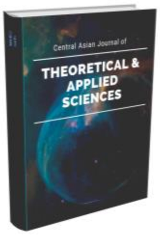

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Article

Potential of Biosynthesized Heavy Metal Nanoparticles as Antibacterial Agents in Water Treatment Applications: A Review

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Abstract: The need to explore new, sustainable water treatment methods is defined by an increasing prevalence of pathogenic bacteria in rivers. Biosynthesized heavy metal nanoparticles, or "BHMNs", are "an" examples of what could be termed environmentally heavy technology. The antibacterial efficiency of "BHMNs" in water treatment applications is systematically studied in this article. We surveyed many biological sources used to preparation "BHMNs" and gave reasons why these methods should be regarded as alternatives to traditional ones. The review also explores the different mechanisms by which "BHMNs" exercise their antibacterial effects including membrane rupture, DNA breakdown, and the production of reactive oxygen species. Another topic dealt with in the review is an appraisal, based on recent studies, of the efficiency of "BHMNs" as an antidote to a range of aquatic maladies. In addition, the review discusses potential disadvantages of widespread use of "BHMNs" in water treatment, including output increase and stability over time as well as environmental impact. based on recent studies We point out that the increased application of BHNs in water treatment is expected to yield a greater antimicrobial effect by showing the potential of BHMNs as a sanitary alternative to traditional techniques. This review aspires to further contribute developments in sustainable.

Keywords: Biosynthesized heavy metal nanoparticles, Antibacterial agents, Water treatment, and Green synthesis.

1. Introduction

If contaminants get into a body of water, that water becomes polluted, and can cause severe damage both to water creatures and human health Pesticides, nitrogen fertilizers and phosphate with their polluting effect, their fronts which send the paved surface water into rivers Thousands of tons of heavy metals, plastic wastes and petroleum and mineral oil pollute lakes on our planet air. The damages that result once water becomes polluted are gaining in reach. Even drinking and "recreational water" is now infected by garbage. The excessive input of pollutants adds on yet more burdens for clean-ups, while it disrupts the balance of life forms in rivers and lakes [1]. We have seen the balance of life forms being disrupted, diseases flourishing and biodiversity declining in the wake of a contaminated water source. These consequences of water pollution are likely to be especially long-term ecological damages as some pollutants, if they cannot decompose or be excreted by the living world around us and fall liable to accumulate in the environment [2,3]. "The damage that results when water becomes polluted becomes uncontrollable."

Microbial pollution, a variation of water pollution, is characterized by the proliferation of deleterious microorganisms in aquatic environments. These microorganisms, which include viruses, bacteria and protozoa, usually result from untreated or inadequately treated sewage; run-off from farms and factories; the overflow of stormwater in urban settings. When "found in water" these pathogenic cells seriously endanger a person 's "health". For example, "Pesticides, nitrogen and phosphate fertilizers with their precursors send polluting effect into surface water then into rivers. On the other hand , thousands of tons of heavy metals, plastic wastes, and petroleum and mineral oil pollute lakes on our planet". Furthermore, this type of pollution is compounded by the adaptability of some pathogens to water environments and their rapid reproduction. This form of contamination calls for comprehensive methods of wastewater treatment, ground water disinfection techniques, and careful management of urban and agricultural discharge. These steps are necessary to protect the health of humans and the integrity of aquatic ecosystems [4,5].

Waterborne bacterial contamination causes a huge public health hazard on the worldwide stage: these include different types of common water borne diseases like cholera, typhoid fever and dysentery [6]. However, while traditional methods such as chlorination can effectively wipe out harmful bacterium in contaminated drinking water sources, there are also worries that carcinogenic substances produced through reaction between chlorine and organic matter may pose potential health risks to individuals drinking treated tap water [7]. Besides, the matter is exacerbated by traditional interventions which make a new type of challenge [8]. In contrast to chemical nanoparticles produced by harsh and toxic chemicals with harmful by-products, "BHMNs" also is more green- the synthesis involved which are considered green since they utilize plant extract , bacteria [9]. Green synthesis also has a number of inherent advantages:

- low toxicity, high biocompatibility: However, BHMNS display little cytotoxicity compared with the chemically engineered alternatives. This offers great potential in areas of human health and the environment [10].

- Stability and Functionality Enhancement: The addition of some biological components to BHMNS is a very good caping agent, as gives increased nanoparticles stability and improved activity [11].
- Little or no damage for eco-friendly production: The effect of Green Synthesis is that it takes out all hazardous chemicals therefore reducing environmental pollution which often comes from conventional methods of producing nanomaterials. Typos: anthetypical should be anthropophilic . Heavy metal nanoparticle biosynthesis is a major breakthrough in environmental technology, providing an environmentally sustainable approach to solve water pollution issues. In this process, living organisms such as fungi, bacteria, or algae are programmed to produce nanoparticles made out of materials like iron and zinc. When compared with traditional physical or chemical methods, biosynthesis stands out in terms of its low environmental impact, energy saving effects and cost-effectiveness [12].

Nano-materials also have promise, particularly in water treatment. They can react with large surface area and high surface reactivity to remove pollutants from water more efficiently than simple mixtures - In the case of iron nanoparticles; for example even ion exchange resins loaded with heavy metals dissolved salts can be completely decontaminated using them [13].

Moreover, there is a positive effect on the breakdown of nitrate in wastewater when these materials are discharged into it and they will take Blue Nile Colorfast material out in turn. The presence of biological agents in the synthetic process can enhance the biocompatibility and reduce environmental footprint of nanoparticles, as they are then used in environmental remediation. [14]

Invariably, the detail of synthesis is BHMNS generated from biological sources. This review will provide an overview of BHMNS synthesis, looking specifically at processes within its component organisms that set it apart from conventional approaches. Then the different antibacterial properties of BHMNS membrane disruption The methodological approach to this review will be to investigate the seven pathways for BHMNS antibacterial effects by categories or sections. Moreover, the review will critically assess existing research findings concerning the effectiveness of BHMNS in inhibiting different waterborne pathogens. In addition, problems that arise when BHMNs are applied on a large scale for water treatment will be addressed. These include the issues of production scalability, long-term stability assurance and environmental impact mitigation. will suggest Finally, the review will suggest future directions for research and potential strategies of BHMNS optimization to upgrade its antibacterial efficacy more effectively and at a practical level integrate into the water treatment process In conclusion, by demonstrating the potential of BHMNS as a promising alternative to traditional water treatment methods, this review aims to promote more sustainable and efficient strategies for maintaining clean drinking water supplies [14].

The researcher believes that biosynthesized heavy metal nanoparticles can have strong antibacterial properties, making them promising in water treatment applications. These nanoparticles are often synthesized using biological methods, such as using plant, bacterial fungal extracts, which can reduce environmental impact compared to traditional chemical synthesis methods. Their effectiveness against a wide range of bacteria can help improve the safety and quality of treated water, especially in areas lacking advanced water treatment facilities [15].

1. Microbial Pollution in wastewater.

Water is an essential element for the support of life. However, a large segment of the world's population faces problems getting clean and safe drinking water in sufficient quantities. Consequently, people catch fatal diseases from drinking large quantities of contaminated water. conducive to infection and complicated by poor living conditions indeed Microbial pollution is always a major problem in aquatic environments across the globe. Various sources, including the discharge of fecal matter, effluents from hospitals, industrial discharges, and runoff from cattle farms, contribute to an increase in bacterial loads within water bodies. Coliform bacteria, particularly Escherichia coli, have traditionally served as key indicators of microbial contamination, shaping perceptions of public health security [15].

Inadequate wastewater treatment exacerbates the problem, as treatment plants that are not well-designed, maintained, or appropriately sized may fail to effectively eliminate microbial contaminants. The lack of disinfection methods, such as chlorination or *UV* treatment, further compromises the ability to neutralize pathogenic microorganisms. *Combined sewer overflows (CSOs)* during heavy rainfall events can lead to the release of untreated sewage into water bodies, significantly increasing microbial pollution. "fail to eliminate microbial contaminants effectively".

Access to clean water is essential for the well-being of all living organisms. Unfortunately, as industry has come to develop too rapidly and populations are much larger than in the past, the contamination of existing water source is a worldwide problem[15].

Water demand in different sectors has been soaring, in particular that of agriculture where it is as high as 70% flows through irrigation channels, 20% of house consumption and 10 percent others such as industrial uses [16].

The major pollutants in water are heavy metal ions and dyes which threaten public health. After these pollutants have entered water sources, getting them out again becomes extremely difficult indeed [17].

Heavy metal ions can cause damage to ecosystems, and all living organisms. To counteract these effects and ensure safe drinking water, we must promptly remove these pollutants from polluted water: The improper disposal of septic tank systems, especially in places where there is no collective sewage treatment, may also result in untreated sewage entering the ground, and thus leachate contaminating groundwater. Farming practices are another factor that counts. Piling up animal manure and letting farm runoff flow straight into nearby water bodies may introduce microbial contaminants on a large scale into these bodies. Addressing microbial pollution in wastewater requires a multifaceted approach, including effective wastewater treatment through well-designed treatment plants, public awareness campaigns to promote proper waste disposal, and regular inspection and maintenance of sewer systems, septic tanks, and industrial facilities. By understanding and mitigating the sources of microbial pollution, communities can work towards safeguarding public health and the integrity of their water resources. There are different sources of wastewater as illustrated in Figure 1.

Figure 1: Varieties of Wastewater Sources

Wastewater is a liquid byproduct of municipal and industrial activities, comprising contaminants such as organic materials, microorganisms, and inorganic soluble compounds, including toxic heavy metals. These contaminants alter the chemical, biological, and physical properties of clean water [18]. Wastewater is categorized into municipal and industrial wastewater, originating from sources that often include feces, urine, industrial discharges, agricultural runoff, and a variety of domestic and organic-inorganic chemical compositions [19]. Different pollutants in water are depicted in Figure2.

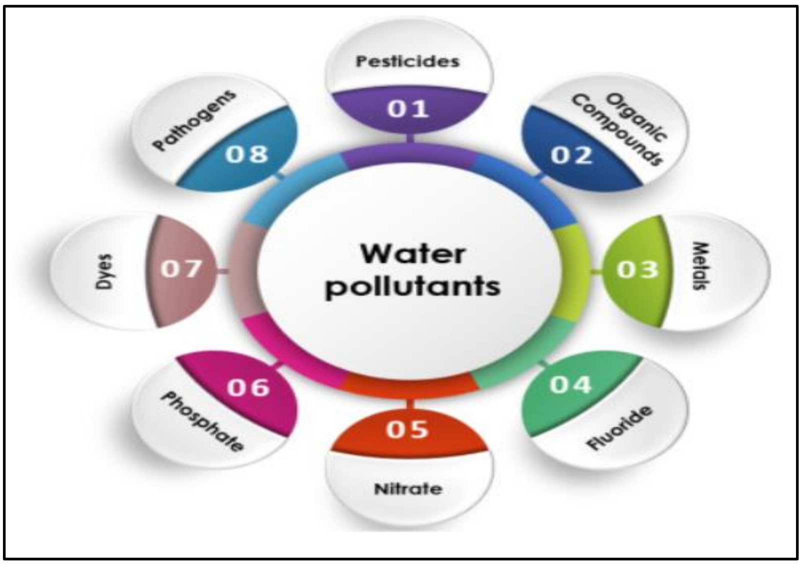

Figure 2: Various pollutants found in water

Escherichia coli

Escherichia coli, a member of the coliform group, is a reliable indicator of fecal contamination. Conventional methods, such as the multiple-tube fermentation technique, have been employed to detect coliforms in water samples. These are the acids and gas formed by the fermentation of lactose [20]. The potability of water is often estimated by the absence or presence of coliform bacteria within cut-off limits, as determined by reference to the Most Probable Number (MPN). 100 ml of water is the index value [21].

In addition to coliform bacteria, fecal streptococci, and Clostridium perfringens are also commonly used as indicators for fecal pollution. These alternatives are usually identified by means of special tests such as esculin hydrolysis, detection of catalase-negativity and/or sulfite reduction. Molecular techniques, such as polymerase chain reaction (PCR) and enzymatic methods have emerged as rapid and efficient modes for detecting indicators and other enterics in water samples. This represents an advance in water quality assessment [22]. This multi-faceted approach is necessary for safeguarding water quality and in consequence public health.

1.2 S*almonella* Bacteria

However, the most common route by which the *Salmonella* bacterium reaches wastewater channels is contamination from fecal matter. The presence of *Salmonella* in wastewater poses a potential health risk [22]. This wastewater carries with it the genetic seed of this disease.Although some intracellular bacteria are present in wastewater, gradually emerging as they breed, there is still a long way for waterworks to adopt full-scale treatment plants. The resilience of *Salmonella* enables its survival across diverse environmental conditions within wastewater, a capacity influenced by factors such as temperature, pH, and the coexistence of other microorganisms.

Earlier research efforts [23] have delved into the presence of *Salmonella* in wastewater; however, these studies have proven insufficient in offering comprehensive insights into the diversity and antibiotic resistance profiles of *Salmonella* [24]. Consequently, gaps persist in our understanding of *Salmonella* transmission through wastewater, its environmental impact, and the sources of contamination. In the specific context of Morocco, there has been limited discussion on *Salmonella* in wastewater, and the available bibliography is notably scarce. Addressing this research gap, our current work stands as the pioneering study on *Salmonella* in the southern region of Morocco. Our focus is on the identification, serotyping, and antibiotic susceptibility testing of *Salmonella* strains extracted from the Agadir wastewater treatment plant. This research aims to contribute significantly to the broader understanding of *Salmonella* dynamics in wastewater systems, shedding light on critical aspects of its presence and characteristics in the studied region.

2. The biosynthetic nanoparticles

The term "nano" originates from the Greek word "nanos," meaning "little," representing one billionth (10^9). Nanoparticles *(NPs)* define solid colloidal particles with at least one dimension ranging from 1 to 100 nm [25]. Notably, materials utilized in drug delivery often fall within the 100–200 nm range. Due to their distinctive electronic structure, high conductivity, extensive surface area, and quantum size effects, nanoparticles can undergo changes in their chemical and physical properties. Today, nanoparticles find applications in various fields, such as anti-viral treatments, cosmetics, electronics, and textiles [26,27]. The exploration of nanotechnology has unveiled numerous advantages, contributing significantly on a global scale. Nanotechnology has spurred the development of diverse material industries, including its expanding role in the food industry. Furthermore, its influence in the biomedical field is on the rise, promising enhanced outcomes in future medical applications [28,29].

Metallic nanoparticles have been the focus of extensive research owing to their distinctive properties, primarily attributed to their diminutive size. Gold (Au) nanoparticles find widespread application in drug delivery [30, 31]. Silver (Ag) nanoparticles exhibit potent antimicrobial properties effective against a spectrum of microorganisms, including bacteria, fungi, protozoa, and certain viruses [32,33]. Platinum (Pt) nanoparticles demonstrate commendable catalytic properties [34]. Copper (Cu) nanoparticles, known for their biocompatibility, are well-suited for applications in nanomedicine [35]. Palladium (Pd) nanoparticles, while extensively synthesized, are valued more for their robust catalytic prowess than for their antimicrobial attributes [36, 37].

Generally, In the synthesis and stabilization of nanoparticles various physical and chemical methods have been employed. Recently, nanoparticle synthesis has emerged as a captivating field of scientific exploration, with a growing emphasis on producing nanoparticles through environmentally sustainable approaches, often referred to as green chemistry. Green synthesis methods, such as mixed valence polyoxometalates, polysaccharides, Tollens, irradiation, and biological processes, offer advantages over conventional methods that involve chemical agents harmful to the environment. As described in Figure 3.

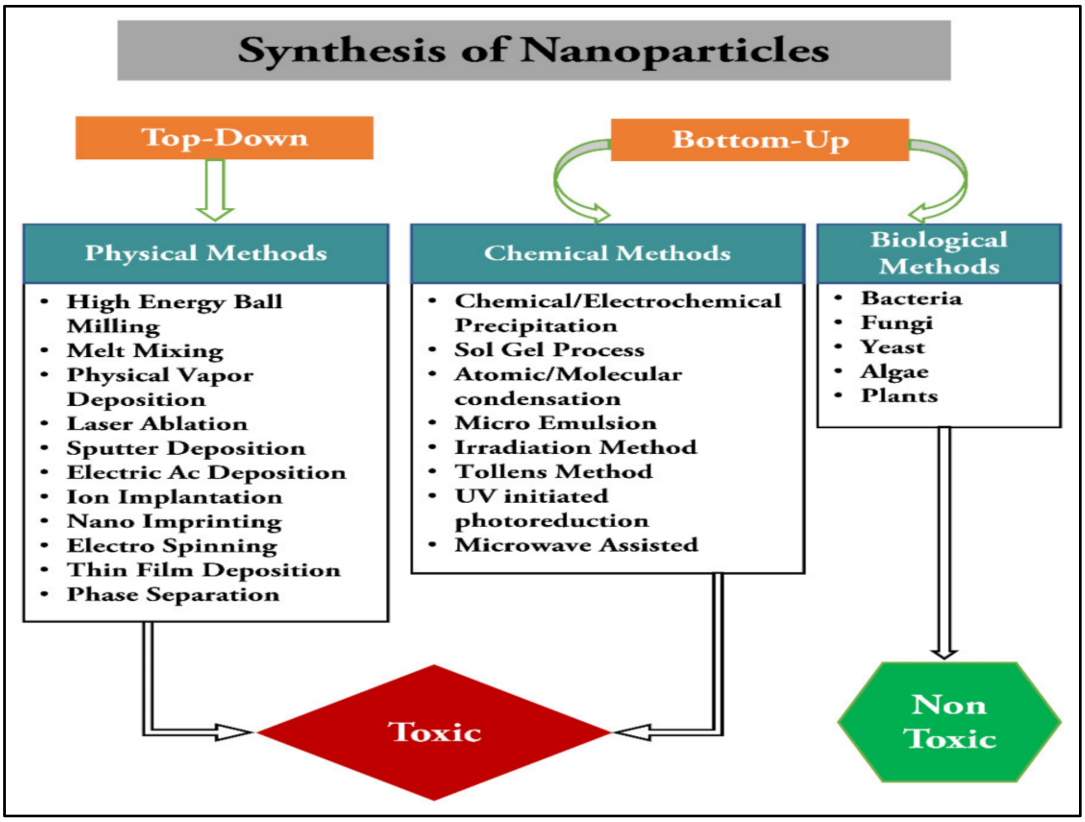

Figure 3: Diverse Methods Employed in Nanoparticle Synthesis

Classification of Nanoparticles

Nanoparticles are primarily categorized into two groups: organic and inorganic nanoparticles. Among the organic nanoparticles are carbon nanoparticles, including fullerenes. Conversely, inorganic nanoparticles encompass materials like gold, magnetic nanoparticles, silver, and semiconductor nanoparticles such as titanium dioxide and zinc oxide[38]. The appeal of inorganic nanoparticles has grown due to their superior material properties and functional utility. Their compact structure and advantages over chemical imaging agents and medications make them a promising tool for medical applications and disease treatment. Gold nanoparticles, for instance, have found extensive use in imaging, medication delivery, and thermotherapy targeting biological entities [39]. Both metallic and semiconductor inorganic nanoparticles exhibit core optical properties that can enhance the transparency of polymer-particle composites. Consequently, there is heightened interest in exploring the optical properties of inorganic nanoparticles in composite studies [40].

Carob

Carob *(C. siliqua L.)* is recognized as a medicinal plant indigenous to numerous Asian countries and prevalent in the Middle East [41]. Traditionally, the leaves and beans of this plant have been employed in herbal medicine, as documented by studies [42]. Furthermore, a series of investigations have delved into the impact of *P. farcta* on various physiological and pathological processes. Notably, animal studies have provided evidence regarding the influence of *P. farcta* seed extract. These studies have observed enhancements in serum catalase and superoxide dismutase activities, coupled with a reduction in liver concentrations of malondialdehyde [43]. Figure 3 shows the carob plant.

Figure 4: Carob Plant.

Nanoscale Oxides

Zinc oxide (ZnO)

Zinc oxide (ZnO) stands out as a distinctive material with multifaceted properties, showcasing semiconducting, piezoelectric, and pyroelectric characteristics. Employing a solid-vapor phase thermal sublimation technique, an array of nanostructures such as nano combs, nano rings, nano helixes/nano springs, nanobots, nanobelts, nanowires, and nanocages of ZnO has been successfully synthesized under carefully controlled growth conditions. These remarkable nanostructures unequivocally establish ZnO as perhaps the most diverse family of nanostructures across all materials, showcasing a richness in both structural variety and unique properties [44]. The potential applications of these nanostructures extend into various fields, including optoelectronics, sensors, transducers, and biomedical science, given its biocompatibility.

Zinc oxide nanoparticles release zinc ions "Zn+2" when exposed to a liquid medium. These ions can enter a bacterium and destroy the structure of the cells, thereby inhibiting the multiplication and growth of bacteria. ZnO nanoparticles can also have the ability to make reactive oxygen species (ROS) when placed under certain conditions, which accounts for their antibacterial properties. This reduces bacteria growth and increases their virulence to human cells. This action causes the structural integrity of the bacteria to be destroyed and their permeability increased. This process leads to disintegration of bacterial cells, with subsequent release of cell contents and death. This feature of ZnO is now a widely recognized one. In the case of E. coli the antibacterial properties of zinc oxide nanoparticles were also found. The zinc ions leaching out from them disturb cellular functions, block DNA replication, and excite oxidative stressors. These factors in combination make the surrounding environment uninhabitable for E. coli. ZnO, with its unique environmental properties, is a very promising new kind of catalytic material for treating dirty water. Some of its important attributes that contribute to this potential include: [45]

- Cost-effectiveness
- Abundant availability
- Non-toxic nature

Iron(III) oxide (Fe2O3)

The antimicrobial effect of iron (III) oxide "Fe2O3" nanoparticles can work in various ways, such as through oxidative stress or through the struction of bacteria cells by microbial cell components"Fe2O3"nanoparticles may interact mainly with the bacterial cell membrane and interior cellular components. This could lead to disordering of membrane integrity and the loss of cellular function. Studies are continuously made on the effects of iron(III) oxide on Escherichia coli *(E. coli)* [45]. While iron based nanoparticles have been researched for their antibacterial properties in general, the detailed mechanisms and responses of E. coli may be different and need further study. When iron oxide nanoparticles are used to remove dinitrophenol, they are effective and easy to handle, two of the features which have drawn widespread interest in recent years. This nanoporous powder has better hydrophilic properties than conventional materials, its specific surface area is larger, it is much stronger, and there are more nanometer-one particles. [46]. Nano adsorbents, including magnetic magnetite "Fe3O4", nonmagnetic hematite (α-Fe2O3), and magnetic maghemite (γ-Fe2O4), find frequent application in this context. The efficient separation and recovery of these nano adsorbents from contaminated water pose significant challenges in water treatment, primarily due to their small size.

However, Fe3O4 and γ-Fe2O4 stand out for their ease of separation and recovery from the system. Both have proven effective in the removal of various heavy metals from wastewater as sorbent materials [47,48]. Diverse methods have been employed for the synthesis of iron oxide nanoparticles, as illustrated in Figure 5.

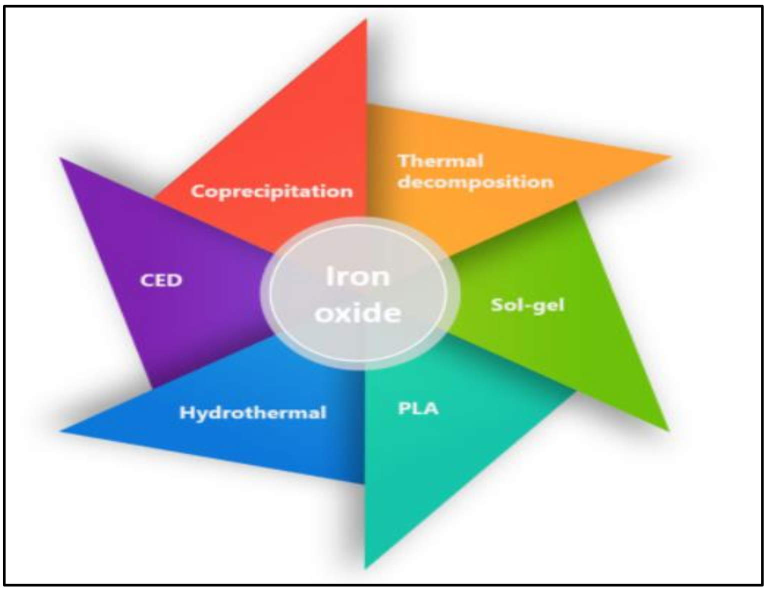

Figure 5: Primary Fabrication Approaches Employed in the Production of Iron Oxide Nanoparticles.

Nanoparticles containing iron oxides have been meticulously engineered to tailor their adsorption characteristics through the utilization of diverse ligands (such as L-glutathione, ethylenediaminetetraacetic acid, α-thio-ω-(propionic acid) hepta (ethylene glycol) (PEG-SH), mercaptobutyric acid, and meso-2,3-dimercaptosuccinic acid) [49], as well as polymers (including copolymers of crotonic acid and acrylic acid) [50]. Notably, a flexible ligand shell has been reported, facilitating the incorporation of a wide array of functional groups into the shell while maintaining the inherent properties of Fe3O4 nanoparticles [51]. Moreover, a polymer shell has been identified to prevent particle aggregation and enhance the stability of nanostructural dispersion [52]. Polymer molecules play a pivotal role as binders for metal ions, serving as a "carrier" for transporting metal ions from treated water [53].

Recent advancements in iron-based nanomaterials have showcased outstanding sorption capabilities owing to their elevated porosity, specific surface area, and robust magnetic response, resulting in remarkable sorption capacities [54,55]. The attention garnered by iron-based nanomaterials stems from their high BET surface area, superb magnetic properties, and substantial pore volume [56]. Various carbon forms, such as multiwall nanotubes expanded carbon and graphene, alongside paramagnetic particles like Fe2O3, have proven effective in removing toxic heavy metals such as Cd(II), Cu(II), and Pb(II) [57].

Silver oxide (Ag2O)

In the case of silver oxide "Ag2O", antimicrobial properties are primarily due to silver ions (Ag+). Whether placed in a moist environment or liquid medium, the release of these silver ions is the most crucial factor in killing off germs or similar microorganisms such as bacteria [58]. The reactivity of these silver ions is very high and they are able to pass through the cell walls and membranes of bacteria. Yet the ions cannot be absorbed by any part of the bacterial cell that is not membrane-bound [59]. Once inside a bacterial cell, silver ions impede the essential metabolic functions of life. These include enzyme activities and DNA replication processes. That damage to cellular functions leads ultimately to bacteriostasis (inhibition of bacterial growth) and even death of the cells themselves.

The lipid layer of bacteria cell walls is disrupted by silver ions. That allows impurities to form on this boundary and weakens the natural shield effect for outer cell coats; silver ions affect normal transport function which in turn increases detrimental events caused by these chemicals gathered just inside the bacterial body further compounding its effect. This usually results harmlessly for nearly any organism but a tough little devil such as bacteria will not shy away from taking nourishment breaks Ionous Activity and Lipoidal Inactivation In the end, when silver ion activity interferes with the DNA replication process, there can only be harm for our microorganisms. It attaches to DNA molecules and prevents their accurate reproduction, adding insult to injury by activating bacterial activity in a way that poisons the whole cell.

In the case of Escherichia coli *(E. coli)*, silver oxide achieves its killing purpose through cell membrane disintegration. The junction is highly active herbicides like Lforms Most UTIs are caused by specialized Escherichia coli (E. coli) strains referred to as uropathogenic E. coli (UPEC). UPEC possess a variety of virulence factors (VFs), which the organism uses to attach, invade, and injure the host. The silver ions come into contact with the lipid layer of E. coli's cell membrane:r rupture and permeability are both raised heavily. This destruction leads to the release of cellular contents and seriously undermines the structural integrity of the bacterium's life-factory. In addition, silver ions hinder reproduction of DNA in E. coli through their binding with DNA molecules, hence preventing proper replication. The level of reactive oxygen species *(ROS)* within a bacterial cell induces strain on its metabolism which disrupts biochemistry tubule: block up what flows through paint thinner. It can be regarded as an oxidant and noxious byproduct mixed in with unfinished gasoline, which causes greater destruction to its vascular organs and keeps it from living anymore [60].

Nanosilver oxide significantly distinguishes itself from the other substances with known intensity of antibacterial and antimicrobial properties. The reason it is so effective is that in bacteria, "Nanosilver oxide is widely applied in medical devices, antibacterial textiles, and disinfectants, nanosilver oxide distinguishes itself for its versatile antimicrobial capabilities and pivotal role in advancing diverse. This is mainly a result of its on the bacterial cell wall. This interference, in turn, extends to the bacterial cellular membrane. As a result, contents leak out through an opening in the cell itself (an apoptotic fit) [61]. Nanosilver oxide further contributes to its antimicrobial effects by inhibiting enzymes within bacterial cells, disrupting vital metabolic processes. At the nanoscale, it generates free radicals, causing damage to bacterial cellular structures, and partakes in chemical reactions that compromise essential bacterial functions. Noteworthy is nanosilver oxide's demonstrated ability to diminish antibiotic resistance in bacteria, augmenting its effectiveness. Widely applied in medical devices, antibacterial textiles, and disinfectants, nanosilver oxide distinguishes itself for its versatile antimicrobial capabilities and its pivotal role in advancing diverse applications.

3. Plants contributes to creating Nanoscale Oxides

There are some plants that can contribute to the formation of nanooxides, but this formation typically involves specific laboratory techniques. Some plant compounds could be employed in said process, while other compounds can not. For example, turmeric (Curcuma longa) contains curcumin, an effective compound for forming nano oxides. Research has shown that extracts from another popular herb, basil (Ocimum basilicum), help produce nano oxides. The antioxidants in green tea (Camellia sinensis) also may be helpful in forming nano oxides. In preparing nano oxides, compounds from ginger (Zingiber officinale) and garlic (Allium sativum) may be of use further Anyhow, however, when these plants are used for nano oxide formation.The final products will be effective and chemically stable is one thing that remains to be studied carefully.

4. Related works

There is evidence that photocatalysis may be used as an efficient means of disinfecting water, Baruah et al [62]. This involves a metal oxide to accelerate the removal of contaminants in carbon dioxide and water in place of vessel technologies. Photocatalysts of high energy gap Will The electrons in the valence band will be excited to the conduction band in positive charge and the valence band Electra should when materials with lower energy gaps are exposed to photons. The photogenerated electrons and holes play a crucial role in degrading microbial contaminants.

The photocatalytic efficacy of various concentrations of ZnO in contaminated water was examined by [63]. Synthesized from Zn(NO3)2 and (NH4)2CO3, ZnO with a particle size of 20–40 nm exhibited enhanced photocatalytic efficiency. The reduced particle size and the quantum confinement effect activated ZnO, resulting in the production of reactive oxygen species (ROS) and an increased decay constant for bacteria.

In a study by [64], lower ZnO concentrations were observed to exhibit antibacterial activity, attributed to smaller particle sizes or a relatively low salt/protein growth medium. This minimized nanoparticle coagulation and revealed that gram-positive Bacillus Subtilis was more affected than gram-negative Escherichia coli upon nanoparticle addition.

Ray et al. [65] explored the activation of ZnO in the laboratory using a small amount of UV or fluorescent light emitting 4% UV light. Results indicated that environmental laboratory conditions were sufficient for ZnO nanoparticulate biocidal activity, dependent on nanoparticle size. ZnO demonstrated antibacterial effectiveness under visible light.

The removal methods of commercial nanoparticles for water treatment were investigated by Zhang et al. [66], focusing on Fe2O3, ZnO, NiO, and SiO2. The behavior of metal oxide nanoparticles in water was found to depend on their physical properties and interaction with other water components.

Tso et al. [67] studied the stability of SiO2, ZnO, and TiO2 nanoparticles in water, showing that they quickly aggregate and precipitate in pure water. Ultrasound proved to be the most efficient method for nanoparticle dispersion in water. The stability of nanoparticles varied under different water conditions, with the presence of organic colloids accelerating aggregation.

Esmailzadeh et al. [68] tested nanocomposites of low-density polyethylene and ZnO against Bacillus subtilis and Enterobacter aerogenes, demonstrating a direct relationship between antimicrobial effect and ZnO nanoparticle concentration.

El Saeed et al. [69] observed antibacterial activities in ZnO polyurethane nanocomposites against gram-negative (Escherichia coli) and gram-positive "Bacillus subtilis" bacteria. Motshekga et al. [70] developed a nanocomposite with bentonite-supported silver and ZnO nanoparticles, showing ZnO's superior antibacterial activity.

Adams et al. reported antibacterial effects of ZnO nanoparticles against Bacillus subtilis and Escherichia coli [71], with no significant impact of particle size on activity.

Premanathan et al [72]. found that ZnO nanoparticles were more effective against gram-positive bacteria like Staphylococcus aureus than gram-negative bacteria like Escherichia coli. The growth reduction percentages varied for different bacteria and ZnO concentrations.

Iron oxide nanomaterials have emerged as effective agents in wastewater treatment, particularly for dye removal. Singh et al. [73] synthesized supermagnetic Fe3O4 nanoparticles coated with green tea polyphenols for efficient dye removal from aqueous solutions.

Es’haghzade et al. [74] employed magnetic iron oxide nanoparticles for the absorption of azo dye, demonstrating commendable dye removal performance across a wide range of pH levels.

Angamuthu et al. [75] innovatively prepared nanomaterial with an Fe3O4 mesoporous carbon shell, showcasing excellent catalytic activity in degrading methylene blue dye.

Ebrahiminezhad et al. [76] reported that processed iron nanoparticles exhibited a high potential for dye removal, achieving 95% efficiency in decolorization of methyl orange within six hours. Furthermore, Asfaram et al. [77] investigated the application of ultrasound-assisted Mn-doped Fe3O4 carbon nanoparticles in the removal of brilliant green and malachite green dyes.

Study Title	Authors	Description	Year
"Biosynthesis of Silver Nanoparticles: A Review"	Rai, M., Yadav, A., Gade, A. [78]	This paper examines the different ways that silver nanoparticles can be biosynthesised as well as their possible uses, such as their antimicrobial qualities.	2009
"Antibacterial Activity of Biosynthesized Copper Nanoparticles"	Suresh, A.K., Pelletier, D.A., Wang, W., et al.[79]	Investigates the antibacterial activity of biosynthesized copper nanoparticles and their potential role in water treatment processes.	2012
"Green Synthesis of Gold Nanoparticles: A Review"	Dreaden, E.C., Alkilany, A.M., Huang, X., et al.[80]	This review provides insights into the green synthesis methods of gold nanoparticles and discusses their applications, including antibacterial properties relevant to water treatment.	2012
"Biogenic Synthesis of Metal Nanoparticles and Their Antibacterial Potential"	Iravani, S. [81]	Explains the biogenic creation of metal nanoparticles, assesses their antibacterial efficacy, and discusses the implications for uses in water treatment.	2014
"Biosynthesis of Iron Oxide Nanoparticles and Their Applications in Water Treatment"	Patel, A., Apte, M., Hingankar, N., et al.[82]	Investigates the biosynthesis of iron oxide nanoparticles and explores their potential applications in water treatment, particularly in removing contaminants and pathogens.	2015
"Nanoparticles in Water Treatment: Opportunities and Challenges"	Zhang, et al . [83]	Provides an overview of the opportunities and challenges associated with the use of nanoparticles in water treatment, emphasizing the need for sustainable and effective solutions.	2016
"Impact of Nanoparticles on	Handy et al. [84]	Examines the effects of nanoparticles on aquatic	2018

Water Quality and Aquatic Ecosystems"		ecosystems and water quality, illuminating the possible drawbacks and advantages of using them to remediate water.	
"Silver Nanoparticles for Water Disinfection: A Review"	Rai et al. [85]	Examines how silver nanoparticles are used to sterilise water, going over their antibacterial properties and possible uses in treating diseases that are spread by water.	2019
"Applications of Titanium Dioxide Nanoparticles in Water Treatment"	Zhang et al.[86]	explains how titanium dioxide nanoparticles are used in water treatment, highlighting how their photocatalytic qualities can be used to break down contaminants and sanitise water.	2020
"Applications of Biosynthesized Nanoparticles in Water Treatment"	Sharma, et al. [87]	The various uses of biosynthesized nanoparticles in water treatment are covered in this paper, with an emphasis on how well they work to remove microbiological contaminants.	2020
"Heavy Metal Nanoparticles for Water Treatment: Synthesis, Applications, and Challenges"	Wang et al.[88]	Explores the synthesis methods, applications, and challenges associated with heavy metal nanoparticles for water treatment, highlighting their potential as antibacterial agents.	2021

Challenges

While promising, biosynthesized heavy metal nanoparticles face challenges like potential resistance development and scaling up production. Strategies must be developed to mitigate resistance and ensure long-term efficacy. Integrating these nanoparticles into existing treatment processes requires overcoming challenges related to scale-up and maintaining consistent performance. It is essential for comparison and reproducibility that the synthesis and characterization of materials and their performance should all be standardized. To achieve public acceptance, it was important to communicate transparently and educate the public as well. However, in the face of all these difficulties, looking for eco-friendly, cost-effective and yet highly effective antibacterial agents is still worthwhile for further research and development. One can illustrate the issue as follows:

- Safety Concerns: A serious concern is the safe application of heavy metal nanomaterials in water treatment for antibacterial purposes. If not properly managed, heavy metals can lead to human poisoning and environmental pollution--which is why tests of toxicity, risk assessment studies and evaluations are necessary.
- Environmental Impact: " In water treatment procedures which are carefully managed even if nanoparticle-sized heavy metal is released into the environment" aquatic ecosystems and biodiversity can be damaged. It is necessary to understand what are the possible long-term environmental impacts.
- Regulatory Compliance: Heavy metal nanoparticles can be a difficult set of chemicals to manage, which undergo regulations due to their particular circumstance as water treatment agents. It is necessary to make sure that these nanoparticles meet regulatory regulations in order to win large numbers of consumers.
- Cost-effectiveness: Making and using heavy metal nanoparticles will be costly. The biggest difficulty is how to apply it into water treatment facilities large scale and affordably at that. User contributed notes.
- Stability of Nanoparticles: To be effective in water treatment applications, biosynthesized nanoparticles must be stable. Various factors such as these need to be dealt with: aggregation degradation gradual loss of antibiotic activity. At the same time, these mechanisms provide ample ransomers which can lead directly into studies of natural wastewater treatment systems such as aseptic digestion and wetland lagoon bacteria filtering beds may also be studied from this point of view.
- Antibacterial Resistance: As a new disinfectant, heavy metal nanoparticles are bound to encounter the problem of resistance in the future. It is imperative to knock it out at an early stage. Strategies that can reduce and monitor resistance development are essential.
- Scale-up and Integration: Scaling up from laboratory experiments requires good work on how to add it to the existing treatment processes and what kind of performance you want. The technology must produce predictable results even in difficult circumstances.
- Characterization and Standardisation: Consensus on the synthesis procedures standardizes them so that people can repeat with comparable results, and similarly in characterizations and performance evaluations therefore this means through of how nanotechnologies are said to be real.
- Public Perception and Acceptance: The public may think of heavy metal nanoparticles used in water treatment differently from their favorite carbon filters. They may be afraid that by using "stronger" technology, something bad will happen in their bodies. Changing this set of attitudes calls for effective education and communication strategies, raising acceptability and trust among stakeholders.
- Durability and Long-term Efficacy: Only by continuous research and monitoring of biosynthesized heavy metal nanoparticles as antibacterial agents for water treatment can their long-term durability and efficacy be guaranteed. A longer-term study in real-world settings is needed.

CONCLUSION

Finally, the collected study indicates that biosynthetic heavy metal nanoparticles have outstanding potential for the removal of bacteria in water. Analyzing much previous literature, there are signs that with bio-synthesis the nanoparticles offer several advantages. These include their environmental compatibility, anti-bacterial effectiveness and potential concern of microbial contamination in drinking water supplies Although they hold great potential, some problems must be solved before biosynthesized heavy metal nanoparticles can be fully realized for use in water treatment. Such problems include human health and environmental safety, legislative restrictions and compliance considerations, expense and cost efficiency issues, stability of nanoparticles in water and during radiation process, antibacterial resistance, sample size requirements, integration into current treatment systems, characterization and reliability parameters and what to rely on. Public Quick removal? Long-term efficiency of operation.

Interdisciplinary collaboration among researchers, policymakers, process engineers, industry stakeholders, and regulatory bodies will be vital to surmount these challenges and realize the responsible development and deployment of biosynthesized heavy metal nanoparticles in water treatment. After confirming their effectiveness, safety, scale and any other emerging issues from researching moves to normal levels for R&D funding this rapidly.

REFERENCES

1. Bashir I, Lone FA, Bhat RA, Mir SA, Dar ZA, Dar SA. Concerns and Threats of Contamination on Aquatic Ecosystems. 2020.
2. Amoatey P, Baawain MS. Effects of pollution on freshwater aquatic organisms. Water Environ Res. 2019;91(10):1272-87.
3. Sharma A, Sharma A, Sharma M, Navneet S. M.: A Review on Impact of Water Pollution on Aquatic Ecosystem. Current Research and Innovations in Life Sciences, Eds Sharma, AK, Thakur, R, Sharma, M and Sharma, M. 2021:129-48.
4. Jamieson R, Gordon R, Joy D, Lee H. Assessing microbial pollution of rural surface waters: A review of current watershed scale modeling approaches. Agricultural Water Management. 2004;70(1):1-17.
5. Kløve B, Margrethe H, Kvitsand L, Pitkänen T, Gunnarsdottir MJ, Gaut S, et al. Overview of groundwater sources and water-supply systems, and associated microbial pollution, in Finland, Norway and Iceland. Hydrogeology Journal. 2017;25(4):1033.
6. Hua, G., Zhang, S., Pan, B., Yang, Y., & Lv, L. (2016). Disinfection byproducts in drinking water: Formation, occurrence, and health effects. Frontiers in Chemistry, 4, 15.
7. Zhang, Y., Maraccini, S., & Kim, Y. (2020). Combating antibiotic-resistant bacteria using nanomaterials. Chemical Society Reviews, 49(8), 2860-2899.
8. Iravani, S. (2011). Green synthesis of metal nanoparticles: mechanisms and applications. Chemical Communications, 47(1), 303-321.
9. Ahmad, N., Sharma, S., Singh, S., Shamsi, S., &najeeb, M. (2019). Synthesis of silver nanoparticles using plant extracts and their applications in biomedicine. Environmental Science and Pollution Research, 26(8), 7618-7638.
10. Ingle, A. P., Gade, A. K., & Rai, M. (2014). Mycosynthesis of silver nanoparticles and their enhanced antifungal activity against Candida albicans. Nanoscale research letters, 9(1), 1-8.
11. Saxena A, Tripathi RM, Zafar F, Singh P. Green synthesis of silver nanoparticles using aqueous solution of Ficus benghalensis leaf extract and characterization of their antibacterial activity. Materials Letters. 2012;67(1):91-4.
12. Saravanan A, Kumar PS, Karishma S, Vo DN, Jeevanantham S, Yaashikaa PR, et al. A review on biosynthesis of metal nanoparticles and its environmental applications. Chemosphere. 2021;264(Pt 2):128580.
13. Saif S, Tahir A, Chen Y. Green synthesis of iron nanoparticles and their environmental applications and implications. Nanomaterials. 2016;6(11):209.
14. Some, Sudip, et al. "Microbial pollution of water with special reference to coliform bacteria and their nexus with environment." Energy Nexus 1 (2021): 100008.
15. Ali, Imran, and Hassan Y. Aboul-Enein. Chiral pollutants: distribution, toxicity and analysis by chromatography and capillary electrophoresis. John Wiley & Sons, 2005.
16. Helmer, Richard, and Ivanildo Hespanhol. Water pollution control: a guide to the use of water quality management principles. CRC Press, 1997.
17. Rai, Harpreet Singh, et al. "Removal of dyes from the effluent of textile and dyestuff manufacturing industry: a review of emerging techniques with reference to biological treatment." Critical reviews in environmental science and technology 35.3 (2005): 219-238.

18. K. M. M. Abou El-Nour, A. Eftaiha, A. Al-Warthan, and R. A. A. Ammar, “Synthesis and applications of silver nanoparticles,” Arab. J. Chem., vol. 3, no. 3, pp. 135–140, Jul. 2010.
19. L. K. Adams, D. Y. Lyon, and P. J. J. Alvarez, “Comparative eco-toxicity of nanoscale TiO2, SiO2, and ZnO water suspensions,” Water Res., vol. 40, no. 19, pp. 3527–3532, Nov. 2006.
20. Rompre, Annie, et al. "Detection and enumeration of coliforms in drinking water: current methods and emerging approaches." Journal of microbiological methods 49.1 (2002): 31-54.
21. Balogun, S. A., et al. "Bacteriological pollution indicators in Ogun River flowing through Abeokuta metropolis." Journal of Science and Technology (Ghana) 36.3 (2016): 54-63.
22. A. El Boulani, R. Mimouni, H. Mannas, F. Hamadi, and N. Chaouqy, ‘Salmonella in Wastewater: Identification, Antibiotic Resistance and the Impact on the Marine Environment’, Current Topics in Salmonella and Salmonellosis. InTech, Apr. 05, 2017. doi: 10.5772/67298.
23. Koivunen, Jari, Anja Siitonen, and Helvi Heinonen-Tanski. "Elimination of enteric bacteria in biological–chemical wastewater treatment and tertiary filtration units." Water research 37.3 (2003): 690-698.
24. Chahal C, van den Akker B, Young F, Franco C, Blackbeard J, Monis P. Pathogen and Particle Associations in Wastewater: Significance and Implications for Treatment and Disinfection Processes. Adv Appl Microbiol. 2016;97:63-119. doi: 10.1016/bs.aambs.2016.08.001. Epub 2016 Sep 15. PMID: 27926432; PMCID: PMC7126130.
25. Emami Moghaddam S.A., Ghadam P., Rahimzadeh F. Biosynthesis of cadmium sulfide nanoparticles using aqueous extract of Lactobacillus acidophilus along with its improvement by response surface methodology. J. Clean. Prod. 2022;356:131848.
26. Xiang H., Meng J., Shao W., Zeng D., Ji J., Wang P., Zhou X., Qi P., Liu L., Yang S. Plant protein-based self-assembling core–shell nanocarrier for effectively controlling plant viruses: Evidence for nanoparticle delivery behavior, plant growth promotion, and plant resistance induction. Chem. Eng. J. 2023;464:142432.
27. Yazdanian M., Rostamzadeh P., Rahbar M., Alam M., Abbasi K., Tahmasebi E., Tebyaniyan H., Ranjbar R., Seifalian A., Yazdanian A. The Potential Application of Green-Synthesized Metal Nanoparticles in Dentistry: A Comprehensive Review. Bioinorg. Chem. Appl. 2022;2022:2311910. doi: 10.1155/2022/2311910.
28. Elizabeth M.K., Devi R.U., Raja K.P., Krishna K.B. Synthesis of Phyto Based Metal Nanoparticles: A Green Approach. J. Pharm. Res. Int. 2022;34:20–32. doi: 10.9734/jpri/2022/v34i25A35944.
29. Mubarik N., Gulelala G., Iqbal S., Shahmeel M., Hussain A.A., Razzaq K., Akram M.N. Different Methods, Novel Tools towards the Synthesis of Nanoparticles and Applications in Engineering, Chemical, Physical Sciences and Technology. Sch. Bull. 2022;8:71–74. doi: 10.36348/sb.2022.v08i02.004.
30. M. R. Papasani, G. Wang, and R. A. Hill, "Gold nanoparticles: The importance of physiological principles to devise strategies for targeted drug delivery," Nanomedicine: Nanotechnology, Biology and Medicine, vol. 8, pp. 804-814.
31. S. Rana, A. Bajaj, R. Mout, and V. M. Rotello, "Monolayer coated gold nanoparticles for delivery applications," Advanced Drug Delivery Reviews, vol. 64, pp. 200-216, 2012.
32. C. Ramteke, T. Chakrabarti, B. K. Sarangi, and R.-A. Pandey, "Synthesis of silver nanoparticles from the aqueous extract of leaves of Ocimum sanctum for enhanced antibacterial activity," Journal of Chemistry, vol. 2013, 2012.
33. G. M. Sulaiman, W. H. Mohammed, T. R. Marzoog, A. A. A. AI-Amiery, A. A. H. Kadhum, and A. B. Mohamad, "Green synthesis, antimicrobial and cytotoxic effects of silver nanoparticles using Eucalyptus chapmaniana leaves extract," Asian Pacific Journal of Tropical Biomedicine, vol. 3, pp. 58- 63.2013.
34. A. Ravindran, P. Chandran, and S. S. Khan, "Biofunctionalized silver nanoparticles: Advances and prospects," Colloids and Surf. B, vol. 105, pp. 342-352, 2013.
35. S. Harne, A. Sharma, M. Dhaygude, S. Joglekar, K. Kodam, and M. Hudlikar, "Novel route for rapid biosynthesis of copper nanoparticles using aqueous extract of Calotropis pro cera L. latex and their cytotoxicity on tumor cells," Colloids and Surf. B, vol. 95, pp. 284-288, 2012.

36. O. Metin, E. Kayhan, S. Ozkar, and J. J. Schneider, "Palladium nanoparticles supported on chemically derived graphene: An efficient and reusable catalyst for the dehydrogenation of ammonia borane," International Journal of Hydrogen Energy, vol. 37, pp. 8161-8169,2012.
37. K. Amarnath, J. Kumar, T. Reddy, V. Mahesh, S. R. Ayyappan, and .T. Nellore, "Synthesis and characterization of chitosan and grape polyphenols stabilized palladium nanopartic1es and their antibacterial activity," Colloids and Surf. B, vol. 92, pp. 254- 261,2012.
38. Raj, S.; Trivedi, R.; Soni, V. Biogenic Synthesis of Silver Nanoparticles, Characterization and Their Applications—A Review. Surfaces 2022, 5, 67-90. https://doi.org/10.3390/surfaces5010003.
39. Cheon, J.; Horace, G. Inorganic nanoparticles for biological sensing, imaging and therapeutics. J. Mater. Chem. 2009, 19, 6249–6250.
40. Bhattacharyya, A.; Datta, P.S.; Chaudhuri, P.; Barik, B.R. Nanotechnology-A new frontier for food security in socio economic development. In Proceedings of the Disaster risk Vulnerablity Conference, Kottayam, India, 16–18 February 2011; 2011; pp. 116–120.
41. Pasiecznik, N. M., Phil JC Harris, and Steve J. Smith. Identifying tropical Prosopis species: a field guide. Coventry, UK: Hdra Publishing, 2004.
42. Ali-Shtayeh, Mohammed S., et al. "Traditional knowledge of wild edible plants used in Palestine (Northern West Bank): a comparative study." Journal of Ethnobiology and Ethnomedicine 4 (2008): 1-13.
43. Mohammad Pour Zehab, Maryam, et al. "The effect of Syrian mesquite (Prosopis farcta) seed extract on thioacetamide-induced oxidative stress in rats." KAUMS Journal (FEYZ) 22.1 (2018): 25-30.
44. Wang, Zhong Lin. "Nanostructures of zinc oxide." Materials today 7.6 (2004): 26-33.
45. Chavali, M.S., Nikolova, M.P. Metal oxide nanoparticles and their applications in nanotechnology. SN Appl. Sci. 1, 607 (2019). https://doi.org/10.1007/s42452-019-05923
46. Nizamuddin, Sabzoi, et al. "Iron oxide nanomaterials for the removal of heavy metals and dyes from wastewater." Nanoscale materials in water purification (2019): 447-472.
47. Y. Lei, F. Chen, Y. Luo, L. Zhang Three-dimensional magnetic graphene oxide foam/Fe3O4 nanocomposite as an efficient absorbent for Cr(VI) removal J. Mater. Sci., 49 (12) (2014), pp. 4236-4245.
48. A.-F. Ngomsik, A. Bee, D. Talbot, G. Cote Magnetic solid-liquid extraction of Eu(III), La(III), Ni(II) and co(II) with maghemite nanoparticles Sep. Purif. Technol., 86 (Feb. 2012), pp. 1-8.
49. C.L. Warner, et al. High-performance, superparamagnetic, nanoparticle-based heavy metal sorbents for removal of contaminants from natural waters ChemSusChem, 3 (6) (Jun. 2010), pp. 749-757.
50. F. Ge, M.-M. Li, H. Ye, and B.-X. Zhao, "Effective removal of heavy metal ions Cd2+, Zn2+, Pb2+, Cu2+ from aqueous solution by polymer-modified magnetic nanoparticles," J. Hazard. Mater., vol. 211–212, pp. 366–372, Apr. 2012.
51. R.A. Khaydarov, R.R. Khaydarov, O. Gapurova Water purification from metal ions using carbon nanoparticle-conjugated polymer nanocomposites Water Res., 44 (6) (Mar. 2010), pp. 1927-1933.
52. S.-H. Huang, D.-H. Chen Rapid removal of heavy metal cations and anions from aqueous solutions by an amino-functionalized magnetic nano-adsorbent J. Hazard. Mater., 163 (1) (2009), pp. 174-179.
53. Y. Pang, et al. Preparation and application of stability enhanced magnetic nanoparticles for rapid removal of Cr(VI) Chem. Eng. J., 175 (2011), pp. 222-227.
54. J. Bartram Water Quality Monitoring: A Practical Guide to the Design and Implementation of Freshwater Quality Studies and Monitoring Programmes Taylor & Francis (1996).
55. S. Baruah, S.K. Pal, J. Dutta Nanostructured Zinc Oxide for Water Treatment Nanoscience & Nanotechnology-Asia, 2 (2) (2012), pp. 90-102.
56. M.A. Gondal, M.A. Dastageer, A. Khalil, K. Hayat, Z.H. Yamani Nanostructured ZnO synthesis and its application for effective disinfection of Escherichia coli microorganism in water J. Nanopart. Res., 13 (2011), pp. 3423-3430.
57. L. K. Adams, D. Y. Lyon, and P. J. J. Alvarez, "Comparative eco-toxicity of nanoscale TiO2, SiO2, and ZnO water suspensions," Water Res., vol. 40, no. 19, pp. 3527–3532, Nov. 2006.
58. Terlizzi, M. E., Gribaudo, G., & Maffei, M. E. (2017). UroPathogenic Escherichia coli (UPEC) infections: virulence factors, bladder responses, antibiotic, and non-antibiotic antimicrobial strategies. Frontiers in microbiology, 8, 1566.

59. Yin, I. X., Zhang, J., Zhao, I. S., Mei, M. L., Li, Q., & Chu, C. H. (2020). The antibacterial mechanism of silver nanoparticles and its application in dentistry. International journal of nanomedicine, 2555-2562.
60. S. Baruah, S.K. Pal, J. Dutta Nanostructured Zinc Oxide for Water Treatment Nanoscience & Nanotechnology-Asia, 2 (2) (2012), pp. 90-102.
61. C. Tso, C. Zhung, Y. Shih, Y.-M. Tseng, S. Wu, R. Doong Stability of metal oxide nanoparticles in aqueous solutions Water Sci. Technol., 61 (1) (2010), pp. 127-133
62. L. K. Adams, D. Y. Lyon, and P. J. J. Alvarez, "Comparative eco-toxicity of nanoscale TiO2, SiO2, and ZnO water suspensions," Water Res., vol. 40, no. 19, pp. 3527–3532, Nov. 2006.
63. B. Ray, N. Jones, A.C. Manna, K.T. Ranjit Antibacterial activity of ZnO nanoparticle suspensions on a broad spectrum of microorganisms FEMS Microbiol. Lett, 279 (1) (2008), pp. 71-76.
64. Y. Zhang, Y. Chen, P. Westerhoff, K. Hristovski, J.C. Crittenden Stability of commercial metal oxide nanoparticles in water Water Res, 42 (8) (Apr. 2008), pp. 2204-2212.
65. C. Tso, C. Zhung, Y. Shih, Y.-M. Tseng, S. Wu, R. Doong Stability of metal oxide nanoparticles in aqueous solutions Water Sci. Technol., 61 (1) (2010), pp. 127-133
66. H. Esmailzadeh, P. Sangpour, F. Shahraz, J. Hejazi, and R. Khaksar, "Effect of nanocomposite packaging containing ZnO on growth of Bacillus subtilis and Enterobacter aerogenes," Mater. Sci. Eng. C. 58, pp. 1058–1063, Jan. 2016.
67. A. M. El Saeed, M. A. El-Fattah, and A. M. Azzam, "Synthesis of ZnO nanoparticles and studying its influence on the antimicrobial, anticorrosion and mechanical behavior of polyurethane composite for surface coating," Dye. Pigment., vol. 121, pp. 282–289, Oct. 2015.
68. S.C. Motshekga, S.S. Ray, M.S. Onyango, M.N.B. Momba Preparation and antibacterial activity of chitosan-based nanocomposites containing bentonite-supported silver and zinc oxide nanoparticles for water disinfection Appl. Clay Sci, 114 (Sep. 2015), pp. 330-339.
69. Adams, L. K., Lyon, D. Y., McIntosh, A., & Alvarez, P. J. J. (2006). Comparative toxicity of nano-scale TiO2, SiO2 and ZnO water suspensions. Water Science and Technology, 54(11-12), 327-334.
70. M. Premanathan, K. Karthikeyan, K. Jeyasubramanian, G. Manivannan Selective toxicity of ZnO nanoparticles toward gram-positive bacteria and cancer cells by apoptosis through lipid peroxidation Nanomedicine Nanotechnology, Biol. Med., 7 (2) (2011), pp. 184-192.
71. K.K. Singh, K.K. Senapati, K.C. Sarma Synthesis of superparamagnetic Fe3O4 nanoparticles coated with green tea polyphenols and their use for removal of dye pollutant from aqueous solution J. Environ. Chem. Eng., 5 (3) (2017), pp. 2214-2221,
72. Z. Es'haghzade, E. Pajootan, H. Bahrami, M. Arami Facile synthesis of Fe3O4 nanoparticles via aqueous based electro chemical route for heterogeneous electro-Fenton removal of azo dyes J. Taiwan Inst. Chem. Eng., 71 (2017), pp. 91-105.
73. M. Angamuthu, G. Satishkumar, M.V. Landau Precisely controlled encapsulation of Fe3O4 nanoparticles in mesoporous carbon nanodisk using iron based MOF precursor for effective dye removal Microporous Mesoporous Mater., 251 (2017), pp. 58-68.
74. A. Ebrahiminezhad, S. Taghizadeh, Y. Ghasemi, A. Berenjian Green synthesized nanoclusters of ultra-small zero valent iron nanoparticles as a novel dye removing material Sci. Total Environ., 621 (Apr. 2018), pp. 1527-1532.
75. A. Asfaram, M. Ghaedi, S. Hajati, A. Goudarzi, E.A. Dil Screening and optimization of highly effective ultrasound-assisted simultaneous adsorption of cationic dyes onto Mn-doped Fe3O4-nanoparticle-loaded activated carbon Ultrason. Sonochem., 34 (2017), pp. 1-12.
76. Rai, M., Yadav, A., & Gade, A. (2009). Biosynthesis of Silver Nanoparticles: A Review.
77. Suresh, A.K., Pelletier, D.A., Wang, W., et al. (2012). Antibacterial Activity of Biosynthesized Copper Nanoparticles.
78. Dreaden, E.C., Alkilany, A.M., Huang, X., et al. (2012). Green Synthesis of Gold Nanoparticles: A Review.
79. Iravani, S. (2014). Biogenic Synthesis of Metal Nanoparticles and Their Antibacterial Potential.
80. Patel, A., Apte, M., Hingankar, N., et al. (2015). Biosynthesis of Iron Oxide Nanoparticles and Their Applications in Water Treatment.
81. Zhang, H., Chen, G. (2016). Nanoparticles in Water Treatment: Opportunities and Challenges.

82. Handy, R.D., Owen, R., Valsami-Jones, E. (2018). Impact of Nanoparticles on Water Quality and Aquatic Ecosystems.
83. Rai, M., Ingle, A.P., Gupta, I., et al. (2019). Silver Nanoparticles for Water Disinfection: A Review.
84. Zhang, X., Li, S., Wang, Z., et al. (2020). Applications of Titanium Dioxide Nanoparticles in Water Treatment
85. Sharma, V., Shukla, R., Pandit, V., et al. (2020). Applications of Biosynthesized Nanoparticles in Water Treatment.
86. Wang, Y., Zhao, J., Li, D., et al. (2021). Heavy Metal Nanoparticles for Water Treatment: Synthesis, Applications, and Challenges.