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Review Article

EcoRestoration and Nano Bioremediation of Polluted Soil Using Nanomaterial-Synthesized Biosurfactants

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Abstract - *The speedy development of industry and urbanization, combined with the rate of arrival of a new century, in the present century, has led to environmental degradation, which has become the most serious threat faced by the world. The most common problems that bother every living creature on the planet are different kinds of pollution, industrial effluents, deforestation, natural calamities and domestic waste. Chemical cleaning and treatment are also associated with several biohazard issues, and the effluent suffers from difficult, expensive, and ineffective treatment. Therefore, it is crucial to explore an effective, low-cost and environmentally friendly natural technology to reduce pollutants and noxious substances in a sustainable environment. The new emerging field of bioremediation with nanotechnology has demonstrated, to some extent, the robust interaction of nanoparticles with microorganisms and the degradation of toxins. Conversely, toxicogenic interactions between microorganisms and nanomaterials were also detected in some cases. A recent review was posted to explore the quality and safety of the available nano-bioremediation approaches that are used to remediate the soil. The objective of the nano-bioremediation approach would be to utilize a nanoscale material synthesized by microbes for removing or detoxifying pollutants. Based on a literature review, it is concluded that this method holds a variety of perspectives for large-scale soil remediation, which is effective, efficient and generates the least possible toxic residues. Although nano-bioremediation is a promising remediation technology for contaminated soil, as is well-agreed, more studies are required to establish optimized conditions for achieving better risk benefit ratios involving pollutant, micro-organisms and nano particles.*

Keywords - *Industrial effluents, Chemical treatment, Bioremediation, Pollution, Pollutant removal.*

1. Introduction

Green nanomaterials can be applied to anything that is being discussed. For example, they may be employed to recognize and cleanse unsuitable (waste and risk) or for recycling. They can also be employed to provide clean drinking water [1] in various settings, big and small. Bioremediation refers to a range of organisms, including bacteria, parasites, protozoa, or groups that help reduce contaminants and non-organic elements. It appears that `Remedy" resolves this issue [2]. The advantages of bioremediation vs conventional treatment include the directivity, high potential, less mixing and organization required by the nasal passage, absence of fixed-gold extraction, no further needs for foreign investment, cost of the promotion and recovery of the adsorbents, and chances for the recovery of fetal recovery [3]. Some of the most used bioremediation technologies are bioventing, bioleaching and bioreactor technology, bioaugmentation techniques such as bioaugmentation, soil fertilization, bio stimulation, and/or enhanced in situ bioremediation, land farming, solidification/stabilization, phytoremediation, and rizofiltration. Where biological activity is the only process, it is termed bioremediation improvement or bioremediation enhancement, and when specifically for composting feedstock for further enhanced bioavailability and media content, bioremediation bio stimulation is used. Corrupted websites' identification strategy usually has two paths. First, it tends to be rare , along with other air pollutants. In the second, noxious compounds and germs are atomized so they can feed on the “food” they can access based on the bacteria they eat. Accordingly, the bioremediation of the application is broadly divided into two categories: "in place" and "displace." It can be done as bioremediation that happens in the spraying of pesticides in a region where it is abundant and since the pollen from this area does not contain toxins or toxins or pollutants present in the climate, therefore treat it there, otherwise it could provoke A foreign substance poisonings (material coated phases) or the nano materials poisonings that can occur at either large or small scales [4]. Remediation programs involve the removal of disease or poison before it can be cured. Slow processes can be hard to identify, and slow detoxification can be mistaken for disease. The ex-situ technique is expected to be less time-consuming, more user-friendly, and more effective in the treatment of different soils/impurities than the in-situ method. The botanical showcases note many aspects of life in the area and details modern-day living and action in the park. They present organisms that inhabit the Earth, either vertically or horizontally [5]. The potential of a plant to reach its maximum level of development depends on the presence of a benevolent environment and a favorable climate.

Soil becomes part of an artificial soil formed by soil erosion, humus displacement, fabric disruption, and the transport of moisture and contaminants. Therefore, soil is the most important ingredient for the survival of plants [6]. But after the Earth is well examined, it is a great strange thing, that here is such a little islet in infinite space, with its mud infrastructure of living things, which are a sort of efflorescence of the Earth in space, as clouds are of the sky. "In this case, you need to estimate the evolutionary potential of (bacteria) and establish their relationship with plants. Likewise, they both provide mechanisms to decrease their target below the conditions where they counter two of the main threats to long-term sustainability of the soil and overcome pollution through soil conservation and innovation [7]. Consumer applications generated to date by the basics of nanoscience and nanotechnology are numerous. Most are built on desktop analytics that are fed and programmed on online business websites. However, the pursuit of nano-particles, nanomaterials, and nanodevices continues because of their known or potential use and potential human health [8]. Along the same line, new jargons have also appeared in nanoscience and nanotechnology, such as nanotoxicology, nano-particle biotechnology, and nano processing, which may construe data in relation to the application of nano-particles to make clean heaps of Earth, presently being manufactured anywhere in the world.

It should be mentioned that data analysis on fast tracking must be maintained, but research from this important study also stimulated some cross-sectional interest in several subject areas for some of the authors [9]. It is reported that compounds, along with wastewater, polyacrylamide and nanoparticles, can enhance the release of PAHs into contaminated soils. Nevertheless, the progress of technology in the management of the polluted soils with nanotechnology will start at the beginning of compliance with the complete scope of human beings and environmental consciousness [10]. Against this, the application of nanotechnology through soil sterilization has become gentle and diffuse in recent years. There is still a significant knowledge gap about the complex nexus between soil biodiversity and the ecosystem, and specifically for cultural ecosystem services. This lag is because the soil is complex and has far-reaching influences on biotic and abiotic processes and ecosystem services that support human well-being. Furthermore, more work is required to establish the extent of global soil pollution, the number of polluted sites, the pollutants involved, and the consequences of pollution on a significant proportion of agricultural land, food production, and our environment. In this work, several topics, such as nanoparticles in the environment and soil, will be discussed. In addition, bioremediation and microbiology were reported. Lastly, future development of environmental nano applications based on molecular biotechnology was highlighted.

2. Soil Environment

To take one example, a world tire is a three-wheeled machine over solid horizontal, position, water, and gas. Moreover, biotic and abiotic interactions exist, where micro-organisms, including bacteria, viruses, fungi, and almost all other forms of single-cell organisms, are active players in the development of the plants and the agro-ecosystems. These interactions develop from sink materials such as minerals and evolution, correlating to the soil environment and the breakdown of natural sediments. One possibility of adding more aggregates to the soil is micro-organisms like biogeochemical systems of carbon, nitrogen, phosphorus and potassium. Application of nano-particles in the soil results in increased sensitivity of the nano particles to toxins, hence biological hazards to it [11], and producing nano particles in some materials like commercial, therapeutic, and horticultural properties of nano-particles, so on [12]. Some types of nanoparticles or gold compounds are toxic to soil microorganisms and affect different types of microbes in soils.

The specifics and variable increases in the abundance of micro-organisms, eukaryotes and salts produced by these micro-organisms can be quantified using an advanced data technique, real-time PCR (Real-time PCR), or so-called quantitative PCR (qPCR), measuring these metabolic activities under the influence of nano-particulate matter, that of a mineral or metal oxide. Role of soil microflora against the silver nano particles (at 0.1, 1 and 10 mg wt-1 of soil), including the main environmental capacity microbial metabolism, soil mobility, nitrification potential, number of micro-organisms and salinization. It is the same cure that makes microorganisms vanish. On the other hand, ferrous oxide nanoparticles have been shown to impact soil microbe metabolism (at 1 and 10 mg/kg as low) and flow nitrogenization capacity (at low 0.1 and 1 mg/kg). The previous two studies have also reported that gold compounds may be toxic to soil microorganisms. Gold complexes also damage cell membranes and alter the permeability of the cell walls, causing cell death. Although some bacteria can resist and grow in the presence of gold compounds, the majority are inhibited. Gold nano-particles used in the present invention generally have at least two dimensions of from 1 to 100 nm and are aggregates of several tens to several hundreds of atoms and may have a variety of sizes and morphologies (amorphous, crystalline, needle). These particles form a new class of materials that are distinct from either traditional bulk metal or from atoms and have been the subject of much attention owing to their unique electronic, optical, thermal, and catalytic properties. Size-controlled gold nanoparticles have been employed by analytical chemists due to their unique optical properties, while gold nanoparticles have been utilized in biomedicine because of their ability to function with biological molecules allowing for optical detection of biological molecules. This expanded usage also implies that more and more nanoparticles will eventually end up in the environment either during their manufacturing or following their application.

3. Nanoscience and Nanotechnology as Useful Tools in Agriculture

These original items are intentionally designed to evoke the perfect feeling for classic events. The mass in the nanoscale region became an important natural mass, 260,000-309,000 tons in 2010. The percentage of engineered nanomaterials released into soils, water, and the atmosphere was estimated as 8–28%, 0.4–7% and 0.1–1.5%, respectively. Nanotechnology is an interdisciplinary scientific research project focusing on the design, fabrication, imaging, and application of materials and devices. Nanoscales (atoms with atomic and atomic sizes below 100 nm) sizes and shapes are combined with shaping to produce these novel products. The objective has been to develop long-term research that raises awareness and prevents environmental problems. As per a report of the Food and Agriculture Organisation, nanotechnology has great potential in food and horticulture.

Some of their results were the more extensive use of nano-bio mixtures, time of cultivation, lower potential for drug interaction, and access to a wide range of variables (diseases and seed coating). The FAO's expert talk in 2009, "How to manage the world by 2050," estimates that by 2050, we will need to produce 70% more grain. Nanotechnology can help to store food in the present day and convey knowledge about food's miles and good cheer in a positive way. The worth of the food industry is predicted to increase to $9.9 billion by then. For example, like to support resources (soil, water and irrigation) or to dispose of garbage on agricultural land. Prolonged drought reduces soil movement and changes the plant's form. Accompanied by novel nano-particles, nanocomposites and nano capsules, natural mechanisms must now be fashioned to regulate energy efficiency in various systems, to boost the crop out-turns, to avoid overdose positives, and to minimize information disclosure and waste. It was pointed out that the knowledge of the interaction between the environment and soil is limited; indeed, due to the originality of the technique, the behavior of anthropogenic nanoparticles is not yet completely understood. The land conversion of the past 15 years has yielded energy and natural resources. It strengthens enrichment, diminishes damage, and gets rid of impurities or damage, as well as senses beyond pollution [13]. Efficiency and control of usage consumption are effective for reducing cleaning costs. Custody and disposal of contaminated land. These could be, for instance, pesticides, herbicides, parasitoids, or developmental disturbances [14].

4. Natural and Man-Made Nanomaterials in the Soils

Earth harbors a plethora of extraordinary nanoparticles with application interests. This has stimulated debate on their effect on biological systems, especially humans, their influence on (bio)chemical processes and their effects on the environment [15]. Nano-particles are regarded as building blocks of nanotechnology and are defined as particles [16] having one single particle size smaller than 100 nm. Furthermore, nanomaterials have been reported to possess a size between 1 and 100 nm.

Natural and anthropogenic nanomaterials are found in soil with different origins, effects and potential impacts [17]. Natural nanomaterials are widely present in soil (clay minerals, oxides, hydroxides, and organic colloids), while artificial nanomaterials, which are frequently a nanomaterial engineered by humans, are intentionally (various human activities such as industrial processes) or unintentionally introduced. These nanomaterials influence soil properties, plant productivity, and environmental safety, and their potential and effects are still being investigated. Natural inorganic nanomaterials found in soil include such particles as clay minerals (aluminosilicates), oxides and hydroxides of Al, Fe, and Mn, and iron nanoparticles. Organic colloids, enzymes, humic substances, viruses, and micro-organisms also belong to the natural nanoscale realm in soil.

5. Nanoparticulate Materials in the Environment

As mentioned above, these nanomaterials are the ultimate mix of natural and synthetic nanostructures [18]. The atmosphere became a host to nanoparticles before the discovery of nanoparticles through the nanotechnology industry. Among the most important in this nanoscale liquid subset are Earth-derived soils, volcanic ash, carbon dioxide, eruptive products, life force, travel, and refining. Because the aim is to use the materials according to the invention for fast industrial and human applications, there is no expected change in their composition and building blocks in modern reactions, waste disposal in disposal clinics, landfill sites, etc.

The detection of nanomaterials is related to their specific design and to unexpected attenuation due to installation or re-deployment. There are many types of nanoparticles, and due to nanotechnology's wide range of applications, particles may enter the atmosphere in several different ways. Such particles can include soil and water-transported airborne particles, airborne particles of nanotechnology applied to remediate contaminated soil, due to liquid treatment, an accidental spill, or otherwise. Air particles, also called particulate matter, significantly affect the quality of soil and water. These metals can result in soil acidification, changes in soil structure and nutrient capacity and affect water bodies, which will bring undesirable effects on the ecosystem and human health [19]. Due to the rapid industrialization and urbanization in the recent Anthropocene era, various kinds of disturbance, such as dust or particulate matter pollution, have emerged.

The solid matter, solid at room temperature, is particulate matter, which is stuff that is not necessarily man-made (whatever that might mean in this rather post-nature age). Environmental pollution and human exposure to dust pollution have increased significantly in the past decade, especially in developing countries, such as India. Biomolecules are affected by ambient air pollutants in such a way that they diminish plants' whole growth and development. The influence of different pollutants present in the atmosphere on the physiology and biochemistry of plants has been well studied for decades [20].

Plant acclimation to fluctuating environmental conditions comprises short-term physiological adjustments as well as long-term changes at the physiological, structural and morphological levels. These alterations allow plants to reduce stress and make the best use of resources in and around the plant. The variation of the physically charged ambient atmosphere, which is a polluted atmosphere caused by particulate matter pollutants in urban areas, is of great importance to plant morphological, biochemical, physiological, and genetic status.

6. Humic and Fulvic Water

Fulvic water is merely mineral water mixed with fulvic acid, a natural substance abundant in trace minerals, antioxidants, and other good stuff. It is frequently sold as a means of increasing hydration, maximizing nutrient absorption and promoting detoxification. Fulvic acid is a part of the humic structure in composted organic waste, also known as humus. Humic water is water that contains humic substances, which are complex biochemicals that result from the gradual decomposition of organic matter, particularly plants. It is composed in large parts of humic substances (primarily humic and fulvic acids), which make the water brown/dark in color and can also affect pH, taste and odor. Humic substances occur naturally in soil and water, which is the result of the breakdown of organic matter under anaerobic conditions. Humic acids are less soluble in water than fulvic acids. They can also chelate metals or other organic compounds. The coil comprises clay, dirt, and other smaller impurities smaller than 2 µm. However, since these are nanoscale-shaped plates, it is understandable to identify colloidal particles in sizes ranging from 1 to 100 nm. The nature of the problem can be affected by various factors, such as high viscosity and electrical charge [21], which affect the agglomeration/specification. The significance of space depends on the traditional support of the microbial network as well as its potential as a food supplement. Additionally, fulvic and humic acids are related to electron receptors and play a role in the biodegradation of toxic compounds. When they interact with natural resources, nanoparticles work in the ground and can affect important elements, such as plants, nature, and the environment. In certain cases, they are involved in the transportation of toxins and can increase the damage. Humic acid and fulvic acid are the two primary components of humic substances. Generally, the differences between humic acid and fulvic acid are: (i) the difference in molecular weight, (ii) the difference in elemental and functional group contents. Humic acid has a higher molecular weight and lower oxygen-containing functional groups compared to fulvic acid. Nevertheless, the common functional groups of carboxyl, phenol, hydroxyl, amine, and quinine in HA and FA of water bodies can lead to various serious environmental and health issues. Heavy metals are highly complex, including humic acid or fulvic acid; therefore, they facilitate the transfer of heavy metals into water [22]. Humic acid or fulvic acid can also be combined with chlorine during the water process and generate harmful disinfection byproducts, such as trihalomethanes.

7. Non-Geogenic Oxide

Nano-particles and nanomaterials are most permanently stored in the desert. Shi and co-workers [23] reported that fifty percent of the minerals in the cloud over-concentrate in the Earth's atmosphere from the desert. The minor gopanoic nano particulates are dominated by metal (such as Al, Fe, Mn) oxides, hydroxides, and oxyhydroxides produced by microbial and silicate pathways. These fall under the unique features of adaptation and adaptation to climate change. For instance, nano-particles of aluminum on the ground are found as pouches at the bohemite site that are activated according to the ground size.

These organic compounds are generated through the production of organic solvents, and by microorganisms and organic matter in the soil. By the same token, iron hydroxide, the most common material found on Earth, is an elemental transformer in the next phase of consumption due to its electrostatic charge. For example, a non-geogenic oxide is an oxide that is not the result of geology. On the other hand, geogenic oxides are produced via natural geological processes [24], like rock weathering. Analogous to non-geogenic oxides (the oxides generated by industrial processes and burning fossil fuels). Some of the oxides can be produced by the atmosphere in the mediation of chemical reactions, such as the oxidation of sulfur dioxide to form sulfuric acid (an acid rain component). Some biological processes may also lead to the production of oxides, albeit usually to a lesser extent than artificial or chemical sources.

8. Anthropogenic Nano-Particles

Anthropogenic nanoparticles are small (typically less than 100 nanometers), human-made particles emitted to the environment through different human activities. The particles can be generated purposefully (engineered nanomaterials) or incidentally during activities such as combustion or waste production [25]. Thousands of tonnes of man-made nano-particles are released by major industrial activities, and in current society, power stations, jet aircraft and other automobiles have assumed the dominant proportions of these nano-particles.

Meteorology has an impact on all human endeavors. Innovation has now been pushed to the extended nanoscale range for various applications. To maximize the access/contact and thus the assistance of the maintenance process (static or flexible), anthropogenic fluids are required to be stored on the nanoparticles and nanomaterials [26]. The availability of vital elements in a "green" surrounding hardly depends on renewable energy, the processing of iron and non-ferrous metals, and the deployment of feedstock for construction provided by key sources, which are also effectively implemented by the main factor.

9. Carbon Nanotube

Jaisi and Elimelech [27] studied the fate of carboxyl-modified single-walled carbon nanotube in a column of natural agricultural soil (fine sandy loam). They showed that functionalized single-walled carbon nanotube deposition was reasonably high over a broad ionic strength range of mono and divalent cations added to the soil solution. It was found that the functionalized single-walled carbon nanotube was not likely to enter the soil through transport processes in any significant amount due to efficient retention by the soil matrix.

Kasel and co-workers [28] investigated the fate of 14C-labeled MWCNT in two different natural soils. When the sorption of both loamy sand and silty loam soils was compared, the sorption of carbon nanotubes was found to be higher in the silty loam soil than in the loamy sand. The overall conclusion was that multi-walled carbon nanotubes were retained in the soil, and more than 85 % of the applied radioactivity was recovered in the soil fraction.

Lu and co-workers [29] studied the effect of MWCNT on three types of soils. Positively charged Multi-Walled Carbon NanoTubes (MWCNT) were totally retained in soils, whereas negatively charged carbon nanotubes broke through the soil column and were detected in the outlet. They also showed that MWCNT mobility was governed by soil type rather than organic matter. Cornelis and co-workers [30] examined the destiny and bioavailability of engineered nano materials in soils. The bioavailability of engineered nanomaterials is greater in soil that is saturated, has a coarse texture, and has a high organic matter content compared to other soil types. In unsaturated silty soils of low organic matter content, low nanomaterial bioavailability is anticipated.

10. Oxide Materials

Oxides of soil are natural constituents of practically all soils. They are often only present in low concentration (tens to thousands mg/kg), but they dominate the chemistry of soils. Soil oxides are very small and have low solubility across the range of typical soil pH values. Metal oxides have been widely investigated as potential stabilization amendments in metal-contaminated soils for their significant sorption properties.

Researchers show that ZnO dissolves and a zinc (Zn) precipitate forms within a near-neutral noncalcareous soil, following the contamination with emissions from a brass foundry. The Zn precipitation is largely of the Layered Double Hydroxide (LDH) type but could also include a minor phyllosilicate-type component. Zn precipitate constitutes approximately 51% of total Zn after 9 months [31]. This stresses the role of precipitate phases for insight into the effect and fate of Zn in polluted soil. Even though Zn-phyllosilicate is the thermodynamically more stable phase, kinetic considerations apparently also promote the formation of a Zn-LDH phase in this soil in the initial stage. Zn-LDH formation was shown in laboratory experiments with soil. Studies of heavy metal–contaminated soils strongly influenced by smelter emissions also showed the presence of Zn-phyllosilicate and Zn-LDH phase formation in the field. The two forms are layered phases consisting of octahedral layers of Zn, as Zn-LDH and Zn-phyllosilicate. Replacement of Zn by Al in the trioctahedral layers of Zn-LDH creates a positive charge, which is balanced by anions present in the interlayer space.

Copper nanoparticles enter the soil environment predominantly through the applications of nano-fertilizers or nano-pesticides or by land applications of biosolids as a waste product of the water treatment process. Nevertheless, even though the release of copper-containing nanoparticles to sewage works is low owing to their low usage in consumer products [32], with repeated application of biosolids to agricultural land, there may be accumulation in the soil with potential risk to terrestrial environments.

Phytotoxicity of copper nanoparticles is largely facilitated by the amount of solubilized Cu^{2+} through copper nanoparticles. Solubility studies of nCuO have indicated that it can dissolve and release Cu^{2+} under common soil environmental conditions, and this release rate is related to soil factors such as pH [33]. Copper is highly adsorbed to Soil Organic Matter (SOM) and forms strong inner-sphere metal-organic ligand complexes via covalent-type bonding; and soil pH regulates the availability of binding sites, which increases as the pH rises (via deprotonation reactions). Although very few studies have been conducted on the sorption of metallic nanoparticles in soils, it is becoming increasingly clear that the mobility and activity of nanoparticles are predominantly conditioned by soil pH (increasing pH leads to aggregation)/ the presence of mineral colloids (type Fe and Al oxides), where metallic nanoparticles become deposited and then aggregate. The effects of soil organic matter upon the behavior of metal-based nanoparticles are much less clear. While there is some evidence to indicate that humic acid can stabilize and disperse NPs, other evidence suggests that it could also promote aggregation and retard dispersion, thus retarding the dissolution reactions. Bioavailability of copper (Cu) by extraction analysis showed that extractable Cu^{2+} was significantly greater in $CuSO_4$-spiked soils than in nCuO-spiked soils. For nCuO at exposure concentration of <265 mg Cu kg−1 soil, stimulatory responses were reported in terms of β-glucosidase and nitrification activity. nCuO had no significant inhibitory impact on soil microbial growth [34], activity or diversity, except for the enzyme activities of the dehydrogenase and the phosphatase at the greatest content applied (627 mg Cu/kg soil).

The objectives were to assess if the metal oxide NMs ($nCeO_2$, $nTiO_2$) often employed in metal remediation protocols could also influence phytoavailability of selected nutrients N, P, and trace elements (Cu, Fe, Mn and Zn) in a selection of representative contaminated Australian soils. Even better, both engineered nanomaterials likewise greatly influenced the phytoavailability of N, P and Zn in the soils [35]. In some cases, more than 90% of soil N was lost in the presence of both engineered nanomaterials, while for other cases, the phytoavailability of P and Zn tripled and doubled, respectively, with engineered nanomaterials. With respect to N, it was speculated that both engineered nanomaterials changed the organic N mineralization. For P, the anti-microbial activities of the two engineered nanomaterials could have changed the function of P-solubilizing microbes, which were considered as the possible reasons. For Zn, the competition occurred, with positively charged engineered nanomaterials and Zn^{2+} ions being the predominant mechanism in the change of Zn phytoavailability.

11. Nanotechnology for Levelling the Soil

Nano remediation approaches involve using reactive nanomaterials for the conversion and removal of contaminants. These nanomaterials are capable of undergoing chemical reduction, serving as catalysts, and addressing the targeted pollutants. With in situ nano remediation, no groundwater is pumped for treatment above ground [36]. Nanomaterials are attractive for in situ applications due to their unique physical and chemical properties. Due to their ultrasmall size and advanced surface coatings, the nano-particles could penetrate highly confined spaces in the subsurface and maintain suspension in groundwater; thus, they may be transported to more distant locations than larger macro-sized particles and distributed more widely. Yet, in practice, transport of today's nanomaterials for remediation does not exceed a short distance from the point of introduction. While nanotechnology is a relatively new material in the living space, when applied to pollutants, it is known as nano processing [37]. This is immediately used to process hazardous waste. Over time, leading researchers have provided very important ideas for applying nanotechnology to habitat improvement, which indicates the need for natural handling, but new systems are needed.

When used regularly, substances including pesticides, dyes, nitrates, heavy metals, hallucinated natural hydrocarbons, and nitrates can become irritable and filthy. Although there is little research on the application of nano-particle innovation to enhance surface roughness, this technology has been especially used for water purification or treatment. According to literature, biological methods, photocatalysis, advanced oxidation process, adsorption process, and membrane technology could be used to absorb and degrade pollutants [38]. Photocatalysis relies on light and a catalyst, such as titanium dioxide, to strip dye molecules of their color and convert them into simpler substances, typically water and carbon dioxide. It is effective, creates no toxic byproducts, and can be scaled up for different wastewaters. In biological processes, the dyes can be degraded by micro-organisms, such as bacteria and fungi, through enzyme reactions where long dye molecules are complexed and degraded to less toxic substances. These techniques may be aerobic, anaerobic or a combination of both.

These advanced oxidation processes, such as ozonation [39], Fenton's reagent, photo-Fenton, and others, relying on powerful oxidants, oxidize the dye molecules to destroy them. They can work, but often result in cytotoxic metabolites, or may depend on pH. Adsorption is the surface effect in which atoms, ions, or molecules in a gas or liquid become attached to a solid or liquid. This is not the same thing as absorption, which is based on penetration of the material through the lattice of the solid. Adsorption can be due to physical forces (physisorption) or chemical bonding (chemisorption).

Sizes of nZVI are either 10 to 100 nanometers in diameter [40], but some commercialized "nanomaterials" are micrometer iron powder. A noble metal (like Pd, Ag, Cu) may be doped as a catalyst. The second metal provides a catalytic synergy between the second metal and Fe and aids in the distribution and mobility of the nanoparticles within the ground after being injected. The bimetallic nanoparticles can have more than two metals. The second metal is generally less reactive, so it boosts the iron oxidation or electron transfer. Some non-recalcitrant noble metals, especially palladium, can catalyze dechlorination and hydrogenation, potentially speeding up the remediation. The main degradation routes of chlorinated solvents can be described by two different processes, namely beta elimination and reductive chlorination. Beta elimination is the most observed process when the contaminant is directly coordinated at the Fe particle. The organosolv lignin-stabilised nanoscale zero valent iron (designated as BL-nZVI) was prepared by using organosolv lignin as a stabilizing agent and bentonite as support. XRD spectra results indicated that the nZVI particles have been successfully loaded onto bentonite [41]. It is also worth noting that the presence of organosolv lignin can effectively increase the loaded amount and dispersity of nZVI. Comparison experiments were conducted to show the variance of the samples' Cr(VI) removal capacity. Compared with the other two materials, BL-nZVI had a wider suitable pH range, and the kinetic rate for Cr(VI) via BL-nZVI was 0.225 min−1 during pH 3, 2–4 times as much as bare nZVI and B-nZVI. Iron concentration, pH, in the aqueous solution were monitored with reaction time, the BL-nZVI system held a higher iron concentration and equilibrium pH, but a lower dissolved oxygen concentration than bare nZVI and B-nZVI systems at the same initial status.

12. Bioremediation and Microbiology

In a natural process, fungi, bacteria and other micro-organisms will be used to remove pollutants, which is called the bioremediation process. This process is considered an eco-friendly technique to eliminate unwanted materials from air, soil and water [42]. Microbiology is defined as specific investigations on very tiny micro-organisms such as protozoa, bacteria, fungi and viruses.

In general, microbiology will determine specific properties such as function, structure and classification of micro-organisms. The various Non-Metal salts (NMs) used in bioremediation have various explanations. For instance, when an object is inserted into a nanometer network, its local area per unit area increases [43]. This means that the amount of material penetrating the surrounding material affects its reaction. Non-metal salts showed different effects; the minimal energy required to improve the synthetic response was taken. Another surprising demonstration of nanoparticles' importance is plasmonic resonance, which is applied to the area of the lesion. Take into consideration all the different non-metal salts that can be used for residential activities. For instance, it can use different nanoparticles, bimetallic nanoparticles, and carbon-based non-metal salts. It was noted that nano particles can expand or penetrate the contaminated zone that microparticles cannot reach, and these nano particles contain more reactions to visible pollutants.

As a further advance in the development of photooxidation processes for water and wastewater treatment, a novel photoelectrode was made by routine sol–gel and subsequent NaOH treatment to achieve the tubular feature of the TiO_2 nanotube electrode. The results of the tests indicated that anatase TiO_2 was a dominant phase of its component, and there was an obvious blue-shift of the spectrum of UV–vis absorption. Its potential was explored for environmental applications in the degradation of Pentachlorophenol (PCP) in aqueous solution by photoelectrocatalytic processes. A pronounced photoelectrochemical synergetic effect was found. The kinetic rate constant of the Photoelectrocatalytic (PEC) degradation of PCP with a TiO_2 nanotube electrode was 64.7% higher than that with a TiO_2 film electrode. The influences of some relevant factors, such as applied potential, electrolyte and pH value on the rate constants were also studied in detail in the photoelectrocatalytic process [44]. The photoelectrocatalytic degradation of pentachlorophenol was more efficient under acidic conditions than in alkaline conditions. In the PEC photocatalytic process, there was an optimum pH.

Metal nanoparticles are widely used in the field of heterogeneous catalysis, including energy conversion and storage, sewage treatment, and molecular sensing. The traditional wet impregnation method for the preparation of catalysts has several drawbacks: (i) It exhibits low utilization efficiency of active materials due to poor distribution on the catalyst support [45], leading to a decrease in the catalytic activity. (ii) Agglomeration and bad dispersion inhibit the exposure of active sites and result in low active site accessibility, which leads to poor overall catalytic behavior. (iii) It is difficult to precisely control the loading and distribution, and the approach is time - consuming, complex, and environmentally unfriendly. On the contrary, noble metal electrocatalysts supported on bio-organism-derived carbons present a sustainable, renewable and abundant resource. These generated carbons also have a large specific surface area and high porosity, leading to efficient catalytic reactions. These carbons possess special surface chemistries that are beneficial to catalytic activity and stability. It can be tuned to carbon-based catalysts by carbonization [46]. Applications and research into this area can offer new technologies in fabricating noble metal electrocatalysts through sustainable, tunable, and catalytically active manners.

13. Nano-Iron and its Derivatives in Bioremediation

Nanoscale Zero-Valent Iron (NZVI) was prepared and evaluated for the adsorption of As(III) ions, which is considered highly mobile and the prevalent species of As in the anoxic groundwaters. Particle sizes were found under AFM in the range between 1 and 120 nm. XRD and SEM studies indicated that NZVI transformed slowly to mixed magnetite/maghemite corrosion products [47] with lepidocrocite in 60 days. Kinetics for As(III) adsorption were fast, took place within five minutes, and were described by a pseudo-first-order rate expression with apparent rate constants ranging between 0.07 and 1.3 min^{-1}. The adsorption data supported the Freundlich adsorption isotherm, with a 3.5 mg As(III)/g NZVI capacity. Based on electrophoretic mobility measurement, NZVI-As(III) inner-sphere surface complexation was detected. Synthetic nanoscale zero-valent iron (NZVI) was utilized for the uptake of As(V) (one of the prevalent toxicants found in groundwater). The core-shell structure of the fresh NZVI was characterized by HR-TEM, and more than 90% nanoparticles were below 30 nm in size [48]. Its composition was also verified by Mössbauer spectroscopy, fully 19% reduced, while the remaining 81% was covered with iron oxides. According to diffraction results, As(V)-treated NZVI transits to magnetite/maghemite corrosion products in the period of 90 days. The XPS result showed that 25% of As(V) was transformed into As(III) by NZVI after 90 days. The adsorption kinetics of As(V) were rapid and completed by a pseudo-first-order rate expression at different NZVI concentrations. Results of laser light scattering demonstrate that NZVI-As(V) is complex (inner-sphere surface).

Reinjection of Solutes Abstract High surface-area nickel–iron (1:3 Ni:Fe) nano-particles (s-NiFe) were explored for use as a reagent for dehalogenation of trichloroethylene (TCE). Ni–Fe (0.1 g) nano-particles in 40 mL of the saturated aqueous TCE solution (24 ppm) were degraded to <6 ppb in 120 min. Dehalogenation was found to be about 50–80 times slower with the addition of nano-iron or iron filings [49]. The reaction on the bimetallic particles is by nickel-catalysed hydrodechlorination, and iron is corroding actively. Then the adsorbed TCE on the Ni surface is hydrogenated. This reaction kinetically competes with the formation of molecular hydrogen. The ultimate degradation products of TCE are typically even-chain saturated HCRA compounds, including butane. In faint traces, the toxic dehalogenation product Vinyl Chloride (VC) and the dehalogenation byproducts 1,1-Dichlorethylene (1,1-DCE), cis-Dichlorethylene (cis-DCE) and trans-Dichlorethylene (trans-DCE) are produced, but are non-persistent. It was noted that C–H bond construction is considered the rate-determining step.

Pentachlorophenol (PCP) is perhaps the most used wood preservative, as well as a fungicide, insecticide, and general biocide. The potential for using Ni/Fe nano-particles (NPs) coated with a surfactant agent, Cetyltrimethylammonium Bromide (CTAB), to remediate soil solutions from a southern Taiwan contaminated site was tested by researchers [50]. When Ni/Fe-CTAB containing 2 mass% of Ni was employed at one CMC of CTAB, the percentage of removal reached almost 100% within 5 minutes. This higher reduction of PCP by Ni/Fe-CTAB was attributed to the easy dechlorination of PCP at the Ni/Fe surface. The greater adsorption of PCP had been assigned to the electrostatic attractive force between the electronegative phenolate groups of PCP and the positively charged Ni/Fe-CTAB produced by coating with cationic CTAB. The dehalogenation of PCP generates phenol and weakly chlorinated phenol derivatives, which are less toxic and more biodegradable than PCP.

14. Dendrimers in Bioremediation

The word "dendrimers" comes from the Greek "dendron" meaning tree, and "meros", meaning parts. Dandruff, a more pervasive and common cousin, emerged first in the monoclonal macro-polymer region back in the 1980s. Corn is a polymer that is heavy on fibrillation in fiber, binding up lots of heavy molecules, worn oil, skin, and sebum. The applications of dendrimers are many. There are three parts of the system- central, inner cell (or the plane of expansion) and the cheap branch price. The macro-molecule dandruff is a semi-enlarged and quickly stretching one, which has been reviewed by us, that it can be regulated by a system including three components: the center, inner cell or the plane of growth. As a result, researchers have conditioned a set of air-purification agents by TiO_2-injecting methods, alkylated poly(propyleneimine) dendrimer, poly(ethylene) red polymer and β-cyclodextrin. This kind of imitation is used because it is faster, cheaper, and less destructive in the water treatment and dyeing industry. Then, researchers offered that clean water should be used.

Poly (amidoamine) (PAMAM) dendrimers with different generations and terminal functional groups have also been reported and characterized as effective for the decontamination of copper (II) in a sandy soil [51]. More than 90% of the initially sorbed copper from the soil could be eluted by passing 0.10% (w/w) of a generation 4.5 dendrimer with carboxylate terminals at pH 6 through 66 bed volumes of soil. From the equivalent dose comparison, copper was extracted to a greater extent by dendrimers of lower generations. The decrease in pH values increased the copper removal of all dendrimers tested. On the other hand, terminal groups (COOH, NH_2, and OH) types only slightly influenced the efficiency of removal. Sequential extraction results indicated that dendrimers extracted mainly exchangeable and carbonate-bound copper. Remaining copper in treated soil is primarily held by soil organic matter, which is less available physically, chemically, or biologically. The spent dendrimers were also recycled using a commercially available nanofiltration membrane. Recovered dendrimers were recycled to the polymerization with acid, which performed as well as the virgin dendrimers. The dendrimers could serve as a recyclable and high-capacity extracting agent for ex-situ removal of heavy metals from the contaminated soils.

Selected dendrimers were studied for the possibility of Pb^{2+} removal from three Pb-contaminated soils. Adsorption of lead was examined in a fixed-bed column, in which the dendrimer solution was forced through a soil containing lead [52]. All the results demonstrated that removal of the constructed dendrimers was pH-dependent, where acidic conditions led to better removal and lower generation of dendrimers was more effective than higher generation of dendrimers in terms of the same dose; meanwhile, the effect of the terminal group was insignificant. Removal was higher in sandy soil than in clay soil. A step-extraction analysis showed that treatment specifically extracted mostly (>82%) of the carbonated-bound Pb^{2+} cations. Nanofiltration in combination with acid regeneration allowed for the recovery of almost 95% of the expended dendrimers. It is estimated that just 96% of the Pb^{2+} cations in the solution could be retained by nanofiltration and that 94% of the retained Pb^{2+} cations could be desorbed with acid regeneration.

15. Single Enzyme in the Nanoparticle's Life Cycle

It was noticed that a unique protein is an important target for biological and therapeutic studies. However, their limited half-life and worse health conditions make their transition even less realistic than they coordinated. Chemical use is ineffective due to oxidation, a decrease in energy, and a shortening of life. The efficiency with which the motors can be made longer-lived and more reusable is to include the motors in the nanoparticle attractive machine. When the present is associated with a nano particle absorbing machine, the chemicals are no longer removable by a magnetic field from the product and the reactor [53]. Therefore, two separate catalysts, trypsin and peroxide, were used to prepare the connection between nano-whites and the brain.

Enzymes are natural catalysts that catalyze numerous biochemical and chemical reactions. In contrast, enzymes are highly efficient catalysts: they work under mild conditions (at temperature/pressure, pH and in water) and possess high specificity, chemo-, stereo or regio-specificity and selectivity [54]. These biocatalysts are attracting widespread applicability in various sectors owing to their simplicity of preparation, substrate specificity and eco-friendly synthesis. Enzymes are widely used in organic synthesis industries. Enzymes for health care and pharmaceuticals, as well as for chemicals and pharmaceutical production, some of the largest industrial sectors, are grown through the catalytic properties of enzymes. Nevertheless, enzymes have high potential in industry, and all these enzyme features and broad applications are frequently restricted due to their low stability at elevated temperatures and in organic solvents.

There are different methods, like protein engineering, the use of additives, and immobilization, to enhance the stability of enzymes. Enzyme immobilization is the desirable mode of enzyme modification techniques due to the simple operations of catalyst handling and of catalyst recovery. Recent advances in the field of nano and hybrid technology have generated accessible surfaces of various materials as hosts for enzyme immobilization. Nano-particles provide an excellent support to immobilize enzymes because they overcome the constraints of diffusional limitations as well as have a high specific surface area per unit mass, enabling relatively higher loading of enzymes. Additionally, the enzyme-immune nanoparticle exhibited the Brownian movement when diluted into the aqueous solution, demonstrating that the enzymatic activities are relatively higher than those of the non-bound enzyme. It has been reported that the immobilisation of enzymes on the nanoparticle reduces protein unfolding and increases stability and activity. Here, a simple procedure to attach trypsin to magnetic nanoparticles is described. Fe_3O_4 nano-particles were prepared by co-precipitating $Fe^{2+}$and Fe^{3+} in ammonia solution, and coated with silicon dioxide were prepared by a sol–gel technique [55]. Thereafter, silica-coated Fe_3O_4 nanoparticles were treated with 3-aminopropyltriethoxysilane, leading to the presence of amine groups. Trypsin from porcine pancreas was subsequently immobilized on the magnetic core-shell particles by glutaraldehyde as the cross-linker. The results indicated that enzyme immobilization enhanced the enzyme activity at various pHs and temperatures. Stability studies revealed that trypsin thermostability was improved by immobilization of the enzyme without and with 10% v/v of the solvents used. The reusability studies showed that it retained 85% of its activity for six successive cycles.

The potential benefits of in situ hydrogen peroxide (H_2O_2) production for biocatalysis are manifold. Cleansing wastewater and other pollutants using enzymes is an environmentally friendly practice. Bioelectrocatalysis offers among some of the highest total turnover numbers for enzymes, but only for complex designs [56]. Cold plasma is thus pinpointed as a novel source of hydrogen peroxide production for biocatalysis. Hydrogen peroxide is capable of reparation of wastewater as a strong oxidant, degrading pollutants and purifying water. It is employed to lower Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), as well as other pollutants and to disinfect and remove odors. H_2O_2 effectively oxidizes several pollutants, such as organic compounds, metals, and sulfides, so that they are in much less toxic forms [57]. It can kill micro-organisms, including bacteria, viruses and fungi, and lower the incidence of water-borne diseases. The pigment in industrial wastewater color is dismantled by H_2O_2, facilitating the decolorization of water.

Domestic wastewater treatment and reuse is an efficient solution for water scarcity in Tunisia. After oxidation by hydrogen peroxide, the recalcitrant organics in wastewater were depolymerized. COD, odor offensive and effluent foaming decreased with increasing dose. H_2O_2 decomposes both organic and inorganic pollutants, which form BOD and COD. The Conversion of the sulfides to sulfates by H_2O_2 can be used on water wastes that contain these odorants. The bactericidal ability of H_2O_2 oxidation on the bacteria in the secondary effluents was studied [58]. A decrease in the population of total coliform was logarithmic with dose, reaching a low level at 2.5 ml/L.

16. Bioremediation of Heavy Metal Pollution by Crops

Over the last 20 years, countless nations have gone to extraordinary lengths to clean up both locally sourced and man-made pollution, improve soil and water quality, and discover native nail trees growing on lion-led heaps. Giant machines were put on the ground, and piles of wood filled with grass to hold it in place with a fire suppression system. All toxic metal compounds (Cu, Zn, Pb and Ni) were detected at levels higher than in ordinary soil.

N. mucronata is a weed of arid and semi-arid rangelands in its native range, especially in some North African (Egypt and Morocco) and Middle Eastern (Iraq, Iran and Syria) countries. New records at the edge of its range might reflect an additional range expansion (in southern Russia). Spiny and otherwise generally unpalatable to any respectable catch. It becomes more frequent and widespread if over-usage occurs, and its relative dominance is an indicator of poor grazing and land deterioration. According to the findings, N. mucronata Chenopodiaceae is the most Pb accumulator and other heavy metals, including Zn, Cu and Ni, are good accumulators, as Fe is by R. lutea and Cd by M. vulgare. Accumulation potential of N. mucronata-derived nanoparticles in the experimental water containers [59]. The quantity of heavy metals was found to decrease by two to three times by the end of the third day of bioremediation of the polluted water.

Phytormediation is an interesting technology that is efficient and low-cost. The search for an accumulator plant [60] was made in a drying waste pool at Angouran (Iran). Heavy metal concentrations were calculated in soil and plants. According to the results, N. mucronata is the best accumulator of nickel, lead, cadmium, copper and zinc. Also, it was observed that the best iron accumulator was in A. retroflexus. The level of heavy metals in polluted soil was reduced after the experimental process. The variation with respect to concentration of metals was significantly different in root, leaf and shoot parts of N. mucronata, but all the metal concentrations were higher than those in natural soils.

Amaranthus retroflexus occurs eastward in the northern half of the US, through the same areas of Canada and northeast Mexico. It is also found in Africa, Asia and Europe. It has also become naturalized in the newer environments of temperate climates and the northern and southern hemispheres. Amaranthus retroflexus is a considerable hyperaccumulator, an organism that can sequester pollutants from the environment. It was noted that A. retroflexus is a medicinally important plant and an agricultural weed that has recently begun to be of interest for phytoremediation. It can uptake large concentrations of metals such as lead, cadmium, nickel, and zinc, and is applicable in phytoremediation.

The metal phytoaccumulation potential of a European weed species, Amaranthus retroflexus, was shown by the researchers in moderately and strongly metal-contaminated areas. Metal uptake in roots, stems, and leaves was investigated [61]. A correlation between metal accumulation and metal concentration was noted, which means that plant organs accumulated metal with an increase in the metal content of the soil in the contaminated compared to the control area. It was realized that the highest concentration of zinc, manganese, and barium was present in leaves and copper, iron, lead and chromium in the roots. Strontium had a high bioaccumulation factor in all areas studied, indicating that this metal has a high ability to accumulate in Amaranthus retorflexus. Zinc, barium, iron and copper had high translocation factors. However, these metals were effectively transported to aerial plant organs.

For meta-analysis, researchers investigated the metal accumulation capacity of Amaranthus plant parts (root, stem, and leaf). There were significant differences between plant parts for copper and iron, small for lead, nickel and zinc, and practically none for cadmium [62]. The bioaccumulation factor values showed that there was high bioaccumulation in the leaf, moderate for that in the root and stem for cadmium, moderate for that in each plant compartment for lead and very low for that in each plant compartment for nickel, iron and zinc. Heavy metal content in the aboveground parts of Polygonum aviculare was studied at the city of Kraljevo and its environment [63]. The results indicate that concentrations of Pb differ significantly by district, 0-17.7 mg/kg. The highest content of Pb (17.7 mg/kg) was found in a sample from a site by the Ibar highway. On the other hand, the largest content of Ni in samples was determined on the Ibar highway (15.52 mg/kg), city center (14 mg/kg) and Ibar Riverside (17 mg/kg), respectively. In Belgrade, the Mn concentrations are different because of the different soil types. Results of investigations concerning Mn accumulation in the area studied. The results of investigations into the accumulation of Mn in the studied area prove that localities from Avala have greater values of Mn than the locality in the centre of Belgrade.

Elemental levels in Polygonum aviculare are investigated under urban pollution conditions. The P. aviculare was observed to be higher in the Wrocław metropolitan area because of vehicular traffic. The shoots had the highest lead, cadmium, zinc, and copper content under heavy street traffic and industrial emissions [64], while the shoots had the highest iron and nickel content under highway exhausts. The sequestration of lead, nickel, and cadmium in the roots may allow P. aviculare plantlets to grow unhindered, an important strategy for metal tolerance. This species accumulates and partitions the necessary micronutrients (copper, zinc and manganese) in photosynthetic tissues.

Noaea mucronata is a tiny, densely branched shrub with stiff, spine-tipped branches. It is native to North Africa, the Arabian Peninsula, and some parts of Asia. The variety is a promising bioaccumulator of heavy metals and has been evaluated for phytoremediation. Then N. mucronata was identified as a hyperaccumulator of metal (particularly Pb) and was used for metal remediation. Its performance in the remediation of Heavy metals from contaminated water has also been assessed [65]. These prepared nano-particles from the N. mucronata plant were retained in the experiment pots for three months. After the nitrate study, it was removed by filter and the heavy metals were compared with the initial remediation. The concentration of all the studied metals, including Pb (92%), Zn (76.05%), Cu (74.66%), Cd (69.08%), and Ni (31.50%), was found to be decreased, particularly Pb, which showed the maximum reduction. The results revealed that N. mucronata nano-particles act as a potential candidate for detoxification and bioremediation of aqueous media under extreme conditions.

17. Current and Future Development of Environmental Nano Applications

Intensive industrial growth, energy generation, and mining activities have resulted in a higher release of pollutants like heavy metal ions, metal cyanides, and nuclear waste into the environment than ever before. Existing methods for treating polluted water are generally costly, and there is thus a great need for alternative measures. Here, scientists described that cheap hybrid membranes composed of protein amyloid fibrils and activated porous carbon could be used to eliminate some pollutants, such as radioactive wastes and heavy-metal ions [66]. Heavy metal ion concentration drops by 3–5 orders of magnitude per pass of filtration and can be cycled many times. Remarkably, their performance is even preserved if several ions are to be filtered at the same time. The membrane operates based on the amyloids' capability to selectively uptake the heavy metals from solutions. Scientists explain that saturated membranes containing heavy metal ions were thermally reduced with the aid of a prepared membrane, thus recycling expensive heavy metal pollutants in the form of elemental metal nanoparticles and sheets.

The possible presence of multiple binding sites on the amyloid fibrils is why amyloid-carbon hybrid membranes have a superior performance for heavy metal ion removal from water. To elucidate the binding of amyloid to the metal ions, optimal isotherm experimental results are obtained, comparing the adsorption behaviour of reduced amyloid derived from β-lactoglobulin amyloid fibrils and four typical heavy metal ions, including Cr, Ni, Ag and Pt. For the binding process, a thermodynamic analysis result is a conclusion from the direct determinations of the enthalpy and entropy changes, the association binding constant, and the average number of binding sites of the protein monomer and amyloid fibril [67]. Thanks to the strong amyloid-binding affinity of many amino acids for metal ions, when proteins are transformed into amyloid fibrils that are assembled into membranes, the amyloid-activated carbon hybrid collected all the heavy metals we tested at greater than 99% efficiency. Notably, the efficiency has not decreased even at the last several sequential cycles, indicating that the as-prepared membranes have a high adsorption capacity and long service life and reusability. The absorption-recovery of absorbed precious metal ions in the form of metallic elemental state is demonstrated to be a general feature of these membranes; supersaturated hybrid membranes with Pt and Ag are only examples successfully recovered by mere thermal reduction. The separation performance obtained with real electroplating industrial wastewater with chromium and nickel is above 99% at a permeability of as high as 2.92×10^{-16} m^2, which is at least 4 orders of magnitude higher than that of a regular nanofiltration membrane, thus enforcing the technology also with real and stricter conditions.

A new coordination model for the co-capture of Ni^{2+} and Cu^{2+} via the biosynthesis of amyloid fibrils under extreme conditions was examined [68]. In the in-situ procedure, the adsorption capacity of Ni^{2+} and Cu^{2+} could be enhanced by 18.5% and 34.1% respectively, compared to those that were added after amyloid fibril preparation. In addition, it can prevent acidic waste liquid production during the preparation of amyloid fibrils. The adsorption of Ni^{2+} and Cu^{2+} fits the pseudo-second-order kinetics and the Langmuir isotherm. According to the above analysis, amide, hydroxyl, and carboxyl were the functional groups that were determined during the adsorption process. Furthermore, during the preparation of the amyloid fibrils in the presence of Ni^{2+} and Cu^{2+}, which we called in-situ adsorption, the metal ions appeared to occupy the functional sites, thus causing the inhibition of protein aggregation, and subsequently affecting the long amyloid fibrils synthesis. The metal ion-binding site prediction server was employed to predict the metal ion binding site on the protein sequence of amyloid fibrils, and the binding was found to be predominantly specific towards a particular amino acid, such as glutamic acid, cysteine and serine. The amyloid fibrils may be useful in removing heavy metals from strongly acidic wastewater, such as acidic mining drainage.

An amyloid fibril derived from protein waste as a functional scaffold for MOF-D biomimetic mineralization. The prepared amyloid fibrils/ZIF-8 hybrid aerogels exhibit great water clean-up ability for nine kinds of heavy metal ions [69]. Notably, the amyloid fibrils/ZIF-8 hybrid aerogels exhibit a high removal capacity and good capability for removing Hg^{2+} and Pb^{2+} via five desorption–adsorption regeneration cycles. Moreover, a two-step rejection mechanism indicated that the aerogel retains its porous structure and the integrity of the functional ligands in the ZIF-8. Lastly, these hybrid aerogels have been demonstrated to perform excellently as oil-water separators. In view of the easy synthesis process, good removal efficiency, low cost and regeneration performance, the amyloid fibrils/ZIF-8 hybrid aerogel may qualify as a promising candidate for meeting the growing demand in wastewater treatment and water purification. Organic pollutants induced by water pollution are common and global issues. An excellent adsorber for organic pollutants in water, such as amyloid fibrils, aerogel has been reported. Amyloid fibrils derived from β-lactoglobulin are the main constituent of milk. These substances were employed herein as constitutional units for the formation of the aerogels [70]. With the adsorption of amyloid fibril aerogel, remarkable removal of Bentazone (92%), Bisphenol A (78%), and Ibuprofen (98%) is achieved. Finally, the regeneration performance of the aerogel after three cycle times is investigated, showing its excellent reusability without a remarkable loss of the removal effectiveness. These results turn the spotlight onto amyloid fibril aerogels as sustainable, efficient, and low-cost assets to mitigate the globally spread organic pollutants and water contamination.

18. Global Markets and Regulations of Nanotechnologies

The worldwide nanotechnology market is undergoing a rapid expansion with numerous applications across a multitude of fields such as healthcare, electronics, energy, and agriculture. Nanotechnology legislation is being developed and designed to protect and facilitate responsible innovation. Both technological development and demand for common safety procedures are in the process of creating the market [71]. Regulations are being updated to account for the special features of nanomaterials, including their health and environmental effects.

There remains an escalating global demand for bioremediation technologies, where nanotechnology is of significance, providing a promising solution in remediating environmental pollution. Bioremediation processes have generated renewed interest in nanotechnology, with emphasis on removing both heavy metals and organic pollutants, aiming to achieve higher efficiency and selectivity [72]. The regulatory climate is evolving, but institutions such as the US Environmental Protection Agency (USEPA) play an active role in advancing and practising environmentally friendly technologies, including bioremediation.

Bioremediation nanotechnology is set to progress in technological development for the enhancement of environmental quality in both developed and developing countries. Considerable work has been done to investigate the decontamination and remediation mechanisms. The biosafety of nanomaterials: the concerns of the application and use of nanomaterials on human health [73], the loss of biodiversity, and bioaccumulation. Knowledge and validated protocols are needed to measure the impact of nanomaterials on human and ecosystem health. Various international organizations such as USEPA, European Observatory for Nanomaterials, the Organizatiuon for Economic Co-operation and Development Working Party on Manufactured Nanomaterials and ISO Technical Committee TC 229 “Nanotechnologies” have defined international collaboration to enhance the use of existing regulatory requirements. Also, the nanotechnology and bioremediation world markets will keep expanding and finding new niches to ameliorate both the environment and the human way of living.

19. Conclusion

The main enemy of the twenty-first century is the presence and extremely rapid growth in levels of pollutants in the environment, both organic and inorganic. These pollutants are not only a threat to the environment but are also hazardous to the health of human beings and other species of the Earth. Chemical remediation or treatment methodologies have been associated with numerous biohazards and are expensive and inefficient; therefore, researchers are seeking alternatives for safer treatments. In that sense, to mitigate pollution and pollutants and sustain nature, increasing concern must be given to the investigation of effective, affordable and environmentally friendly natural technology. There are records of strong interactions between bacteria and nanoparticles in nanobioremediation related to the remediation of pollutants. However, in some cases, microbes had deleterious effects on nanomaterials. Based on literature reviews, several types of nanomaterials have been used to remove heavy metals and organic pollutants in selected areas in specific countries.

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