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Review Article

Role of Nanoparticles in Biodegradation and Their Importance in Environmental and Biomedical Applications

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In recent decades, research in nanomaterial specific to biodegradation has gained attraction owing to its physicochemical characteristics. Biodegradation is the main strategy used in the management of wastes. The role of nanoparticles helps in controlling the biodegradation rate. The biodegradation might not be quite effective in certain cases like high chemical deposition, due to its toxic nature towards microorganisms. The conventional strategies demonstrated a limited use of nature source, and this could be overcome through microbes and enzyme-based biodegradation. Nanoparticles have improved the biodegradation rate through low-density polyethylene development, thereby corrupting microbes. Thus, a major problem is confronted. Though innovation in science had a great impact in everyone's life, it also has a negative impact through the increased use of toxic materials. Recent development and use of biodegradable nano-based compounds have led to many secured forms of nanomedicines. In this review, we would discuss the more recent findings of nanoparticles related to biodegradation applications and elaborate how their characteristics could influence in various biomedical applications.

1. Introduction

In modern world with many established factories, we see our atmosphere being fully contaminated with unknown components owing to various human activities related to increased usage of manufacturing design and processes. Organic pollutants such as dyes, pharmaceutical waste, pesticides, herbicides, humic substances, phenolic and petroleum compounds, surfactants, and by-product of manufacturing such as dioxins are widely present in the blood of a major population. Inorganic pollutants such as chromium arsenic, mercury, lead, cadmium, nitrates, nitrites, and fluorides which are present in the environment are toxic at lower concentrations. The crude oil, coal, and natural gas combustion through activities of humans have a deteriorating effect on emission from natural gas [1]. The cause of pollution by water is mainly due to wastewater discharge, spillage of chemicals, fertilizers and insecticides, various manufacturing defects, extraction process, and combustion of fossil fuels [2].

Pollutants are mixed in the air, water, and soil and contaminate the environment. So, a streamlined monitoring system would make our environment free from pollutants by enforcing laws to monitor the waste disposal from industries and manufacturing units. In this regard, the role of nanotechnology is more effective in providing a pollutant-free environment. Nanotechnology provides improved functions and characteristics through the formation and monitoring of nanoscale material. The ultrasmall nanomaterials which are in the size of 1-3 nm are capable of detecting sensitive pollutants as the ratio of surface area per unit to density seems relatively higher. The unique structural technologies and methods of nanotechnology help in reducing the pollutant or toxic load in the environment. The nanomaterial exhibits high surface area to volume ratio that enables its application in pollutant detection and remediation. The surface of the nanomaterial enables modification with superior selectivity and affinity. Nanotubes have been employed for separating gases from industrial emissions, and nanocatalysts have been used to transform harmful gases into harmless gases and also speed up the process. The latest nanotech approaches harvest CO_2 and convert it into useful products like alcohol. Metal and metal oxide nanoparticles are widely used in water treatment and water filtration [3, 4]. Plastics are used on a daily basis in our everyday lives. They exist as thermosets, elastomers, and thermoplastics. The various forms are formed depending on the chemical characteristics and the presence of side chains. The polymers that form the plastic exist as branched, cross-linked, non- cross-linked, crystalline, amorphous, or rubbery in nature. Plastics are polymers with different side chains such as carbon-based units, methyl groups, nonpolar groups, alkyl, and vinyl groups that alter the property of the material like solubility and water repellency and thereby determine its application. Polyethylene terephthalate (PET) commonly used for bottle production contains repeated units of aromatic terephthalic acid and ethylene glycol which cannot be easily degraded by microbes. Further, adding additives offers desirable properties including dyes and fillers. But in certain cases, they cause damage to our health system as they are nondegradable; the fragmented particles continue to exist in the environment and enter the food chain, which results in health concerns such as neurotoxicity, reduced fertility, oxidative stress, cancer, and metabolic diseases [5–7]. Dumping of huge amount of polyethylene wastage into the water sources as landfills for further degradation/decomposition is piled at the ratio of 25 million per annum and has caused a huge burden to the ecosystem. So, the major concern remains about their recycling and incineration approaches. The wastage deposits on soils are comparatively lower, but incineration of the same emits highly poisonous gases into the atmospheric system, affecting all individuals and the ecosystem. Researchers are striving to identify a new "eco-sustainable" method to develop bioplastics that could degrade petroleum plastics and successfully be used as an alternative for conventional plastics. These conventional plastics are made from nonrenewable resources like petroleum or natural gas such as polyethylene, polypropylene, polystyrene, polyester, nylon, and acrylic and produces toxic by-products (bisphenol A) that are hazardous. Complete negligence of the usage of plastics from everyday life seems impossible. Degradation frequently occurs either through photolytic or chemical reaction, and hence, various reactions such as enzymatic, microbe-mediated, and oxidation processes are well studied with respect to soil and water, respectively. Oxidation degradation occurs by the action of oxygen on the substrate to disintegrate macromolecules. This leads to changes in the chemical structure and reduction of the molecular weight, thereby resulting in the change in brittleness of the polymer, cross-linkage, and the degradation temperature [8–10].

Environmental nanotechnology strives to play a critical role in fine-tuning the preexisting aspects of environmental science and engineering [11]. The nanoscale characteristics including low-cost biodegradation approaches have led to novel innovations in emission control, catalysis, and others. On the other hand, scientists and even public are interested in unraveling the impact of nanoparticles in health, environment, and other biota. Hence, understanding more about nanotoxicology has gained much interest currently [12–14]. Researchers are focusing on novel ways to eradicate plastics that are nonbiodegradable and replaced with a novel biodegradable plastics and this remains a major concern. The microbial and enzymatic approaches are used mainly in environmental degradation until now [15–19]. The biodegradation occurs in the presence of sunlight, UV radiation and artificially carried out by UV irradiation, introduction of bacteria at the site. Other important factors for degradation are varied temperature and pressure for different types of biomass [20]. The nanoparticle could further be used in improving the degradation aspects through microbes.

More researches concerning the degradation of nanoparticles and their applications have revealed the biodegradation of nano-based carbon compounds *in vivo* through the enzymatic activity of the cells. This investigation creates new ideas to obtain a direct relation between nature and nanoparticles, leading to expansion of medicine-based nanotransporters and upgrading bio-nanodegradation and investigating the inflammatory reactions and toxic effects as well. The other main criteria are the selection process of the desired nanoparticles used in degradation. Nanoparticles are selected based on their mechanical and physicochemical properties eligible for biodegradation. The mechanical properties of the nanoparticle such as hardness, elastic modulus, adhesion, and friction and physicochemical properties such as high surface area to volume ratio, crystallinity, and shape-dependent properties offer several advantages over bulk particles. The usage of nanoparticles as fillers could enhance the properties of materials alongside corruption [21]. A brief outline on the microorganism-based biodegradation along with nanoparticles as enhancers used in degradation is also explained. This review further elaborates possible outcomes of nanoparticles for both environmental and biomedical applications.

2. Biodegradation

Biodegradation is the breakdown of natural compounds that have accumulated in the ecosystem (Figure 1). They contribute to the regeneration of soil nutrients such as carbon, nitrogen, humus, and nitrification. Quite intriguingly, this

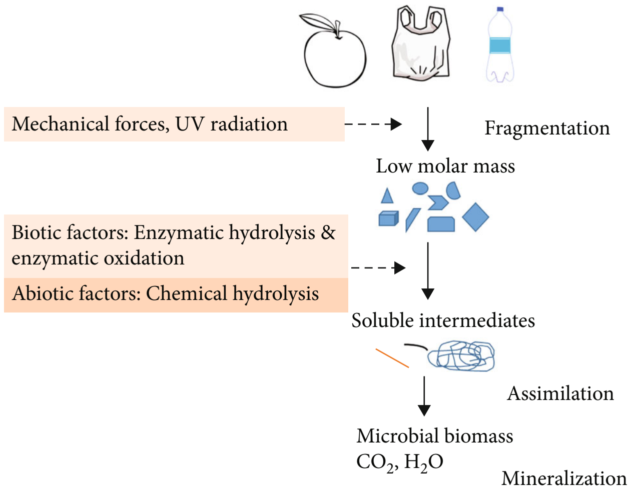

Figure 1: Overview of the biodegradation process.

is a strategy that aids in the provision of nutrition for the environment's nourishment. The complicated natural compounds are destroyed and transformed to carbon dioxide and water during biodegradation of some components such as organic matters. Biodegradation is a key feature of hazardous synthesis chemicals as the biodegradation rate is great, and thus, the fastening and the resultant toxic effects decrease rapidly, whereas persistent artificial components maintain the detrimental effect permanently. The rates of biodegradation are broad—from quick biodegradation of monomeric carbohydrates, subatomic alcohols, and acids to high-head mixes that have for fairly some time organic subsistence with dichlorodiphenyltrichloroethane or dioxins for instances. Biodegradation is carried out by a variety of organisms at a basic stage, although we often assume microbiological biodegradation to be foremost important from an environmental standpoint [22, 23]. In particular, microorganisms' rate of biodegradation in water and soil is high. It is, however, not a signature value that can be used as a constant for a component, because biodegradation is entirely dependent on the circumstances for microbes in the water and soil. Biodegradation is also influenced by the composition or absence of oxygen, implying aerobic or anaerobic circumstances.

The biodegradation technique utilized to restore soil and water characteristics without impacting the microorganism in the ecology is regarded as fairly innocuous. Biodegradation does not take much of its work than other procedures; it is thus usually much cheaper and may be substituted by artificial or real substances. It also allows hygienic workers to remain away from polluted water and soil linkages. The degrading microorganisms may be resident to a fragmented territory or might be disassembled and transferred to the degraded region from anywhere outside [24, 25]. By certain activities owing to their metabolic processes, external chemicals are modified by live biological organisms. Many organic entities often biodegrade a molecule through fragmentation, enzymatic hydrolysis, photolysis, and assimilation. The bioaugmentation is a process where the microorganisms break down the larger particles into smaller particles and convert them into simpler forms like water, carbon dioxide, and methane. The microorganisms change the poisons and turn them into harmless things in an attempt to achieve a robust biodegradation. Basically, biodegradable substances are divided into two classes according to distinct methodologies: biodegradable characteristics and biodegradable materials produced (Table 1).

Since it is successful if microbial growth and activities are allowed by biological conditions, biodegradation is commonly employed to manage environmentally friendly factors to enable more rapid advancement to microbial proliferation and manipulation. It helps in maintaining a clean environment, by converting waste into crude oil, reduces toxic effect, and generates energy, carbon, and/or nitrogen that is usable by microorganisms. However, biodegradation has its obstacles, just like in the case of various advances and there are certain inconveniences [26]. Many factors hinder the leverage and optimization of biological degradation systems. The microorganism's communities have capacity to destroy contaminants; they have access to toxicants and ecological factors including soil quality, climate, acidic conditions, sufficient amount of oxygen supply, and nutrients are necessary. Bioavailability toward a thriving microbial density is among the foremost noteworthy feature of the bioelimination of hydrocarbons from a polluted ecosystem. The physiological state of the hydrocarbon, the aqueous-resistant characteristic, hydrophobicity, contextual composite sorption, and permeability of the soil constituent will further impact the bioavailability of a compound. If contaminants have low water solubility, they never properly segregate the biological cycle components into the water medium to limit their survival. Pollutants may divide the organic soil content and make it considerably less bioavailable [27]. Nonaqueous phase liquid (NAPL) was constructed and used in the hydrocarbon-contaminated earth biodegradation using biphasic bioreactors (inclusive of aqueous and nonaqueous phase). However, in kinetic parameters, microbial adhesions to NAPL-water may still have a role [28]. This bioreactor could be used in biocatalysts of hydrocarbons (styrene included) [29]. If the carbon availability is limited, the metabolism rate and consequently the availability of the biodegradation are dictated instead of the catabolic ability of the cells or the existence of oxygen or other micronutrients. In watercourse biodegradation, similar parameters are employed. In complex conditions, some hydrocarbons may be retrieved diversely than others, and the process of biodegradation can be enhanced with the use of electron acceptors that accelerates the process. For example, in the case of aromatic substances, benzene-toluene-ethylbenzene-xylenes (BTEX), (1) removal of toluene could be preferred in the case of inherent circumstances; (2) benzene degradation is noticeably gradual; (3) sulfate enhancement could mainly promote o-xylene degradation; ethylbenzene may be recalcitrated; as in the modern way, biodegradation is a chain reaction used in the fight against chemical pollution, and commonly degradation is processed by microorganisms of component [30–34]. Unlike traditional (physical and chemical) cleanup methods, this method employs natural microorganisms. Numerous research findings offer information

Table 1: The sources, benefits, and drawbacks of biodegradable products.

Biodegradable products	Source	Availability	Benefits	Drawbacks	Reference
Natural biodegradable products	Chitosan	Isolated from shrimps, crabs, insect shells, and cartilages	Biodegradability, biocompatibility, and mucosal immunity	Only acidic soluble and limited usage	[35, 36]
	Hyaluronic acid	From animal tissues and through fermentation of microbes	Biocompatibility and limited toxicity	High cost and no assurance of purity	[37, 38]
	Liposomes	Available as phospholipids and ceramides through self-assembly	Contains adjuvants with multiple layers	Instability and cannot be synthesized in abundance	[39–41]
	Sodium alginate	Available in seaweed through microbial processes	Water soluble and retains more chitosan properties	No targets in complex phase	[42, 43]
Synthetic biodegradable products	Chitosan by-products	Chitosan produced through chemical alteration	Enables incorporation of various antigens and immunomodulators	Toxicity due to inclusion of chemicals for synthesis	[36]
	PLGA	Obtained by the polymerization of lactic and glycolic acid	Used in most parts of the body including mucosa	Instability, more usage of required organic solvents and administration route through mucosa is ineffective	[44]
	Polyanhydrides	Available as methyl vinyl ether and maleic hydride	Enables sustained drug delivery and surface deprivation	Higher hydrolytic sensitivity with limited benefits	[45]
	Micelles	Using amphiphiles	Hydrophobic core incorporates water-soluble drugs	Inconsistency and not produced in abundance	[46]
	Poly-L lysine dendrigraft	By polycondensation of lysine	Mild toxicity and enables targeted delivery	Interference between immunogenicity and booster immunity and processes are quite complex	[47]

on the effects of chemical or chemical formulations in the ecosystem including oil spills and industrial effluents, enabling research aims to produce innovative removal techniques by (1) assessing contaminated areas, (2) identifying the appropriate environmental policy, and (3) enhancing rejuvenation procedures, making a contribution to the development of new technology solutions.

2.1. Biodegradation through Aerobic and Anaerobic Systems. Aerobic biodegradation or the breakdown of pollutants by microorganisms happens in the existence of oxygen. More specifically, it denotes the availability of oxygen or microorganisms that can only survive in the context of oxygen; therefore, oxidative states characterize the biochemistry of a unit, environment, or an organism. In an aerobic atmosphere, aerobic bacteria, also known as aerobes, rapidly break down many organic contaminants. Aerobic bacteria's metabolism is oxygen-dependent. Aerobes obtain energy by oxidizing compounds such as carbohydrates and lipids with oxygen, as indicated by their cellular respiration. Before cellular respiration begins, glucose is broken down into two basic molecules [48]. These components are then taken up by mitochondria. Oxygen is used in chemical reactions that break down simpler compounds into water and carbon dioxide. As a consequence of this situation, heat is also emitted. In most situations, the aerobic procedure results in complete digestion of solid waste, reducing buildup by even greater than half.

It also aids in the prevention of infections and improves the working and living circumstances of people and animals. Anaerobic digestion occurs when anaerobic microbes outweigh aerobic microorganisms. It occurs in oxygen deprival condition. Cellulose and similar products deteriorate very gradually over lengthier time periods than they usually do in a short time. Methane, a component of biogas, has a global warming potential of about 21-fold than that of carbon dioxide. The biological gas is accumulated and utilized for producing eco-friendly power in the cradle. Anaerobic digestion is a physiological series, in which microorganisms, in the lack of oxygen, break down biodegradable material. As the overall density of the discarded raw materials used for waste water disposal [49–51] is reduced, waste gas emissions to the ecosystem are eliminated through a comprehensive waste treatment technology, and this decreases waste gas emissions. It creates the perfect biogas for energy production for the development of methane and carbon dioxide, which is a clean form of energy that may assist in replacing renewable resources. The solid remains even after decomposition seems to be rich in nutrients and, hence, used as fertilizers [52]. The process is initialized with bacteria hydrolyzing the source, decomposing hydrophobic natural polymers and making it accessible to different microbes. The peptides and carbohydrates are subsequently changed into CO_2, H_2, NH_3, and natural acids through acetogens. Acetogenic bacteria help in the conversion of organic acids along with more amounts of NH_3, H_2, CO_2, and CH_3COOH [53]. Finally, methanogens can convert these molecules to methane and carbon dioxide. Acetic acid and microorganisms are also involved in the production of methane. The microorganisms eat the initial feedstock and convert it into intermediate components such as H_2, CH_3COOH, and other sugars before the biogas conversion [54–57]. The diagrammatic representation of the process is given in Figure 2.

Various phases of anaerobic digestion are elaborated in detail as follows.

Hydrolysis: in most situations, large polymer composites constitute the bulk of biomass. To acquire the energy potential of the compound for the microorganisms in anaerobic digesters, the chains are converted to smaller ones. The constituents such as carbohydrates are easily accessible to different microorganisms. Hydrolysis involves separation of networks and discharging the simpler molecules as solvent. Therefore, hydrolyzing these monomers is the preliminary stage in anaerobic digestion.

Methanogens can use the initially generated H_2 and acetate efficiently. Certain molecules with high volatility fatty acids (chains greater than acetate) should initially be converted into compounds capable of effectively using methanogens.

Acidogenesis: acidogenesis is a biological process that occurs when acidogenic, fermentative bacteria progressively degrade the leftover components. Furthermore, volatile fatty acids (VFAs), ammonia (NH_3), carbon dioxide (CO_2), hydrogen sulfide (H_2S), and certain other by-products are also generated. It operates in the same way as sour milk does.

Acetogens are enzymes that decompose basic components generated throughout the cycle to generate acetic acid (CH_3COOH), CO_2 and hydrogen.

The final stage is the methanogenesis. So, the methanogens generate methane, CO_2, and water (H_2O) from the intermediary remaining from the previous stages. They seem to be the main essential components contributing for the major biogases generated.

3. Nanoparticles and Their Importance

Nanotechnology uses engineered molecules that resemble ultrasmall particles with size less than 10 nm, while nanoparticles are those in the size range of 1-100 nm and microparticles are those in the range of 1 and 1000 μm in diameter. These particles are in the range of 1-100 nm with their physicochemical aspects manipulated and are called to be an assemblage of atoms or molecules. Nanoparticles function differently based on their chemical nature such as shape, volume, and structure. They are known to be composed of various composites. In nature, these are more adaptive and mobile [58]. They exist in nature in the form of volcanic dust, mineral composites, and others. They could also occur incidentally such as contaminants arousing from various emissions such as welding, coal combustion, and diesel. In recent years, engineered nanoparticles (NPs) have been identified, which may include quantum dots, AuNPs, Zn NPs, Al NPs, TiO_2, ZnO, and Al_2O_3, which may be classified under metallic products [59]. The unique size of the nanoparticles in the nanorange makes them feasible to incorporate tiny sensors that could be used in most rural regions. Some of the nanosensors that are used are for detection of pesticides, humidity of soil, pH of the soil, nutrient requirement, and crop pest identification. Nanomaterials are considered as the best in comparison with conventional materials with respect to resource conservation and environmental biodegradation. The excellent applications of nanomaterials owe to its efficiency and low cost, and it acts as a substitute with environmental sustainability (Figure 3). The demand for bio-based stability and their potential applications in electronics, drug delivery, agriculture, and others are increasing. Though nanomaterials could be produced or synthesized through various conventional routes, the bio-based approach is more sought after. The chemical method of synthesis involves the use of strong reducing agents, and the top-down synthesis involves methods such as lithography, laser ablation, sputtering polyol synthesis, ball milling, electrochemical method, chemical vapor deposition, and thermal decomposition. The bottom-up methods that are used for nanomaterial synthesis are sol-gel synthesis, spinning, plasma synthesis, and microwave-assisted synthesis. Among these, the biological approach is preferred due to the ease of preparation, limited toxic nature, cost-effectiveness, tendency of size manipulation, and eco-friendly approaches [60–62]. Various bio-based contaminants including microorganisms and certain environmental organic contaminants are also widely extracted by the use of nanoparticles [63, 64].

4. The Science behind Nanoparticle-Based Biodegradation

The important properties of nanoparticles lie mainly in their ability to biodegrade. The process of degradation is irreversible and causes structural change in the material including reduction in mechanical aspects, damage, and depolymerization. Further, the degradation is also subjective of climatic conditions that could be constant or keep altering with respect to time. For decomposition of big particles, our body system undergoes hydrolysis and degradation by enzymes. The primary hydrolysis method is selected for synthetic polymers to be utilized in medicine. Different factors are involved in the pace of polymer resulting in residence time of the host [65–67]:

(1) Water-polymer interaction: here, the diffusion coefficient and, mainly, the water absorbing capacity of the polymers remain significant. There is a direct relation between the rate of material decomposition and water interaction

(2) Polymer's crystalline nature: the amorphous material is permeable and allows easier water penetration.

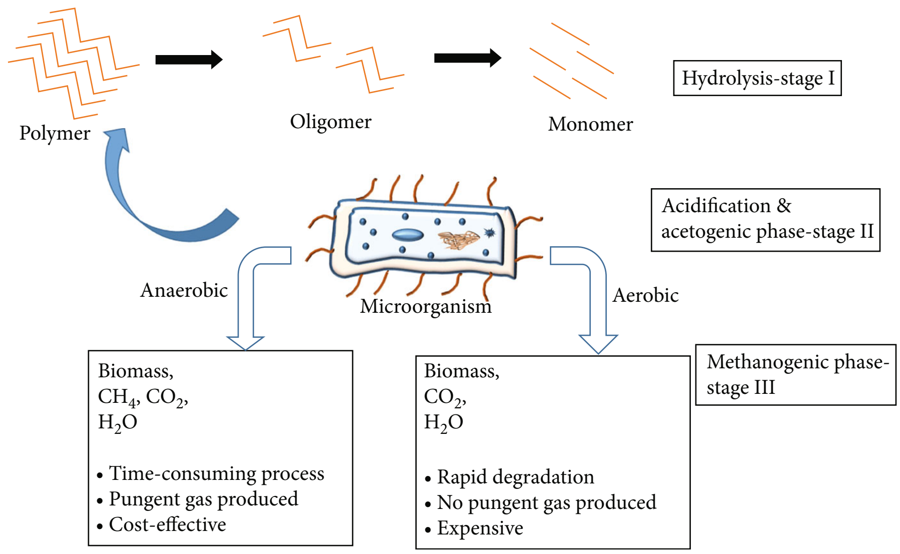

Figure 2: Overview of the biodegradation by aerobic and anaerobic methods.

Figure 3: The importance of nanoparticles that enables application in diverse fields.

There is direct correlation between the resistance of material towards degradation and crystallinity

(3) Temperature: this plays a role in enhancing the reaction kinetics and the total of transferable chains

(4) Structural morphology of polymer structure: the degradation is caused through the insertion of heteroatoms, hydrophilic groups, ethereal, ester, urethane linkages, etc.

The process of hydrolysis could also be improved by the effect of salt, water, and pH. The products obtained on hydrolysis of biocompatible polymer are mostly monomers, and these are eliminated from the body system. A polymer could be termed degradable, if the degradation process occurs within a short time. If longer time period is required for a substance to degrade, then it could be termed as nondegradable [68]. The overview of nanoparticle biodegradation by endocytosis and hydrolysis is represented in Figure 4.

The benefits of biopolymers are listed as follows:

(i) Biopolymers are chemically inert and exhibit low toxicity as compared to other nonbiodegradable substances

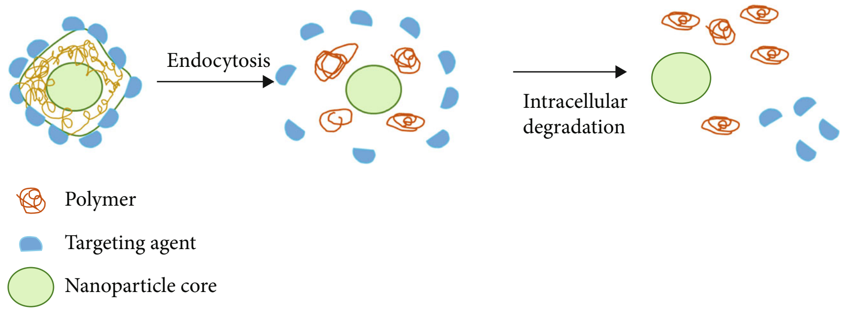

FIGURE 4: Nanoparticle biodegradation by endocytosis and hydrolysis.

(ii) The process of degradation is controlled *in vivo* and allows easy absorption and elimination, avoiding the necessities for surgery, thereby managing the burden for patients

(iii) Biopolymers could be engineered for efficient drug release kinetics

(iv) The extraction process of biopolymers is routed *via* synthesis of plant CO_2, and thus, they are easily regenerated by the biosystems. Biopolymers could be nature-derived or synthetic-derived [69]

4.1. Biodegradable Nanoparticles

4.1.1. Carbon Quantum Dots (CDs). Carbon quantum dots are carbon-based nanoparticles synthesized by hydrothermal method. There are numerous methods used to produce CDs such as physical, chemical, and biological. The green biosynthesis is biodegradable and some of the materials like fruit peel, sugarcane, and gelatin have been used for the same and are characterized [70]. The different types of biodegradable nanoparticles and its properties are represented in Table 2.

4.1.2. Nanobarium Titanate (NBT). NBT can control the growth of low-density polyethylene- (LDPE-) disintegrating bacterial populations and was synthesized with limited broth. This affects the time delay, increasing phase and stationary phase by reducing the delay step period, which increases the stationary and increasing phase spread. NBT serves as a nutritional aid supply for bacterial consortiums' rapid evolution, allowing the consortium to biodegrade plastic pollution. The deposit is evaluated and classified based on Fourier transform infrared (FTIR) spectroscopy and thermogravimetric analysis (TGA) with the control LDPE. The maximum wavelength shifts from 209 to 225.3 nm when the polymeric composition alters. This shift requires four days in the apparent lack of NBT. When NBT is available, the spectrum shifts from 209 to 224.11 nm in 48 h, demonstrating a significantly enhanced degrading quality [71].

4.1.3. Fullerene 60. This type of nanoparticle exhibits a strong analysis of degradation when employed in minimal Davis broth lacking dextrose, in managing the development phase of LDPE disintegrating consortia of bacteria. Such nanomaterials were only utilized at 0.01% *w*/*v*, as exceeding this concentration might be detrimental to the growth of bacteria. Fullerene 60, a low-density polyethylene, was put into practice. Because the microbial species are harmful to low-density polyethylene, they are produced as a result of polyethylene breakdown. These are capable of breaking down polyethylene (HDPE), epoxy, and silicone epoxy, which serves as a catalyst for the enzyme production causing degradation of waste plastic materials [72].

Considering increased levels of high concentrations, like those of 0.25, 0.5, and 1 percent, which are harmful to bacterial development, their concentration was optimized. Two different consortia tested these NPs with LDPE and fullerene 60 [73]. Bacterial strains that degrade low-density polyethylene were recovered from degrading polyethylene [74]. They are also capable of degrading HDPE, epoxy, and their silicone combinations [25, 75].

They stimulate the enzyme spread involved in plastic waste breakdown. Lack of fullerene 60 NPs causes polymeric shape change, resulting in a shift in max of 209, 220, and 223 nm for 2, 3, and 4 days, respectively. Fullerene 60 max in fullerene samples, on the other hand, raised 209 to 224.97 nm on day one, showing a higher deterioration rate.

4.1.4. Superparamagnetic Iron Oxide (SPION) Nanoparticles. In nearly the very same approach as NBT and fullerene 60 nanomaterials, superparamagnetic iron oxide NPs were examined. The 10.6 nm SPION particle size was utilized to aid consortium formation. The nanoparticles were made by coprecipitating ammonia with ferrous and ferric chloride solutions. The particle size had been determined using X-ray diffraction (XRD). An identical degradation method was used.

A comparison research done using SPION has undergone the similar analysis compared to NBT and fullerene 60 NPs [24]. The adoption of SPION with 10.6 nm aided consortium's expansion. The NPs were produced by coprecipitating ferrous and ferric chloride solutions with ammonia [76]. The proper particle size is determined using XRD, UV, and FTIR, and a thermal analyzer was used to examine the results of the degrading procedure [77]. For a higher rate of degradation and endurance of polyethylene, polyethylene nanocomposites can be produced employing one of the techniques mentioned above [78].

4.1.5. Titanium Dioxide (TiO_2) Doped with LDPE. TiO_2 have shown to improve the catalytic performance photolytically, allowing it to successfully degrade gaseous and water-based contaminants, making it useful in filtration. Metal doping

Table 2: The different types of biodegradable nanoparticles and its properties.

Nanoparticle	Property	Reference
Liposomes	Biocompatible, carries hydrophobic material	[38]
Alginate	Water soluble, biocompatible	[42]
Poly-D-L-lactide-co-glycolide (PLGA)	Biocompatible, nontoxic by-products	[44]
Micelles	Capable of carrying water-soluble drug	[46]
Poly-L-lysine	High loading capacity, biodegradable, targeted delivery	[47]
Superparamagnetic iron oxide (SPION) nanoparticles	Superparamagnetic, paramagnetic	[78]
Gold	Biocompatible, hyperthermia	[84]
Chitosan	Nontoxic, blood viable, antitumor, antioxidant, antimicrobial, inexpensive, and biodegradable	[89]

agents were used to alter the biochemical composition of the substance and aid in the absorption of light in the visible range, resulting in the beginning of photocatalytic activity. There are many dopant metals on the market and the LDPE-degrading dopants included silver, gold, and bronze [79].

Following that, doping titanium dioxide with a metal doping agent was utilized to defeat it by changing its material structure and causing a change in absorbance, allowing it to stay near to visible reach. In the presence of catalysts, this causes a chemical process using light to accelerate [80]. Metals may be used as doping agents in a variety of ways. Fe and Ag are suggested to be doping agents for the breakdown of LDPE [81].

The doped TiO_2 NPs may be made by metal expansion by placing in 100 mL H_2O with TiO_2 (1%) convergence, storing at 24 h, and then drying using a burner at about 100°C for certain hours. Fe and Ag composite TiO_2 NPs are created through the addition of a doper to each titanium dioxide NP at a 0.6 percent convergence [82].

4.1.6. Gold (Au) Nanoparticles. Au are natural nontoxic metals and do not aggravate on consumption. The AuNPs were synthesized using gold (III) chloride with the addition of sodium borohydride [83], and due to its biocompatibility and inert nature, certain biodegradable polymers are incorporated. This is being used as contrasting agent in photoacoustic imaging and for photothermal therapy (PTT) [84].

A new green receptor with gold nanoparticles synthesized using chemical reduction method as colorimetric method in aqueous solution for detection of metals has been reported [85].

4.1.7. Micellar Particles. The organization of micelles is caused by self-assembly of nonpolar components in water after a large number of water-soluble peptides are pulled to each other [86]. Micelles are commonly used to characterize and transport insufficiently hydrophilic peptides [87]. Micelles can be made up of a wide range of particles and can increase the water dissolution rate of packed medicines or chemicals and determine whether compounds are widespread in the ecosystem [88].

4.1.8. Chitosan Nanoparticles. Chitosan (Ch) is a type of natural polymer produced by cells that has been proven to have properties such as preventing and stopping hemorrhage, increasing immunological reactivity, tissue structure, and a variety of other therapeutic applications. Ch is a biomaterial that can be produced using green methods, biodegradable, acts as a substance that stimulates the immune system, has the property of adhesive between different substances, is nontoxic, blood viable, antitumor, antioxidant, antimicrobial, and is inexpensive and readily available [89]. Ch is widely used in medicine, food, synthetic, cosmetic goods, freshwater treatment, metal processing and reuse, and other sectors due to its remarkable characteristics [90].

4.1.9. Poly-L-lysine Dendrigraft (DGLs). It is a water-soluble polyelectrolyte depending on $(C_6H_{12}N_2O)_n$ and is structured by a condensation process of $C_6H_{14}N_2O_2$ [91]. DGL, which takes the shape of a dendrimer, has a direct center and a more customizable design than a polymer. DGL is biodegradable, has consistent distribution, can be penetrated by one or even more types of microorganisms, and has been linked with negatively charged substances by electrical energies. The amino acid given post-DGL degradation is hazardous. It possesses a larger layer of amino subatomic collects on its atomic surface, as well as more accumulating modifications [92].

4.2. Environmental Applications of Biodegradable Nanoparticles. Nanotechnology-based avoidance of pollution relates to the decreased usage of raw products, fuel, or numerous other facilities, including storage or recycling of wastewater. Implementing the concepts of green chemistry for the production of nanoparticles and for nanotechnological applications in mainstream chemical engineering could contribute to a significant reduction in waste generation, less harmful chemical synthesis, improved catalysis, and ultimately intrinsically healthy chemistry [2]. The environmental applications of biodegradable nanoparticles are illustrated in Figure 5.

4.2.1. Biofuel. Biodegradable nanoparticles synthesized using orange peel have been used as biodiesel additives to reduce severe toxicity, stability, and cost-effective issues. Nanobiofuels have been shown to reduce emissions of unburned carbon and nitrogen oxides leading to a full combustion process [70].

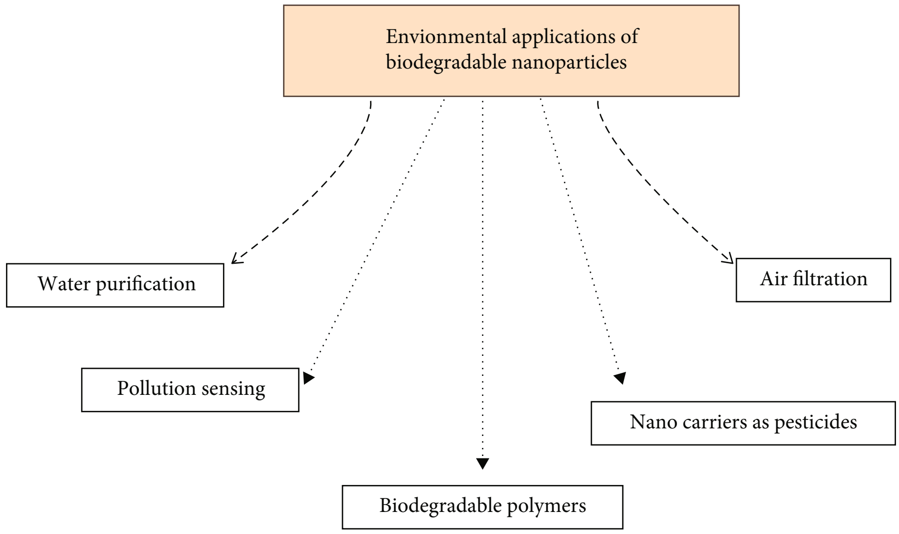

Figure 5: Environmental applications of biodegradable nanoparticles.

4.2.2. Detection of Contaminant. Glucose is a biodegradable molecule functionalized with gold nanoparticles to detect the element arsenic (III) in aqueous solution. This is the process that has been shown to be environmentally friendly and nontoxic and has also allowed for rapid detection [85].

4.2.3. Water Purification. Nanofiltration membranes (NF membranes) are used for handling water for drinking water supply or for wastewater treatment. NF membranes are pressure-driven membranes with properties varying from 0.2 to 4 nm, such as reverse osmosis and ultrafiltration membranes. NF membranes also evidenced the removal of turbidity, microorganisms, and inorganic ions to include calcium and sodium. These are used to transform soil, extract dissolved organic matter and trace surface water contaminants, and handle wastewater. Biodegradable polyvinyl alcohol (PVA) with silver nanofiber has been used in water purification, which has long been proved to have fantastic antimicrobial properties [93].

4.3. Biomedical Applications of Biodegradable Nanoparticles. Various NPs have different epitome efficacy, pharmacokinetics, and delivery components according to their size, character, and organization/design. For example, the organization, epitome efficacy, and stability of nanoparticles produced of poly-lactic-co-glycolic acid (PLGA) and those composed of polycaprolactone differ [94]. Therapeutic implementations will benefit from a greater emphasis on the characteristics of these biodegradable NPs. Nevertheless, in the therapeutic utilization of biodegradable NPs, its role in health impact has enhanced owing to their characteristics employed, and the traditional complications such as the medicines merging or presumably delivering efficacy remain as they must compete with the nanocompound degradation yield. Table 3 represents the capability of nanobiodegradable in collecting clinical needs. The biomedical applications of biodegradable nanoparticles are illustrated in Figure 6.

4.3.1. Imaging. The use of nanodrugs in diagnostic imaging for identifying cause involves the use of nanocompounds as distinction experts, as the minor change and concentrating on characteristic of NPs enables the interest on limiting cell mass and monitor with high accuracy. The NPs may be used in a variety of imaging methods, including ACT scans, MRIs, PET scans, and optoacoustics [95]. Targeted delivery using nanocarriers could significantly reduce the convergence of different experts and the risk of renal disease segregation. AuNPs have a vital role in imaging agent development [96, 97]. In 2010, a phase for polymer biodegradable nanocomplexes smaller than 100 nm was developed for the first time. As the improvement of nanoimaging comparison experts drew more attention, imaging specialists went through more twists and turns [98].

Nanotechnology-assisted imaging has proven to be beneficial not only in the field of cancer but also in the field of cardiac disease [72, 73]. Micelles have proven to be effective in concentrating on cancerous cells with the use of tumor molecular probes for cancer treatments [99].

4.3.2. Theranostics. Another unique notion is that theranostics has become a widely sought model in the development of new nanodrugs. These bright NPs collaborate with imaging professionals, concentrating on outcome analysis and therapy delivery [92]. They can be made to stand out due to natural characteristics [92]. NPs based on poly-lactic-co-glycolic acid have been developed [100]. Several biodegradable PAM employed as a transport module for another chemical are utilized for theranostics in disorder control. Small membranes that carry chemical signals are being developed for optoacoustic microscopy and the therapy of various medical conditions with electromagnetic radiation, a restorative methodology that activates cell attempting to pass using the warmth energy converted from acculturated light source to enable the least obtrusive malignant growth therapy. The SH link at the base of the copolymer [poly(ethylene glycol)-b-poly(-caprolactone-co—dimethyl maleamidic acid—caprolactone)] could allow

Table 3: Application oriented biodegradable NPs for biomedicine.

Purpose	Uses	Benefits of NPs (biodegradable)
Bioimaging [113]	MRI and imaging in optoacoustics	(i) Compressed contrast capacity (ii) Adequate signalss (ii) Directed imaging
Nanotheranostics [114]	Diagnosis and treatment of cancer	Improved aspects in treating methods
Targeted drug delivery [115]	Therapeutic efficacy	(i) Encompassing hydrophobics (ii) Limitation of early disintegration (ii) Improved medication delivery techniques (iv)Sustained concentration of drugs used (v) Limited toxic effects
	Gene-based treatment	(i) Prevents DNA disintegration (ii) Host rejection is greatly reduced
Implantations [110]	Stents	(i)Improved image cutting (ii) Secondary stage of surgery could be prevented
	Suture	(i) Limited toxicity (ii) Improved response to host physical aspects are enhanced

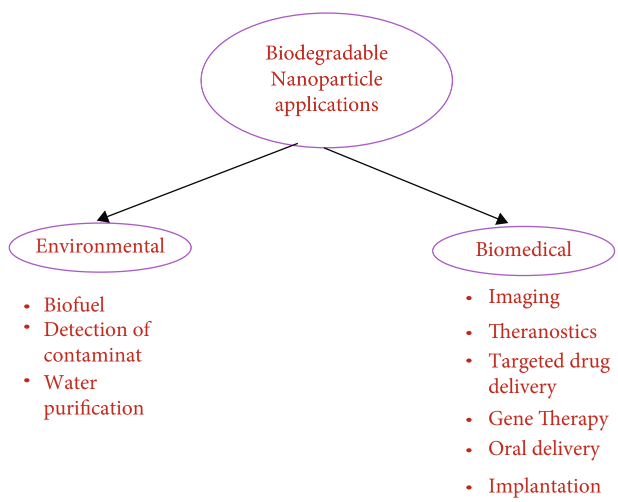

Figure 6: Applications of biodegradable nanoparticles.

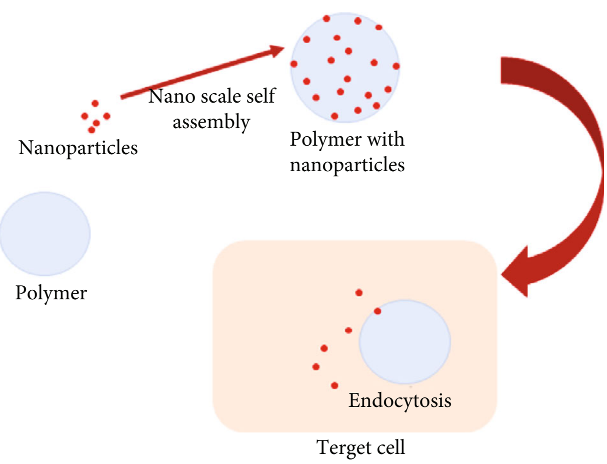

Figure 7: Targeted drug delivery.

gold NPs to be thickly pressed, allowing for simultaneous optoacoustic imaging [84]. The NPs' designs have also been continually improved in order to improve biodegradability and fractional TT (thromboplastin time). The polymer-based biodegradable nanoparticles are used. Biomimetic breakdown of molecules in organic materials are used to generate biodegradable tumor nanoparticles [100].

4.3.3. Targeted Drug Delivery. Nanomedicine, which uses biopolymer NPs as a targeted delivery, has been developed to treat cancer in a variety of ways, including targeting particular infected cells, supplying nutrients and oxygen to tumor cells, and using safe cells to promote malignant illness through therapeutic intervention (Figure 7). Clinical preliminaries for NPs for targeted cancer illness therapies have been published [101]. The usage of PLGA in an exemplification technique can assist prolong the course of drugs that are unsecure under physiological conditions with reduction in the signs encountered in particular drugs. The antitumor agent rubitecan possesses poor aqueous solubility and low security of natural pH. PLGA helps in elimination of rubitecan for up to 160 h [102].

Regarding cardiovascular diseases, a guided nanodrug delivery device is also being investigated. Nanoparticles may be a better medication conveyance framework than traditional medicines for limiting negative effects while enhancing medication effects. Current therapeutic goals for heart-related infections are based on renovating standard blood supply rate to heart and also anticipating occasional cardiovascular abuses. Antithrombotic treatment is considered the best therapy for preventing heart diseases, but increases the risk of bleeding to a greater extent [103]. However, studies focusing on the treatment of cardiovascular diseases with nano-based medicine delivery vehicles have only proven efficacy at the theoretical step [89, 90].

4.3.4. Gene Therapy. This therapy is a type of beneficial approach that attempts to adjust the permeability of particular genes in order to change certain organic features, and it has got a lot of attention recently [104]. We are close to the fact of acknowledging the usage of excellent treatment in the medical area with the help of NPs for targeted conveyance. To administer low impedance ribonucleic acid (siRNA), cationic PLA and PEG NPs are used as an important delivery method [105]. Polylactide NPs coupled to tiny interfering RNA enter cells to delete or inactivate genes. Nonetheless, there are certain obstacles in the acceptance of these therapies in clinics. NPs containing short interrupting RNA showed exceptional efficacy in stage I clinical preclinical cancer therapy, which was later terminated [106].

4.3.5. Oral Delivery. The goal of biodegradable NPs is to improvise the possibility of certain drugs that could be insufficiently or infrequently consumed for stomach disorders and cured by oral drug delivery. The technique has the potential to improve the organization cycle created by living organisms, protein, and peptides. Peptide insulin, for example, is digested in the digestive tract. Despite the fact that insulin was discovered over a century ago, it is administered yet through subcutaneous infusion only, causing discomfort and illness to patients, as well as psychological loads to the person with high blood sugar. Research is underway to make oral administration of insulin plausible for the personal delight of a person with high blood sugar [107]. In order to truly comprehend insulin's oral arrangement, Zn insulin (1.8%) in PLGA was developed by 2010 [108]. Regardless of the fact that PLGA NPs incorporating insulin had 12.4% sufficiency of Zn insulin delivered by the peritoneum, they did provide evidence on the probable destiny of insulin *via* oral route. Currently, mixtures of multiple biodegradable NPs like chitosan are also employed [90].

4.3.6. Bio-Based Implantable Devices. Many studies in this sector have resulted in implanted medical devices that use biodegradable chemicals. Biodegradable NPs can be utilized to enhance an existing cellular structure in the system including muscle obsession gadget and a biodegradable metal stents for percutaneous coronary interventions (PCI) to relieve disruptive damages [109]. Few devices have been successfully permitted and are widely available. The bio-based NPs enable the implanted devices to gradually degrade as the supporting tissues undergo better regeneration, trying to replace the implant [110].

Substantial improvements have been achieved, notably in the management of anatomical cardiovascular diseases using catheters. Novel therapy of small mesh tubes is developed to restrict postinterference stenosis because of vascular muscle cell propagation and reduce reappearance of stenosis postperfusion preservation of the body part, but also to restrict the use of stents for internal organ hemorrhage, a problem visualized at a greater reappearance with the original stents. Combining the modified $MgOH_2$ NPs employed to coat drug-eluting blood vessel tubes successfully decreased the stimulating response in pig models [111]. Their findings suggested that altering biodegradable NPs might be beneficial in increasing the relevance and therapeutic success in different clinical settings. The biodegradable stents are being developed to promote vulnerable metal stents due to the increased threat of a section of an artery with a stent getting clogged utilizing metallic components [112].

4.4. Nanoparticles in Medicine. Silver nanoparticles have been synthesized using safflower by an environmentally friendly method. This was found to be effective against bacteria that causes food spoilage and hence can be used as a potential antibacterial agent in medicine and against food spoilage [116]. Nanocarriers enable increased drug loading and targeting, which helps in preventing toxicity and undesirable side effects like Doxil, the approved drug for cancer. It has been used for delivery of imaging agents as well with high accuracy [117].

5. Conclusion

The various biodegradable nanoparticles available and the usage in biomedical applications are elaborated. These demonstrated a frequent analysis on the nondegradable substances with unconceivable medical constraints. To innovate biodegradable nanoparticle-based nanomedicines remains a major concern. Also, microorganism-based nanomaterials that are biodegradable could probably be a greater advantage with better financial and economic understanding. On the other hand, chemical nanotechnology has provided stable, dynamic, and strong proteins that enhanced employment. The degradation ability of nanoparticles and microorganisms against pollutants is tested in bunch tests, but there is lack of information concerning the synergy between nanotechnology and biotechnology regarding biodegradation ability and if it could result in toxicity in a new form. Though not much information is reported regarding nanoparticle usage along with microorganisms, it is demonstrated that bio-based nanoparticles represent higher advantages as compared to metallic nanoparticles such as the biodegradable nature exhibiting limited or no toxicity towards the ecosystem. The nano-bio interaction on the degradation property may add excellent value owing to its environmental advantages in comparison with other approaches. Also, its significance in the biomedical field in combination with natural drugs has reduced toxicity, which is an added advantage.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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