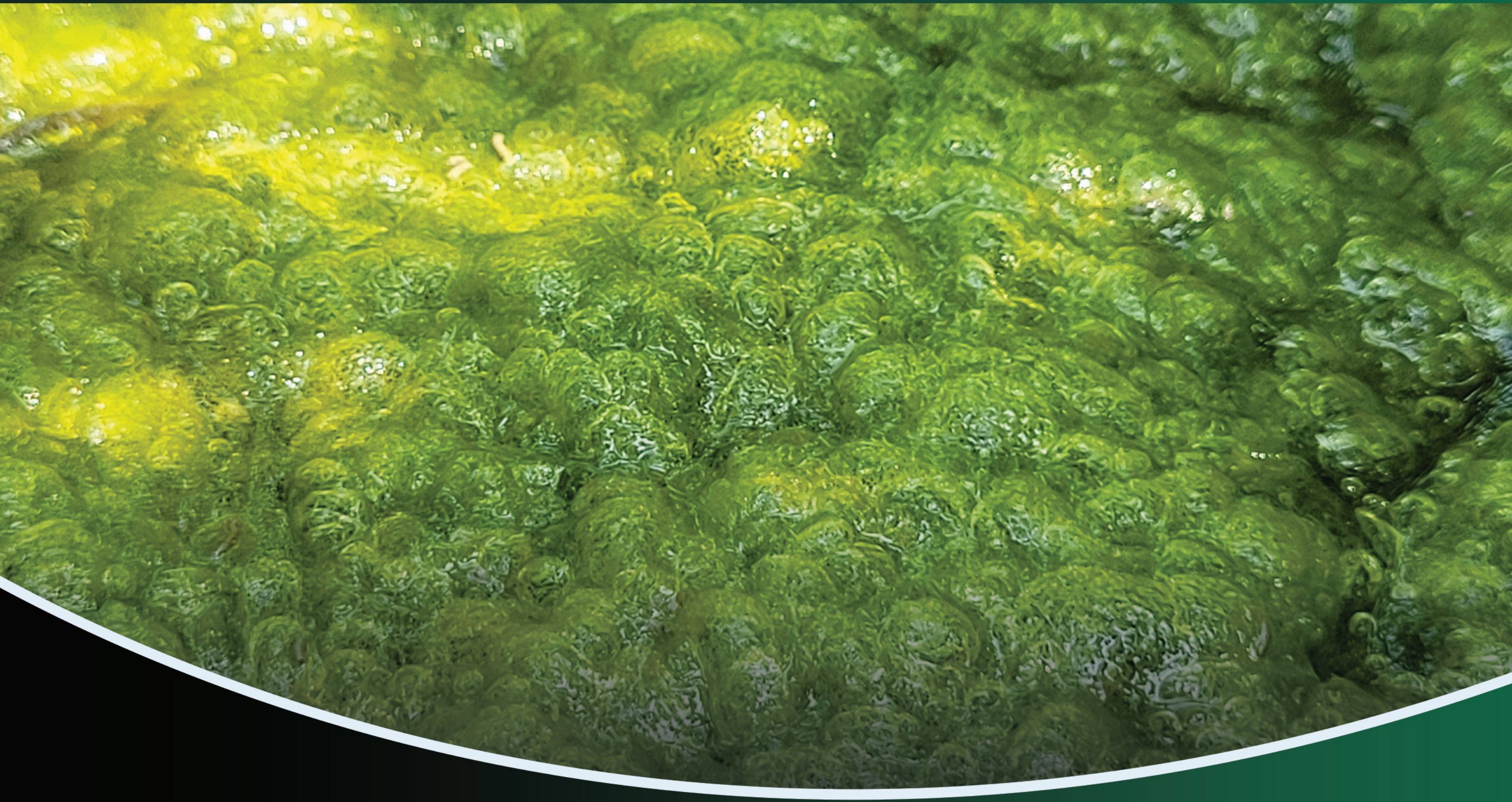
GREEN SOLUTIONS FOR DEGRADATION OF POLLUTANTS



Editors:
Neha Agarwal
Vijendra Singh Solanki
Sreekantha B. Jonnalagadda

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Green Solutions for Degradation of Pollutants

Edited by

Neha Agarwal
Department of Chemistry
Navyug Kanya Mahavidyalaya
University of Lucknow
Lucknow, India

Vijendra Singh Solanki
Department of Chemistry
Institute of Science and Research
IPS Academy
Indore, India

&

Sreekantha B. Jonnalagadda
School of Chemistry and Physics
University of KwaZulu-Natal, Westville Campus
Durban, South Africa

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Editors: Neha Agarwal, Vijendra Singh Solanki, Sreekantha B. Jonnalagadda

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PREFACE

The rapid industrialization, urbanization and technological advancement have generated various contaminants on a global level. The presence of these contaminants in different environmental matrices, either from natural or anthropogenic activities, represents a threat to the natural environment and living entities. Therefore, much control and research are required to eradicate and minimize the negative impacts of these pollutants from the contaminated environment. Though conventional treatment approaches and advanced techniques are effective in the removal of pollutants from the environment, these techniques are highly expensive, energy consuming and non-environment friendly in nature. In this view, there is a need for eco-friendly and sustainable solutions with minimal negative post-environmental impact.

The book "Green Solutions for Degradation of Pollutants" is a compilation of chapters on environment friendly techniques of remediation of pollutants. Green solutions are basically a collection of techniques and practices that are based on the generation of non-toxic end products, renewable energy sources and other factors that mitigate the negative impacts caused by human activities. The book will be highly useful for students, researchers, environmentalists, academicians, environmental microbiologists, life sciences and nanosciences experts, waste treatment industries, and for a well-read audience. It will also serve as a learning resource for researchers and students in environmental science, microbiology, nanotechnology, freshwater ecology, and microbial biotechnology.

Agarwal *et al*., in chapter one, have discussed the transport fate and accumulation of emerging environmental pollutants and critically assessed their toxic impacts on the environment and living beings. They have also highlighted the possible solutions that could be used to remove these contaminants in a sustainable manner.

Amrit Mitra, in chapter two, has given a comprehensive description of microbial potential for biodegradation of organic pollutants, their removal mechanisms, and distribution of pollutants in environmental matrices, biodegradation pathways and the efficacy of biodegradation for complete mineralization.

Shankar *et al*., in chapter three, have given an overview of the green synthesis of metal nanoparticles using plant extracts, the pollutants degradation mechanism, and their environmental and biological applications in detail.

Amrit Mitra, in chapter four, has given a detailed account of the current advancements in green bioremediation methods, how various contaminants are broken down by microorganisms and what the future holds for bioremediation in terms of lowering global pollution levels.

Mishra *et al*., in chapter five, have thrown light on carbon dots as a new group of zero-dimensional luminescent nanomaterials, their synthesis, classification, properties and applications in environmental pollution control and environmental protection measures.

Kumar *et al*., in chapter six, have given a detailed account of green synthesis of nanoparticles using plant extracts and multiple applications of these nanoparticles in environmental remediation along with their biological applications. They have also discussed why green synthesis is more advantageous than classical chemical synthesis.

Saivenkatesh *et al*., in chapter seven, have discussed the nanoparticles synthesized by microalgae, their characterization methods, and their multiple applications with a special focus on environmental remediation. They have also highlighted the challenges involved in using microalgae-derived NPs along with their future perspectives.

Shahi *et al*., in chapter eight, have summarized the green synthesis methods of various nanomaterials, their remediation methodology, mechanism of action, and prospective applications in environmental remediation. Additionally, they have also highlighted the efficient removal and valorization of waste materials using nanobioremediation.

Kumar *et al*., in chapter nine, have talked about the remediation of heavy metal-contaminated soil using phytoremediation as a sustainable approach. According to them, modern phytoremediation methods may be used for large-scale decontamination of contaminated soil in a sustainable manner.

Bais *et al*., in chapter ten, have given a detailed discussion on the immense potential of nanomaterials in the bioremediation of polluted water. They have given a comprehensive comparison of nanobioremediation with other conventional bioremediation methods to make water environmentally non-hazardous.

Srivastava *et al*., in chapter eleven, have addressed the biogenic and green synthesis of palladium nanoparticles to remove different types of pollutants from wastewater.

Jangid *et al*., in chapter twelve, have given a comprehensive review of different domains of nanotechnology in the treatment of wastewater and also thoroughly covered various fundamental aspects of nanotechnology such as types, synthesis, applications and future directions for a green and sustainable environment.

Manoj Kumar *et al*., in chapter thirteen, have given a comprehensive overview of eco-friendly initiatives, methods and preventive measures to remove microplastic and nanoplastics from the global environment. They have also underlined the potential of green nanomaterials to solve the growing problem of plastic pollution and emphasized the importance of sustainable and environmentally friendly solutions.

Neha Agarwal
Department of Chemistry
Navyug Kanya Mahavidyalaya
University of Lucknow
Lucknow, India

Vijendra Singh Solanki
Department of Chemistry
Institute of Science and Research
IPS Academy
Indore, India

&

Sreekantha B. Jonnalagadda
School of Chemistry and Physics
University of KwaZulu-Natal, Westville Campus
Durban, South Africa

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List of Contributors

Amrit K. Mitra	Department of Chemistry, Government General Degree College, Singur, Hooghly, West Bengal, India
Anupma Singh	Department of Chemistry, DDU Govt. P.G. College, Sitapur, Lucknow, India
Anamika Srivastava	Department of Chemistry, Banasthali Vidyapith, Banasthali, Rajasthan, India
Annu Yadav	Department of Chemistry, Banasthali Vidyapith, Banasthali, Rajasthan, India
Azhar Ullah Khan	Department of Chemistry, School of Life and Basic Sciences, Jaipur National University, Jaipur, India
Deepankshi Shah	Department of Environmental Science, Parul Institute of Applied Sciences, Parul University, Vadodara, Gujarat, India
E. Rajalakshmi	Department of Chemistry, Bishop Heber College, Tiruchirappalli, Tamil Nadu, India
Gitanjali Arora	Department of Chemistry, Banasthali Vidyapith, Banasthali, Rajasthan, India
J. Princymerlin	Department of Chemistry, Bishop Heber College, Tiruchirappalli, Tamil Nadu, India
Jaya Dwivedi	Department of Chemistry, Banasthali Vidyapith, Banasthali, Rajasthan, India
Keshav Lalit Ameta	Centre for Applied Chemistry, School of Applied Material Sciences, Central University of Gujrat, Gandhinagar, Gujrat, India
M. Nanda	Bioresource Product Research Laboratory, Department of Botany, School of Life Science, Guru Ghasidas Vishwavidyalaya (A Central University), Bilaspur, Chhattisgarh, India
Manoj Kumar	Department of Hydro and Renewable Energy, Indian Institute of Technology Roorkee, Roorkee, Uttarakhand, India
Manish Srivastava	Department of Chemistry, University of Allahabad, Prayagraj, Uttar Pradesh, India
M.K. Gupta	Department of Chemistry, H. R. College, Jai Prakash University, Amnour, Chapra, India
Mohd. Tariq	Department of Life Sciences, Parul Institute of Applied Sciences, Parul University, Vadodara, Gujarat, India
N. Maurya	Department of Chemistry, Kamla Rai College, Gopalganj, Jai Prakash University, Chapra, India
Nakul Kumar	Gandhinagar Institute of Science, Gandhinagar University, Gandhinagar, Gujarat, India
Neha Agarwal	Department of Chemistry, Navyug Kanya Mahavidyalaya, University of Lucknow, Lucknow, India
Neetu Singh	Department of Physics, Government Degree College, Kuchalai, Sitapur, Lucknow, India
Nirmala Kumari Jangid	Department of Chemistry, Banasthali Vidyapith, Banasthali, Rajasthan, India
Pankaj Kumar	Department of Environmental Science, Parul Institute of Applied Sciences, Parul University, Vadodara, Gujarat, India

Rajendra	Department of Chemistry, Banasthali Vidyapith, Banasthali, Rajasthan, India
Ramesh Kumar	Department of Environmental Science, School of Earth Sciences, Central University of Rajasthan, Ajmer, Rajasthan, India
Rekha Sharma	Department of Chemistry, Banasthali Vidyapith, Banasthali, Rajasthan, India
Ruchi Shrivastava	Department of Chemistry, Institute of Science and Research, IPS Academy, Indore, Madhya Pradesh, India
Sreekantha B. Jonnalagadda	School of Chemistry and Physics, University of KwaZulu-Natal, Westville Campus, Durban, South Africa
Sankara Rao Miditana	Department of Chemistry, Government Degree College, Puttur, Tirupathi, Andhra Pradesh, India
Saivenkatesh Korlam	Department of Botany, SVA Government Degree College, Srikalahasti, Tirupati, Andhra Pradesh, India
S. Mishra	Department of Chemistry, Jai Prakash University, Chapra, India
Snigdha Singh	Department of Environmental Science, Parul Institute of Applied Sciences, Parul University, Vadodara, Gujarat, India
Sunil Soni	School of Environment and Sustainable Development, Central University of Gujarat, Gandhinagar, India
S. Padmavathi	Department of Botany, SVA Government Degree College, Srikalahasti, Tirupati, Andhra Pradesh, India
S. Agrawal	Bioresource Product Research Laboratory, Department of Botany, School of Life Science, Guru Ghasidas Vishwavidyalaya (A Central University), Bilaspur, Chhattisgarh, India
S.K. Shahi	Bioresource Product Research Laboratory, Department of Botany, School of Life Science, Guru Ghasidas Vishwavidyalaya (A Central University), Bilaspur, Chhattisgarh, India
Shivraj Gangadhar Wanale	School of Chemical Sciences, Swami Ramanand Teerth Marathwada University, Nanded, Maharashtra, India
Shipra Choudhary	Department of Microbiology and Biotechnology, Meerut Institute of Engineering & Technology, Meerut, Uttar Pradesh, India
Shraddha Bais	Department of Chemistry, Institute of Science and Research, IPS Academy, Indore, Madhya Pradesh, India
Shruti	Department of Chemistry, Banasthali Vidyapith, Banasthali, Rajasthan, India
S. Ambika	Department of Chemistry, Bishop Heber College, Tiruchirappalli, Tamil Nadu, India
Vijendra Singh Solanki	Department of Chemistry, Institute of Science and Research, IPS Academy, Indore, India
Virendra Kumar Yadav	Department of Life Sciences, Hemchandracharya North Gujarat University, Matarvadi Part, Gujarat, India
Vimala Bind	Department of Zoology, Navyug Kanya Mahavidyalaya, University of Lucknow, Lucknow, India
V. J. Maodiswari	Department of Botany, Bishop Heber College, Tiruchirappalli, Tamil Nadu, India

Y. Manojkumar Department of Chemistry, Bishop Heber College, Tiruchirappalli, Tamil Nadu, India

CHAPTER 1

Emerging Pollutants in Aquatic Environment: Critical Risk Assessment and Treatment Options

Neha Agarwal[1,*], Vijendra Singh Solanki[2], Sreekantha B. Jonnalagadda[3], Keshav Lalit Ameta[4], Neetu Singh[5], Anupma Singh[6] and **Vimala Bind[7]**

[1] *Department of Chemistry, Navyug Kanya Mahavidyalaya, University of Lucknow, Lucknow, India*

[2] *Department of Chemistry, Institute of Science and Research, IPS Academy, Indore, India*

[3] *School of Chemistry and Physics, University of KwaZulu-Natal, Westville Campus, Durban, South Africa*

[4] *Centre for Applied Chemistry, School of Applied Material Sciences, Central University of Gujrat, Gandhinagar, Gujrat, India*

[5] *Department of Physics, Government Degree College, Kuchalai, Sitapur, Lucknow, India*

[6] *Department of Chemistry, DDU Govt. P.G. College, Sitapur, Lucknow, India*

[7] *Department of Zoology, Navyug Kanya Mahavidyalaya, University of Lucknow, Lucknow, India*

Abstract: The chemical compounds that have been identified as dangerous to the environment, ecosystem and human health are classified as Emerging Pollutants (EPs). EPs include a variety of compounds such as dyes, pesticides, antibiotics, drugs, endocrine disruptors, hormones, industrial wastes and chemicals, and microplastics. These pollutants are malignant and non-biodegradable in nature, so they are responsible for the unhealthy and unsustainable environment. The occurrence of these pollutants has raised global concerns not only in various environmental matrices (air, water, and soil) but also in biological systems due to their toxic nature. These pollutants get accumulated in the environment and ecosystem and cause intensified environmental problems, global warming, deterioration of soil quality, the greenhouse effect, and ecological imbalance. Consequently, they affect the quality of life and the maintenance of the environment on a global level. Recent research indicates that if this trend is continued, situations will worsen in the near future. Sustainable solutions, such as bioremediation, nano-bioremediation, microbial degradation *etc.*, are becoming increasingly important for the removal of these EPs as an efficient tool for sustainable development and pollution control. Therefore, the main aim of this chapter is to assess the current threats and future challenges associated with emerging pollutants so that focus can be drawn on sustainable green solutions for a greener and healthier environment.

[*] **Corresponding author Neha Agarwal**: Department of Chemistry, Navyug Kanya Mahavidyalaya, University of Lucknow, Lucknow, India; Tel: +91-9454784074; E-mail: nehaagarwal4074@gmail.com

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Keywords: Bioremediation, Emerging contaminants, Ecosystem, Environment, Green solutions, Nano-bioremediation, Non-biodegradable, Pollutants, Pollution control, Sustainable.

INTRODUCTION

With the rapid technological advancements and industrialization, the environmental quality has deteriorated, which is an alarming sign for sustainability. Different categories of emerging contaminants (ECs), like heavy metals, pesticides, pharmaceuticals, endocrine disrupting agents, personal care products, dyes, detergents, plastics, *etc.*, are causing menace at a global level as they adversely affect the environment, ecosystem and living beings [1 - 3]. Among different types of pollution, water pollution is an important subclass that severely affects global life. Water is a vital component of life; it has been contaminated due to high industrialization in recent decades and severely affects the quality of life [4]. For the last few decades, EPs have attracted worldwide attention, and many attempts have been made to mitigate the release and accumulation of EPs into the environment to prevent the dangerous impact on the environment. Many studies have been conducted to monitor progress in this field. For instance, in a study performed by Barbosa *et al.*, various treatment techniques were reviewed with their removal efficacy of EPs that concluded the future research perspective for a risk-free environment. They also reviewed the interaction of microplastics with pollutants and concluded that marine microplastic debris may dangerously affect human health [5]. Another review done by Taheran *et al.* emphasized that if EPs are present in scarce concentrations, conventional sewage treatment processes are not capable of treating them efficiently [6]. In fact, chemical and physical methods that are used to treat effluents do not degrade these pollutants completely, but rather change their forms, which are more toxic to the environment and human health, even in low concentrations [7]. Literature studies also suggest that current information on mechanisms available for water remediation needs to be updated to avoid future risks to the ecosystem and environment [8, 9].

Due to high costs, difficult techniques and improper efficiency involved, the issue of emerging pollutants has become a challenge. Therefore, there is an urgent need to protect the environment and living beings by developing sustainable methods for the removal of these pollutants [10]. Bioremediation is the most promising technology over conventional methods of wastewater treatment because it is an eco-friendly and cost-effective technique with the possible recovery of elements and for solving environmental problems [11, 12]. Nanotechnology has also emerged as a promising technology, which has shown great potential in various fields along with the treatment of pollutants [13]. Currently, bionanotechnology is attracting great attention in the remediation of pollutants as green solutions, which are eco-friendly, cost-effective and easy-to-handle tools for the bioremediation of wastewater and other categories of environmental pollutants. This chapter presents a concept to assess the occurrence, fate and risk assessment of emerging pollutants and also provides an overview of sustainable solutions for water resource management.

EMERGING POLLUTANTS IN AQUATIC ENVIRONMENT: TRANSPORT, FATE AND BIOACCUMULATION

As a result of uncontrolled urbanization, industrial development, healthcare activities and other anthropogenic activities, there is a rapid increase in EPs on a global level [14]. The synthetic persistent organic chemicals that adversely affect the ecosystem and human health but are not monitored in the environment are known as EPs. Different routes and fate of EPs are shown in Fig. (**1**).

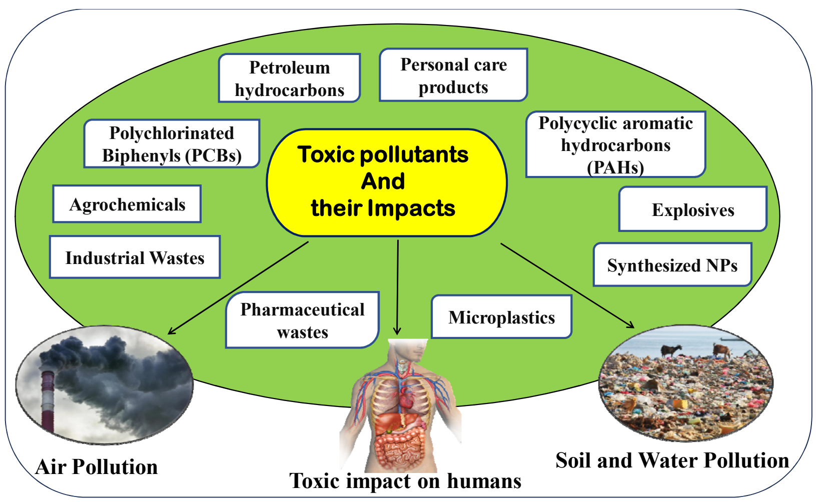

Fig. (1). Different types of toxic EPs and their impacts.

Many studies have been conducted on the route and fate of EPs in aquatic environments [15]. However, EPs can enter into an aqueous environment through various direct and indirect routes and can get bioaccumulated through food chains and food webs, causing serious health hazards to living beings. Therefore, many studies have focused on their fates and bioaccumulation [16 - 18]. In aquatic environments, the concentrations of EPs can vary over a wide range from ng/L to g/L. Their toxicological effects on living organisms may result in acute and chronic toxicity, endocrine disruption, resistance to antibiotics and human health hazards [19]. According to a recent study, EPs, such as pharmaceuticals,

CHAPTER 2

A Critical Review of Microbial Potential for Biodegradation Mechanism of Organic Pollutants

Amrit K. Mitra[1,*]

[1] *Department of Chemistry, Government General Degree College, Singur, Hooghly, West Bengal, India*

Abstract: The rise in environmental pollution is a major issue of concern in the current times. Due to globalization and the Industrial Revolution in the 20th century, pollution has become a problem for the world's population. Numerous factors, including unchecked human activity, careless use of petroleum products, industrial waste emissions, poor waste management, release of toxic organic by-products, and increased use of pesticides, insecticides and fertilizers have contributed to increased pollution and its detrimental effects on the planet Earth. For all forms of life, organic molecules are known to have the potential to be carcinogenic and poisonous. To reduce organic pollutants and dispose of industrial waste properly, several techniques have been put forth and put into action, but some of them are either not relevant or have not produced the expected outcomes. For the past few decades, research has been focused on finding biological methods of degradation of complex organic contaminants. Numerous microbial species obtained from polluted native environments have been shown to digest hazardous, complex organic chemicals and can be used to effectively biodegrade contaminated areas. The development of recombinant DNA technologies has revitalized the area of bioremediation by enabling the emergence of microorganisms and entire microbial communities that contain novel genes and enzymes with improved efficiencies. This chapter discusses the significance of isolating efficient indigenous microbial species, different factors that affect the distribution of pollutants in the soil matrix, biodegradation pathways, and physiological factors that affect the efficiency of biodegradation for complete mineralization. In addition to these, efforts to enhance the biodegradation potential of microbes through multiple pathways have also been highlighted.

Keywords: Anthropogenic pollutants, Bioaugmentation, Biodegradation, Bioremediation, Biostimulation, Mineralization, Organic Pollutants, Pollutant management.

* **Corresponding author Amrit K. Mitra:** Department of Chemistry, Government General Degree College, Singur, Hooghly, West Bengal, India; Tel: +91-33-2630-0126; +91-9432164011; Fax: +91-33-2630-0126; E-mail: ambrosia12june@gmail.com

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INTRODUCTION

The organic substances of human origin cause severe environmental pollution. Since the beginning of the Industrial Revolution, the biosphere has experience significant increase in pollution [1 - 4]. Petroleum-based hydrocarbons, as well as various pesticides used in agriculture and pest management, are examples of common organic pollutants of public concern [5, 6]. Textiles, hydrocarbon oils, soaps, detergents, and other useful materials were among the chemically generated commodities that expanded substantially in the late 1800s and early 1900s [7]. The impacts of these substances on the environment are determined by several processes that differ in the properties of each component. Halogenated chemical pollutants, including polychlorinated biphenyls (PCBs), dichloro-diphenyl-trichloroethane (DDT), dechlorane plus, and dibromide-phenyl-ethane are of great concern due to their longevity, bioaccumulation and potential exposure to humans and animals [8, 9]. Other industrial by-products, for instance, phthalates (plasticizers found in bottles), toys, and personal care products, also act as organic pollutants. Polybrominated diphenyl esters (PBDEs) that are utilized in a variety of consumer goods are now found in the environment. There are numerous industrial uses for chlorinated ethanes, chlorinated ethenes and chlorinated benzenes as solvents and degreasers, as well as biocides and their precursors [10, 11]. They pose serious threats to both human and environmental health due to their acute and chronic toxicity, persistence and bioaccumulation. The EPA (Environment Protection Agency) has listed several organochlorines as priority contaminants, emphasizing the potential environmental danger they pose [12]. The primary factor in water and soil contamination is the release of hydrocarbons into the environment. It is well recognized that petroleum-based hydrocarbon contaminants negatively impact both terrestrial and aquatic life as well as soil productivity. The extensive use of pesticides, drugs (such as non-steroidal anti-inflammatory medications (NSAIDs), and antibiotics) and other chemicals, their unplanned disposal, and subsequent presence in different ecosystems are matters of keen concern [2]. These compounds are now more prevalent due to their widespread use in soil, water and sediments. Consequently, there is an increased understanding of the risks imposed by these organic pollutants and their removal from the environment.

The microorganism's ability to break down and detoxify these contaminants is known as microbial degradation or biodegradation. Different varieties of microorganisms, such as bacteria, fungi, and protozoa, decompose diverse substrates biologically [13, 14]. After being released into the environment, organic pollutants can undergo degradation, sorption-desorption, volatilization, uptake by plants, runoff into surface waters and transfer into groundwater. Through biotic or abiotic degradation and transformation, these organic pollutants are assimilated into the environment. These mechanisms either mineralize organic contaminants into a carbon field or turn them into degradation products [15]. Microorganisms can adapt themselves to changing environmental conditions. Due to recent developments that have allowed for extensive and high-throughput research of ecologically relevant microorganisms, interest in the microbial breakdown of contaminants has increased. This adds to our understanding of their biodegradation mechanisms and metabolic pathways [4, 16 - 19]. This chapter intends to offer a cutting-edge review of the microbial potential in the degradation of organic pollutants for the green remediation of the environment.

ORIGIN AND OCCURRENCE OF ORGANIC POLLUTANTS

Organic pollutants (OPs) are those chemical substances that have a blatantly adverse effect on the environment. OPs are a class of exceedingly poisonous synthetic organic molecules that can persist in the environment under natural conditions for a long time. To safeguard both human health and the environment, the international community has developed tools to detect the existence and regulation of these pollutants [16]. The Stockholm Convention of 2013 was the most well-intentioned plan, which attempted to eliminate organic pollutants and, if that is impossible, to restrict emissions and discharges [16].

A considerable amount of OPs are released into the soil as a result of the rapid population growth, increased fuel consumption and production of industrial chemicals, fertilizers, pesticides and medications. Based on their environmental half-lives, OPs are divided into two classes *i.e.*, persistent organic pollutants (POPs) and non-POPs. Non-POPs can be broken down into simple, non-polluting components like carbon dioxide and nitrogen by chemical reactions or natural microbes [20 - 22]. One illustration of a non-persistent contaminant is organic waste. Due to their high persistence and toxicity in soil, the POPs pose significant health concerns to humans through food chains [23 - 27]. These OPs become highly toxic, poisonous compounds and pose threats to living beings when they cross the acceptable limits. Detergents, petroleum hydrocarbons, plastics, organic solvents, pesticides, insecticides and dyes are the main sources of release of these organic compounds into the environment [23, 24]. Since the 20th century, the POPs have drawn attention due to their highly hazardous bio-accumulative qualities. Owing to their possible toxicological characteristics, POPs have been deemed to be more harmful and are further listed as follows:

1. They stay intact for many years and are vulnerable to long-distance transportation.
2. Since they are widely dispersed in the environment, including soil, water, and most significantly in air, they build up in the fatty tissue of living things,

CHAPTER 3

A Study of Green Synthesis of Metal Nanoparticles using Plant Extracts and their Biological and Environmental Applications

Sankara Rao Miditana[1,*] and **Saivenkatesh Korlam**[2]

[1] *Department of Chemistry, Government Degree College, Puttur, Tirupathi, Andhra Pradesh, India*

[2] *Department of Botany, SVA Government Degree College, Srikalahasti, Tirupati, Andhra Pradesh, India*

Abstract: Nanomaterials (NMs)-based technology is a powerful tool in the current scenario because of their size and unique physicochemical properties. Green synthesized NMs are promising in creating new and vital products that are beneficial to the environment, industry, and humans. Due to its simplicity, nontoxicity, and environmentally benign advantages, the synthesis of metal nanoparticles (NPs) using green techniques has received a lot of attention recently. Every day, attention is drawn to recycling waste and putting it to good use. NPs are easily manufactured in a green, energy-free manner using plant extracts that are not intended for human consumption. Metal-based NPs are widely used due to their applications, including medicine, biomedical sciences, biosensing, food, cosmetics, and electronics. NPs produced from novel synthesis techniques using plant extracts have remarkable qualities. In the synthesis of NPs *via* the green approach, many metals such as silver, gold, copper, zinc, manganese, nickel, and magnesium are used due to their unique physical and optical properties. In this chapter, the authors have reported the mechanisms of various green methods of synthesis of NPs, their biological and environmental applications along with their challenges and prospects.

Keywords: Antioxidant, Antimicrobial, Anti-bacterial, Anticancer, Biodegradable, Catalytic activity, Dye degradation, Green synthesis, Nanoparticles.

INTRODUCTION

NMs are materials that have at least one dimension (length, width, or height) in the nanometer scale, typically ranging from 1 to 100 nanometers [1]. They exhibit unique physical and chemical properties that are different from their bulk

* **Corresponding author Sankara Rao Miditana:** Department of Chemistry, Government Degree College, Puttur, Tirupathi, Andhra Pradesh, India; E-mail: sraom90@gmail.com

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counterparts due to their small size, high surface area to volume ratio, enhanced catalytic activity, and quantum confinement effects. They have novel electronic, optical, and magnetic properties, making them attractive for a wide range of applications in various fields, including medicine, electronics, energy, and environmental science [2, 3]. To synthesize NPs, two methods are employed, namely the chemical method and the physical method [1]. Chemical synthesis methods include electrochemical techniques, chemical reduction and photochemical reduction [4]. Although most chemical methods succeed in producing pure and well-defined NPs, they are expensive and inefficient and release hazardous wastes into the environment, so more environmentally friendly methods are preferred [5]. On the other hand, physical synthesis methods include condensation, evaporation, and laser ablation.

The traditional methods for synthesizing NPs involve the use of toxic chemicals, high-energy inputs, and complex procedures that are not environmentally friendly and can cause harm to human health [6]. Green synthetic processes are being established as an alternative to physical and chemical processes. Green synthesis has many advantages compared to chemical and physical methods: it is non-toxic, pollution-free, environmentally friendly, economical, and more sustainable [7 - 10]. Environmental issues like agriculture production and catalysis can be approached by green synthesis. Green synthesis of NPs involves the use of natural sources such as plants, microbes, and biopolymers as reducing and stabilizing agents. These methods have advantages such as low cost, biodegradability, and scalability, making them an attractive alternative to traditional synthesis methods. According to Christophe *et al.*, green synthesis *via* plant materials plays a key role in the determination of the size and morphology of prepared NPs [11]. Plant extracts can act as reducing and capping agents. In terms of the size of the NPs formed, the green-synthesized products are larger than those obtained by chemical methods [12]. The green synthetic approach produces an optimum yield of NPs than the physical and chemical techniques.

In recent years, there has been growing interest in developing green synthesis methods for NPs that are sustainable, non-toxic, and eco-friendly [13]. In this context, the study of NPs *via* green synthesis has gained significant attention along with exploring the use of various plant extracts, microorganisms (bacteria, algae, viruses, fungi) and other natural sources (solar mediated and green chemistry synthesis) to synthesize NPs with controlled size, shape, and composition. In the green approach of NP synthesis, metal atoms play a crucial role as they are the building blocks of the NPs. The properties of the metal atoms, such as their size, shape, and surface chemistry, influence the properties of the resulting NPs [14, 15]. Metal atoms are often used as the precursor for NP synthesis. Gold, silver, manganese, magnesium and copper are commonly used metals for the synthesis of metal NPs. Metal atoms can also act as a reducing agent to convert metal ions into NPs. By varying the concentration and type of metal atoms used, it is possible to control the size and shape of NPs. They have a wide range of applications in catalysis, electronic and biomedical fields [16]. In the present study, authors focus on various green methods of synthesis of NPs, which offers a promising avenue for developing sustainable and eco-friendly materials and exploring their potential applications in various fields like drug delivery, biosensing, catalysis, and wastewater treatment. This chapter also reports the various applications of plant-extract mediated green synthesized NPs.

GREEN METHODS OF SYNTHESIS OF METAL NPS

Green synthesis of NPs involves the use of natural sources such as plants, microbes, and biopolymers as reducing and stabilizing agents. Here are some of the commonly used methods, including plant extract-mediated synthesis, microbial-mediated synthesis, solar-mediated synthesis, and green chemistry-based synthesis for the preparation of NPs.

Plant Extract-mediated Synthesis

This method is a green and sustainable approach to the synthesis of NPs. Various parts of the plant, such as leaves, stems, and fruits, have been used for the synthesis of NPs [17 - 21]. The process involves the reduction of metal salts in the presence of plant extracts, which provide the necessary reducing agents and stabilizing agents for the formation of NPs [22]. The detailed procedure is discussed below.

- Select a plant material and prepare an extract by grinding the plant material in a solvent such as water, ethanol, or methanol.
- Heat the extract to a suitable temperature, typically between 60-100°C.
- Add a metal precursor solution to the extract, typically a salt such as silver nitrate, gold chloride, or platinum chloride.
- Allow the reaction to proceed for a certain amount of time, usually from 30 minutes to several hours, while stirring.
- Monitor the formation of NPs by measuring the absorbance of the solution using UV-Vis spectroscopy. The absorption peak indicates the formation of NPs. The scheme of preparation of NPs by plant extracts is shown in Fig. (**1**).

CHAPTER 4

Current Trends in Green Bioremediation of Environmental Organic Pollutants

Amrit K. Mitra[1,*]

[1] *Department of Chemistry, Government General Degree College, Singur, Hooghly, West Bengal, India*

Abstract: A biological process termed bioremediation transforms waste into a form that can be used and reused by other microbes. Recent research has revealed that xenobiotic pollution and other associated refractory substances pose a serious threat to both human health and the environment. Many contaminants, including heavy metals, polychlorinated biphenyls, plastics and different agrochemicals, are prevalent in the environment because of their toxicity and inability to biodegrade. The key objective of bioremediation is the degradation of pollutants and their transformation into less harmful forms. Depending on several variables like cost, kind and concentration of the contaminant and other considerations, *ex-situ* or *in-situ* bioremediation may be used. Bioremediation can be done with the help of microorganisms that can withstand all circumstances due to their metabolic potential. Microbes have a tremendous nutritional capacity, making them useful in the bioremediation of environmental contaminants. With the complete and coordinated activity of microorganisms, bioremediation is significantly involved with the decomposition, expulsion, immobility or decontamination of different chemical pollutants and physically dangerous chemicals from the natural atmosphere. Enzymatic processes and other techniques, including bioventing, bioaugmentation, biostimulation, biopiles and bioattenuation, are widely used throughout the world based on their characteristics, benefits and drawbacks. This chapter aims to portray the current advancements in green bioremediation methods, how various contaminants are broken down by microorganisms and what the future holds for bioremediation in terms of lowering global pollution levels.

Keywords: Biodegradation, Bioattenuation, Biostimulation, Bioaugmentation, Bioventing, Biopiles, Bioremediation, Contaminants, Environment, Microorganisms, Monitoring and stimulation, Pollutants, Sustainable technologies.

[*] **Corresponding author Amrit K. Mitra**: Department of Chemistry, Government General Degree College, Singur, Hooghly, West Bengal, India; Tel: +91-33-2630-0126; +91-9432164011; Fax: +91-33-2630-0126; E-mail: ambrosia12june@gmail.com

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INTRODUCTION

Microorganisms are regarded as the first living things to have evolved. They can adjust themselves to a wide range of difficult environmental conditions.

They are distributed across the biosphere due to their outstanding metabolic capability and ease of growth in a variety of environmental circumstances. From extreme environmental circumstances like frozen settings, acidic lakes, and bottoms of deep oceans to the small intestines of animals, they play a significant role in regulating biogeochemical cycles. The global biogeochemical cycle is governed by microorganisms which are also in charge of carbon and nitrogen fixation and methane and sulfur metabolism [1].

Bioremediation is a well-organized activity of microorganisms where a variety of metabolic enzymes are produced, which can be used to remove contaminants in a green manner [2]. This can be done either by directly destroying the pollutants or by converting them into less toxic intermediates. The process is continued depending on the specific capacity of microbes to transform hazardous contaminants to produce biomass and generate energy [3, 4]. Microorganisms provide a suitable platform for bioremediation of plastics, heavy metals, hydrocarbons, greenhouse gases *etc*. [2 - 6]. As a result, bioremediation employs low-cost and less technical approaches that can be performed on-site frequently. However, because of the narrow spectrum of pollutants onto which it is effective, the lengthy time frames needed and the inappropriateness of the achievable residual contamination levels, it may not always be suitable [7]. Even though the procedures used in bioremediation are not technically sophisticated, considerable expertise may be required to develop and implement them successfully [3]. The principal agents of bioremediation are bacteria, archaea and fungi. The terms 'bioremediation' and 'biodegradation' are increasingly interchangeable [3]. Various sites across the world, particularly in Europe, have tried bioremediation with varied degrees of effectiveness. Unfortunately, there is a lack of knowledge and understanding of the principles, methods, benefits and drawbacks of bioremediation, particularly among site owners and regulators [8 - 10].

This book chapter has been written to discuss the current trends in bioremediation to address environmental threats. This is a significant research area because microorganisms are environmentally friendly and have the potential to produce valuable genetic material that can be used effectively [3]. This chapter will also provide a practical view of the bioremediation processes, the benefits and drawbacks of the method and the considerations to be taken into account when dealing with a proposal for bioremediation.

PRINCIPLES OF BIOREMEDIATION

Anthropogenic activities cause the release of huge amounts of pollutants into the environment every year. These releases can be intentional and strictly controlled in some situations (such as industrial emissions) or unintentional (such as chemical or oil spills). Many of these substances persist in both terrestrial and aquatic habitats and are harmful. The accumulation of these harmful substances above the allowable amounts causes the poisoning of land and water resources [11 - 13]. The bioremediation process reduces the organic wastes to a benign state or levels below concentration limits set by regulatory authorities under controlled settings. A pollutant's biodegradation is frequently the consequence of the activity of numerous organisms. Bioaugmentation occurs when microorganisms are brought to a contaminated site to aid in degradation [14].

Microbial enzymes attack the contaminants and transform them into toxic compounds because bioremediation is only successful in those sites that support microbial activity and growth. But, some pollutants, like high aromatic hydrocarbons or chlorinated organic compounds, are immune to microbial attack. Bioremediation techniques can remediate some pollutants on-site, minimizing exposure hazards for workers. They are often more cost-effective than conventional procedures like cremation and are operated in aerobic circumstances. Operating a system under anaerobic conditions may allow microbial organisms to break down resistant compounds [15]. A representative diagram related to the principles of bioremediation is in Fig. (**1**).

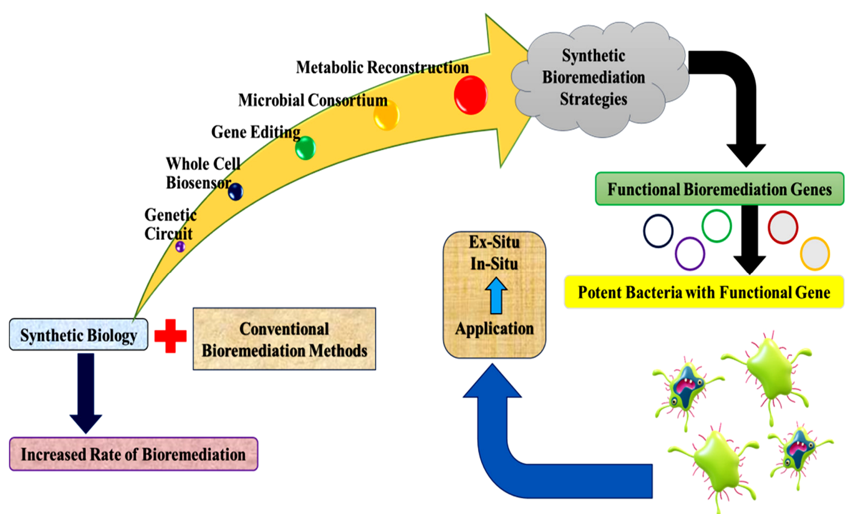

Fig. (1). Representative diagram related to the principles of bioremediation.

CHAPTER 5

Carbon Dots and their Environmental Applications

N. Maurya[1], **S. Mishra**[2,*] and **M.K. Gupta**[3]

[1] *Department of Chemistry, Kamla Rai College, Gopalganj, Jai Prakash University, Chapra, India*

[2] *Department of Chemistry, Jai Prakash University, Chapra, India*

[3] *Department of Chemistry, H. R. College, Jai Prakash University, Amnour, Chapra, India*

Abstract: CDs (Carbon dots) are a new group of zero-dimensional luminescent nanomaterials. They have drawn a lot of attention due to their excellent properties, for example, easy preparation, strong optical properties, low toxicity, significant biocompatibility, low cost, facile functionalization, tunable porous structures and high specific surface area. CDs have found many applications in the fields of bioimaging, sensing, catalysis, optoelectronics and energy conversion. Recently, CDs have demonstrated promising applications in the control of environmental pollution and remediation. CDs have been applied for environmental pollutants sensing, adsorption of contaminants, membrane-based separation, photocatalytic degradation of pollutants, and antimicrobial coatings for protection. In this chapter, we have discussed the classification of CDs, synthesis, properties and applications of CDs in environmental pollution control and environmental protection measures.

Keywords: Antimicrobial, Air pollution, Contaminant adsorption, Carbon dots, Environment, Hydrothermal, Membrane separation, Pollutants sensing, Photocatalytic, Water pollution.

INTRODUCTION

Global development and urbanization are leading to an alarming increase in environmental issues. Concerns are being raised worldwide, particularly, about the harmful and toxic pollutants resulting as a consequence. Over the past few decades, several efforts have been made worldwide to reduce environmental pollution and safeguard human health [1]. Among them, the use of advanced materials is one of the best ways to safeguard the environment. Nanomaterials, particularly those with carbon, metal, and metal-organic framework bases, have developed rapidly and has been successfully utilized to treat and protect the environment [2 - 4].

* **Corresponding author S. Mishra:** Department of Chemistry, Jai Prakash University, Chapra, India; E-mail: shachicdri2013@gmail.com

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Numerous environmental applications, including membrane-based separation, energy conversion and storage, pollutant sensing, adsorptive removal of contaminants, and catalytic degradation, have made extensive use of carbon-based nanomaterials, such as pristine graphene, graphene oxide, carbon nanotubes (CNTs), CDs, *etc*. [5 - 9]. Among carbon-based nanomaterials, CDs have attracted more attention due to their unique qualities, such as excellent and tunable photoluminescence (PL) efficiency, easy preparation, low toxicity, notable biocompatibility, tiny cost, facile functionalization, substantial pore sizes, and high specific surface areas [8, 9]. The typical CDs are defined as zero-dimensional fluorescent carbon nanoparticles (NPs) with a size below 20 nm, consisting of a graphitic and turbostratic sp^2/sp^3 carbon core with special functional groups (*e.g.*, -COOH, -OH, and $-NH_2$) on the surface [10, 11]. Unique properties of CDs have also been utilized for optoelectronic devices, solar cells, biomedical applications, and environmental applications such as adsorption and elimination of contaminants, photocatalytic degradation of pollutants, creating water treatment membranes, and serving as antimicrobial materials [8 - 17].

Major developments in CD synthesis, their unique properties and applications in several fields, such as sensing, bioanalysis, bioimaging, energy conversion, environmental control and remediation, *etc.*, have been reviewed and reported from time to time by researchers [8 - 17]. Recently, Long *et al.* reported the recent developments and different environmental applications of carbon dots [8]. Hebbar et. al. summarized various methods of CD synthesis, characterization techniques and their environmental applications [9]. In this outlook, firstly, we will discuss the classification of CDs, recent developments in synthetic measures of CDs apropos to the environment and their properties. Then, the current progress in the applications of CDs for the adsorption of contaminants, sensing of environmental pollutants, membrane-based separation, photocatalytic degradation of pollutants, and antimicrobial coatings for protection have been discussed in detail.

CLASSIFICATION OF CDS

CDs are a generic group of carbon NPs made up of distinct and almost spherical NPs. They were initially discovered through single-walled carbon nanotube purification in 2004 [18]. Initially, these carbon NPs were termed “carbon quantum dots (CQDs)” by Sun *et al.*, who anticipated a method to produce CDs by chemical modification and surface passivation to boost fluorescence emission [19]. In 2016, Cayuela *et al.* recommended CD sub-categories, viz. CQDs, graphene quantum dots (GQDs), and carbon nanodots (CNDs) based on specific carbon core structures, surface groups, and properties [11]. GQDs are π-conjugated single sheets or multiple layers of small graphene fragments with supremacy of sp^2 carbon and chemical groups connected within the interlayer defect or on the edge/surface. They are anisotropic with typical dimensions of less than 20 nm in width, exhibit a quantum confinement effect, and are mostly synthesized by the top-down approach. CQDs are usually quasi-spherical, with a mixture of sp^3 and sp^2 hybridized carbon possessing multi-layered graphitic structures and chemical groups lying on the surface. They also exhibit a quantum confinement effect. CNDs are amorphous and have high carbonization and polymer features without obvious crystallinity and quantum confinement [20, 21]. Some of the researchers have classified CDs into four categories, namely CPDs, CQDs, GQDs and CNDs (Fig. **1**) [22, 23]. CPDs have polymer frame-carbon cluster hybrid structures resulting from non-conjugated linear polymers or molecules. However, few studies have pointed out that polymer dots are completely different entities based on their structural features and methods of preparation [24, 25].

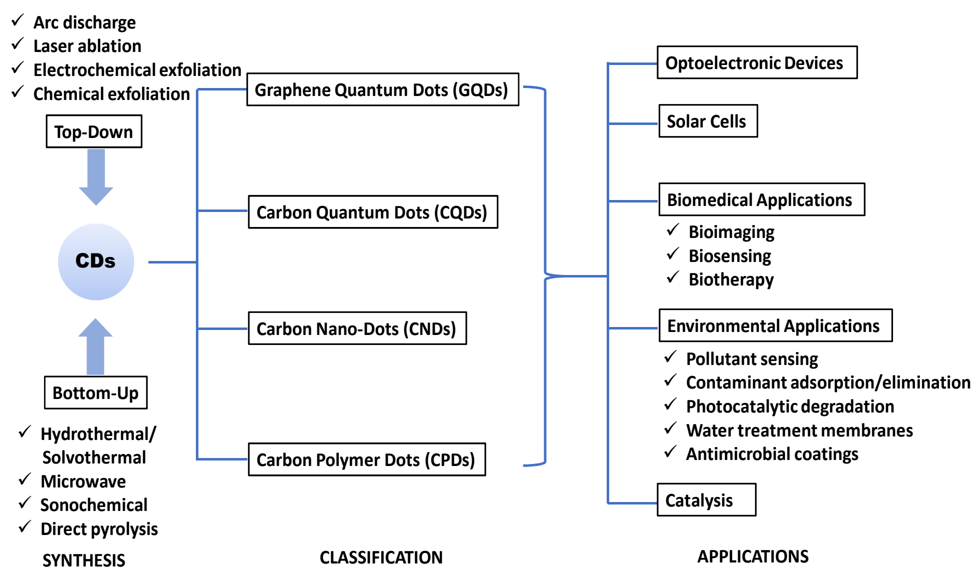

Fig. (1). Synthesis, classification and applications of carbon dots.

SYNTHESIS OF CDS

Xu and colleagues serendipitously discovered CDs through the purification of single-walled carbon nanotubes (SWCNTs) from arc-discharged soot through gel electrophoresis in 2004 [18]. Since then, many synthetic techniques have been developed to synthesize CDs. Broadly, there are two types of synthetic approaches: "top-down" and "bottom-up" techniques, as mentioned in Fig. (**1**).

CHAPTER 6

Green Synthesized Nanoparticles and Different Domains of their Applications

Nakul Kumar[1], **Pankaj Kumar**[2,*], **Snigdha Singh**[2], **Virendra Kumar Yadav**[3], **Deepankshi Shah**[2], **Mohd. Tariq**[4], **Ramesh Kumar**[5] and **Sunil Soni**[6]

[1] *Gandhinagar Institute of Science, Gandhinagar University, Gandhinagar, Gujarat, India*

[2] *Department of Environmental Science, Parul Institute of Applied Sciences, Parul University, Vadodara, Gujarat, India*

[3] *Department of Life Sciences, Hemchandracharya North Gujarat University, Matarvadi Part, Gujarat, India*

[4] *Department of Life Sciences, Parul Institute of Applied Sciences, Parul University, Vadodara, Gujarat, India*

[5] *Department of Environmental Science, School of Earth Sciences, Central University of Rajasthan, Ajmer, Rajasthan, India*

[6] *School of Environment and Sustainable Development, Central University of Gujarat, Gandhinagar, India*

Abstract: Science has undergone a revolution with the development of nanotechnology. The vast applications of nanoparticles (NPs) have greatly helped every area of technology. Nanomaterials (NMs) can be created *via* a range of physical and chemical practices along with the use of ultrasound and microwave heating processes, but green synthesis has drawn great attention, especially when it involves the use of microbes or plant extracts. Green synthesis is a recent and advanced method to make NPs because it is simpler, cheaper, more reproducible and environmentally friendly than other approaches. When compared to other classical methods of NP synthesis, plants produce NPs that are more stable and simpler to scale up and have a variety of applications. This chapter has reviewed and discussed various applications of green synthesized NPs along with the latest developments in the eco-friendly synthesis of gold, silver, copper, palladium, iron, and iron oxide NPs. Due to the widespread use of nanoscale metals in different industries, including engineering, medicine, and the environment, the topic of nanoscale metal synthesis is currently relevant. The bulk of nanoscale metals is currently produced chemically, which has unintended effects like environmental contamination and serious health issues. To overcome these challenges, green synthesis can be used as a commercial chemical method to decrease metal ions from the environment. Green synthesis is more advantageous than classical chemical synthesis because it improves environmental quality and is also safe for human health.

* **Corresponding author Pankaj Kumar:** Department of Environmental Science, Parul Institute of Applied Sciences, Parul University, Vadodara, Gujarat, India; Tel: +918460571814
E-mail: pankaj.kumar25135@paruluniversity.ac.in

Neha Agarwal, Vijendra Singh Solanki and Sreekantha B. Jonnalagadda (Eds.)

Keywords: Biological method, Environmental sustainability, Green synthesis, Human health, Nanomaterials, Plant extracts.

INTRODUCTION

With the advent of nanotechnology, it has become possible to create and evaluate objects on a molecular scale, between 1-100 nanometers, which are known as NMs. NMs have vital applications in many fields, including optics, electronics, mechanics, medicine, biotechnology, microbiology, environmental cleanup, multiple engineering disciplines, and material science. Their most significant attribute is their enormous surface area to their respective volume ratios. Different production procedures have been developed for the synthesis of metallic NPs, such as bottom-up and top-down approaches [1]. In a nutshell, the top-down strategy includes the size decrease of bulk material *via* lithographic techniques and mechanical methods like grinding and milling, whereas the bottom-up approach involves the gathering of small building blocks into bigger structures, such as chemical synthesis. However, the bottom-up strategy, in which an NP is "grown" from simpler molecules known as reaction precursors, is an acceptable and efficient technique for creating NPs [2]. By varying precursor amounts and reaction conditions, it may be feasible to regulate NP size and form depending on its intended use (temperature, pH, *etc.*). Fig. (**1**) is an illustration of the generic manufacturing of green NPs and their different uses.

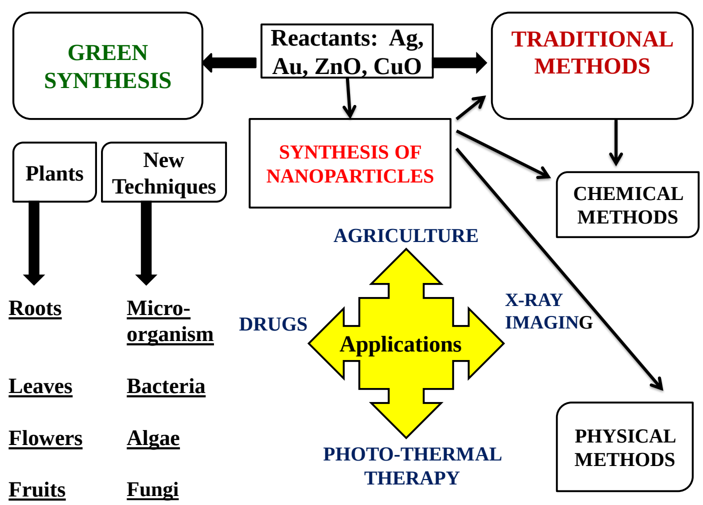

Fig. (1). Illustration of the generic manufacturing of green NPs and their use [3].

Both physical and chemical methods utilize very poisonous and reactive reductants like sodium borohydride and hydrazine hydrate that have unfavorable effects on living beings and the environment. Researchers are still working to create simple, reliable, and efficient green chemistry procedures for making NMs. Numerous species serve as safe, environmentally acceptable, and long-lasting precursors to create stable, well-functionalized NPs from bacteria, actinomycetes, fungi, yeast, and viruses. Therefore, it is crucial to look for a more dependable and long-lasting method of producing NMs. NM production raises issues on their commercial feasibility, environmental sustainability, social adaptability, and accessibility to local resources (Fig. **1**). To restrict the overall costs of finished products of nanotechnology-based materials and to increase affordability, industries must strive hard to maintain a balance between eco-friendly operations and sustainability. Nano-based ecologically friendly production techniques are solutions that work without the usage of dangerous chemicals.

Apart from environmental remediation, NPs also have multiple biological applications. For instance, new viruses are constantly evolving, creating a problem that is becoming more widespread. Therefore, in addition to developing novel antiviral medications, inventive procedures must be improved to maximize the efficacy of already available medications and other methods for restricting viral spread [4]. New approaches are frequently being tried to boost the effectiveness of vaccines. Recently, intriguing antibacterial and antiviral techniques based on nanotechnology have come under investigation [5]. These might include antiviral facemasks, clothing, and other coatings that, when in touch with a surface, could potentially destroy the virus. A huge number of studies have confirmed that NPs are also considered agents that enhance cellular immunity and extend the impact of antigens. Due to their multiple targeted mechanisms of action, silver NPs (AgNPs), in particular, synthesized utilizing plant extracts, are a promising contender for novel antiviral medicines [6]. These NPs have been demonstrated to be antiviral against the influenza virus, hepatitis B virus, herpes simplex type 1, chikungunya virus, and HIV [7]. A similar method was used to create gold NPs (AuNPs-As), which work as a reducing agent and have antiviral action against the measles virus. Additionally, CuO NPs were created using *Syzygium alternifolium* fruit extract and function as an antiviral agent against the Newcastle Disease Virus (NDV) [8]. NPs preserve antigens from deprivation and are concentrated on delivery in antigen-introducing cells and sub-cellular regions of interest because of their significant bio-physicochemical properties.

BIOTIC COMPONENTS FOR “GREEN SYNTHESIS”

In medicinal and nanoscience, many physico-chemical synthesis techniques need higher radiation, extremely lethal reductants, and alleviating agents, all of which can be harmful to living organisms. In contrast, the environmentally friendly bio-

CHAPTER 7

Efficiency and Applications of Nanoparticles Synthesized from Microalgae: A Green Solution

Saivenkatesh Korlam[1,*], **Sankara Rao Miditana**[2] and **S. Padmavathi**[1]

[1] *Department of Botany, SVA Government Degree College, Srikalahasti, Tirupati, Andhra Pradesh, India*

[2] *Department of Chemistry, Government Degree College, Puttur, Tirupathi, Andhra Pradesh, India*

Abstract: Nanotechnology has gained significant attention in the fields of biotechnology and biomedicine and has been widely used in drug delivery, imaging, diagnosis, and sensing. Nanoparticles (NPs) are submicron-sized particles that have unique properties due to their high surface area-to-volume ratio. NPs have gained significant attention in recent years due to their potential applications in biotechnology and biomedicine, including drug delivery, imaging, diagnosis, and sensing. Microalgae are photosynthetic microorganisms that are widely distributed in aquatic environments. Recently, microalgae have been explored as a potential source of NPs due to their unique chemical and physical properties. Microalgae-derived NPs have several advantages over chemically synthesized NPs, including lower toxicity, biocompatibility, and eco-friendliness. In this chapter, we have discussed the various types of NPs produced by microalgae, their synthesis and characterization methods, and their different domains of applications, with a special focus on environmental remediation. Additionally, we have highlighted the challenges and prospects of using microalgae-derived NPs.

Keywords: Biomedical and industrial fields, Eco-friendly, Environmental remediation, Microalgae, Nanotechnology, Nanoparticles, Toxicity.

INTRODUCTION

NPs are tiny particles with dimensions in the range of 1-100 nanometers, which exhibit unique physicochemical properties due to their small size and high surface-to-volume ratio. Nanotechnology is a multidisciplinary field that involves the design, synthesis, characterization, and application of NPs and other nanostructured materials. NPs can be classified into organic, inorganic, and hybrid categories based on their composition and structure [1]. Organic NPs, such as liposomes and dendrimers, are made of carbon-based molecules and are often

* **Corresponding author Saivenkatesh Korlam**: Department of Botany, SVA Government Degree College, Srikalahasti, Tirupati, Andhra Pradesh, India; E-mail: k.saivenkatesh@gmail.com

used in drug delivery and imaging applications [1]. Inorganic NPs, such as metal and metal oxide NPs, are typically synthesized using chemical or physical methods and are used in various fields, including electronics, catalysis, and energy conversion. Hybrid NPs, which combine organic and inorganic components, exhibit a wide range of properties and are used in diverse applications. Nanotechnology has numerous applications in medicine, electronics, energy, and environmental remediation. For instance, Wang *et al.* reported the use of nanotechnology for cancer diagnosis and therapy, highlighting the potential of NPs as contrast agents, drug delivery vehicles, and photothermal agents [2]. In the field of electronics, nanotechnology has enabled the development of miniaturized devices and high-performance materials, such as carbon nanotubes and graphene [3]. In the energy sector, NPs are being explored for solar energy conversion, hydrogen production, and energy storage [4].

Microalgae are photosynthetic microorganisms that play a crucial role in aquatic ecosystems and have a variety of potential applications in biotechnology, biofuels, and food production. Microalgae are characterized by their small size (typically ranging from 1 to 100 µm), high surface area-to-volume ratio, and rapid growth rates, which make them ideal candidates for mass cultivation. According to a study, microalgae are capable of producing a wide range of valuable compounds, including proteins, lipids, carbohydrates, pigments, and bioactive molecules, which have potential applications in a variety of industries [5]. These compounds can be extracted from microalgae using a variety of methods, including mechanical extraction, chemical extraction, and enzymatic hydrolysis. Microalgae are also known for their ability to fix carbon dioxide (CO_2) through photosynthesis, which makes them a potential source of biofuels. A study conducted by Chisti found that microalgae can produce up to 100 times more oil per unit area than traditional biofuel crops such as soybeans and can do so in a much shorter time frame [6]. In addition to their potential applications in biotechnology and biofuels, microalgae also play an important role in aquatic ecosystems. A recent study found that microalgae are critical to the functioning of marine food webs, providing a primary food source for a wide range of organisms, from zooplankton to whales [7].

CURRENT APPLICATIONS IN NANOTECHNOLOGY

Nanotechnology is a rapidly evolving field of research that involves the design, production, and application of materials and devices at the nanoscale level. Some of the current research areas in nanotechnology are as follows, and the details are shown in Fig. (**1**).

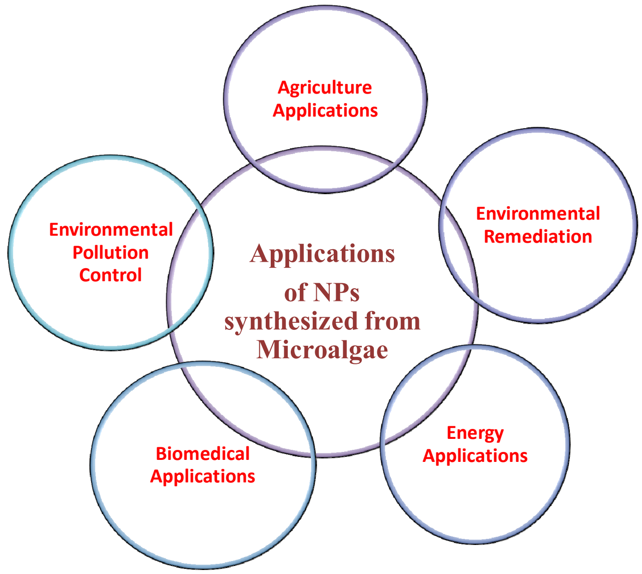

Fig. (1). Applications of NPs synthesized from microalgae.

Nanomedicine

The application of nanotechnology in medicine has revolutionized the diagnosis, treatment, and prevention of diseases. NPs, nanorobots, and nanosensors are being used for targeted drug delivery, imaging, and biosensing. For example, a recent study published in the journal ACS Nano showed the potential of using nanorobots to deliver chemotherapy drugs to cancer cells with high precision [8].

Energy Sector

Nanotechnology has the potential to revolutionize the energy sector by improving the efficiency of energy production, storage, and utilization. Researchers are working on developing high-performance solar cells, batteries, and fuel cells using nanomaterials (NMs). A recent study reported the development of a new type of high-performance lithium-sulfur battery using a sulfur-nitrogen dual-doped graphene aerogel as the cathode [9].

Environmental Remediation

Nanotechnology has the potential to address environmental challenges by developing materials and technologies for pollution control, water treatment, and air purification. NPs and nanocomposites are being developed for the removal of heavy metals, organic pollutants, and pathogens from contaminated water and soil. A recent study published in the journal "Environmental Science &

CHAPTER 8

Application of Green Synthesized Nanomaterials for Environmental Waste Remediation: A Nano-Bioremediation Strategy

M. Nanda[1], **S. Agrawal**[1] and **S.K. Shahi**[1,*]

[1] *Bioresource Product Research Laboratory, Department of Botany, School of Life Science, Guru Ghasidas Vishwavidyalaya (A Central University), Bilaspur, Chhattisgarh, India*

Abstract: In the current scenario, dangerous refractory organic and inorganic pollutants are continuously released into the environment as a result of industrialization that poses a significant threat on a global scale. One of the greatest challenges that needs to be solved is the effective management of various pollutants and waste. Despite their effectiveness, traditional treatment methods have several drawbacks, such as the fact that they are time-consuming and target-specific. As a result, it directs the search for a suitable replacement. Researchers are paying close attention to the novel technique of nano-bioremediation to remove pollutants from various contaminated locations. This approach combines the benefits of bioremediation and nanotechnology to develop a remediation process that is quicker, more productive, and less harmful to the environment than either approach individually. This chapter summarizes the green synthesis methods of various nanomaterials (NMs) along with an explanation of the remediation methodology, its mechanism, and prospective applications in environmental remediation. Additionally, the removal and valorzsation of waste materials using green nanotechnology supported by microbes and enzymes are highlighted. This chapter also discusses the multiple constraints of nano-bioremediation as well as the factors responsible for the efficiency of NMs.

Keywords: Biofabrication, Green synthesis, Immobilization, Microemulsion, Nano-bioremediation, Nanocomposite, Nanotechnology.

INTRODUCTION

In the present scenario, the rate of urbanization and industrialization is accelerating and releasing unsustainable pollutants into the atmosphere. These xenobiotic pollutants cannot be easily removed from the environment and cause harmful effects on ecological safety and human health [1].

* **Corresponding author S.K. Shahi:** Bioresource Product Research Laboratory, Department of Botany, School of Life Science, Guru Ghasidas Vishwavidyalaya (A Central University), Bilaspur, Chhattisgarh, India;
E-mail: sushilkshahi@gmail.com

Neha Agarwal, Vijendra Singh Solanki and Sreekantha B. Jonnalagadda (Eds.)

"Environmental waste remediation" refers to the process of addressing and mitigating environmental pollution or contamination by removing, treating, or neutralizing harmful substances in the air, water, soil, or other environmental media. The goal is to restore or improve the quality of the environment by eliminating or reducing the negative impacts of pollutants or hazardous materials. The removal of dangerous pollutants from the environment is performed through biological, chemical, and physical methods. Nevertheless, the widespread use of the conventional approach is constrained by time and energy requirements, high operational costs, and maintenance [2]. Among several existing technologies, the most promising and cost-effective strategy for removing contaminants is bioremediation in combination with nanotechnology. Bio-based technique or bioremediation is a hygienic, sustainable, and an "environmentally suitable" green method for the removal of pollutants. In recent times, the removal of pollutants from contaminated sites in a sustainable manner has become crucial due to the lesser risk involved and for improving the quality of contaminated sites by restoration method [3 - 5].

Nanotechnology has gained significant interest in recent years across a variety of industries, including textiles, electronics, medicine, and pharmaceuticals. The scope of nanotechnology has provided greater opportunity to manage the major environmental challenges such as remediation of environmental contaminants [6, 7]. Nanoparticles (NPs) possess unique shapes and sizes. They have increased adsorption and catalyst properties and high reactivity; therefore, new technologies are gaining more attention in the preparation of NPs by researchers. Nanoparticles are fabricated by chemical or physical methods through the top-down or the bottom-up method. The top-down method includes arc discharge, diffusion, lithographic techniques, high-energy ball milling, and irradiation, where large molecules break down and form nano-sized particles. Meanwhile, the bottom-up method includes chemical and biological approaches; in these methods, atoms combine and form clusters, and then cluster aggregates in the form of nanoparticles. To produce nanoparticles, biological approaches are being used due to the numerous drawbacks of physiochemical methods, including their high cost and potentially harmful by-products [8]. The utilization of fungal, bacterial, and algal cultures, as well as their metabolites and biomolecules, for the long-term synthesis of NMs, is gaining popularity and possesses a potential application in the field of bioremediation [9, 10]. To achieve an effective, economical, and long-lasting solution for a clean environment, nanobiotechnology and bioremediation have been combined [11 - 13].

Another application for nanocomposites or NPs is the removal of dangerous substances from wastewater. For instance, an absorbent made of a reduced amount of graphene and iron oxide was produced to get rid of phenazopyridine

[14]. The ligand-dependent functional materials are appropriate for removing heavy metals and other pollutants from wastewater because they have additional advantages. Nickel had been removed from petroleum-polluted water using an embeddable composite absorbent. To extract caesium from wastewater, a synthetic zeolite-based absorbent was also developed. Carbon and its derivatives are the most often utilized nanoabsorbents for removing heavy metal ions and organic dyes from aqueous solutions. The degradation of organic pollutants in the treatment of organic wastewater has attracted the attention of numerous investigations. These materials are based on carbon nanotubes (CNTs). Some of the NMs that have recently been utilized to remove the dye from wastewater include multiwalled CNTs, chitosan nanoabsorbents, mesoporous silica, and nanocopper oxide made from e-waste [15]. Adsorptive or reactive procedures that are used for on-site (*in-situ*) or off-site (*ex-situ*) treatment of pollutants are at the heart of efforts to achieve "environmental improvement". While the latter method dissolves the organic impurities, leaving no toxic byproducts like CO_2 and H_2O, the former technique involves the removal of heavy metal contaminants through sequestration. The present chapter compiles and summarizes the brief knowledge of nanotechnology in synthesis methodology related to the application in the degradation of pollutants and limitations of NPs in the field of remediation.

HISTORICAL ASPECTS OF NPS

Professor Richard Feynman initially outlined the concept of nanotechnology in his lecture "There's Plenty of Room at the Bottom", and Professor Norio Taniguchi coined the term [16, 17]. The technique is frequently described as the "Next Industrial Revolution" [18]. This technology is characterized by using tiny NPs (<100 nm), and the United States National Nanotechnology Initiative (USNNI) has defined it as "the understanding and control of NMs (dimensions 1-100 nm), where unique phenomena occur, allowing for novel nanotechnology applications". Numerous scientific fields, including agriculture, the removal of pollutants from soil and water, *etc.*, have adopted nanotechnology [19, 20]. Due to its extremely small size, high surface area to volume ratio, ease of usage and flexibility for both *In vivo* and *In vitro* applications, nanotechnology plays a crucial role in the process of bioremediation [20].

CLASSIFICATION OF NPS

According to previous studies, particles (atomic or molecular aggregates) having different shapes like rod, circular, spherical, triangular, polygon and stars with a size range of 1-100 nm are denoted as NPs [21]. The uniformity of the size, shape, and structure of nanoparticles determines their attributes, including magnetic, reactivity, stability, and optical features. The structure of the nanoparticles

CHAPTER 9

Phytoremediation/Phytoextraction: A Sustainable Approach to the Restoration of Chromium-Contaminated Soil

Pankaj Kumar[1,*], Deepankshi Shah[1], Manoj Kumar[2], Snigdha Singh[1], Virendra Kumar Yadav[3], Mohd. Tariq[4], Ramesh Kumar[5], Nakul Kumar[6], Shivraj Gangadhar Wanale[7] and **Shipra Choudhary[8]**

[1] *Department of Environmental Science, Parul Institute of Applied Sciences, Parul University, Vadodara, Gujarat, India*

[2] *Department of Hydro and Renewable Energy, Indian Institute of Technology Roorkee, Roorkee, Uttarakhand, India*

[3] *Department of Life Sciences, Hemchandracharya North Gujarat University, Matarvadi Part, Gujarat, India*

[4] *Department of Life Science, Parul Institute of Applied Sciences, Parul University, Vadodara, Gujarat, India*

[5] *Department of Environmental Science, School of Earth Sciences, Central University of Rajasthan, Ajmer, Rajasthan, India*

[6] *Gandhinagar Institute of Science, Gandhinagar University, Gandhinagar, Gujarat, India*

[7] *School of Chemical Sciences, Swami Ramanand Teerth Marathwada University, Nanded, Maharashtra, India*

[8] *Department of Microbiology and Biotechnology, Meerut Institute of Engineering & Technology, Meerut, Uttar Pradesh, India*

Abstract: Chromium is a major component that is responsible for environmental stress. It also has profound effects on the health of living beings because trace amounts of chromium in the environment have been linked to serious health problems in humans and plants. The dangers to human health, bioavailability, plant response to chromium toxicity, and phytoextraction storage in plants are issues of major concern. Understanding and optimizing the phytoextraction process would be immensely beneficial to know about metabolic pool changes that occur in plants in response to Cr toxicity. Therefore, the removal of chromium from the environment is necessary due to its toxic nature. However, the removal of chromium from the environment is a daunting task. Physico-chemical and biological techniques are either too expensive or inefficient to be widely implemented to eradicate chromium from the contaminated soil and environment. The challenges of widespread implementation can be met by adopting

* **Corresponding author Pankaj Kumar:** Department of Environmental Science, Parul Institute of Applied Sciences, Parul University, Vadodara, Gujarat, India; Tel: +918460571814;
E-mail: pankaj.kumar25135@paruluniversity.ac.in

Neha Agarwal, Vijendra Singh Solanki and Sreekantha B. Jonnalagadda (Eds.)

integrated approaches, which are currently under consideration. The removal of chromium from the environment can be more economical and sustainable using phytoremediation technology.

In this chapter, we have discussed the phytoremediation technique as a green solution for the removal of chromium from polluted soil because phytoremediation, and especially phytoextraction, is a viable and sustainable solution to restore chromium-polluted soil.

Keywords: Chromium, Health hazard, Phytoremediation technology, Phytoextraction, Sustainable approaches.

INTRODUCTION

Soil is one of humanity's most valuable and important natural resources. Healthy soil is necessary for the continued success of agriculture and the well-being of civilization [1]. However, heavy metal-polluted soil poses severe health hazards to humans and is a major issue around the world that causes serious illnesses [2 - 4]. The harmful impacts of metals on humans have been observed since ancient times but acquaintance with the harmful effects of these chemicals is still insufficient. Metals can have devastating health impacts and can be lethal to humans. Anthropogenic activities are responsible for the release and accumulation of toxic chemicals into the environment. Heavy metal pollution also results from human activities as well as industrial operations, as mentioned in Fig. (**1**) [5 - 7].

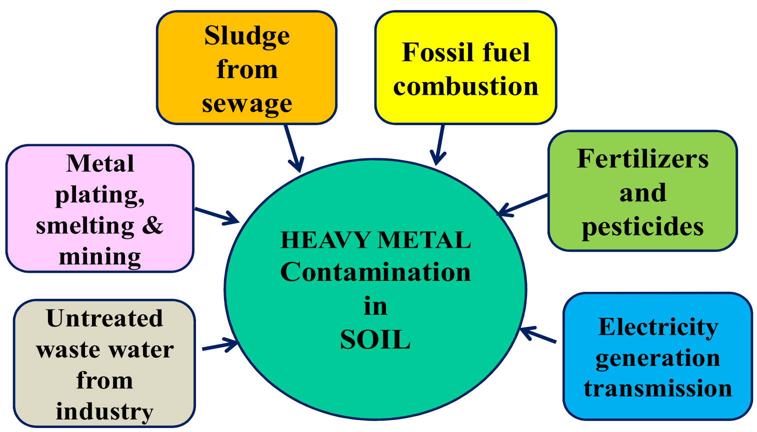

Fig. (1). Possible anthropogenic activities responsible for metal contamination in soil.

Heavy metals are metals with densities greater than 5 g/cm^3 and atomic numbers greater than 20 [8]. Toxic metals such as Arsenic (As), Nickel (Ni), Mercury (Hg), Zinc (Zn), Cadmium (Cd), Chromium (Cr), and Lead (Pb) are widely distributed in the soil and water. Trace elements are metals that account for less than 0.1% of a rock's total mass [9]. Some metals are necessary for the survival of human beings, whereas others are not. The important heavy metals are considered micronutrients but become toxic in high doses. Pb, Cd, and Hg are poisonous metals that are not required to live and are categorized as nonessential [10]. As the seventh most common element in the earth's crust, Cr is a major pollutant that affects ecosystems and human health when it continues to leak into the environment [11]. Sources of Cr include metal extraction, electroplating, leather industry, fertilizer use, and other anthropogenic and natural processes (Fig. **2**) [12]. Chromium and its derivatives have multiple practical applications; for instance, the metallurgical industries employ 90% of the world's chrome ore output to make steel, alloys, and non-ferrous alloys, the chemical (leather tanning and plating) and refractory (iron & steel, cement, and glass) sectors have utilized about 5% of each [13]. Approximately 0.13% of the country's arable land is polluted with Cr and is therefore not suitable for cultivation, but 1.26% is in high danger of Cr contamination. This data suggests that a systematic exploration is required to alleviate unfavorable impacts from the persistence of Cr pollution in soil [14]. Traditional ways of getting rid of metal are usually expensive, harmful, time-consuming, and cause more problems. Alternatively, phytoremediation is a cutting-edge, low-cost, environmentally-friendly remediation approach that is particularly well-suited to developing countries [15, 16]. Phytoremediation is among the most proficient approaches to cleaning metal-contaminated soil since it uses plants to lessen the pollutant's concentration [16, 17].

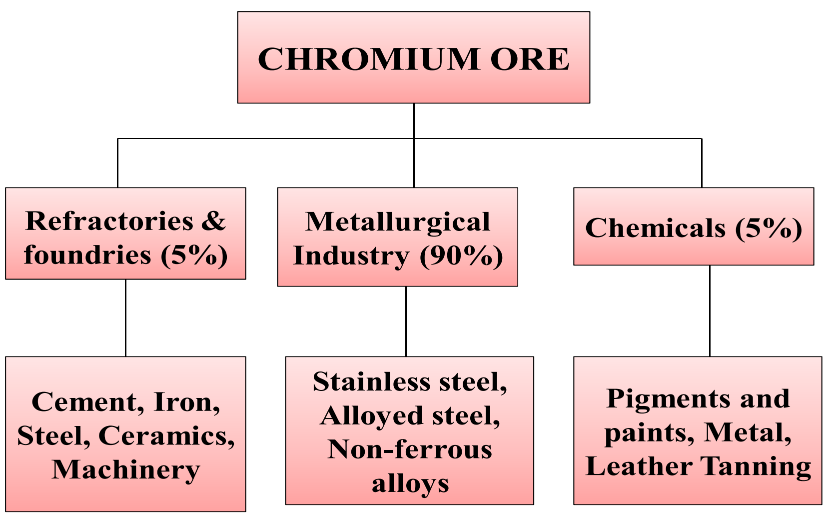

Fig. (2). Usage of chromium in different industries [13].

CHAPTER 10

Significance of Nanobioremediation for the Removal of Contaminants from Water: Challenges and Future Prospects

Shraddha Bais[1,*] and **Ruchi Shrivastava**[1]

[1] *Department of Chemistry, Institute of Science and Research, IPS Academy, Indore, Madhya Pradesh, India*

Abstract: Water is the most crucial natural resource required for the survival of humankind, but chemical industries, household activities, foul practices, *etc.*, are responsible for polluting it. This leads us to work on the purification and bioremediation of water contaminants. Diverse techniques have been developed globally for decontamination/purification of water, but owing to their high cost, tediousness and time consumption, it has become necessary to work on those methods that are comparatively cheaper, techno-feasible and employ a green process. In the contemporary world, the use of nanotechnology in the bioremediation of water pollutants revolutionarily provides a way to incorporate functional chemicals in notably reduced quantities to fulfil the desired purpose. Globally, water pollution is primarily caused by the rainwater containing the pollutants present in the air. Industrial and domestic wastewater, which is a major source of toxic heavy metals, industrial dyes, pesticides and insecticides, is used in agriculture. These water pollutants adversely affect the health of human beings as well as the whole ecosystem of the affected region. The employment of nano-materials (NMs) degrades the pollutants from the water source to its standard permissible level. The current chapter comprises a detailed discussion on the immense potential of NMs in the bioremediation of polluted water using different NMs and also provides a comprehensive comparison with other conventional bioremediation methods to make water environmentally non-hazardous.

Keywords: Bioremediation, Contaminants, Conventional treatment techniques, Green methods, Heavy Metals, Metal oxides, Nanotechnology, Nanomaterials, Toxic pollutants, Wastewater, Water pollutants, Zero-valent metals.

* **Corresponding author Shraddha Bais:** Department of Chemistry, Institute of Science and Research, IPS Academy, Indore, Madhya Pradesh, India; E-mail: shraddhabais@ipsacademy.org

Neha Agarwal, Vijendra Singh Solanki and Sreekantha B. Jonnalagadda (Eds.)

INTRODUCTION

Toxic pollutants are of serious public health concern because they flow with effluents like heavy metals, pesticide residues, antibiotics, chemicals and hydrogen. There is an urgent need to address the environmental issues caused by these effluents. Bioremediation is one of the major water treatment techniques that involve the use of microorganisms in the degradation of hazardous pollutants. By this technique, the pollutants get degraded either to their permissible limit or to less harmful substances [1]. This method can be mostly employed in situ by creating microbial consortia under required conditions like humidity, temperature, and nutrition to promote the growth of required microorganisms. Microorganisms that are used to remove contaminants from water have different impacts on different pollutants and are capable of mineralizing the contaminant into mineral acids [2 - 5]. Different categories of wastewater effluents and their bioremediation outcomes are mentioned in Table **1**, while some of the bioremediation agents and their effects are listed in Table **2** [6, 7].

Table 1. Different categories of wastewater effluents and their bioremediation outcomes.

Effluent	Bioremediation Outcomes
OMWs-Olive Mill Wastewater	Saprophytes are widely employed in the removal of heavy metals like Hg, Pb, Fe, U
Dyes, Colorants, Textile Industries	Bacilli are frequently used in the degradation of heavy metals like Hg, Pb, Cd, Zn, dyes, pesticides
Pulp, paper, Textile	Saccharomyces cerevisiae decreases COD and also removes heavy metals and organic matter.
Sewage water	Algae remove toxic metals and reduce BOD and COD to optimum levels.
Pharmaceutical Industries' wastewater	Enzymes and microorganisms eliminate and reduce active pharmaceutical ingredients, drugs, hormones, detergents, disinfectants, antioxidants, *etc.*
Battery industries' wastewater	Lysinibacillus, Paenibacillus, Bacillus, and Acidithiobacillus are employed to remove heavy metals and lithium from the battery wastewater.
Plastic industries' wastewater	Enzymes mediated removal of by-products or intermediate products of polymerization process released in water *i.e.*, resin, organic acids, tetrahydric alcohol, pentaerythritol, formaldehyde, sodium formate, phenols, urea, benzene, *etc.*

CONVENTIONAL TECHNIQUES TO TREAT WATER POLLUTANTS

Water pollution is primarily caused by microbial infections and the presence of hazardous organic as well as inorganic chemical compounds. The most ancient method to disinfect water was introduced by Holmes in 1835 in Boston and Semmelweis in Vienna in 1837 [10]. They used chlorine as chlorinated lime for water disinfection and after that, a solution of chlorine of 1-3 ppm concentration was used as a major treatment to disinfect drinking water. However, the major flaw in the chlorination of water was that it did not work against most of the chemical pollutants. Later on, oxidation by various oxidizing reagents like H_2O_2 was done to treat polluted water containing chemical pollutants [11]. Other conventional techniques that are used to treat water pollutants are listed in Table **3**. Most of the chemicals and heavy metals cannot be removed easily by normal physical, chemical or biological methods. Therefore, electrochemical treatment, ion exchange chemical redox process, membrane filtration, reverse osmosis, photocatalytic degradation, microbial treatment, NMs-based treatments and their combined approaches are some common techniques that are under the area of research to treat water pollutants commercially in the near future [12, 13].

Table 2. Different types of bioremediation techniques, their significance and deficits [8, 9].

Bioremediation Techniques	Significance	Deficits
Mycoremediation	• This involves the use of fungi, which act as decomposers. They feed on dead organic matter, degrade oils, hydrocarbons, and aromatic compounds • Some examples like mushrooms *Agaricus, Amanita, Cortinarius, saprotrophs, hyphae, Suillus,* and *Phellinus* are used for mobilization/complexation of different heavy metals in soil	Incapable of complete removal of pollutants.
Phytoremediation	• Phytoextraction and phytostabilization are remediation techniques that absorb contaminants from water.	Only relocate the toxic pollutants and applicable only on the surface of the wastewater.
Phycoremediation	• This is the most effective method for aquatic ecosystems. Microalgae present in water grow as an algal bloom and easily absorb pollutants through bioassimilation and biosorption.	Low toxin tolerance capacity and slow toxin removal rate.
Microorganisms	• Genetically modified microorganisms absorb pollutants and heavy metals like mercury and aromatic hydrocarbons • Especial microorganisms are effective in remediating oil spills, which is a major cause of aquatic pollution • Bioaugmentation is another advanced method that degrades pollutants.	Some microorganisms produce more toxic products during bioremediation; pollutants with higher molecular weight (PAN, PAH *etc.*) are difficult to be removed by microorganisms.

CHAPTER 11

Current Trends in Biogenic Synthesis and Applications of Palladium Nanoparticles: A Sustainable Approach to Environmental Remediation

Gitanjali Arora[1], **Anamika Srivastava**[1,*], **Manish Srivastava**[2], **Jaya Dwivedi**[1], **Shruti**[1] and **Rajendra**[1]

[1] *Department of Chemistry, Banasthali Vidyapith, Banasthali, Rajasthan, India*

[2] *Department of Chemistry, University of Allahabad, Prayagraj, Uttar Pradesh, India*

Abstract: Nanotechnology is a multidisciplinary area with a wide range of applications. Recent developments in nanotechnology and nanoscience have also triggered the development of new nanomaterials (NMs), enhancing the hazards to human health and the environment. There has been a rise in interest in creating ecologically friendly techniques for producing metallic nanoparticles (MNPs). The aim is to reduce the harmful effects of synthetic technologies, the chemicals used in association with them, and the derivative products. A useful strategy in green nanotechnology is the utilization of various biomolecules for the fabrication of NPs. MNPs that are inexpensive, energy-efficient, nontoxic, and beneficial to the environment have been produced using biological resources, including bacteria, algae, fungi, and plants. Plant components are mainly employed as capping and reducing agents in green synthesis. MNPs of various sizes and forms have been created using bark, leaves, fruits, and flower extracts. In this chapter, we have addressed the green synthesis of palladium NPs to remove positive ions, negative ions, and dye from wastewater, their potential applications and the directions for future research.

Keywords: Application of nanoparticles, Dye removal, Green synthesis, Ions removal, Leaf extracts, Palladium nanoparticles, Wastewater treatment.

GREEN NANOTECHNOLOGY FOR SUSTAINABLE DEVELOPMENT

Water microbiological contamination and purification are major global issues, and the majority of commonly used treatments have a variety of drawbacks, such as being expensive and hazardous to the environment. Therefore, to solve the problem of water filtration, new methods and materials are urgently needed.

* **Corresponding author Anamika Srivastava:** Department of Chemistry, Banasthali Vidyapith, Banasthali, Rajasthan, India; E-mail: anamika.chemistry2011@gmail.com

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Numerous industries, including those in the leather, textile, agricultural, pharmaceutical, plastic, paper, wood, and cosmetics sectors, have drastically increased their production of organic pollutants and dye-containing wastewater.

According to claims, the textile sector is the biggest wastewater source containing wastewater that contains highly concentrated dyes (10–200 mg/L) [1 - 3]. Wastewater discharged into an aquatic environment containing these cancer-causing chromophores can limit light penetration in aqueous systems, hindering photosynthesis, affecting human health, and destroying aquatic living particles.

Therefore, more study is required to eliminate these toxins. Although several techniques for treating colored wastewater (such as activated carbon-based adsorption, biological techniques, coagulation-flocculation, chemical oxidation, *etc.*) have previously been industrialized, their shortcomings prevent their widespread use [4 - 8]. Chemical approaches, for instance, are expensive, ineffective at removing pollutants, and produce secondary pollutants in the form of sludge. Developing suitable, economical, and environmentally acceptable wastewater treatment methods that do not produce secondary pollutants is now necessary. Due to their strong reactivity, substantial surface area, and efficiency, MNPs have become a popular choice for use as catalysts [9 - 11].

Usually, MNPs are formed by employing a potent alkaline substance (reducing agent), such as sodium borohydride or sodium hydroxide, to chemically reduce metal ions found in salt solutions, followed by the addition of a stabilizing agent. However, the chemicals utilized as reducing agents and the solvents used to dissolve the stabilizers are frequently hazardous materials that might harm human health and the environment if residues are present in the finished nanosystems. As a result, this may give rise to several issues surrounding the safety of MNP applications as well as the search for creative new ways aimed at their synthesis. One of these options is the use of biological systems in the green synthesis of MNPs, which is based on the ideas of green chemistry (Fig. **1**) [12 - 16].

Prokaryotic or eukaryotic organisms (including microbes, plants, and animals) or components thereof may be used in the green synthesis of MNPs, which can take place through intracellular or extracellular routes. To encourage the reduction of a target metal ion and the creation of MNPs, the biological components function as agents. The surface of MNPs may develop a stabilizing layer (coating) from the same reducing substances or other nearby molecules, avoiding or at least minimizing the formation of agglomerates or disordered growth. Most MNPs made using green synthesis techniques exhibit traits that are desirable from a sustainability perspective, including being eco-friendly (using less toxic chemicals and solvents), quick and easy to make (fewer steps), biocompatible, biodegradable, low cost of production, and high yield [17 - 20]. Important examples of biosynthesis of MNPs by plants are summarized in Table **1**.

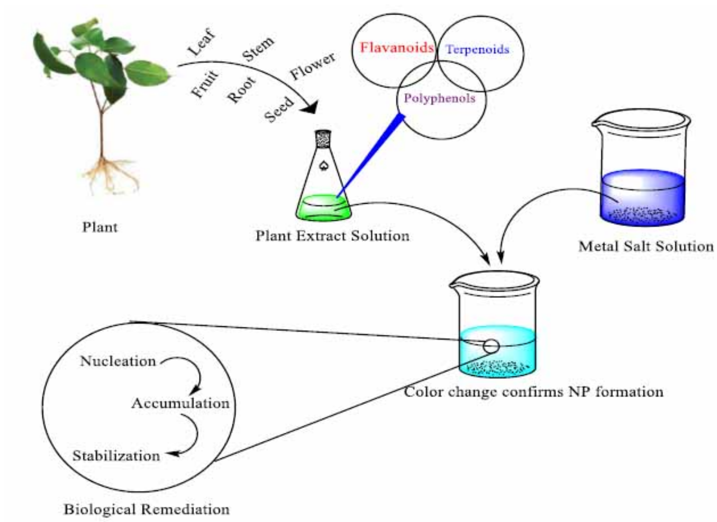

Fig. (1). Green chemistry involved in biological remediation.

Table 1. Important examples of biosynthesis of MNPs by Plants.

Plant Origin	NPs	Size(nm)	Morphology	Refs.
Aloe-vera	Au & Ag	_	Spherical, triangular	[28]
Acalypha indica	Ag	5-50	Spherical	[29]
Anogeissus latifolia Gum	Pd	4.8	Spherical	[30]
Apiin (from henna leaves)	Ag	39	Spherical, triangular	[31]
Apiin (from henna leaves)	Au	7.5-65	Quasi-spherical	[32]
Black tea leaf extract	Au & Ag	20	Spherical, prism	[33]
Brassica juncea (mustard)	Ag	2-35	Spherical	[34]
Camellia sinensis (green tea)	Au	40	Spherical, triangular, irregular	[35]
Carica papaya	Ag	60-80	Spherical	[36]
Chenopodium album	Au & Ag	10-30	Quasi-spherical	[37]
Cinnamomum camphora	Pd	3.2-6	_	[38]
Cinnamomum zeylanicum Bark	Pd	15-20	Crystalline	[39]
Citrus limon (lemon)	Ag	<50	Spherical, spheroidal	[40]
Coriandrum sativum (coriander)	Au	6.75-57.91	Spherical, triangular, truncated triangular, decahedral	[41]
Curcuma longa Tuber	Pd	10-15	Spherical	[42]
Cymbopogon flexuosus (lemongrass)	Au	200-500	Spherical, triangular	[43]

CHAPTER 12

A Comprehensive Review on Applications of Different Domains of Nanotechnology in Wastewater Treatment

Annu Yadav[1], **Nirmala Kumari Jangid**[1,*], **Rekha Sharma**[1] and **Azhar Ullah Khan**[2]

[1] *Department of Chemistry, Banasthali Vidyapith, Banasthali, Rajasthan, India*

[2] *Department of Chemistry, School of Life and Basic Sciences, Jaipur National University, Jaipur, India*

Abstract: In the process of purification of water, nanotechnology provides the possibility of an effective removal of pollutants and germs. In recent times, nanoparticles (NPs), nanopowder and nanomembranes have been used for the detection and removal of chemical and biological substances that contain metals like cadmium, copper, lead, mercury, nickel, zinc, *etc.*, nutrients like phosphate, ammonia, nitrate and nitrite, algae, cyanobacterial toxins, viruses, bacteria, parasites, and antibiotics. Commonly, four classes of nanoscale materials that are being evaluated as functional materials for water purification are metal-containing nanoparticles, carbonaceous nanomaterials, dendrimers and zeolites. Carbon nanotubes and nanofibers are also used in the techniques of water purification. Nanomaterials (NMs) give the best results in water treatment in comparison to other techniques because NMs have a high surface area (surface/volume ratio). Silver NPs affect the activated sludge of microorganisms and play an important role in wastewater treatment since they restrain their activity and significantly reduce their number. Carbon nanostructures are widely used as nanoadsorbents for wastewater treatment owing to their abundant availability, cost-effectiveness, high chemical and thermal stabilities, high active surface areas, excellent adsorption capacities, and environmentally friendly nature. Due to the high utility of nanotechnology in the treatment of pollutants, this chapter further highlights various fundamental aspects of nanotechnology, such as types, synthesis, applications and future directions for a green and sustainable environment.

Keywords: Activated carbon, Carbon nanotubes, Dendrites, Graphene, Green synthesis, Nanoparticle, Membrane filtration, Nanofiber, Nano silver, Nanocomposites, Photocatalytic, Zeolite.

* **Corresponding author Nirmala K. Jangid:** Department of Chemistry, Banasthali Vidyapith, Banasthali, Rajasthan, India; E-mail: nirmalajangid.111@gmail.com

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INTRODUCTION

Water is essential for life, but it is very difficult to have clean and hygienic water every day due to continuous contamination of fresh water. Advanced technology is necessary to meet this challenge and provide people with clean water for a healthy life [1 - 4]. Nanotechnology can help by providing clean water for growing humans. The term nanoscience and the scale defined by nano is a combination of nanotechnology. The adverb “nano” is derived from nannos (Greek), which means “very short people” [5]. This technique refers to the technique that uses nanoscale particles. Depending on the size of the field, NPs have special physicochemical properties in which the structural components are sized (in at least one dimension) between 1 and 100nm [6]. Due to the nanoscale size of NMs, their electrical, optical and magnetic properties are different from those of conventional materials. NMs have a high surface area to volume ratio that allows them to effectively absorb and remove contaminants from water. The adsorption capacity of materials such as carbon nanotubes, graphene, and nanoparticles such as titanium dioxide or iron oxide has been extensively studied [7]. These NMs can selectively target and capture pollutants, including heavy metals, organic compounds and bacteria, thereby improving overall water quality. Nanotechnology has emerged as a promising field with its applications in many areas, such as the environment and water treatment. NPs can act as catalysts in various oxidation reactions, such as photocatalysis or electrocatalysis, to effectively decompose or convert pollutants into harmless products. For example, photocatalytic NMs such as titanium dioxide, when activated by light, produce reactive oxygen species that can degrade organic compounds. This approach shows promise in breaking down pollutants that are difficult to remove using conventional treatments. Nanotechnology also plays an important role in membrane separation processes, which are widely used in wastewater treatment. Reverse osmosis membranes with nanofiltration and nanoscale pores provide selective elimination of bacteria while retaining essential water. Functionalized NMs can be incorporated into tissues to improve their performance, such as improving fouling resistance, increasing permeability or facilitating selective ion removal and purifying water [8 - 10].

According to many studies, the use of NMs in water and wastewater treatment shows great promise. Currently, the most researched NMs for water and wastewater treatment mainly include zerovalent metal NPs, metal oxide NPs, carbon nanotubes (CNTs), and nanocomposites [11, 12]. Magnetic nanoparticles, metal zeolite, carbon nanotubes and other nanostructure materials can be used to remove Hg(II), Pb(II), Cr(III), Cr(VI), Ni(II), Co(II), Cu(II), Cd(II), Ag(I), As(V) and As(III) from wastewater because these metal ions can cause serious illness [13]. Nanoscale zero-valent ions are used as adsorbents and also catalyze photochemical oxidation. Due to their general adsorption properties, carbon nanotubes and dendrimers are often used to create advanced water systems [14, 15]. The introduction of nanotechnology into wastewater treatment has brought a revolution by providing oxidation, disinfection, membrane development and time management. With further research and development, nanotechnology holds great promise for the future of wastewater treatment, contributing to sustainable water management and environmental protection. Table **1** shows different types of NPs and the categories of pollutants that are removed by these NPs.

Green synthesis of NPs for wastewater treatment is focused on developing environmentally friendly methods to produce NPs and use them in water treatment processes. Conventional NP synthesis methods often involve chemical and energy-intensive processes. However, green synthesis aims to reduce or eliminate the use of chemicals and reduce energy consumption. Green synthetic methods use natural extracts, biomolecules or environmentally friendly reducing agents for production [16].

NEED FOR ADVANCED WASTEWATER TREATMENT TECHNOLOGIES

The need for advanced wastewater treatment technologies arises from many factors and problems associated with traditional methods. These include:

Emerging Contaminants

Conventional treatments are ineffective at removing emerging pollutants such as chemicals, personal care products, endocrine disruptors and microplastics that enter the environment and pose a threat to human health and hazardous ecosystems. Advanced treatment technologies are required to target and remove contaminants from wastewater.

Table 1. Different types of pollutants degraded by NPs.

Type of NPs	Type of Pollutants Degraded
Carbon nanotubes	Organic Contaminant
Nanoscale metal oxide	Heavy metals, radionuclides
Nanocatalyst PCB	Azodyes, pesticides, *etc.*
Ni/Pd nanoparticles	Dichrolophenol, trichlorobenzene
Bioactive nanoparticles	Removal of bacteria, fungi
Biomimetic membranes	Removal of salts
Photocatalysts	Heavy metal ions, Azo Dye and aromatic pollutants

CHAPTER 13

Application of Nanomaterials in the Degradation of Micro and Nano Plastics

V. J. Maodiswari[1], E. Rajalakshmi[2], S. Ambika[2], J. Princymerlin[2] and **Y. Manojkumar[2,*]**

[1] *Department of Botany, Bishop Heber College, Tiruchirappalli, Tamil Nadu, India*

[2] *Department of Chemistry, Bishop Heber College, Tiruchirappalli, Tamil Nadu, India*

Abstract: In recent years, microplastics (MPs) and nanoplastics (NPs) have become significant environmental concerns due to their persistent nature and potentially harmful effects on ecosystems and human health. Most of the reported materials and methods for the degradation of such toxic pollutants show limitations such as low recovery, high energy consumption and environmental impacts. As a result, more efficient green materials and methods are the need of the hour. Recently, researchers have reported efficient materials for the degradation of MPs and NPs. Hence, in this chapter, a comprehensive overview of eco-friendly initiatives and preventive measures is highlighted. It covers detailed information about the sources of MPs and NPs and their toxic impact on the environment and human health. It also highlights the existing techniques for processing and degradation of MPs and NPs and the potential of green nanomaterials in the degradation of plastics. The authors believe that this information will pave the way for the design and development of new alternate methods for further implementation.

Keywords: Eco-friendly, Environmental impacts, Degradation, Green nanomaterials, Microplastics, Nanoplastics, Preventive measures.

INTRODUCTION

Plastic consumption is constantly increasing worldwide, and last year, 390.7 million tons were produced [1]. Plastics have many useful properties, such as lightness, affordability, adaptability, durability and resistance to corrosion and flame. These materials significantly improve the quality of life of millions of people, making them safe to use. However, the disposal and mishandling of plastics have caused serious environmental and health issues that require urgent global attention [2]. Plastics have a remarkable resistance to degradation, which

* **Corresponding author Y. Manojkumar:** PG and Research Department of Chemistry, Bishop Heber College, Tiruchirappalli, Tamil Nadu, India; E-mail: yrmanojkumar@gamail.com

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allows them to remain in the environment for centuries. Plastics are classified by size into macroplastics and microplastics. Macro plastics are larger and have been the main focus of environmentalists for many years.

However, currently, more attention has been paid to MPs in the scientific community. Thompson coined the term "microplastic" in 2004 to describe the tiny fragments of plastic found in the marine environment [3]. The pieces of MPs, known as NPs, are the biggest threat to the environment and human health as they are even smaller in size than MPs. Polymers are classified commonly as macroplastics (>25 mm), mesoplastics (5-25 mm), MPs (<5 mm) and NPs (>100 nm) (Fig. **1**) [4].

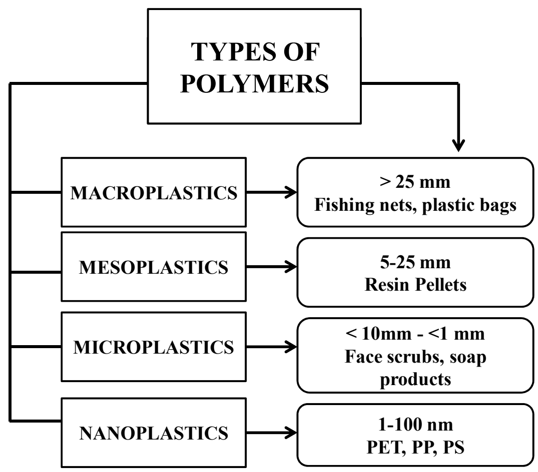

Fig. (1). Classification of plastics with their dimension.

MPs and NPs have a large surface area that facilitates the absorption and release of pollutants and chemicals and their possible entry into the food chain and subsequent migration to trophic levels [5]. Compared to MPs, NPs have been relatively less studied in the field of marine litter, which continues to pose serious threats to both the environment and human health. The widespread use of plastics in consumer goods and industrial applications, along with their slow rate of degradation, has led to the accumulation of MPs and NPs in various ecosystems, including oceans, rivers, soil and even the atmosphere. These small particles can persist in the environment for hundreds of years and pose a long-term threat to biodiversity and ecosystem functioning. These particles can end up in water bodies, where they pose a threat to aquatic organisms when they are ingested, causing physical damage, reducing feeding efficiency and disrupting reproductive processes. In addition, the accumulation of MPs and NPs in sediments affects benthic organisms and bottom-dwelling species, while in terrestrial ecosystems, they pollute the soil, affecting soil health, nutrient cycling and plant growth. Further, MPs and NPs can become airborne, polluting the air, which can have an impact on air quality and, subsequently, on human health. From a human health perspective, there is increasing evidence that MPs can enter the human body through the consumption of contaminated food and water, as well as inhalation [6]. The combined environmental and health concerns associated with MPs and NPs emphasize the need to intervene and mitigate their spread in our ecosystems. Due to the global and constant presence of MPs and NP pollution, there is an urgent need to develop effective strategies for their mitigation and elimination [7].

Traditional plastic degradation methods are not effective in processing MPs and NPs due to their small size and fragmentation. Green NMs offer a promising solution in this regard, as they are derived from renewable natural resources and have unique properties suitable for the degradation of MPs and NPs. These materials can enhance degradation processes through surface modification, enzymatic reactions, photocatalysis, chemical reactions and biodegradation [8]. By harnessing the power of green NMs, we can effectively mitigate the harmful effects of MPs and NPs and at the same time, avoid the additional environmental burden. The introduction of sustainable degradation methods is essential to prevent the accumulation of these particles in the ecosystems.

SOURCES OF MICROPLASTICS AND NANOPLASTICS

Fragmentation of Larger Plastics

Large plastic items such as bottles, bags and packaging materials can break down over time due to weathering, UV radiation and mechanical stress. This fragmentation process leads to smaller plastic particles such as MPs and NPs [9].

Synthetic Textiles

Synthetic fibers such as polyester, nylon and acrylic, commonly used in clothing, carpets and other textile products, can release microfibers during washing, use as well as disposal. Reports indicate that washing processes for synthetic textiles are the major source of MPs in the oceans. These microfibers can enter water bodies through sewage systems and contribute to MP pollution [10, 11].

Industrial Processes

Various industrial operations can produce MPs and NPs. For example, the production and processing of plastics, including the manufacturing, molding and extrusion of plastics, can lead to the release of plastic particles into the environment [12].

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Neha Agarwal

Prof. Neha Agarwal is currently working as assistant professor in the Department of Chemistry, Navyug Kanya Mahavidylaya, University of Lucknow, Lucknow, India. She completed her Ph.D. from the University of Lucknow. She has qualified UGC-CSIR-NET chemical science and GATE-chemical science. She has published many research papers and review articles on environmental remediation, nanomaterials, etc. in highly reputed Scopus Indexed journals. She has published 4 patents, edited many books with Nova Science Publishers, Bentham Science Publishers, Springer Nature, etc. authored one text book for undergraduate students. She is an active member of Association of Chemistry Teachers- India, Singapore National Institute of Chemistry, Royal Society of Chemistry, IUPAC-Affiliate member and also the editorial board member of various international, referred and peer reviewed journals. Her research interests include the study of the environmental impacts of a vast variety of organic pollutants, such as pharmaceuticals, dyes, pesticides and to find out those economically viable treatment techniques which degrade these pollutants into simple and non-toxic substances in an environmental-friendly manner to achieve a green and sustainable environment. Currently she is working in the field of environmental remediation including wastewater remediation with special focus on nanomaterials.

Vijendra Singh Solanki

Prof. Vijendra Singh Solanki did Ph.D. in Chemistry from Government Madhav Science, PG College (Vikram University) Ujjain in 2012. With more than 10 years of experience of teaching and research in the field of chemical science, he is currently working as Assistant Professor with ISR, IPS Academy, Indore, India. He has published more than 26 research articles in the journals of national and international repute and presently is the co-editor of many books with reputed international publishers such as Bentham Science, Springer Nature and CRC Press.

He is an affiliate/associate member of different academic bodies like American Chemical Society, Royal Society of Chemistry, Association of Chemistry Teachers, c/o Homi Bhabha Centre for Science Education, Mumbai and Vigyan Bharti. He had received a research grant from Madhya Pradesh Council of Science & Technology in 2019. He is the editorial board member of various national and international journals.

He has organized many national and international conferences and presented his work on environmental remediation. He is actively engaged in promoting IUPAC-GWB events in India since 2022 as national co-coordinator. His research interests include working on synthesis of various nanomaterials, wastewater treatment technology and green chemistry.

Sreekantha B. Jonnalagadda

Prof Sreekantha B. Jonnalagadda is currently working as an emeritus professor and senior research associate since 2023. He has been a senior professor of chemistry at the University of KwaZulu-Natal, South Africa, from 2003 to 2022. He received Ph.D. in chemistry from the Vikram University, Ujjain, India. He worked as a DFG research associate at the University of Bonn, Germany, and in different faculty positions at the University of Nairobi and Zimbabwe. He is an elected fellow of the University of KwaZulu-Natal (2012), South African Chemical Institute (2014), African Academy of Sciences (2015), and A.P. Academy of Sciences, India (2017). He has more than 12800 citations and an H-index of 53, has published more than 485 research papers and review articles in many reputed and high-impact journals. He has participated in over 165 research conferences as a plenary or invited speaker in over 45 countries. His research interests include green chemistry, value-added conversions, heterogeneous catalysis and water treatment.