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# Recent Advances and Sustainable Approaches Towards Efficient Wastewater Treatment Using Natural Waste Derived Nanocomposites: A Review

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## ABSTRACT

Pollutants like arsenic, chromium, or other toxic heavy metals have the most dreadful impact on humans or animals and also become a threat worldwide. Introducing these contaminants into the environment is not just due to the chemical industry but also coexists in combined form in underground rocks, contaminating groundwater during breakdown. Epidemics are now largely blamed on toxic pollution in many different nations worldwide. The issue has gotten worse in underdeveloped nations, where metal contamination of the groundwater affects more than a million people. Different techniques are used to remove toxic pollutants from water, but most are expensive and energy intensive. Adsorption is preferable for removing contaminants such as heavy metals or chemical dyes. As nanomaterials have been demonstrated to be more effective as nanocomposites, we used an adsorbent of nanomaterial to use the adsorption approach. These materials have become more well-liked because of their useful applications and improved characteristics. Magnetic synthesized nanocomposites have magnetic properties, which become beneficial for adsorption as it enhances adsorption capacity. The insertion of the plant or aggregate waste material for nanocomposite synthesis inhibits the growth of bacteria or other microorganisms, preventing the material from getting infected if it is in the environment. In this review paper, we have focused on the green synthesis of nanomaterials used for water treatment.

## INTRODUCTION

Nanoparticles play an essential role in today's world as they are classified as advanced materials in nanotechnology. They are defined as modifying a matter through physical and chemical techniques to produce a material with specific characteristics that are helpful in many applications (Nazri & Sapawe 2020). Plants, animals, and bacteria have cell walls consisting of cellulose, lipids, and chitin, which are used to form different natural nanomaterials by the electrostatic interaction or hydrogen bonding. These materials are abundant, renewable, biodegradable, and easily prepared (Visakh & Thomas 2010). These cell walls have various functional groups on their surfaces that interact with organic or inorganic nanoparticles to form nano biocomposite materials. Nanoparticles come in the range of 1 to 100 nm, which has a very important contribution to the advancement of nanoscience and nanotechnology which is increasing quickly (Ahmad et al. 2011). Nanotechnology came into the picture after its scientific discovery in the twenty-first century. This developing area started grabbing attention as it includes the creation, handling, and use of those materials scaling in size less than 100 nm, which can become of great use as applications of nanoparticles are vast (Jadoun et al. 2021). Researchers and scientists have started showing great interest in exceptional features and discovered that these contain individual applications in diverse fields. The green synthesis is a method of producing nanoparticles using eco-friendly and biocompatible precursors, reducing agents, and solvents. This approach can significantly reduce the toxicity of the resulting nanoparticles compared to conventional synthesis methods, which often use hazardous chemicals. Natural precursors, such as plant extracts, can also add advantageous functional groups to the nanoparticles' surfaces, reducing their toxicity and increasing their biocompatibility. Additionally, compared to conventional synthesis techniques, using green synthesis techniques frequently results in nanoparticles with enhanced stability and higher purity, significantly lowering their potential toxicity (Jadoun et al. 2021). With time, green chemistry has become the first choice for many scientists as it is an efficient method for nanoparticle synthesis. Plant extract-based green synthesis is widely used for synthesizing various nanoparticles and has been considerably studied over the last decades (Mondal et al. 2020). Numerous strategies have been used to enhance the recycling of used cartons to safeguard the environment. Some of these are composting, exploiting biomethane sources, using them as raw materials to make lactic acid and bioplastics, and other techniques. However, there are restrictions because these methods can only partially encourage the recycling of used cartons. Additionally, they have several drawbacks, such as complicated processes, little financial value, and secondary contamination, which restricts the range of applications (Han et al. 2018). Recycling concrete waste addresses the increasing demand for plant, coal, and aggregate wastes. The burden of disposing of the enormous amount of construction and demolition waste also decreases and helps the environment. These usages of concrete recycled plant, coal, and aggregate waste have drawn the interest of researchers and scientists worldwide. They are believed to be a vital step toward the growth of the sustainable development of the construction industry (Yue et al. 2020). There is an immense need to develop better approaches using green nanotechnology to synthesize antiviral, antibacterial, or antimicrobial materials for water treatment (Naikoo et al. 2021). Recent studies revealed that nanoparticles are highly promising for antiviral and antimicrobial properties. A deep insight was provided into these nanoparticles' antibacterial and antimicrobial activities and how these antibacterial materials are used for water treatment (Naikoo et al. 2021). Hence, in this paper, we have discussed the preparation of nanoparticles in four critical domains: plant-based nanomaterials, coal waste nanomaterials, aggregate waste nanomaterials, and microbial waste, and discussed their beneficial applications.

## PLANT-BASED NANOCOMPOSITES

Plants have antibacterial, antioxidant, and anti-inflammatory properties, providing great potential for heavy metal accumulation and detoxification (Iravani 2011). According to recent studies, plants and plant waste can be utilized to synthesize nanoparticles. Plant structures and components inside it have drawn researchers' attention to the fabrication of NPs due to the desired properties like minimizing cost, rapid process, eco-friendly, and simplicity in biosynthesis (Nazri & Sapawe 2020). These approaches avoid complicated processes to synthesize and modify nanomaterials for a better purpose and are economical and environmentally benign. Researchers have widely investigated the metal nanoparticles obtained from plant extract that are biocompatible and nontoxic (Naikoo et al. 2021). Many nanoparticles are synthesized using the green approach, such as copper, gold, silver, zinc oxide, and iron (Jadoun et al. 2021). Table 1 demonstrates different plant-based waste materials used for the novel growth of nanoparticles.

### Synthesis of Nanocomposites with Plant Waste

Green synthesis of $Fe_2O_3$-Ag nanocomposite using Plant leaf extract, as represented in Fig. 1. Separate preparations of $AgNO_3$ solution and $Fe(NO_3)_3$ solution were made to synthesize $Fe_2O_3Ag$/GL nanocomposites. The prepared solutions were continuously stirred to ensure proper mixing. The leaf extract was added dropwise to the solution using a burette after the mixture had been well homogenized, with continual stirring. The solution was left undisturbed once the precipitate had fully formed before being centrifuged. The residue was extensively cleaned with DI water to remove any ionic impurities before being cleaned with acetone to remove any organic impurities. After the precipitate had formed, it was oven-dried before being burned. Following collection, the sample was characterized using a variety of techniques.

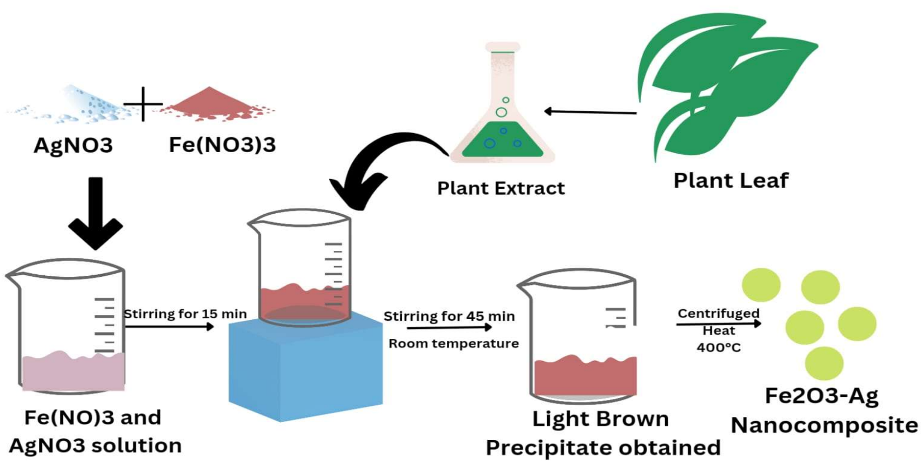


Fig. 1: Green synthesis of $Fe_2O_3$-Ag nanocomposite using Plant leaf extract.

Table 1: Plants waste used for nanocomposite synthesis and their characteristics.

| Plant Origin | Waste | Nanocomposite and technique | Size (nm) | Applications | Reference |
|---|---|---|---|---|---|
| Basil (*Ocimum basilicum*) | Leaf | Alginate-gum acacia-Ag0-Basil, Solvent Extraction | 20 | Antimicrobial Activity | (Kanikireddy et al. 2019) |
| Neem (*Azadirachta indica*) | Leaf | Chitosan-Neem, Solvent Evaporation | 30 | Antimicrobial Activity | (Mohammad & Hasobo 2012) |
| Tulsi (*Ocimum tenuiflorum* ) | Leaf | Ag/ZnO-Basil Mediated Ultrasonication | 50 | Antimicrobial Activity | (Panchal et al. 2020) |
| Aloe vera (*Aloe barbadensis*) | Leaf | PVA/Cellulose Nanofiber-Aloe vera Ultrasonication | - | Antimicrobial Activity | (Kakroodi et al. 2014) |
| Jamun (*Syzygium cumini*) | Leaf | ZnO-Jamun Biogenic | 11.35 | Antimicrobial Activity | (Sadiq et al. 2021) |
| Guava (*Psidium guajava*) | Leaf | $Fe_2O_3$-Ag-Guava Biological | 50-90 | Antimicrobial Activity | (Biswal et al. 2020) |
| Tea (*Camellia sinensis*) | Leaf | Ag-Tea NPs Biological | 50 | Antibacterial Activity | (Loo et al. 2012) |
| Goatsbeard (*Tragopogon collinus*) | Leaf | Ag-Tea NPs Biological | 50 | Antibacterial Activity | (Seifipour et al. 2020) |

## COAL ASH-BASED NANOCOMPOSITES

The usage of coal energy production is significant worldwide, despite the concern generated by the government. According to market analysis, the international coal demand for renewable energy production will increase in the coming years. Still, it also leads to the waste of coal, which is a concern for the environment. However, coal combustion generates immense amounts of solid waste, such as fly ash, bottom ash, boiler slag, fluidized bed combustion ash, and other products. Coal fly ash, also known as CFA, is primarily used for the exhibition of blended cement, as a definite addition, in concrete blocks, road construction, etc. (Boycheva et al. 2020). Ash is a highly available waste generated mainly through industrial and agriculture as a by-product. These waste by-product ashes raise environmental concerns about disposal issues and gained much attention for the sustainable utilization of ash as a renewable supporting material in synthesizing nanocomposites.

The prospective uses of coal waste, including coal fly ash, coal husk ash, and volcanic ash, are now being investigated. These waste materials have key features, including high adsorption activity, ion exchange capacity, surface area, and reusability (Lum et al. 2020). The production of CFA increases by about 5% every year. Therefore, Recycling waste is very important. This can be done by altering coal fly ash into reusable materials rather than dumping it into landfills which could be a problem with removal costs and environmentally dangerous circumstances.

Furthermore, fly ash from coal has been determined to be a valuable substance for photocatalysis and adsorption activity, which is further used to remove toxic pollutants from water bodies. These coal waste nanomaterials contain important metal oxides, including $Fe_3O_4$, $SiO_2$, $TiO_2$, and $Al_2O_3$, and are helpful in photocatalysis and adsorption (Umejuru et al. 2020). In this review paper, Carbon hybrid nanocomposite-coated coal fly ash (CFA/C HNCPs), which was synthesized as the effective removal of pollutants like cadmium ion ($Cd^{2+}$) from wastewater, and the spent adsorbent (CFA/C– $Cd^{2+}$ HNCPs) was recycled in the photocatalytic degradation of methylene blue (Umejuru et

Table 2: Coal waste and its nanocomposites with the applications.

| Coal Waste | Nanocomposite And Techniques | Size (nm) | Applications | Reference |
|---|---|---|---|---|
| Coal fly ash | CFA-$CuFe_2O_4$ (Coal fly ash-copper ferrite), Hydrothermal | 1 | Degrade dye (pollutant) | (Nadeem et al. 2021) |
| Coal fly ash | CFAZ (Coal fly ash-Zeolites), hydrothermally | 2-10 | Substitution, recovery, and use reduction of CRMs (critical raw materials) | (Boycheva et al. 2020) |
| Fly ash | CFA/C HNCPs (Coal fly ash/carbon hybrid nanocomposite), hydrothermal | 100 | Heavy metals can be removed from wastewater. | (Umejuru et al. 2020) |
| Fly ash | CNT -fly ash (Carbon nanotubes-fly ash polymer nanocomposite), Ball Mining | 500 | Environmental-friendly construction and building materials. | (Chaturvedi et al. 2021) |

al. 2020). Table 2 lists the applications for coal waste and its nanocomposites.

### Synthesis of Coal Waste Nanocomposites

For the preparation of CNT supported by fly ash, industrial waste particulates were collected from across India and were prepared through the Ball milling technique, which supports chemical-mechanical grinding, followed by a compressive molding technique underneath an epoxy system at low temperature. The polymer nanocomposite synthesis was also done utilizing a compressive molding apparatus at room temperature. The polymer used was Epoxy, and dimethylformamide or DMF solvent was used to spread the carbon nanotubes in the fly ash waste, as shown in Fig. 2. The prepared synthesized materials were ball milled using a ball milling machine, then rushed into the mold frame and allowed cure at room temperature. Finally, carbon nanotubes having fly ash-based waste polymer nanocomposites were obtained. These nanocomposites have functional groups on the surface, which will be analyzed using FT-IR spectroscopy. These instrumentation techniques were done to analyze the exciting properties of carbon nanotubes and fly ash waste, their interfacial bonding, and the size and structure of the synthesized nanocomposites, which can be used for various applications (Chaturvedi et al. 2021).

## AGGREGATE WASTE-BASED NANOCOMPOSITES

Nanotechnology has become the growing field in the research areas for the synthesis of cellulose-based nanocomposites, which are synthesized using not only plants but also from waste agriculture material such as rice husk, bamboo leaves, sugarcane bagasse, groundnut shell, etc. (Vaibhav et al. 2015). The requirement for the formation of these nanocomposites from waste material is to purify water or remove the heavy metals present in the water by the adsorption activity on the toxic pollutants by using agricultural wastes as a composite material, which will prevent long-term risk to the ecosystem and human beings (Younes et al. 2021). Researchers use agricultural waste or natural fillers to synthesize metallic or polymer-based nanocomposites. These materials are used because they have benefits over conventional filler, including low cost, high toughness, excellent specific strength, and improved energy recovery (Bello et al. 2015). Corn cob is one of the most common agricultural wastes, which produces an estimated amount of waste load of thousands of tons yearly. Yet, it is also a good source of xylem, a crucial bioactive polysaccharide (Viana et al. 2020). The core of the maize plant, the corn cob, is disposed of as waste and burned as fuel, raising environmental issues. Corn cob waste can be used to create green nanocomposite materials that are environmentally safe and have the qualities needed to perform the intended function in the water purification process. Corn cob can be chemically processed to produce new end products with added value at low prices, achieving its value in new research areas (Kumar et al. 2010). A growing argument has been made for using magnetic adsorbents to make separating carbonaceous adsorbents easier and increasing the efficiency

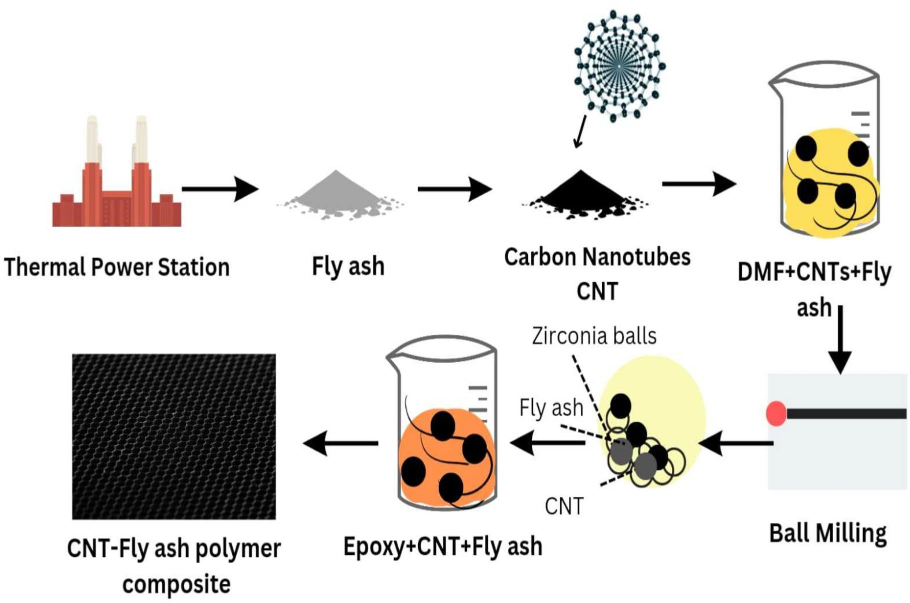


Fig. 2: Representation of preparation of CNT/fly ash.

Table 3: Listed down the origin of Aggregate waste and their nanocomposites with the applications.

| Aggregate waste origin | Nanocomposites and Techniques | Size (nm) | Applications | References |
|---|---|---|---|---|
| Corn cobs | AgNP/CC (xylan extract containing silver nanoparticles), Microwave | 100 | Reducing and stabilizing agent | (Viana et al. 2020) |
| Sawdust | MPSB (magnetic pine sawdust biochar), Biogenic | 50 | Synthesis of magnetic adsorbents for inorganic and organic contaminants | (Reguyal & Sarmah 2018) |
| Groundnut shell | $SnO_2$/GNSAC (Tin oxide groundnut shell activated carbon), chemical precipitation | 1 | Photocatalytic oxidation of MB dye | (Ragupathy& Sathya 2016) |
| Coconut shell | AgNPs/CS (synthesis of silver nanoparticles containing coconut shell), Photochemical | 1.20 - 22.96 | Antibacterial activity against *S. aureus* infections | (Sinsinwar et al. 2018) |
| Bagasse | BAE/AgNPs (Silver nanoparticles with bagasse), Microwave | 100 | Reducing and stabilizing agents | (Shen et al. 2016) |

of the entire adsorption process. The surface of corn cobs has several functional groups that might be used to bind various metal oxides to create nanocomposites, which would remove water contaminants (Younes et al. 2021). Agricultural waste has often been the source of some of the most widely used carbonaceous adsorbents. For various inorganic and organic pollutants, carbonaceous adsorbents such as activated carbon, biochar, charcoal, and char have demonstrated good adsorptive capacity (Reguyal & Sarmah 2018). The origin of aggregate waste and its nanocomposites with the applications is depicted in Table 3.

### Synthesis of Silver Nanocomposite with the Aggregate Waste Bagasse

For synthesis, the required quantity of solution of $AgNO_3$ was prepared by dissolving the desired amount in distilled water. After that, a few drops of diluted sodium hydroxide were added to entirely convert the precipitate Ag+ to silver oxide Ag2O. The aqueous ammonia solution was added until all brown silver oxides were completely dissolved. At this stage, the clear mixture contained Ag+ ions in the form of $[Ag(NH_3)_2]OH$. The $[Ag(NH_3)_2]OH$ solution was diluted with pure water and added to a flask with BAE (Fig. 3). The solution was filtered, and the BAE/AgNPs were successfully synthesized using microwave irradiation. Finally, the BAE/AgNPs nanocomposite was synthesized, followed by the Cysteine for possible applications (Shen et al. 2016).

## MICROBES BASED NANOCOMPOSITES

Green nanocomposite synthesis is an environmentally friendly, highly stable, cost-effective method that does not involve harmful chemicals. This technique reduces and stabilizes agents such as aggregate wastes, microbes, plants, and other natural waste resources to produce sustainable nanoparticles. Synthesis of nanoparticles using microbes is an eco-friendly green procedure that utilizes bacteria, fungi, viruses, and their products to produce nano biocomposites. Natural microbes are used as a component in nanoparticle synthesis as they provide templates for well-defined structures for the synthesized nanoparticles. Inorganic/Metallic nanoparticles like gold, silver, copper, zinc, titanium, palladium, and nickel are synthesized. These synthesized nanoparticles can be accepted both extracellularly and intracellularly using microbes. The filtrate was collected using centrifugation in the extracellular synthesis, and metallic aqueous solutions were mixed. The color change of the hybrid solution monitors the synthesis of NPs (Ali et al. 2020). Nanoparticles now play a crucial

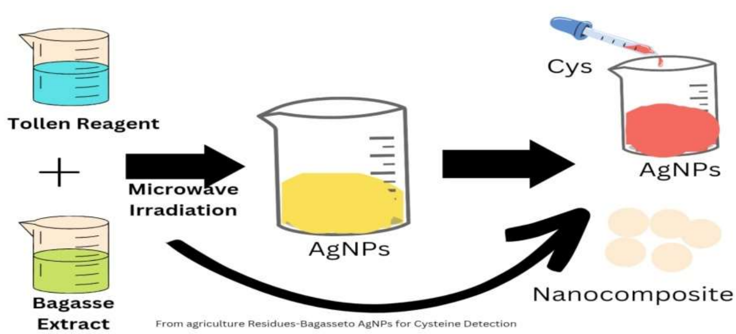


Fig. 3: Green synthesis pathway of silver nanocomposite with the aggregate waste bagasse.

Table 4: List of recently reported nanocomposites derived from microbes.

| Microbes | Nanocomposite & Techniques | Size (nm) | Application | Reference |
|---|---|---|---|---|
| Algae *C. crispus* | AuNPs- *C. crispus* & Biogenic | 50 | Clean method for nanoparticles production | (Castro et al. 2013) |
| Algae *H. alcalis* | AgNPs-*H. alcalis* & Biogenic | 20 | Sensing | (Tomer et al. 2019) |
| Algae *Chlorella ellipsoidea* | AgNPs- *Chlorella ellipsoidea* & Biological | 20 | Degradation of Methylene Blue | (Borah et al. 2020) |
| Cyanobacteria C-phycoerythrin | CdS NPs- C-phycoerythrin & Biological | 5 | biolabeling | (Mubarakali et al. 2012) |
| Fungi *R. oryzae* | AuNPs-*R. oryzae* & Biological extracts | 20 | High-yield and low-cost NPs production | (Das & Marsili 2010) |

role in most technologies (Bahrulolum et al. 2021). Algae are polymer-based molecules such as polysaccharides that can gather together heavy metal ions and recondition them into malleable form with the help of a biological reduction process. The typical algal-mediated synthesis of inorganic nanoparticles is silver and gold, the most examined noble metals algae microbes use for making nano biocomposites (Uzair et al. 2020). Table 4 shows a list of recently published microbe-derived nanocomposites.

## Synthesis of Microbes-Based Nanocomposites

The synthesis of algae-mediated inorganic nanoparticles can be achieved intracellularly or extracellularly (Sabo-Attwood et al. 2012). In intracellular nanoparticle synthesis protocol, algae microbes waste is collected and washed multiple times with distilled water to clear all the contaminants. Afterward, the prepared solution of $AgNO_3$ is mixed with algae. The resulting mixture needs to be incubated at a specific temperature and pH conditions for a fixed period of time, as required for the bioreduction method. Contents are finally sonicated and centrifuged to produce a good yield of stable nanoparticles. The extracellular synthesis protocol begins with collecting and washing an Algae sample with plenty of distilled water to remove the impurities. The collected algae are dried for a specific time, and the dried powder is mixed with distilled water. The algae extract is then sonicated for some time, followed by adding a metal precursor solution. Contents are then incubated for 8-16 hours, and the obtained

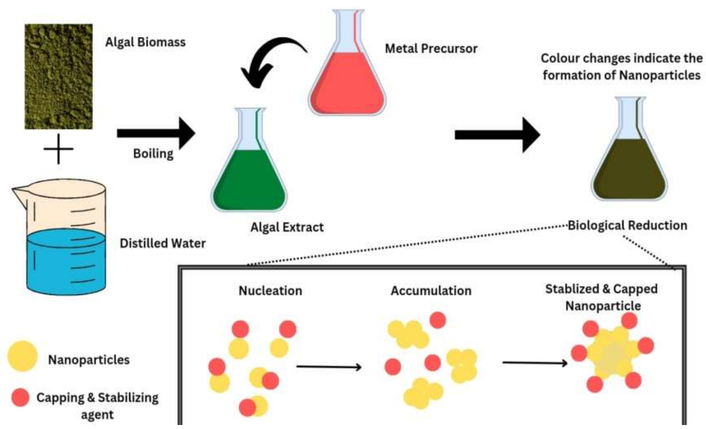


Fig. 4: Mechanism of formation of algae microbe-based nanocomposites.

Table 5: List of some recently reported metal-based nanocomposites and their comparative adsorption capacities.

| Adsorbent | Size (nm) | Adsorption Capability mg/g | Application | References |
|---|---|---|---|---|
| $Fe_3O_4$-GO | 200 | 59.6 | Removal of metals | (Sheng et al. 2012) |
| $Fe_3O_4$-chitosan-GO | 50 | 95.16 | MB dye adsorption | (Fan et al. 2012) |
| $MnFe_2O_4$-GO | 100 | 240.4 | As(V) adsorption | (Lan Huong et al. 2018) |
| Ni $Fe_2O_4$-GO | 41 | 59.52 | As(III) adsorption | (Lum et al. 2020) |
| $MnFe_2O_4$ | 10 | 31.5 | Fast Removal and Recovery of Cr(VI). | (Hu et al. 2005) |
| $MnFe_2O_4$/rGO | 5 | 41 | Adsorption of Tetracycline | (Bao et al. 2018) |

Table 6: Green metal-based nanocomposites and their adsorption capacities.

| Adsorbent | Size (nm) | Adsorption Capability (mg/g) | Application | Reference |
|---|---|---|---|---|
| $Fe_3O_4$ MNPs | 107.5 | 80 | Removing MB dye | (Jabbari et al. 2016) |
| CFA/C HNCPs | 100 | 77 | Heavy metals can be removed from wastewater | (Umejuru et al. 2020) |
| $MnO_2$/BC | 190-220 | 185.185 | Adsorptive removal of Methylene blue | (Siddiqui et al. 2019) |
| $Fe_2O_3$-$ZrO_2$/BC | 200 | 1.01 | Adsorptive removal of arsenic | (Siddiqui & Chaudhry 2019) |
| $Fe_2O_3$-$ZrO_2$/BC | 200 | 38.10 | Adsorptive removal of dyes | (Siddiqui & Chaudhry 2019) |
| FeOx-GO | 5 | 147 and 113 | Adsorptive removal of As(III) and As(V) | (Siddiqui & Chaudhry 2017) |

Table 7: Green polymer-based nanocomposites and adsorption capacities.

| Adsorbent | Size (nm) | Adsorption Capability (mg/g) | Application | Reference |
|---|---|---|---|---|
| SS/$Fe_3O_4$ | 12-15 | 265.4 | Adsorptive removal of Pb(II) | (Ahamad et al. 2020) |
| SS/$Fe_3O_4$ | 12-15 | 247.2 | Adsorptive removal of Cd(II) | (Ahamad et al. 2020) |
| PPy/ $Fe_3O_4$/$SiO_2$ | 500 | 361 | Removal of Congo red dye (CR) | (Alzahrani et al. 2021) |
| PPy/ $Fe_3O_4$/$SiO_2$ | 500 | 298 | Removal of hexavalent chromium Cr(VI) | (Alzahrani et al. 2021) |
| GA-cl-PAM/ZnO | 500 | 766.52 | Malachite Green Dye Adsorption | (Mittal et al. 2020) |
| PAPE/AZO | 100 | 94.46 | Removal of malachite green dye. | (Gouthaman et al. 2019) |

product is then filtered. A distinct change in solution color during incubation indicates the nanoparticles' successful formation. During the bioreduction process of metal ions, nucleation, and successive condensation processes ensures the formation or growth of stabilized nanoparticles surrounded by capping agents, as schematically highlighted in Fig. 4. Synthesized nano biocomposites can be chemically and morphologically characterized by various spectroscopic and microscopic techniques. List of several recently published metal-based nanocomposites in Table 5 along with a comparison of their adsorption capabilities.

Table 6 lists the adsorption capabilities of green metal-based nanocomposites and Table 7 lists the adsorption capabilities of green polymer-based nanocomposites.

## APPLICATIONS OF NANOCOMPOSITES FOR WATER TREATMENT

Severe contamination of soft water resources by organic, inorganic, and biological pollutants is a global environmental crisis causing health and societal problems on a large scale. The biggest culprits among these toxic pollutants are inorganic metal ions and organic dyes commonly released by industries in the environment. These untreated effluents cause tremendous damage not only to the surrounding soil but also to the groundwater and nearby water bodies. Prolonged exposure to such primary pollutants in the aqueous environment, especially heavy metal ions, increases the risk of health problems for plants, humans, and animals (Lingamdinne et al. 2019). Clean water, an essential natural resource, is vital for the healthy coexistence and survival of all living creatures on Earth. Water pollutants endanger the biosphere, so removing toxic pollutants from water resources has become important (Pandey et al. 2017). In this aspect, clean, affordable, and effective solutions are needed to overcome this environmental crisis. Nanomaterials with high separation capacity, good porosity, recyclability, and reusability are attractive for effectively treating polluted water (Dhiman & Sharma 2019). Prodigious progress has happened in the synthesis and properties optimization of nanomaterials with very good control over their size/shape, porosity, hydrophilicity/hydrophobicity, adsorption specificity, and photochemical activity (Pandey et al. 2017). This also makes them more versatile and effective in removing chemically different pollutants from water samples.

### Magnetic Functionalization of Graphene Oxide-Based Nanocomposites

Iron oxide-based nanostructures have become widespread among nanomaterials because of their strong magnetic properties. These favorable magnetic features can be utilized for even more effective water treatment. These materials can also be combined with other entities, such as graphene, to further improve their stability and performance. Protective surface coating of hydrophobic graphene or graphene oxide on iron oxide core has been found to provide excellent stability, high surface area, mechanical strength, and porous nature to the composites. Co-precipitation is commonly employed to synthesize several iron oxide composites with graphene or graphene oxides (Siddiqui & Chaudhry 2017). As can be seen in the schematic in Fig. 5,

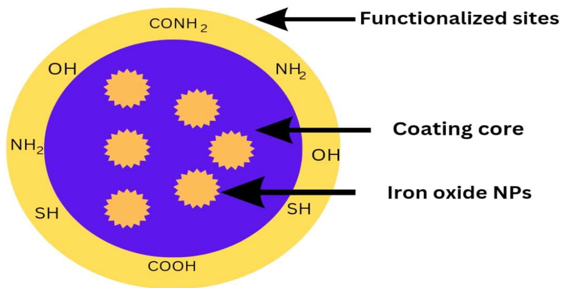


Fig. 5: Functionalized graphene-iron oxide nanocomposites for water treatment.

the graphene layer around the nano iron oxide particles not only provides protection but also enables the attachment of various functional groups such as COOH, $NH_2$, and OH to the material surface, resulting in improved solubilization and enhanced metal ion removal capabilities (Iravani 2011).

## Mechanism of Pollutants Removal with Synthesized Nano Biocomposites

Nano-biocomposites can be easily synthesized using hydrothermal, co-precipitation, sol-gel, or ball-milling techniques. Most materials from plant, coal, or aggregate-based wastes have active functional groups like -OH, -COOH on the surface (Gadore & Ahmaruzzaman 2021). For example, black cumin seed has important functional groups like -OH, -COOH, and $-NH_2$ at the surface that attract $Mn^{2+}$ ions from surroundings to form manganese oxide nanoparticles. The formation of $MnO_2$ in the seed carbon framework resulted from the redox reaction between $MnCl_2$ and $KMnO_4$ (Siddiqui & Chaudhry 2017). All such reactions are highly pH dependent as the charge on functional groups will be governed by it. For solutions having a pH value above the pKa of these functional groups, the overall charge on the composite will be negative. This will generate an electrostatic pulling force for cationic inorganic compounds such as $Mn^{2+}$ ions. These ions get trapped in the plant framework primarily through hydrogen bonding. When bases like NaOH are added, the metal ions change into hydroxide form and form $Mn(OH)_2$, which contain more hydroxy groups wherein

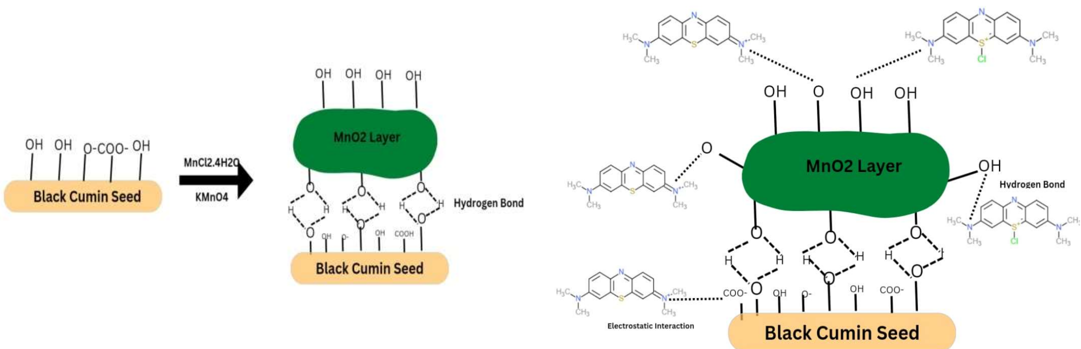


Fig. 6: Mechanism of nanocomposite formation and removal of methylene dye by the adsorption activity.

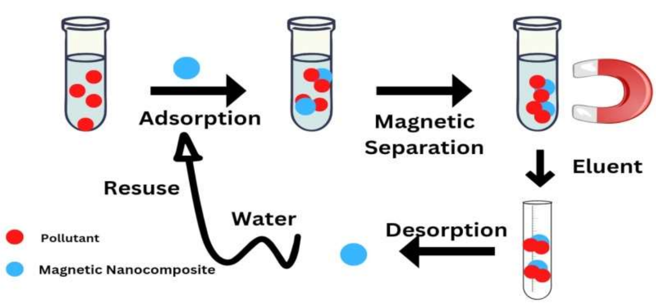


Fig. 7: Schematic representation of removal of pollutants from water.

nucleation and dehydration growth occur. This leads to the development of the $MnO_2$/BC phase. This process is called Nucleation driven dehydration growth and forms the complex structure of nano-biocomposites as shown in Fig. 6 (Siddiqui et al. 2019).

Further studies have shown that the oxygen-containing functional groups play an essential role in the size of the adsorbent material as it enhances the adsorption capacity resulting in the strong interaction of the solute and adsorbent. Toxic chemical species such as arsenic metal ions or dyes attach themselves to the surface's functional groups via intramolecular hydrogen or electrostatic bonding, forming the complex. Pollutants adsorbed on the surface of nanocomposites have further adsorption activity, which can be utilized to remove even more contaminants from the water.

## UTILIZATION AND RECOVERY OF NANOCOMPOSITES FROM WATER SAMPLES

Recovery and recyclability of non-magnetic nanocomposites like Graphene Oxide (GO) are more challenging than magnetized graphene oxide (MGO) containing composites. Moreover, magnetic graphene oxide has a very high adsorption capacity. An external magnet can easily separate the nanocomposite from the water, along with pollutants adsorbed on the surface. Fig. 7 highlights the various important steps in successfully using magnetic GO-based nanocomposites to remove harmful water pollutants and their facile recovery process employing a simple external magnetic field. It is essential to isolate the solute-loaded adsorbents from water for desorption and regeneration (Siddiqui & Chaudhry 2019). Metal ions adsorbed on these magnetic materials can be utilized for other applications. It has been reported that recovered magnetic nanomaterials can be efficiently reused for multiple cycles. This exhausted adsorbent regeneration technique is crucial for creating a cost-effective procedure.

## CONCLUSION

Nanocomposites made from waste materials have gained much attention among the scientific community because of their vastly effective properties, ultrahigh surface area, and easy and cost-effective synthesis protocols. The prospect of using these materials is also high, as indicated by their current annual growth rate of nearly 25 %, which is excellent. Most of the current demand for this material is from tissue engineering and water treatment fields. The global drinking water shortage problem is closely connected to the growth of the world population, industrialization, and water pollution. This problem is especially severe in small, developing countries where the resources for water treatment are very scant. Although many different types of nanoparticles are synthesized using various green processes, biomass-based nanomaterials have received the most significant attention from scientists and researchers. This is because of their outstanding antimicrobial, antibacterial, antifungal, and antiviral properties. Many waste materials, including dead residues from plants, coal ash, and aggregate waste, can be used as a substrate to obtain natural nanoparticles such as iron NPs. The presence of some biomolecular structures is vital to getting highly stable nanomaterials, as revealed by many research studies discussed above. In recent years, the use of nanocomposites for water remediation has increased considerably. Multiple government agencies and pharmaceutical industries worldwide are investing huge efforts and resources toward a facile synthesis of waste-based nanocomposites and their applications in diverse fields.

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