Life Science Informatics Publications
Research Journal of Life Sciences, Bioinformatics, Pharmaceutical and Chemical Sciences
Journal Home page http://www.rjlbpcs.com/
RJLBPCS
ISSN 2454-6348

Original Review Article

DOI: 10.26479/2023.0903.03

GREEN SYNTHESIS OF IRON-BASED NANOPARTICLES AND ITS APPLICATIONS IN WATER TREATMENT PLANTS -A REVIEW

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ABSTRACT: With an emphasis on the utilization of iron-based nanoparticles, the supplied material offers an introduction to nanotechnology and its applications in wastewater treatment. It describes the many techniques for creating nanoparticles, such as top-down and bottom-up procedures. The benefits of using nanoparticles for drug administration over traditional techniques are outlined, with a focus on their potential to improve solubility, bioavailability, pharmacological activity, prolonged drug delivery, and reduced adverse effects. The effects of temperature, pressure, time, particle size and shape, preparation cost, and pore size on the synthesis of nanoparticles are reviewed. The different synthesis techniques are then surveyed, including bottom-up techniques like sol-gel synthesis, colloidal precipitation, and hydrothermal synthesis, and top-down techniques like physical vapor deposition and chemical vapor deposition. Due to their superior adsorption capacity and reactive nature, the emphasis is now on the utilization of iron-based nanoparticles in wastewater treatment. There are several types of iron-based nanoparticles that are studied, including metallic zerovalent iron, iron oxy-hydroxide ($Fe(OH)_3$), hematite (α- Fe_2O_3), maghemite (γ-Fe_2O_3), and magnetite (Fe_3O_4). Co-precipitation is the most often utilized method for producing iron oxide nanoparticles, and the production processes for these nanoparticles are described. Goethite (α-FeOOH) production techniques, such as chemical precipitation and solvothermal synthesis, are presented. There are offered examples of research studies on goethite synthesis. The publication gives a general overview of the use of nanotechnology in wastewater treatment and focuses particularly on the creation and use of iron-based nanoparticles.

Keywords: Iron nanoparticles, Green Synthesis, Water pollution, Treatment plants, Applications.

Article History: Received: May 20, 2023; Revised: June 06, 2023; Accepted: June 24, 2023.

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1. INTRODUCTION

“Nanotechnology is the application of science to control matter at the molecular level”[1]. The capacity to measure, observe, manipulate, and make objects on an atomic or molecular size, typically between one and 100 nanometers, is referred to as nanotechnology. These microscopic products also have a high surface area to volume ratio, which is the primary reason for their widespread application in mechanics, optics, electronics, biotechnology, microbiology, environmental remediation, medicine, a variety of engineering professions, and material science [2,3]. Currently, two methodologies are employed to manufacture nanoparticles: top-down and bottom-up approaches. Briefly, in the top-down approach, nanoparticles are produced by reducing the size of bulk material using lithographic techniques and mechanical techniques such as machining and grinding, etc., whereas, in the bottom-up approach, small building blocks are assembled into a larger structure, for example, chemical synthesis [2,4] . However, the bottom-up strategy, in which a nanoparticle is "grown" from smaller molecules known as reaction precursors, is the most accepted and efficient method for creating nanoparticles. By varying precursor amounts and reaction conditions, it may be feasible to regulate the nanoparticle's size and form depending on its intended use (temperature, pH, *etc.*)[2,3]. Materials with nanostructures have distinctive physical and chemical properties that make them useful in a wide range of disciplines, including biomedical sciences, optics, magnetism, mechanics, catalysis, and energy sciences[5]. The creation, characterization, and manipulation of nanoscale structures are some of the various features of this innovative technology. There are many distinct manufacturing processes in use, and they often include processing atomistic, molecular, and particulate matter in a vacuum or a liquid medium. The majority of the methods waste a lot of resources and utilize energy and materials inefficiently[5].

Different researchers have reported on several kinds of nanomaterials. Some of the nanomaterials employed today include nanoscale metal oxide and chalcogenide semiconductor photocatalysts, polymer nanoparticles, zeolites, carbon-based nanomaterials, self-assembled monolayer on mesoporous substrates (SAMMS), biopolymers, and metal-based nanoparticles. Among these, metal oxide nanoparticles such as titanium dioxide (TiO_2), zinc oxide (ZnO), iron oxide (Fe_2O_3/Fe_3O_4), and cerium oxide (CeO_2) exhibit high reactivity and photolytic properties against wastewater and act as a great adsorbent for water purification due to their large surface area and their affinity towards various functionalized groups [2,3-5]. The high adsorption ability of these nanoparticles for various

1pollutants in water and wastewater is a benefit. These qualities result from possessing special qualities including strong reactivity, selectivity, a sizable surface area, and a high degree of functionalization. They are useful for water and wastewater purification because of their capacity to oxidize, precipitate, reduce, and adsorb pollutants such as nitroaromatic compounds, inorganic anions, phosphates, radio elements, nitrates, phenols, organic dyes, and chlorinated and halogenated organic compounds. Due to their lower cost and second-highest prevalence on Earth, iron-based nanoparticles have attracted more interest than metal-based nanoparticles for removing pollutants from wastewater [5]. Conventional wastewater treatment techniques typically use physical, chemical, and/or biological means of removing solids like colloids, soluble pollutants (metals, organics, etc.), organic matter, and nutrients. The most traditional techniques for treating wastewater are flocculation, precipitation, biodegradation, filtration (with gavels, sands, and other materials), and adsorption. Sewage water, industrial wastewater, and incorrect pesticide, fertilizer, and oil spills in agricultural systems are the primary causes of water and soil pollution. Meanwhile, the rapid advancement of nanotechnology has heightened interest in the application of nanomaterials in improved systems for managing and cleaning toxins in the water, soil, and air components. The adsorption method is among the most cost-effective, simple, frequently utilized, and ecologically benign. Because of its high sorption capacity, activated carbon is one of the most researched and effective nanoporous sorbents. However, its application has been limited because of its high cost, low selectivity, and regeneration issues, making it unsustainable, and researchers have shifted their focus to iron-based nanomaterials[6].

2.0 NANOPARTICLE SYNTHESIS:

Chemical or biological processes can be used to create nanoparticles. Due to the presence of some harmful chemicals absorbed on the surface, chemical manufacturing processes have been linked to several negative consequences. Utilizing microbes, enzymes, fungi, plants, or plant extracts, biological techniques of synthesizing nanoparticles are environmentally acceptable alternatives to chemical and physical processes. The creation of these environmentally benign processes for synthesizing nanoparticles is becoming a significant area of nanotechnology, particularly for silver nanoparticles, which have several uses [3,7–14].

2.1 ADVANTAGES OF NANOPARTICLES:

Table 1 lists the benefits that nanoparticles have over conventional medication delivery methods[6].

Advantages of Nanoparticles
Enhancement of solubility and bioavailability
Enhancement of pharmacological activity
Sustained drug delivery
Protection from degradation
Enhancement of permeability
Decreased side effects compared to conventional drug delivery
Improved therapeutic effect

2.2 FACTORS AFFECTING THE SYNTHESIS OF NANOPARTICLES–

1. Temperature
2. Pressure
3. Time
4. Particle size and shape
5. Cost of preparation
6. Pore size

2.3 METHODS OF SYNTHESIS:

2.3.1 TOP-DOWN STRATEGY:

The top-down method begins with macroscopic structures. The processes begin with bigger particles that are converted to nanoparticles through a series of activities. The primary disadvantages of these systems are that they require vast installations and a considerable amount of cash to set up. The processes are highly costly and unsuitable for mass manufacturing. The procedure is ideal for laboratory testing. The method is based on material grinding. These approaches are ineffective for soft material [2,3].

2.3.1.1 METHODS IN TOP-DOWN STRATEGY:

1. Physical vapor deposition.
2. Chemical vapor deposition
3. Ion implantation
4. Electron beam lithography
5. X-ray lithography

2.3.2 BOTTOM-UP STRATEGY

Bottom-up techniques for nanomaterial synthesis include shrinking material components to the atomic level, with an additional step leading to the formation of nanostructures. Physical forces at the nanoscale merged basic components into bigger stable structures as the process progressed. The approach is primarily based on the molecular recognition concept (self-assembly). Self-assembly entails learning more and more about one's species from oneself. Many of these approaches are still under research or are only now being utilized commercially to produce nanoparticles [2,3].

2.3.2.1 METHODS IN A BOTTOM-UP STRATEGY:

1. Sol-gel synthesis
2. Colloidal precipitation
3. Hydrothermal synthesis
4. Organometallic chemical route
5. Electrodeposition

2.4 SYNTHESIS TECHNIQUES FOR NANOPARTICLES:

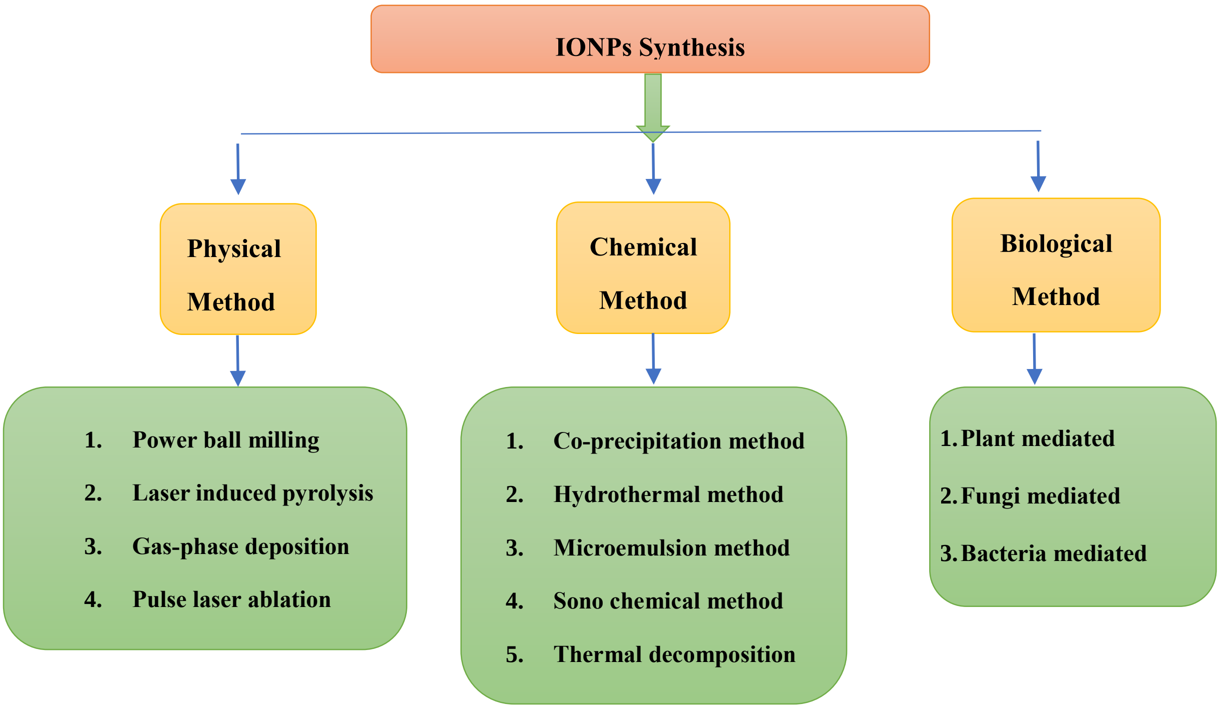

Fig. 1: The general synthesis methods of different iron-based nanoparticles modified from [15,16,17].

There are three different methods for creating nanoparticles.

1. Physical Methods
2. Chemical Methods
3. Biological Methods

Industrialization and urbanization have resulted in the discharge of contaminants into the environment, rendering some water unsafe for human use[18]. Many contaminants are not removed from wastewater and are not biodegraded in the environment. Because of the commitment and scarcity of water resources, as well as the limits of conventional water treatments, the hunt for new solutions to recover tainted water is an essential concern[19,20]. Water is necessary for the survival of life on Earth. Despite its abundance, the chemical composition varies throughout layers, influencing its appropriateness for both home and industrial applications. Groundwater constitutes only 0.6% of all available water resources [21]. It is this 0.6% that meets the world's water demands. However, as fast industrialization has progressed, drinking water quality of drinking water has deteriorated substantially. Groundwater contamination is being caused by the discharge of industrial effluent, solid waste from households and industry, and so on. As a result, numerous approaches, such as the membrane separation process, are used to purify water[22]. Magnetic nanoparticle uses are various; in water treatment, the nanoscale zero-valent iron, Fe_3O_4 known as magnetite, and -Fe_2O_3 known as maghemite are the most often employed iron-based magnetic nanoparticles. Because the nanoparticles display superparamagnetic behavior, magnetic characteristics are only present when an external magnetic field is applied[20,23]. Both laboratory and on-site field studies have demonstrated iron-based nanoparticles' potential to remove different pollutants. Most iron nanoparticles utilized in wastewater treatment today are based on adsorptive and photocatalytic reactions. Other wastewater treatment options include disinfection and microbial control, as well as combination techniques/systems[24]. In addition to magnetite (Fe_3O_4), maghemite (γ-Fe_2O_3), hematite (α-Fe_2O_3), iron oxy-hydroxide (FeOOH), and metallic zerovalent iron, iron-based nanoparticles can also be created in other forms. Iron is a viable and environmentally benign material for industrial wastewater treatment because of its low cost, natural abundance, simplicity of synthesis, and superparamagnetic characteristics[25]. When utilized as nano-adsorbent, they have a remarkable ability to remove different contaminants during wastewater treatment[26]. There are various ways to create iron oxide nanoparticles, each with advantages and disadvantages. The most often used synthesis techniques include co-precipitation, thermal decomposition, microemulsion, and sol-gel[27]. For eliminating pollutants from wastewater, a variety of different nanomaterials, including carbon-based nanoparticles, have been thoroughly investigated and evaluated. Iron-based nanoparticles, in particular magnetite (Fe_3O_4), maghemite (γ-Fe_2O_3), hematite (α-Fe_2O_3), iron oxyhydroxide (FeOOH), and metallic zerovalent iron, are frequently explored due to their availability, lower cost, and ecologically favorable behavior[6].

3.0 SYNTHESIS METHODS OF MULTIPLE IRON-BASED NANOPARTICLES

Various strategies, including physical, chemical, and biological procedures, have been used to create iron-based nanoparticles with appropriate surface chemistry. The most recent synthesis techniques, nanoparticle characterization, and applications are covered in depth[15]. Top-down and bottom-up techniques for nanoparticle production are both possible. The top-down approach includes physical processes, whereas the bottom-up approach includes chemical and biological activities[28]. Top-down preparation methods employ a destructive approach, beginning with the bigger molecule, which is subsequently deconstructed into smaller pieces, which are then turned into suitable nanoparticles[29]. This process includes decomposition procedures like grinding, milling, and physical vapor deposition. In the bottom-up technique, the opposite path is taken to synthesize appropriate nanoparticles. Because nanoparticles are created from simpler materials or compounds, this procedure is also known as a building-up strategy. Bottom-up approaches include sol-gel, green synthesis, spinning, biological synthesis, sedimentation, and reduction procedures(30). Co-precipitation, thermal decomposition, solvothermal synthesis, sol-gel and polyol methods, microemulsion, sonochemical method, microwave-assisted synthesis, electrochemical synthesis, biosynthesis, bio-inspired synthesis, and other methods are the most commonly used methods for producing iron-based nanoparticles[31]. The most widely used method for creating iron oxide nanoparticles is co-precipitation[32]. Typical co-precipitation synthesis techniques involve increasing the pH of a Fe (II) or Fe (III) ion solution with a base[15,33]. The particle phase and size are determined by the concentration of cations, the existence of counter ions, and the pH of the solution[15]. Chemical co-precipitation has been employed as a low-cost and appropriate approach for generating Fe_3O_4 nanoparticles for use as magnetic drug carriers[34]. The size, shape, and composition of iron NPs synthesized chemically are determined by the salt utilized (as a precursor material), the Fe(II) and Fe(II) ratio, pH, and ionic strength. Other parameters influencing NP size include mixing rate, temperature, nitrogen gas intake, agitation, and reactant ratio. For example, the major species generated under basic circumstances is FeO(OH), and this species may change to various iron oxides when heated. Each technique of preparation has its own determining element, benefits, and drawbacks[15,35]. FeO(OH) is the principal species that forms under basic circumstances, and this species can change into other iron oxides when heated. Each preparation technique has its own determining aspect, benefits, and drawbacks[36,37,38].

3.1 PREPARATION OF FEO(OH):

The next section conducted talks for each of the five polymorphs of FeO(OH) and their methods of production.

3.1.1 PREPARATION OF GOETHITE (α- FeO(OH))

One of the frequently occurring polymorphs of iron oxyhydroxide is goethite, which may be produced by the chemical precipitation process. In this process, an iron precursor salt solution (such as nitrates, sulfates, etc.) reacts with a basic solution (such as KOH, NaOH, etc.). Rahimi et al. (2015), for instance, described the preparation of goethite using $Fe(NO_3)_3 9H_2O$ in deionized water and by drop-wise addition of KOH solution under vigorous stirring followed by sonication for 30 min at room temperature, then placed in the oven for 70 min at 100 C and later centrifuged[39]. The resulting solid was rinsed with acetone (CH_3-$COCH_3$) and refined water separately, then allowed to dry at room temperature[39]. Using any solvent under pressure (usually atmospheric and higher pressure) and temperature (generally above solvent boiling point) is known as "solvothermal synthesis." The process is known as the hydrothermal synthesis technique if water is utilized as the solvent. Goethite (α FeOOH) nanorods were made by Zamiri et al. (2014) using a hydrothermal method with thiourea as a coordinating ligand. The appropriate amounts of iron(III) chloride and thiourea ($SC(NH_2)_2$) were combined with deionized (DI) water in their preparation procedure, and 130ºC was maintained for 8 hours in the autoclave before the sample was progressively cooled to ambient temperature. After filtering, the result was a black precipitate that was collected. The filtrate was cleaned and dried in a 70ºC oven for five hours[39]. Although Guo et al. (2020) used different initial dosage values and operating equipment, such as a reaction temperature of 70ºC rather than 100ºC and the product being freeze-dried rather than at room temperature, they followed a similar procedure to that described above to prepare α-FeOOH nanoparticle samples in an alkaline medium[40].

3.1.2 PREAPARATION OF FEROXYHYTE (δ-FeO(OH))

According to Nishida et al. (2016), the oxidation of precipitates from the modified hydrazine reduction reaction of ferric chloride ($FeCl_2$) and hydrazine (N_2H_4) in the presence of sodium tartrate ($Na_2C_4H_4O_62H_2O$) and gelatin in an alkaline condition was used to create δ-FeOOH nanoparticles. They began by dissolving $FeCl_22H_2O$ (ferric chloride), $Na_2C_4H_4O_62H_2O$ (sodium tartrate), and gelatin in water. They then adjusted the pH, mixed the mixture, added $N_2H_4H_2O$ (hydrazine solution), washed the mixture, and dried it[41]. To characterize the generated δ-FeOOH nanoparticles, several techniques including powder X-ray diffraction, high-resolution transmission electron microscopy, Mossbauer spectroscopy, and superconducting quantum interference device (SQUID) were used.

3.1.3 PREPARATION OF LEPIDOCROCITE (γ-FeO(OH))

It is possible to create lepidocrocite (γ -FeOOH) nanoparticles by following the method specified by Sheydaei and Khataee (2015). Initially, 35 C double-distilled water was used to dissolve ferric sulfate[42]. After that, a 3-butyl amine solution was added to the iron solution to raise its pH while a constant CO_2-free airstream was bubbled into the ferric sulfate solution. The color of the solution changed throughout preparation from light green to dark greenish blue, then to orange. After allowing the orange suspension to cool to ambient temperature, filtering was completed. The filtered particle was then desiccated for a day at 70°C in an air oven with γ-FeOOH nanoparticles after being cleaned[42]. The average width of the synthesized γ-FeOOH nanoparticles, which was confirmed by X-ray diffraction, transmittance electron microscopy, scanning electron microscope, and nitrogen adsorption/desorption studies, was 60–70 nm. Rahimi et al. (2015) present a technique for producing lepidocrocite that involves the interaction of ferrous chloride tetrahydrate ($FeCl_24H_2O$), hexamethylenetetramine ($C_6H_{12}N_4$), and sodium nitrate ($NaNO_3$) [39].

3.1.4 PREPARATION OF MAGHEMITE (γ -Fe_2O_3)

Ferric ammonium citrate, 30% H_2O_2, and methyl orange are typical raw materials for the thermal breakdown of ferric ammonium citrate in air, which produces mesoporous magnetic Fe_2O_3 nano-samples with a Fe concentration of 20.5-22.5%. According to Wang et al. (2017), the following process is used to create γ-Fe_2O_3 by pyrolysis without the usage of templates or surfactants[43]. A particular amount of ferric ammonium citrate was first crushed to less than 100 mesh and added to a muffle furnace, where it was heated to 300ºC at a heating rate of 10 C/min for 5 hours while being held in an atmosphere of air, and then cooled to room temperature[43]. The synthesized γ-Fe_2O_3 product was validated when the final product was characterized by XRD, N2 adsorption-desorption, SEM, TEM, and VSM. In addition to this discovery, higher temperature increases such as 400ºC, where a combination of hematite and maghemite nanoparticles occurred, and 550ºC, where pure hematite nanoparticle was formed, were also noted. Similar procedures were used by Ianoș et al. (2018), who started with iron nitrate (Fe $(NO_3)_3 9H_2O$), triethylenetetramine ($C_6H_{18}N_4$), and warm distilled water at 60ºC, stirred the mixture, and then heated it to its highest temperature of around 450ºC for 30 min[44]. The produced nanomaterials were manually milled, cleaned in distilled water, and left to dry for 12 hours at 60ºCelsius. XRD, SEM, and FT-IR studies all supported the production of maghemite nanoparticles. To avoid a high-temperature treatment procedure, Zhang et al. (2020) also reported the production of γFe_2O_3-ZnO-biochar nanocomposites in trimethylene glycol utilizing a thermal decomposition approach with N_2 gas protection[45].

3.1.5 PREPARATION OF HEMATITE (α-Fe_2O_3)

Insecticide cans imported from Egypt were used to create hematite (α-Fe_2O_3) nanoparticles with varied crystallite sizes ranging from 40 to 59 nm, according to Abdelrahman et al. (2019). Urea, glycine, L-alanine, and L-valine were the organic fuels burned[46]. Additionally, magnetite and/or goethite can be gradually transformed into hematite by oxidation. As evidenced by the crystalline phase, the production of hematite from waste iron-based sludge (including iron oxyhydroxide) at 500ºC[47]. Hematite nanoparticles were created by the hydrothermal process using raw ingredients such as Poly (vinylpyrrolidone) (PVP), deionized water, $FeCl_3 6H2O$, NaAc, ethanol, and different tools and materials[48]. In their work, factors influencing the potential creation process of α-Fe2O3 were thoroughly studied. These factors included the precursor concentration, precipitation agent, stabilizing agent, and reaction time. The hydrothermal technique was also used by Lin et al. (2014) to create octa decahedral α-Fe2O3 nanoparticles[49]. The precipitate was recovered and cleaned with ethanol and deionized water following the reaction. The precipitate was dried overnight in a vacuum oven to produce the final a-Fe2O3 powder. Ma et al. (2010) used a hydrothermal approach to create α-Fe_2O_3, but they made various adjustments to the reagents, solvent quantities, and materials[50]. For instance, $FeCl_3 6H_2O$ was initially immediately dissolved in 15 mL of ammonia water, followed by stirring, and a reaction period of 24 hours was permitted to heat the sample. The subsequent steps followed a similar path to the one Lin et al. (2014) detailed. Additionally, Tadic et al. (2014) published the hydrothermal technique for producingα-Fe_2O_3 together with the previously stated equivalent steps[51].

4.0 PLANT-MEDIATED PREPARATIONS OF IRON-BASED NANOPARTICLES

Due to its affordability and environmental friendliness, plant-mediated iron nanoparticle synthesis has gained increasing attention[52,53]. The metabolites created during bioprocesses, such as carbohydrates, glycosides, alkaloids, flavonoids, saponins, phenols, proteins, quinine, steroids, and tannin, provide the basis for the biosynthesis method of iron nanoparticles. Other synthesis processes, including chemical and physical procedures, can replace hazardous compounds since these metabolites are utilized as reducers in the process of making nanoparticles[54]. The eco-friendly plant extract has been used to create iron-based nanoparticles in a green manner. According to analysis, *Camellia sinensis* leaf extract may convert iron ions into iron nanoparticles at normal temperatures. Tannic acid was used as a green synthetic method to create the particles(55), which had a size range of 10 to 30 nm. The produced nanoparticles were also tested for their efficacy against fungi [26]. Although there are many benefits of using plants to manufacture iron nanoparticles rather than conventional physical and chemical methods, there are also several drawbacks, particularly in terms of shaping, homogeneity, and monodispersity. By using controlled reactions and optimization studies, these issues can be resolved[35,53,56]. A unique iron nanoparticle was successfully created utilizing a straightforward, environmentally friendly method using an aqueous extract of Mediterranean cypress (*Cupressus sempervirens*). The created nanomaterial also showed tremendous promise for the time-dependent dye removal from waste aqueous solution[57]. With a 6-hour hour contact period, methyl orange removal has a 95% decolorization efficiency. In other studies, green tea leaf extracts were used to create iron-based nanoparticles. After being characterized with the use of XRD, TEM, SEM, XPS, and FTIR methods, mostly iron oxide, and iron oxyhydroxide were produced[58]. It has been claimed that iron-based nanoparticles are used in a variety of industries. Water treatment [59,16], antibacterial pharmaceuticals[60], and a variety of consumable and domestic applications, such as medicines, energy-based research, and environmental studies [35,61] are a few of the domains.

5.0 APPLICATIONS OF IRON-BASED NANOPARTICLES IN WASTEWATER TREATMENT

Iron-based nanoparticles (IONPs) have several uses in a variety of fields. It is employed as a catalyst, an adsorbent in water and wastewater treatment, and a pigment in the industrial business, among other things. Furthermore, they are important raw materials for coatings, gas sensors, ion exchangers, magnetic recording devices, magnetic data storage devices, magnetic resonance imaging, bio-separation, and pharmaceutical applications [62]. Environmental remediation and waste reclamation sustainable remediation techniques are the focus of the current study[63,64,65,66]. Due to their nanoscale size, high surface area-to-volume ratios, and superparamagnetic nature, iron-based nanomaterials with unique features and uses have recently attracted a lot of attention. The distinctive physicochemical characteristics of IONPs set them apart from other nanoparticles. As a result, several studies have been conducted to create simple production techniques for these particles as well as to make them biocompatible and nano adsorbents[67]. Pathogenic microorganisms, poisonous organics, and inorganic contaminants may all typically be divided into three types and found in water and wastewater[24]. There are numerous potent contaminants in the wastewater produced by many sources. The most environmentally harmful dye, for instance, comes from the leather, paint, and textile sectors[47,68]. Wastewater from numerous sectors is allowed to flow with heavy metals. They may be harmful to humans and aquatic environments, or they may even be cancerous or poisonous[69]. Therefore, efficient treatment of such pollutants is required. Industrial water pollution prevention and industrial wastewater treatment are now the subjects of much research and in-depth scientific thought[70]. Different nanomaterials are used nowadays to combat environmental problems. Among these are iron-based nanoparticles, which come in a variety of forms. Iron oxides, such as magnetite, hematite, and maghemite, as well as iron oxyhydroxides, like goethite (α-FeOOH), aragonite (β-FeOOH), and lepidocrocite (γ-FeOOH), are typically being studied for potential applications in wastewater treatment for the removal of toxic metal ions[62]. One of the widely used nanomaterials in groundwater hazardous waste treatment is nanoscale zerovalent iron (nZVI)[71,72,73].

2. CONCLUSION

In conclusion, the green synthesis of iron-based nanoparticles holds great promise for revolutionizing water treatment processes in a more sustainable and efficient manner. As research in this field continues to evolve, it is expected that these nanoparticles will play a significant role in addressing the challenges of water pollution and paving the way for cleaner and safer water in the future.

ACKNOWLEDGEMENT

The completion of this review article on “Green Synthesis of Iron-Based Nanoparticles and Its Applications in Water Treatment Plants” would not have been possible without the generous support and contributions of several individuals. Furthermore, we are indebted to some institutes and official websites for providing access to the necessary research facilities and resources, enabling us to conduct this comprehensive review.

Last but not least, we want to acknowledge the support and understanding of our faculties and friends, whose unwavering encouragement kept us motivated throughout this hard work.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable.

HUMAN AND ANIMAL RIGHTS

No Animals/Humans were used for studies that are base of this research.

CONSENT FOR PUBLICATION

Not applicable.

FUNDING

None.

CONFLICT OF INTEREST

Authors declare that there is no conflict of interest.

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