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https://doi.org/10.5109/7158004

出版情報：Proceedings of International Exchange and Innovation Conference on Engineering & Sciences (IEICES). 9, pp.376-383, 2023-10-19. 九州大学大学院総合理工学府
バージョン：

A Mini Overview of Wastewater and River Water Treatment by Various Nanoparticles

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Abstract: *Nowadays nanoparticles are utilized vastly for several purposes. Wastewater treatment is a term where both metal based, and metal free nanoparticles are employed. In the case of water such as river water, ground water, sea water, industrial wastewater etc. are contaminated for which we cannot use this in our needs by utilizing nanoparticles. This water can be treated by several processes such as photocatalysis, adsorption, antimicrobial treatment, desalination, and others. By photocatalysis, dye contaminated water is treated with dye degradation. Sea water can be treated by desalination. In ground water, there are several heavy metals which can be absorbed by nanoparticles for the reason of high surface area of these. River water along with other waters contains several microbial organisms and remains unsafe in utilization. As nanoparticles have antimicrobial properties, they can treat this contamination. In our study we will give a short overview of wastewater treatment by nanoparticles.*

Keywords : Nanoparticles; Metal Oxide Nanoparticles; TiO_2 Nanoparticles, Photocatalytic activities; Dye degradation.

1. INTRODUCTION

Nanotechnology integrates principles and insights from various scientific disciplines, including engineering, health sciences, materials science, biology, chemistry, and physics. The broad range of applications in various scientific disciplines and aspects of human existence is noteworthy. Nanoparticles are also showing their vast eligibility in the treatment of wastewater and river water. Nanoparticles are commonly characterized as either particulate dispersions or solid particles, possessing dimensions within the range of 10-1000 nm [1]. Nanoparticles show a wide range of properties. For instance, the optical properties of noble metal nanoparticles are known to vary with their size, leading to the emergence of a distinct UV-visible extinction band that is not observed in the spectrum of the corresponding bulk metal. Magnetic properties of nanoparticles have garnered significant attention among researchers across various disciplines. These disciplines encompass environmental remediation, magnetic resonance imaging, data storage, magnetic fluids, biomedicine, and catalysis, particularly in the context of water decontamination [2].

The properties and behaviors of nanoparticles can be applied in various sectors. Nano sized inorganic substances exhibit one-of-a-kind physical and chemical properties and are becoming an increasingly essential substance in the development of novel nano-devices, which have a wide variety of potential applications in the fields of medicine, biology, physics, and pharmaceutical industry [3]. All disciplines of medicine are becoming increasingly involved in how nanoparticles may deliver medications in the ideal dose range. This typically leads to increased medication therapeutic efficacy, reduced side effects, and increased patient compliance [4]. Nanocrystalline materials are especially intriguing for the subject of material science because their characteristics vary from those of their corresponding bulk materials in a size-dependent way. The physicochemical features that are displayed by manufactured nanoparticles are responsible for the induction of one-of-a-kind electrical, mechanical, optical, and imaging qualities. These characteristics are in high demand for specific applications in the medical, commercial, and ecological fields [5] [6].

Most nanotechnology's applications in the field of environmental science can be classified into one of three categories. Products that are sustainable and do not cause harm to the environment (such as green chemistry or pollution avoidance), the cleaning up of objects that have been polluted with potentially harmful substances, and sensors for environmental stages are all examples of environmental applications of nanoparticles [7]. Because of the negative effects that heavy metals like mercury, lead, thallium, cadmium, and arsenic have on both the environment and the health of humans, there has been a lot of interest focused on the process of removing them from natural water sources. This hazardous soft substance can be effectively absorbed by superparamagnetic iron oxide NPs, which are an efficient sorbent material. Due to the lack of analytical methods that can quantify trace concentrations of NPs, there have been no measurements of engineered NPs that have been made accessible concerning their presence in the environment [8] [9].

Nanotechnology has a significant amount of untapped potential in the areas of water as well as wastewater treatment, namely in the areas of increasing treatment effectiveness and enhancing water supply through the secure utilization of alternative water sources. There is a large body of evidence to support the idea that nanotechnology has beneficial impacts in the field of wastewater treatment [10]. Wastewater is solids and liquids that are carried by water and dumped into sewers. They are the wastes of a city. Wastewater has "putrescible" or naturally decomposable organic solids that are both dissolved and in suspension. There are two main types of wastewaters, which are not completely separate: household and industrial. Most of the suspended solids in wastewaters are taken out by the first and second stages of cleaning. But in a growing number of cases, this level of cleaning has not been enough to protect the receiving waters or provide water that can be used again in industry or at home. So, more treatment stages have been added to plants to get rid of more solids and organic matter or to get rid of nutrients and/or harmful materials [11]. Zinc oxide nanoparticles (NPs) show significant promise as a photocatalyst in the removal of hazardous contaminants from wastewater. This is due mostly to their beneficial properties [12]. In wastewater and water treatment applications, several approaches of nanoparticles like as electrochemical oxidation, adsorption, nanofiltration, and photocatalysis can be used to reduce or eliminate pharmaceutical pollutants [13]. Nanomaterials such as carbon nanotubes, graphene, zeolites, and aquaporin are used in various desalination procedures to improve water filtration techniques [14].

Water from various sources can be contaminated. In this article we have mentioned how to treat wastewater from industry, river, sea, and soil. Water becomes harmful by dye and other chemicals from industries. River water contains various bacteria. Sea water contains salinity. Soil water may contain Arsenic or other heavy metals. This wastewater can be purified by nanoparticles by various processes like photocatalysis, adsorption, antimicrobial treatment, desalination, and others. In this research we will be discussing how wastewater from various sources will be purified by nanoparticles by those various processes.

2. INDUSTRIAL WASTEWATER MANAGEMENT

Most textile businesses use traditional treatment methods like biological or physicochemical. A single flocculation and coagulation procedure to treat textile effluents would produce a lot of sludge, causing handling and disposal issues. Textile wastewater frequently contains hazardous organic compounds that defy biological treatment. One textile effluent was further processed using an adsorption column filled with activated carbon to meet standard effluent discharge or prepare it for recycling. Thus, textile industry uses appropriate treatment techniques to produce technically and economically viable solutions [15]. Large quantities of effluents containing non-biodegradable colors are discharged by the textile sector, making it one of the most significant contributors of environmental pollution. From its initial treatment to its different phases of processing, it uses a lot of water. It takes between 100 and 200 liters of water to produce 1 kilogram of the finished product. Textile effluents contain leftover chemicals and colours from the production process. Because of the widespread use of hazardous, non-degradable pollutants in the textile industry, its effluents are widely regarded as one of the world's greatest environmental problems. To make MgO-NPs and Fe_2O_3-NPs, as well as a biocatalyst, filtrate from the *Aspergillus carbonarious* strain D-1 was employed. The largest deocolorization of textile effluent generated by -Fe_2O_3-NPs was 46.9 ± 0.5% after 8 hours, whereas the greatest decolorization resulting from MgO-NPs was 92.2 ± 0.3% after 4 hours, as demonstrated by changes in chemical oxygen demand (COD), total dissolved solid (TDS), total suspended solids (TSS), and conductivity. These NPs treatments greatly improved wastewater quality [16]. Instead of just being released into the ocean, the purified wastewater that has undergone secondary and tertiary treatment may be put to any number of beneficial uses [17]. There are various types of dyes such as acidic, basic, mordant, pre-metallized which includes Cu, Pb, Zn, Cr, Co etc. [18].

Zinc oxide nanoparticles (NPs) have considerable potential as a photocatalyst in the removal of harmful pollutants, particularly azo dyes, from wastewater. This is primarily attributed to their advantageous characteristics such as photostability, non-toxicity, chemical stability, cost-effectiveness, biocompatibility, thermal and as well as their remarkable UV absorption capacity [12]. ZnO-NPs loaded parthenium weed activated carbon (ZnONPs-PWAC) has the ability to eliminate contaminants from aqueous solutions (such as Methylene Blue and Cr (VI)), and it has also been expanded for cleansing tannery wastewater [19]. Analyses of decolorization and degradation showed that -Fe_2O_3-NPs are excellent biocatalysts for the breakdown of dye in a way that is dose- and time-dependent (see Figureure 1) [20]. It was determined whether zinc oxide nanoparticles generated from *Oedogonium* sp. were effective at removing heavy metals from the wastewater produced by the leather industry [21].

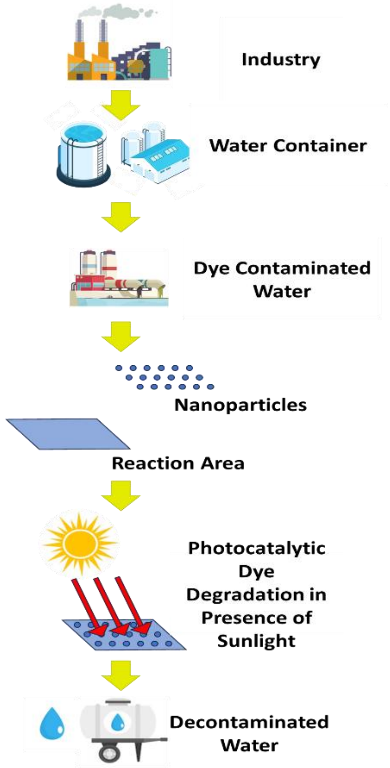

Figure 1: Schematic diagram of decontamination of industrial wastewater.

Organic dyes restrict sunlight and diminish aquatic diversity due to their non-biodegradability and high color intensity. If eaten, some may cause skin, ocular, respiratory, and allergic dermatitis irritations. Phytotoxicity has been shown in agricultural plants when exposed to malachite green, acid violet, and crystal violet triphenylmethane dyes. Additionally, these dyes have demonstrated cytotoxic effects on human cells and have been found to promote tumor growth in some fish species. The consumption of these pigments results in gastrointestinal distress and permanent ocular harm [15]. The elimination and mitigation of the Azithromycin antibiotic using adsorption technology using nano-bioadsorbents can be possible. The elimination of Azithromycin contaminants from the aquatic environment is achieved by the use of biofabricated Hematite nanoparticles (α-HNPs) [22]. Because of the adverse effects that diclofenac sodium has on the surrounding environment, the pharmaceutical industry has begun to target it as a potential contaminant. The anodization of metallic titanium foils was the method that was used to load the Ag-NPs onto the TiO_2-NTs. TiO_2-NTs and Ag-NPs were used to study the photocatalytic effects of the antibiotic diclofenac sodium [23].

3. RIVER WATER TREATMENT

The existence of natural organic matter (NOM) is commonly acknowledged to impact the retention of micropollutants in membrane- based systems. The integration of nanofiltration (NF) with adsorption processes reserves the potential to the achievement tends to 100% removal proficiency. The infliction of treated NOMs over the filters has the capability to enhance the adsorption of nanocontaminants [24]. Surpassing the removal caliber of most sophisticated treatment methods to efficiently eliminate pharmaceutical contaminants presents in low extremely low concentrations metal oxide nanoparticles (MONs) can be appointed [24]. To minimize or eliminate pharmaceutical contaminants, diverse techniques such as electrochemical oxidation, adsorption, nanofiltration, and photocatalysis can be employed in wastewater and water treatment applications. TiO_2 and ZnO, ceramic membranes, polymer membranes, nanowire membranes, CNT, metal (oxides), submicron nano powder, magnetic NPs, or nanostructured boron doped diamond may be utilized by these methods [13]. For the detection of antibiotics or specific pharmaceutical contaminants, graphite oxides are used as quenchers, With their application depending on the aptamer selected for the target recognition [25]. In the process of isolating specific antibiotics, metal oxide nanoparticles are often utilized as separators when combined with aptamers that exhibit affinity towards the target antibiotic(s). An instance of this is the utilization of Fe NPs, along with a gold shell and a specific aptamer in magnetic separation to effectively remove targeted antibiotics [26]. Whenever NPs are doped with transitional metal ions such as Cu, Zn, Mn, Fe it is level ups to its optimum execution in the case of the degradation or photocatalytic activity [27]. The phenol removal efficiency of iron(III)-doped TiO_2 nanoparticles was superior to that of commercially available TiO_2 nanoparticles [28]. One of the precedents with enhanced antibacterial, permeability alongside exceeding benefits is TiO_2. TiO_2 has an eye-catching antibacterial property, and it possesses undeniable photo catalytic behavior when it is in anatase form. The utilization done by nanoparticles composed of iron oxide and TiO_2 was used to examine the impact of particle size on the adsorption of heavy metals. Demonstration of great sorption capabilities for metal pollutants is a worthy characteristics of iron oxide and TiO_2. Nevertheless, nanoparticles based on iron oxide are required to be studied explicitly. The use of iron oxide nanoparticles has displayed significant promise in effectively immobilizing biomass. To eliminate various pollutant extensively varieties macro and microbial biomass has been employed due to their capacity of bio-sorption [29]. Greater antibacterial activities were exhibited on ophthalmic pathogens by Iron(III) oxide(Fe_3O_4), magnesiumoxide(MgO_2), zirconium dioxide(ZrO_2) [30]. Studies have reported significant antibacterial effects of zinc oxide nanoparticles (ZnO-NPs) against various waterborne and environmental bacteria, including *Salmonella typhi*, *E. coli*, and *Pseudomonas aeruginosa* [31]. The complete eradication was done by ZnO NP with the combination of ultraviolet(UV) on waterborne *E.coli* and *P.aeruginosa* [32]. Because of the impact of superior isoelectric point *E.coli*, Fe_2O_3-NPs possess a strong ability to bind to the cell wall of microbes. It was discovered that the nanoparticle mentioned in their study exhibited remarkable efficacy against these microorganisms. Infiltration done by Fe_2O_3-NPs to the organisms, leading them to their demise by causing oxidative stress through the production of reactive oxygen species [33]. CuO-NPs exhibited inhibition zones measuring 14 mm and 16 mm in diameter against *Enterobacter aerogenes* and *S. aureus*, respectively. In contrast, the algal extract containing MON did not produce any inhibition zones in this case. CuO-NPs have been demonstrated to possess the ability to deactivate protozoan parasites such as *Entamoeba histolytica* and *C. parvum* cysts. This quality gives CuO-NPs a significant advantage in water treatment applications by effectively removing chlorine-resistant parasites, thereby reducing the risk of amoebiasis and cryptosporidiosis. Additionally, varying concentrations and particle sizes of CuO-NPs have been optimized to exhibit high potential in inhibiting the growth of P. aeruginosa and Proteus species [34]. Gram-negative bacteria are more susceptible to the inhibitory effects of CuO-NPs compared to Gram-positive bacteria [35]. CuO-NPs at a concentration of 200 ppm and a particle size of 30 nm displayed remarkable removal activity within half an hour. Furthermore, even at very low concentrations (0.5 ppm), CuO-NPs exhibited inhibitory activity, as indicated by the report. The antimicrobial activity of CuO-NPs extends across a wide range of microbial contaminants and is comparable to that of silver oxide nanoparticles [36]. In water treatment, the synthesis of chitosan ZnO nanoparticle (CSZnONPs) composite beads are commonly performed using polymeric methods. These composite beads have shown promising applications in water treatment [37]. The antimicrobial properties of silver ions (Ag^+) have long been recognized and utilized in various applications. They are employed in wound dressings to prevent infections in burn patients, to prevent blindness in newborns, for the treatment of severe chronic osteomyelitis and urinary infections, to control Legionella bacteria in hospitals, and to enhance the effectiveness of drinking-water filters. Silver ions can attach to multiple sites on bacterial cells and enzymes, causing damage and impairing their functionality. This leads to the death of bacterial cells by specifically targeting their DNA and RNA [38]. Despite numerous investigations into the elimination of pathogenic bacteria from drinking-water sources using Ag/zeolite, Ag/sand, Ag/fiberglass, and Ag/resin nanoparticle substrates, there is a lack of comparative data on the efficacy of these technologies. Therefore, there is an importance on the enhancement of these substrates through the incorporation of silver nanoparticles. Their relative performance in eliminating *Escherichia coli*, *Vibrio cholerae*, *Shigella dysenteriae*, and *Salmonella typhimurium* from contaminated groundwater sources also should be assessed [38].

4. SEA WATER TREATMENT

Nanomaterials like carbon nanotubes, graphene, zeolites, and aquaporin are employed in diverse desalination methods to enhance techniques of water filtration [14]. For more than 150 years, sand-based filtration has been employed in sea water purification to manage microbiological contamination. Sand based filters offer a cost-effective and efficient approach to water treatment, and they can be constructed using local expertise, making them accessible for self-construction [38]. To enhance the efficiency of seawater desalination, a new approach could be implied, which involves the development of a mixed matrix membrane (MMM). The MMM is composed of a poly(vinyl alcohol) (PVA) nanofibrous active layer deposited on a cellulose acetate substrate functionalized with 3-triethoxysilylpropylamine. The active layer is fabricated by incorporating zinc oxide nanoparticles (ZnO-NPs) and sodium alginate (NaAlg) into a tetraethyl orthosilicate-crosslinked PVA matrix. The reverse osmosis performance of the MMMs is improved by incorporating ZnO-NPs and NaAlg into the PVA matrix. Optimal concentrations of 0.1 wt% ZnO-NPs and 0.01 wt% NaAlg are determined based on various factors such as permeation flux, salt rejection, salt passage, stability, long-term rejection, membrane antifouling, reusability, and chlorine resistance. The MMMs are evaluated using a dead-end reverse osmosis filtration setup. The results demonstrated that the active layer achieves a permeation flux of 34.6 L/m^2h, a natural sea salt rejection of 97%, and a chlorine resistance of 93%. These findings indicate that the proposed MMMs have the potential to be effective in seawater desalination applications [39].Increased water flux and efficient salt rejection was seen when the introduction of TiO_2 NPs into acriflavine thin-film composite membrane served as performance enhancer. 51.12° contact angle and 67.1 $Lm^{-2}h^{-1}$ pure water flux was exhibited by the TFC 4. Outstanding performance in rejecting divalent ions for both AGS and RO brine feed solutions was demonstrated by salt rejection experiments. It was found that acriflavine TFC membranes with TiO_2 NPs exhibit a robust capability to effectively reject divalent ions, rendering them highly suitable for use in desalination pretreatment and RO brine concentration applications [40]. ZrO_2-doped graphene oxide exhibited improved electrosorption capacity and specific capacitance compared to pristine graphene oxide. The nanocomposite with 10 wt.% ZrO_2 showed a significant nine-fold increase in specific capacitance (452.06 F/g) at 10 mV/s. The electrode demonstrated excellent stability during cycling, high efficiency in removing salt (93.03%), and notable electrosorptive capacity (4.55 mg/g). In summary, the proposed GO/ZrO_2 composite electrode is highly suitable for capacitive deionization (CDI) applications due to its superior salt removal efficiency, which is attributed to its high specific capacitance and stability [41]. CNTs have been extensively studied as a model system to investigate water and ion transport, as well as the interaction between water and ions within their confined inner cores, owing to their high hydrophobicity and structural simplicity. Research on the feasibility of ion transport and adsorption using electrostatically charged CNTs was done by a group of scientists. They discovered that spatially alternating charge patterns on CNTs facilitated water intake while completely inhibiting ion intake into the nanochannels. These findings suggested that by manipulating the applied charge pattern, CNTs could be utilized as effective devices for either water encapsulation or ion encapsulation. The primary obstacle in utilizing this material in large-scale membranes is the integration process and measuring the transport characteristics. Difficulties arise when attempting to scale up the technology from laboratory experiments to industrial-level processes [42]. In a study, thermoresponsive magnetic nanoparticles (MNPs) were utilized as a draw solute in forward osmosis (FO) for water extraction from brackish or seawater. The MNPs consisted of Fe_3O_4 nanoparticles coated with a copolymer known as poly(sodium styrene-4-sulfonate)-co-poly(N-isopropylacrylamide) (PSSS-PNIPAM). This novel draw solution exhibited a high osmotic pressure, making it suitable for seawater desalination. The nanoparticle structure integrated three key components: a magnetic Fe_3O_4 core for easy separation, a thermoresponsive polymer (PNIPAM) that enabled reversible clustering of the particles for enhanced magnetic capture at temperatures above its low critical solution temperature (LCST), and a polyelectrolyte (PSSS) that contributed to a significantly higher osmotic pressure than seawater [43]. Nanoparticles comprising γ-Al_2O_3 and zeolite were synthesized and applied as coatings on a porous geopolymer base, leading to the creation of ceramic membranes for desalination. The salt rejection efficiency of these membranes displayed fluctuations and inconsistency. Among the three membrane variants, the Z membrane showcased the greatest salt rejection rate, reaching up to 87.88% [44].

Development of nanocomposite membranes for water desalination using cellulose acetate (CA) and candle soot (CS) nanoparticles through the phase inversion technique. The membranes exhibited partial hydrophobicity as determined by contact angle measurements. Annealing the membranes with 2% candle soot nanoparticles resulted in an optimized salt rejection of 93%. The crucial step of annealing at 70°C prior to testing significantly influenced the desalination performance. In summary, the integration of CS nanoparticles into the CA membrane holds promise for water desalination due to its high salt rejection capacity and relatively slight flux properties [45]. Membrane distillation (MD) is a cost-effective and efficient water treatment process that utilizes low-grade energy. It employs hydrophobic polymers like PVDF, PTFE, or PP to synthesize MD membranes through techniques such as phase inversion and electrospinning. These membranes play a crucial role in surface water/wastewater treatment and seawater desalination, as evidenced by recent literature. The performance of MD membranes can be enhanced through the incorporation of nanoscale materials, which helps prevent wetting and fouling issues [46]. A novel plasmonic device, referred to as In NP/MPM, is fabricated using a straightforward thermal evaporation method. This device comprises a microporous membrane and indium nanoparticles, offering a lightweight and porous structure. It possesses a wide spectrum light absorption capability and an exceptionally efficient plasmonic heating effect, potentially surpassing other nanoparticles such as gold, silver, and aluminum. The device, when floated on the water surface, greatly enhances the evaporation of solar water and has demonstrated successful utilization in desalinating actual seawater samples. Moreover, the device exhibits robustness and consistent performance throughout multiple cycles of solar seawater desalination [47].

5. GROUNDWATER TREATMENT

TiO_2 nanomaterials are utilized in removing arsenate, arsenite [48], HgO [49], Pb (II), Cu (II) [50], Hg(II) [51] from ground water. TiO_2 nanomaterials can adsorb heavy metals from ground water [48][50]. These nanomaterials can also engage in the photocatalytic reduction of Hg (II) in groundwater, facilitating the removal of heavy metals through a photocatalytic process [51]. Iron doping can significantly enhance the adsorption capacity of a TiO2 nanoparticle-based adsorption medium by inhibiting grain growth and enabling its responsiveness to visible light [52]. This adsorption process additionally rely upon temperature [50] and pH, for instance, arsenate can be fundamentally eliminated below pH 7.25 and arsenite below pH 9.2. [48]

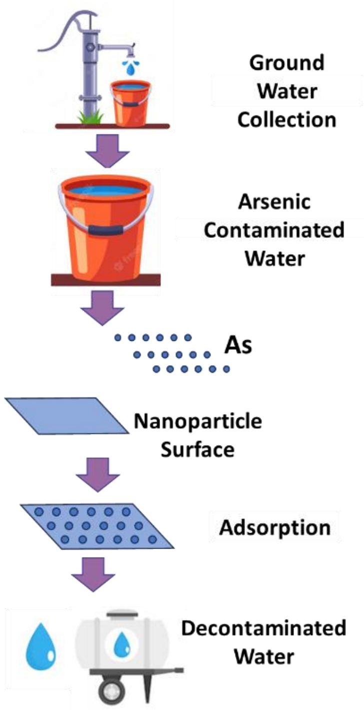

Figure 2: Removal of arsenic from ground water: a schematic

When comparing microscale iron powder to nanoscale zero-valent iron (NZVI), it was evident that NZVI demonstrated superior efficacy in the degradation of hexachlorobenzene (HCB), a type of chlorinated aromatic compound. After a 400-hour period, microscale iron powder achieved only a 12% overall conversion of HCB, with the identification of intermediary substances like 1,2,4,5-tetrachlorobenzene and 1,2,4-trichlorobenzene. This highlights the enhanced capacity of NZVI in breaking down chlorinated organic contaminants such as HCB. Additionally, iron nanoparticles exhibit notable effectiveness in addressing hexachlorocyclohexanes (HCHs), which are commonly used pesticides, due to their potent reducing abilities. Chlorinated pesticides, including HCHs, possess detrimental consequences and tend to persist in the environment while accumulating in animal tissues. Iron nanoparticles offer a promising solution for the degradation of these compounds, including notorious examples like DDT, hexachlorobenzene, hexachlorocyclohexane, chlordane, and dieldrin which can be present in ground water [53]. The ingestion of pathogenic bacteria like *Escherichia coli* O157:H7, *Salmonella typhimurium*, *Shigella dysenteriae*, and *Vibrio cholera* from contaminated groundwater and surface water sources remains a leading cause of diarrheal diseases and gastrointestinal infections .This underscores the importance of access to safe drinking water in maintaining human health and overall well-being [38]. In the environmental and industrial fields, it is very important to keep an eye on the factors that show the quality of water, especially drinking water. To control the quality of water and make sure it meets standards for potable drinking water, analytical methods should be used. Standards like Standard Methods for the Examination of Water and Wastewater are used to judge the quality of water based on its physical and chemical properties. Total hardness is one of these factors that has been looked into because of its effects on the environment, industry, and homes [54]. Hardness is defined by the high concentration of magnesium, calcium, lead, chromium, iron, and mercury [55]. Most of the total hardness comes from Ca^{2+} and Mg^{2+} ions [55]. The ability of water to form a solid when soap is added is linked to its hardness. It was successfully used to determine the total hardness of water thanks to the prepared AgNPs' non-specific but selective activity toward these ions. This was possible because of the AgNPs' non-specific but selective nature. This is the same event that takes place in the usual titrimetric procedure that is carried out by EDTA in order to determine the overall hardness of water [54]. The presence of a high concentration of arsenic in groundwater is a global problem. This is since drinking water containing such a high concentration of arsenic for extended periods of time causes a range of cancerous effects on different organs of humans, which finally results in death. The maximum bed depth (or BV) and the slowest rate of effluent discharge suggest the best arsenic removal capability from high arsenic groundwater. Cost comparisons with other reported materials revealed promising potential for Mn-incorporated Fe(III) oxide nanoparticle (MNFO) in the treatment of arsenic-rich groundwater. Arsenic-rich MNFO was shown to be non-hazardous in a toxicity leaching procedure (TCLP) test. Feed and break-point effluent water quality parameters were evaluated and compared, and the results showed that the MNFO is capable of reducing not only the arsenic level (see Figure 2), but also the parameters such as chloride, phosphate, nitrate, etc. [56]. In the case of TiO_2 NPs, it has been discovered that an increase in water hardness encourages aggregation, provided that the concentration of DOC is lower than 0.6 mg/L. This suggests that divalent ions, including Ca^{2+} and Mg^{2+}, are an effective means of neutralizing the negative surface charge shown by TiO_2 NPs. Ca^{2+} and Mg^{2+} are strongly adsorbed onto TiO_2 due to the attractive electrostatic forces that exist between NPs and divalent cations; this results in TiO_2 NPs having their charge neutralized. This is because TiO_2 NPs are strongly negatively charged at the pH of their environment. It has been discovered that increasing the concentration of DOC causes a decrease in the aggregation of TiO_2 NPs. This is most likely because the creation of Ca^{2+} and Mg^{2+} complexes lessens the impact of these ions on the surface charge of the TiO_2 particles [57].

6. CONCLUSION

In conclusion, treatment of industrial wastewater, river water, ocean, and groundwater are major issues for the environment's sustainability and human health. Numerous nanomaterials have demonstrated considerable potential in tackling the issues related to water pollution and contamination. The usage of nanoparticles like MgO-NPs and Fe_2O_3-NPs has dramatically improved wastewater quality in the textile sector, offering technically and financially viable alternatives for effluent treatment. Near-total removal of hazardous pollutants, pharmaceutical contaminants, and micropollutants from river water is also possible when nanofiltration and adsorption techniques are used. Furthermore, higher efficacy in seawater desalination applications has been shown for nanocomposite membranes and mixed matrix membranes integrating nanoparticles. In the context of groundwater remediation, TiO_2 nanomaterials have successfully removed heavy metals and chlorinated compounds, whereas zero-valent iron nanoparticles have shown promise in the degradation of different pollutants. Waterborne infections and contaminants have been successfully eliminated thanks to the unique characteristics of nanoparticles, such as their high adsorption capacity and photocatalytic activity. While there are many possibilities for water treatment thanks to nanotechnology, it is important to carefully analyze the effects of nanoparticle discharge on the environment and any potential health issues. To maintain the long-term viability of water treatment techniques based on nanomaterials, research in this area should keep investigating safe and sustainable solutions. In conclusion, nanotechnology can fundamentally alter how water is treated, providing creative and effective answers to the pollution problems that are present in groundwater, river water, sea water, and industrial effluent. To secure clean, readily available water supplies for both the present and future generations, continued research and careful application are crucial.

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