are poorly and ineffectively removed by conventional wastewater treatment facilities through activated sludge [12]. As a result, they are released into the environment, where they have been found to be carcinogenic to the endocrine system, and mutagenic.

The Energy Gap of the Valence Band (VB) and Conduction Band (CB)

In the electronic band structure of the semiconducting material, the valence band

CHAPTER 13

A Comparative Study of Different Types of Nanomaterial-Based Carbon-di-oxide Sensors and Their Diverse Applications

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Abstract: Carbon dioxide is one of the greenhouse gases created by human activities like burning fossil fuels for power generation, oil refining, production of natural gas for transportation, and many other such processes. It is a colorless, relatively inert, and highly oxidizing gas; its concentration has a big effect on the world's climate resulting in sea level rise, global warming, the greenhouse effect, and the possible development of subtropical deserts. Thus, both qualitative and quantitative CO_2 detection is crucial for many industries, including food and beverage packaging, air quality, biotechnology, health and medical research, marine and environmental science, and industrial monitoring. This chapter majorly focuses on the different types of CO_2 nano-sensors and their comparison based on their performances.

Keywords: Carbon dioxide sensors, Detection, Environment, Industrial, Monitoring, Medical research.

INTRODUCTION

In the world of technology and scientific instruments, nano-sensors are crucial components that allow the transformation of physical events into data that can be measured and understood [1]. These devices are engineered to identify particular stimuli from the surroundings and convert them into electrical signals or other measurable outputs. The fundamental principle behind sensors is their capacity to

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connect the physical realm with digital data, enabling a more profound comprehension and control of our environment [2, 3].

Fundamentally, a sensor functions by converting physical alterations, like changes in temperature, pressure, light, or chemical composition, into signals that are ready for processing and examination [2]. Sensors are essential due to the restrictions of human senses and the requirement for exactness, precision, and immediate monitoring in different fields. Our human senses have inherent limitations in their range and precision, which can make it difficult to detect small changes or differences in our surroundings [4]. With their advanced mechanisms and technologies, nano-sensors can effectively surpass these limitations by providing a dependable and accurate way to collect data. Essentially, sensors are crucial for improving our capacity to observe, measure, and control physical phenomena. Whether utilized in industrial automation, environmental monitoring, healthcare, or consumer electronics, sensors play a crucial role in advancing technology. They provide a constant flow of data that guides decision-making, enhances system dependability, and encourages creativity. There are several important categories to consider when it comes to the necessity of nano-sensors [5, 6]:

- With nano-sensors, measurements can be made with a level of precision and accuracy that exceeds what humans can achieve, allowing for detailed parameter readings.
- When it comes to automated systems, nano-sensors play a crucial role by detecting changes in the environment and adjusting system parameters to enable the autonomous operation of machinery and processes [7, 8].
- When it comes to safety and monitoring, nano-sensors play a vital role in various applications. They are essential for detecting toxic gases, monitoring structural integrity, and overseeing critical parameters in healthcare settings.
- Efficiency is enhanced through the continuous monitoring and optimization of processes, leading to reduced resource consumption in various sectors such as industrial, agricultural, and energy.
- At the cutting edge of technological advancement, nano-sensors are propelling the progress of smart devices, Internet of Things (also known as IoT) applications, and advanced scientific research [9].

Within the constantly changing realm of environmental monitoring and safety, the identification and quantification of carbon dioxide (CO_2) are crucial. Carbon dioxide, a transparent and scentless gas, is a natural element of Earth's atmosphere [10]. The increasing CO_2 levels, resulting from human activities like industrial production, transportation, and energy generation, highlight the critical importance of thorough monitoring and mitigation strategies [11]. Confronting the concerning CO_2 emission ratios requires a deep understanding of the complex relationship between CO_2 production, its negative impact on the environment, and the crucial role of carbon dioxide nano-sensors in tackling these issues [7].The continuous increase in CO_2 emissions from human activities has disturbed the fragile equilibrium of our atmosphere, leading to global warming and climate change.

Nevertheless, the rising levels of human-made activities have resulted in a significant increase in CO_2 emissions, sparking worries about its effects on climate change and indoor air quality. Researchers are working diligently to understand and address these impacts, making advanced carbon dioxide nano-sensors crucial for progress.

Exploring the complex realm of carbon dioxide sensing technologies, this chapter investigates a wide range of nano-sensors created to measure and analyze CO_2 levels in different scenarios. Whether in industrial settings, commercial buildings, or environmental monitoring stations, the demand for precise and dependable CO_2 nano-sensors is crucial. CO_2 nano-sensors have wide applications in various fields as shown in Fig. (**1**).

CHAPTER 14

Application of Nanotechnology in Air Remediation

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Abstract: The world's persistent daily development continues to cause unceasing damage to the air. As reported by the World Health Organization, over six million people worldwide lost their lives due to residing and working in environments affected by air pollution in 2016. Despite the effectiveness of traditional techniques such as desulfurization, denitrification, and dust removal in reducing emissions from the sources of stationary combustion, they have not proven successful in reducing the frequency of atmospheric haze conditions. Current research globally urges the advancement of technologies to create nanomaterials (NMs) capable of efficiently and intelligently trapping CO_2, CO, and other harmful gases from the air. Diverse NMs play pivotal roles as nano adsorbents, nanocatalysts, nanofilters, and nanosensors, showcasing the versatility and effectiveness of nanotechnological applications in this field. This technology facilitates air pollution remediation by treating volatile organic compounds, greenhouse gases, and bioaerosols through adsorption, photocatalytic degradation, thermal decomposition, and air filtration processes. This chapter specifically delves into the practical use of a range of NMs for air pollution remediation applications.

Keywords: Air pollution, Air purification, Nanotechnology, Nanosensors, Nanofilters.

INTRODUCTION

Air pollution comprises a broad spectrum of volatile organic compounds (VOCs) and damaging gases that originate from different natural and human-related sources. Industrial processes like manufacturing, power generation, and refineries release a wide range of pollutants such as nitrogen oxides (NO_x), volatile organic compounds (VOCs), carbon monoxide (CO), sulfur dioxide (SO_2), and particulate matter (PM) as a result of burning fossil fuels and conducting different production processes [1]. Furthermore, the contribution of agricultural practices to air pollution through activities like livestock farming, fertilizer use, and biomass

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burning illustrates the need to reduce their environmental impact by transitioning to cleaner energy sources. NOx has a strong photochemical reactivity in the atmosphere, as it can cause acid precipitation, haze, secondary particle generation, and negative health impacts [2]. Approximately 90% of the total emissions of NO_x occur from coal-fired power plants, industrial facilities, such as industrial boilers, iron-steel plants, cement, and motor vehicles [3]. The combination of these sources results in a diverse range of pollutants in the air, which not only harms the environment but also plays a significant role in driving climate change. The global concern about the adverse impact of air pollution on human health continues to grow. As per the World Health Organization (WHO), almost 80% of urban populations are exposed to inadequate air quality, which increases the risks of heart disease, stroke, respiratory illnesses, and lung cancer [4]. Recent studies have shown that in 2015, poor air quality contributed to an increased number of premature deaths, affecting 6.4 million individuals. Out of these, 4.2 million deaths were associated with ambient air quality, while 2.8 million were attributable to indoor air quality [5, 6].

Hence, there is a demand for technology capable of monitoring, detecting, and ideally purifying air contaminants. Innovations in nanotechnology offer a novel approach to environmental cleanup and enhance the effectiveness of conventional methods by minimizing emissions or preventing the formation of pollutants [7]. In theory, nanostructured materials are employed for green chemistry and environmental remediation for the reasons: (1) These materials have textile flexibility properties and an increased number of reactive edges, leading to inherently higher surface reactivity; (2) In comparison to bulk materials, they have huge surface-to-bulk ratios and large specific surface areas (SSAs);(3) Their chemical characteristics, including their oxidation and reduction potentials as well as their Lewis acid and Lewis base qualities can be adjusted or customized for specific reactions [8]. Thus, nanotechnology presents promising solutions for efficient air purification through the use of nano adsorbents, sensors, membranes/nanofilters, and nanocatalysts [9, 10]. This chapter delves into the specific applications of NMs in remediating air pollution.

NANOTECHNOLOGY FOR ENVIRONMENTAL POLLUTION REMEDIATION

Nanotechnology refers to the exploration of technology, engineering, and science at the nanoscale, typically ranging from 1 to 100 nanometers. This scale enables innovative applications across diverse disciplines including physics, medicine, chemistry, biology, electronics, and engineering. It is noteworthy that materials sized around 1000 nanometers are also categorized as NMs [11]. Within the nanoworld, nanoparticles (NPs) stand out for their exceptional characteristics, attributed to their significant surface-to-volume ratio, making them inherently more reactive than larger forms of the same materials. Such NMs are being extensively utilized across various environmental sectors, from air pollution control and water purification to soil remediation and renewable energy enhancement. These materials play crucial roles in making renewable energy sources more affordable and efficient. Specifically, they are employed in processes such as particle filtration, gas adsorption, and sensor technologies. NMs are integral components of purification devices aimed at reducing PM, gaseous pollutants like NO_x and VOCs, as well as toxic substances such as formaldehyde (HCHO), as illustrated in Fig. (**1**).

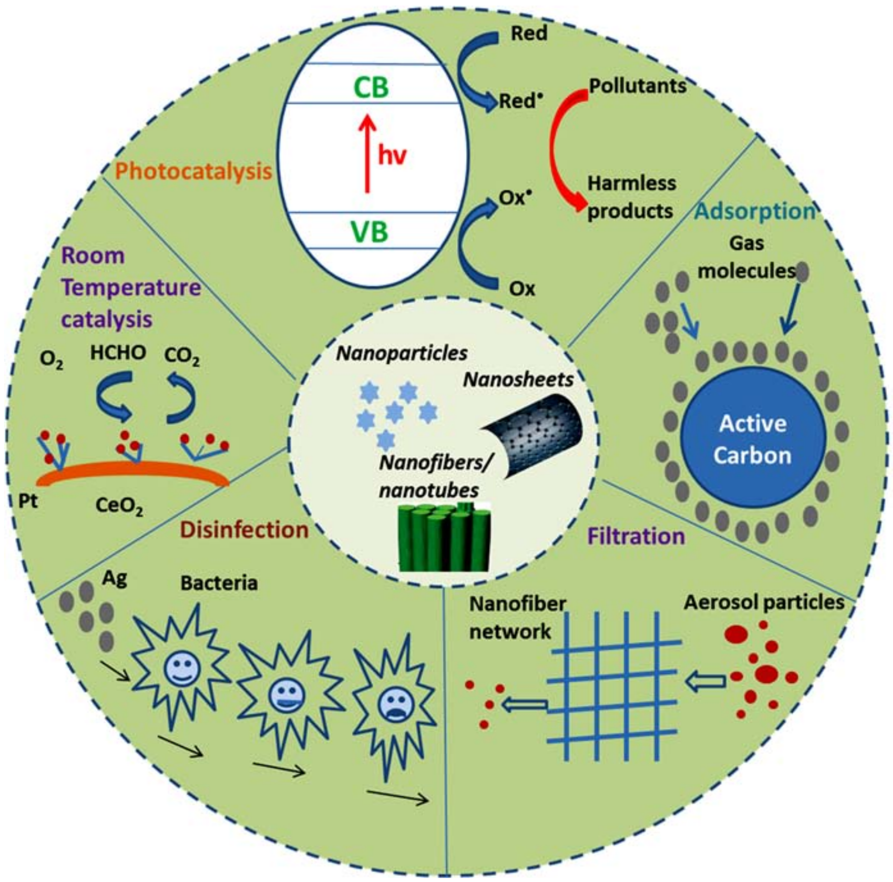

Fig. (1). Various NM-based air remediation technologies [14].

Some applications of nanotechnology are nearing commercialization, including nanosensors and nanoscale coatings that aim to replace thicker polymer coatings, which are less efficient and more wasteful in preventing corrosion. Nanosensors

CHAPTER 15

Applications of Nanotechnology for Remediation of Soil

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Abstract: Soil is a valuable natural resource that favors the growth and development of plants, microbes, and other organisms living in both terrestrial and aquatic ecosystems. At present due to various anthropogenic causes like accelerated urbanization, industrialization, and ever-increasing population, the soil is becoming heavily contaminated due to industrial wastes, mining, excess use of agrochemicals like fertilizers and pesticides, and several other pollutants like toxic heavy metals and poly aromatic hydrocarbons. Due to these contaminants, plants, and soil microbes face various types of stresses which adversely affect the growth of plants and microorganisms. So, the remediation of such valued soil resources is essential to fulfill the need for food grains and to ensure the food security of growing populations throughout the world. Nanotechnology is the recent and most advanced technology that provides efficient, cost-effective, and environment-friendly ways for the remediation of contaminated soils. Various nanoparticles like zinc oxide (ZnO), titanium oxide (TiO_2), silver nanoparticles, nZVI (Nano zero-valent iron), silicon oxide (SiO_2), and aluminium oxide (Al_2O_3), *etc*. are used for remediation purposes of such degraded lands. The application of nanotechnology-based methods has great potential to restore degraded land to its optimal forms that are suitable for the growth of plants and microbes. The use of nanotechnology provides innovative techniques for the remediation of degraded soil due to their reactivity and versatility. So, the promotion of efficient and sustainable use of nanomaterials (NMs) can enhance the productivity and fertility of such soils. It is the necessity of the present time to provide sustainable remediation approaches that ensure a safe and healthy environment without degrading natural resources.

Keywords: Agrochemicals, Contaminants, Fertility, Microorganism, Nanoparticle, Nanotechnology, Nanomaterials.

INTRODUCTION

Soil is one of the most significant components of the environment which provides a critical terrestrial ecosystem in which plants and microorganisms survive and

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acquire all essential nutrients, water, and oxygen [1]. Soil with better and optimal physico-chemical properties is a prerequisite for optimum growth of plants and different microorganisms. Soil also helps in the regulation of the temperature of Earth. The important components of soil are soil separation (sand, silt, and clay), organic materials, minerals, water, and air. Due to rapid population growth, urbanization, and industrialization, this valuable natural resource is being contaminated due to the addition of various harmful substances. Soil, as a natural resource supports the human food production system and the cultivation of vegetation for fuel, fiber, and fodder. Natural resource soil is very important because it is used to meet the needs of living organisms for their survival [2]. Some important functions of the soils are listed as:

- It supports the root system.
- It provides the roots with minerals and nutrients.
- It helps in the exchange of gases and oxygen and protects against erosion.
- It filters various properties of the soil, retains water, and decomposes organic matter.

Soil is the living surface of the crust of the earth, which consists of numerous materials for example minerals, organic material, soil air, and ground water. Soils vary in thickness, texture, configuration, and genetic processes. The creation of different soil types depends on soil, climate, source rocks, organisms, time, and human influence [3]. The aim of this chapter is to explore the possibilities for remediation of contaminated soil having pesticides and their residues, heavy metals, and persistent organic pollutants (POP) using nanotechnology and its role in improving bioremediation and phytoremediation.

CONTAMINATION OF SOIL

Topsoil is deeply affected by environmental toxic waste often considered a "Universal sink". Contaminants usually pass into the soil as sewage, garbage, accidental discharges, or by-products and as remains from the fabrication of different materials. Such pollution of soils can cause unwanted changes in their physical, chemical, and biotic properties, all of which can contribute to changes in soil productivity and potency levels. Any substance found in the soil that exceeds naturally occurring levels and poses a risk to human health is a soil pollutant. For example, Arsenic occurs naturally in some soils, but spraying certain pesticides in the yard can lead to soil contamination, which causes deterioration or loss of one or more functions of soil [1]. Soil contaminants may be of different types such as inorganic and inorganic contaminants or particulate pollutants [5]. Domestic and industrial waste pollutes the soil the most (37%), followed by the industry/commercial sector (33%). Heavy metals and mineral oil are the main pollutants responsible for approximately 60% of soil pollution [6]. There are many ways to contaminate the soil such as:

- Solid waste seepage and waste yards.
- Ejection from industrialized leftovers into the soil.
- Filtration of polluted water into the soil.
- Surplus use of herbicides, pesticides, and fertilizers.

The widespread compounds that are responsible for soil contamination are petroleum hydrocarbons, pesticides, Heavy metals (HMs), and solvents. Soil contaminated with these chemicals has a higher risk of contaminating the food chain on account of the bioaccumulation potential of these contaminants. Cultivation efficiency is severely hampered by both the burden of producing more food and the challenge of stopping more soil deprivation. Nanopowered soil remediation can give a sustainable way to revitalize degraded soil properties. Applications that are based on Nanotechnology are cost-effective, easy to use, and involve adequate treatment and remediation approaches that can significantly diminish soil contamination [7].

SOIL REMEDIATION

Soil remediation is widely regarded as an effective method for mitigating soil contamination. The following measures have been proposed to control soil contamination. We can limit construction in sensitive areas to prevent soil erosion. In general, we would need fewer fertilizers and pesticides if we could all adopt the three R's: reduce, reuse, and recycle. This would reduce solid waste [8]. Some of the soil remediation methods are as follows:

- Extraction and separation techniques
- Thermal methods
- Chemical methods
- Microbial treatment methods
- Reducing the use of chemical fertilizers and pesticide
- Reforesting
- Solid waste treatments.

The main pollutants that soil remediation techniques target are organic composites like pesticides, polychlorinated biphenyls (PCBs), and PAH (polycyclic aromatic hydrocarbons); heavy metals like zinc, lead, arsenic, and chromium; and an extensive variety of combined toxins. Engineered NMs, coupled with different nanotechnology devices and systems, bring forth innovative and enhanced strategies for the restoration of contaminated soil.

CHAPTER 16

Nanotechnology in Remediation of Persistent Organic Pollutants

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Abstract: The growing concern over environmental pollution caused by toxic organic materials has led to intensive research on innovative and sustainable remediation methods. Among the emerging technologies, the use of nanomaterials (NMs) has gained significant consideration because of their exceptional properties as well as high efficiency for the degradation of various pollutants. Contaminated organic materials, including various industrial chemicals, pesticides, pharmaceuticals, and persistent organic pollutants (POPs), pose severe threats to the environment and the health of human beings and other animals. The conventional methods used in the treatment of these pollutants often exhibit limited effectiveness, high costs, and may generate harmful by-products. The use of NMs in degradation processes often requires less energy compared to conventional remediation methods, leading to the overall process being more energy-efficient and environmentally sustainable. In a nanotechnology-based remediation strategy, engineered NMs are used to clean polluted locations because of their efficient, cost-effective, sustainable as well as eco-friendly nature. Nanoparticles (NPs) are very sensitive, have catalytic behavior, high surface area to volume ratio, and excellent electronic properties. NPs have the ability to diffuse in small spaces, which promotes their use as agents for the redressal of polluted soil and water. This chapter highlights the pivotal role of NPs in the degradation of toxic organic materials by leveraging their unique properties, making NMs a promising solution for addressing environmental pollution and promoting sustainable remediation practices.

Keywords: Environmental pollution, Nanoparticles, Nanomaterials, Persistent organic pollutants, Sustainable remediation.

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INTRODUCTION

Soil is the most important and vital component of Earth, which provides a crucial medium for the growth of plants by providing them with essential nutrient elements, water, and oxygen [1, 2]. The optimal physical and chemical properties of soil are very crucial for seed germination, seedling emergence, establishment, growth, and development of different crop plants, and trees as well as global food security and economic sustainability. This valuable natural resource is being adulterated by the addition of many toxic, harmful industrial and domestic waste products. These harmful substances negatively affect the growth and development of plants in such soils. The addition of harmful substances in the soil is carried out by both natural as well as anthropogenic sources. However, anthropogenic sources like industrialization and urbanization are major factors responsible for intense soil pollution at a very rapid rate, which is much higher than natural soil pollution [3]. The important soil pollutants are toxic organic pollutants (such as pharmaceuticals, flame-retardants, pesticides, polycyclic aromatic hydrocarbon (PAHs) biocides, polychlorinated biphenyls (PCBs), surfactants, polychlorinated dibenzofurans and polychlorinated dibenzo-p-dioxins), heavy metals, and radioactive substances due to the excess use of pesticides, herbicides and industrial effluents. These organic pollutants are introduced into soil mainly due to anthropogenic activities [4]. The soil organic pollutants (OPs) include a great diversity of chemical substances that exhibit different chemical properties and lack analytical standards for a whole set of OPs [5]. There is a great environmental threat associated with soil pollution. There are estimations that approximately 30% of land is contaminated and degraded by different pollutants [2]. Maintenance and restoration of soil fertility are essential for the conservation of biodiversity and for the maintenance of equilibrium between earth and environmental processes such as biogeochemical cycling, soil temperature, and soil reactions [6, 7]. The main processes responsible for land degradation are prompted by many factors like urbanization, soil erosion, dumping of wastes, overgrazing, and deforestation [8]. Besides this, chemical contamination and pollution due to the introduction of pesticides, toxic metals/metalloids, PAHs, and POPs are major anthropogenic factors leading to land degradation. Disproportionate application of pesticides, chemical fertilizers, and other contaminants leads to their excessive accumulation in such lands [9, 10].

Certainly, continuous industrialization leads to activities such as transportation, manufacturing, construction, petroleum refining, and mining, which result in the depletion of natural resources. These processes generate a substantial volume of hazardous waste, leading to the pollution of soil, water, and air and disturbing the biotic and abiotic components of ecosystems. The widespread application of pesticides and herbicides by farmers has led to significant environmental pollution. These chemicals often contain nitrogen-based compounds and other substances that are non-degradable in nature and persist in the environment for a long period of time. A reported statistical data collected in 2020 indicated that usually 51.90% of land in India is contaminated with different pollutants of serious concern [11].

Traditional pollution remediation methods often relied on specialized equipment and chemicals, which drove up costs significantly. Moreover, these methods often inadvertently caused more harm to the environment and were not economically sustainable in the long term. This is why there is an urgent need for the development of alternative remediation techniques that are inexpensive, simple, less time-consuming, require minimum labor input, eco-friendly, and sustainable. Consequently, a substantial amount of research is currently underway to develop reliable, versatile, and efficient techniques for the degradation and transformation of such toxic environmental pollutants. The application of NMs for the remediation of toxic environmental pollutants has gained greater attention due to their specific and versatile features like sensitivity, selectivity, cost-effectiveness, environment friendliness, excellent electronic properties, and superior catalytic properties [12, 13].

NMs designed for the protection and remediation of the environment have been effectively developed over the last few decades. In other words, NMs possess exceptional characteristics like electrochemical, and magnetic properties, large surface area-to-volume ratio, and size-dependent physical and chemical traits, which provide these NMs significant advantages in pollution control. The application of NMs in catalytic oxidation, chemical reduction, adsorption, photocatalysis, electrochemical, and filtration processes holds great promise for effectively addressing environmental challenges. Nanotechnology offers innovative solutions that can contribute to cleaner soil, water, and air as well as improved environmental sustainability and human health.

FATE, ACCUMULATION AND TOXIC IMPACTS OF POPS

Soil OPs have been divided into many classes according to their unique toxicological modes of action and physicochemical properties [5, 14]. The most commonly found OPs in soil include chlorinated compounds (PCBs, PCDFs, and PCDDs), monomeric aromatic hydrocarbons (toluene, benzene, xylene, and ethylbenzene), oil hydrocarbons (alkenes, alkanes, and cycloalkanes), PAHs (chrysene, benzo [a] pyrene and fluoranthene), numerous fungicides (lindane, penconazole, metalaxyl, and procymidone), pesticides, herbicides (atrazine, alachlor, acetochlor, and bifenox), insecticides (endosulfan, captan, heptachlor, benomyl, endrin), and their degradation products [14, 15]. Many of these OPs are

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