Nanoadsorbents: A green approach for wastewater treatment

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Abstract: The physical, chemical, and biological characteristics of water have changed as a result of the buildup of diverse pollutants, including organic and inorganic materials, pathogens, heavy metals, and other toxic materials. These unwanted materials make the water unsafe for drinking and for the ecosystem, and we can refer it as wastewater. Industries have meticulously addressed the treatment of wastewater to safeguard its disposal into the ecosystem. Several new technologies are developed over the traditional methods. Nanomaterials, with high degree of functionalization, high reactivity, large specific surface area and size dependent properties, have been used for the wastewater treatment and water purification. The present book chapter provides a concise overview of the latest advancements and the utilization of nanoadsorbents in the field of wastewater treatment. The use of metal and metal oxides nanoparticles, carbon-based nanomaterials, zeolite etc. has been discussed in the purification of wastewater.

Keyword: Wastewater; Pollution; Nano-adsorption; Carbon nanotube; Toxicity.

1. INTRODUCTION

We have unlimited source of water in the world but only 2.5% is useable. Water, as a universal solvent, easily dissolve various substances and origins water pollution. Swage, industrial by-products, and leakage of fertilizer causes water pollution [1, 2]. These types of contamination would spread pathogen microbes and harmful disease. Water has influences on human life through health, food, and energy. 3.6 billion people (~45% of the total world's population) do not have basic sanitation service, clean and safe drinking water is unavailable to 1.2 billion people (~15% of the total world's population). Millions of children have lost their lives due to contaminated water [3, 4]. So, appropriate treatment of wastewater is needed before its release to our ecosystem. Wastewater treatment mainly categorise by three main methods: physical, biological, and chemical. These methods are cost effective, require high energy, large plants infrastructure, significant amount of energy consumed mechanical methods, and engineering expertise. Sometimes chemicals like ammonia, sodium hydroxide, permanganate, chlorine compound, hydrochloric acid, ozone, and ferric salt were used to treat wastewater. But these conventional methods are not effective in removing toxins, phosphorous, nitrogen and heavy metals from wastewater. Therefore, it is very difficult to afford such expensive technologies [5, 6].

Now, it is the challenge for researchers to developed cost-effective alternative wastewater treatment processes with small infrastructure. Nanotechnology has a possible role to purify the wastewater; mainly nanomaterials are contributing more to the development of effective wastewater treatment. Recently, nanostructured materials have found application as adsorbents for the elimination of harmful and toxic components from wastewater [7]. Higher surface functionalization, large specific surface area, and size dependent activity make nanomaterials fit for wastewater and water purification process [8].

This chapter explores some recent development and application of nanoadsorbents in wastewater treatment. The use of various nanomaterials, e.g. carbon nanotube, metal oxide, metal nanoparticles, and zeolite, as nanoadsorbents has been discussed in detail.

2. WASTEWATER: SOURCES, COMPOSITION AND TREATMENT

2.1. Sources and Composition of Wastewater:

The sources of wastewater can be divided into two classes: residential source and non-residential source. Various sources of wastewater are given in Figure 1. Sewage, known as residential wastewater, is released form public residences. It is mainly made up of water (99.90%) and solid matters (0.10%) which include suspended solids, decomposable dissolve organic compounds, inorganic compounds, nutrients, metals, and pathogenic microorganisms [9]. The typical composition of the sewage water has been shown in Figure 2.

Figure 1. Various sources of wastewater.

Non-residential wastewater is mainly released from agricultural fields, industries, and commercial sectors (*i.e.*, hospitals, restaurants, and shops). The composition of non-residential wastewater depends on the types of sources. For example, fatty substances and grease were found from restaurant wastewater, whereas textile industry's wastewater contains organic dyes. Moreover, agriculture fields and industrial wastewater contains biological pollutants, harmful chemicals, and heavy metal ions, and these are toxic to living organisms. Another source of non-residential wastewater rain contains organic and inorganic pollutants from street along with fertilizer and pesticides from agriculture fields.

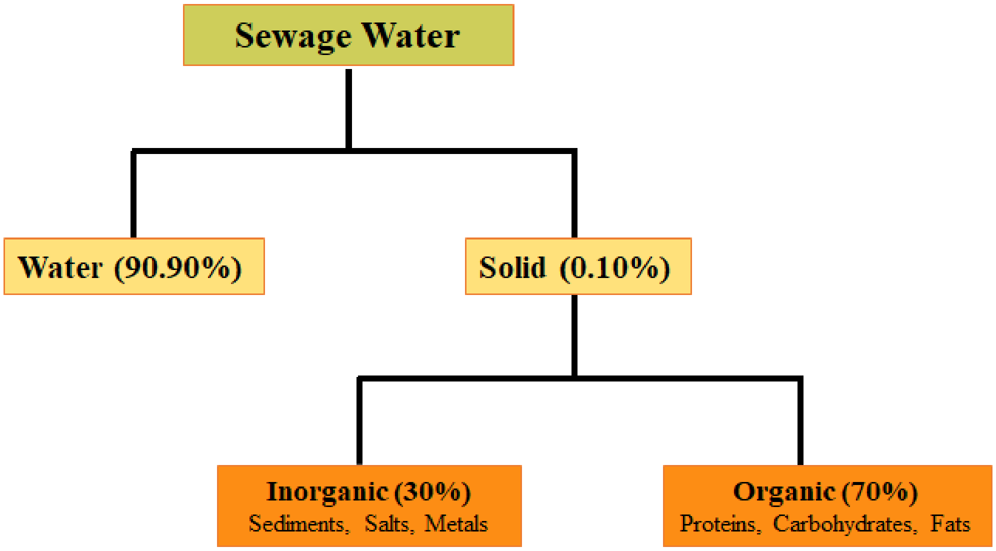

Figure 2. Components of sewage water

2.2. Wastewater treatment:

Wastewater treatment is a procedure where the pollutants were separated using of physical and chemical methods. Residential and non-residential wastewater can be treated in many ways [10]; at first the wastewater is cleaned in a municipal sewage treatment plant. A large amount of the pollutants can be removed in the treatment plant. The treatment procedure consists of three stages: preliminary, primary and secondary stage.

In the preliminary treatment process, large and/or heavy materials were removed. Screening and grit removal processes were usually done during the preliminary treatment. Large floating fragments including rags (~60%), paper (~25%), and plastic (~5%) were removed during the screening process. After the screening, the grit which includes heavy inorganic particles like sand, was removed by settle down method and used for land filling.

After the preliminary treatment, effluent goes to the primary treatment process where sedimentation process was used to separate the major suspended solid materials from the wastewater. The wastewater is passed through the sedimentation tanks. Most of the solid materials were settle down at the bottom of the tanks, which is known as sludge. These sludges are removed from the bottom of the tank and the effluents moved to the secondary treatment process. The biological oxygen demand (BOD) (nearly 40%), suspended solids (80-90%) and up to 55% biological microorganism were removed during the primary treatment process.

In the secondary treatment process organic materials and remaining solid materials were removed. The growth of bacteria and other microorganism were enhanced in this process, and they oxidize the dissolved organic matters to CO_2 and H_2O. In addition, some nutrients such as nitrogen and phosphorus were also removed [9]. A complete process of a wastewater treatment plant is given in Figure 3. After the treatment of sewage, it is crucial to ensure the safety of its release into the environment. Before being released into the environment, the treated sewage is usually disinfected using UV or chlorination method. Anaerobic sludge digestion process is used to treat the sludge, which involves promoting the growth of bacteria inside a digester. The organic particles are reduced by the anaerobic bacteria by degrading them into soluble by-products and gases, mainly CH_4 and CO_2. The methane gas generated during the process can be used as a fuel for heating the digesters, and for running other power equipment in the plant and the treated sludge is used for land filling or sent to solid waste handling plants.

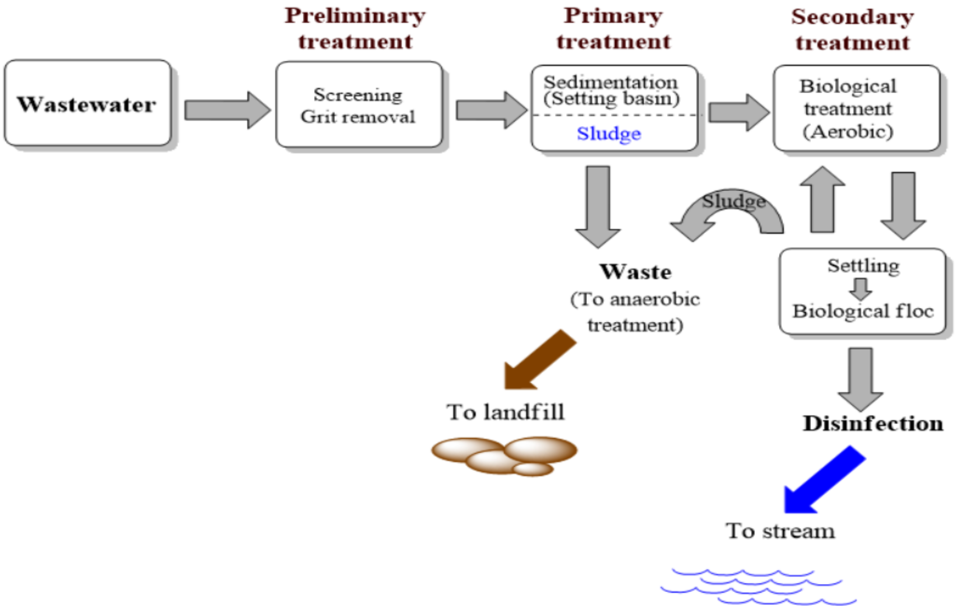

Figure 3. Three stages of the wastewater treatment process in a plant.

Some treatment plants use a tertiary treatment stage along with the above common stages. They use physical and chemical methods to eliminate any remaining organic and inorganic materials as well as microorganisms from the effluent of the secondary stage [11]. The water can satisfy the requirements for drinking water following tertiary treatment.

3. NANOTECNOLOGY FOR WASTEWATER TREATMENT

Nanotechnology is the synthesis of materials, devices or systems at nanoscale using integration of atoms and molecules. Nanotechnology developed various alternative tools and techniques in the treatment of wastewater. These advancements have not only enhanced the efficiency of wastewater treatment but also made it more cost-effective [12]. Nanomaterials can achieve this due to their small size, increased precision, high reactivity, and the ability to be produced using environmentally friendly and cost-effective methods. Some of the important wastewater treatment methods or tools presented by nanotechnology are given below:

- Photocatalysis
- Nanofiltration
- Nanosorbents

3.3. NANOSORBENTS:

In a sorption process, sorbate adsorbs on the surface of sorbent through physical or chemical communications. Sorbents are frequently employed in the process of water purification to remove organic and inorganic pollutants. Generally, there are three processes in sorption through which pollutants were adsorbed on the sorbent surface: (i) the transportation of the pollutants from water to the sorbent surface, (ii) the adsorption on the sorbent surface, and (iii) transportation within the sorbents. Nanoparticles have higher specific surface area than bulk elements and the addition of different functional groups allows for easy functionalization of the nanomaterials, thereby increasing their attraction towards the target pollutants. Pores present in nanosorbents contribute to the sorption process. The reusability of nanosorbents is made possible through the removal of the adsorbed pollutants. For example, it has been shown that the self-assembled 3D flower like iron oxide may successfully filter out heavy metal ions and can adsorb organic dyes from contaminated water [13]. Some of the commonly used nanomaterials used as adsorbents are describe bellow:

3.3.1. Carbon nanosorbents:

Various organic and inorganic contaminants have been effectively adsorbed using carbon nanomaterials due to their high thermal stability, high adsorption capacity, and low cost. The application of granular activated carbon (GAC) has demonstrated its efficacy in the removal of various organic contaminants and odorous pollutants from water [14-16]. Asenjo et al. conducted an investigation on the adsorption of benzene and toluene from industrial wastewater using activated carbon [17] and their study described a moderate adsorption of 860 mg/g for benzene and a higher adsorption capacity of 1200 mg/g for toluene. Activated carbon also active for the elimination of heavy metal ions, like Hg(II), Ni(II), Co(II), Cd(II), Cu(II), Pb(II), Cr(II), and Cr(IV) [18, 19].

In addition to AC, one dimensional carbon-nanotubes (CNTs) gain a lot of attention as an exceptional adsorbent because of their high surface area, excellent thermal and chemical stability, the performace of the CNTs can be modified by easily functionalizing their surface [20]. Luan et al. investigated the application of CNTs for the adsorption of 1,2-dichlorobenzene, Pd and Cd from water [21]. The morphology of CNTs and their surface have shown a significant impact on the adsorption of these pollutants; the treatment of CNTs with oxidants led to improvement in both the adsorption capacity and dispersibility of the CNTs. Additionally, it was observed that CNTs have a very high adsorption efficiency against dichlorobenzene [22]. When CNTs were annealed at high temperature (~2200°C) in an inert atmosphere, the adsorption capacity was decreased with the formation of defect free smooth CNTs surface. Therefore, the defects and rough surfaces of CNTs are essential for the adsorption process [22].

Kuo et al. investigated the application of CNTs in removing organic dyes from water via physisorption process [23]. Both CNTs and AC are suitable for water treatment process because of their thermal and chemical stability, and high adsorption capabilities. But, due to their small sizes, it is quite difficult to separate them from water. Incorporation of magnetic nanoparticles with the CNTs or AC was found to be very effective to resolving the above issue. The separation of these magnetic nanocomposite adsorbents is made very simple with the use of magnetic separation process [24, 25].

3.3.2. Biosorption:

Sometimes, the complete removal of certain organic pollutants from water is difficult due to their low concentration, usually within the nanogram per litter range [26]. Biosorbents, which are often made from biological and agriculture materials, have been found to be effective for elimination of such contamination. Biosorbents have several benefits over conventional absorbents, including minimum cost, high efficiency, low agriculture and biological sludge formation, no additional nutrients required, and possible to regenerate. Liu et al. created a DNA matrix using salmon milt DNA hydrogel beads, which was effective in selectively adsorbing dioxin derivative [27]. After the dioxin adsorption, the DNA beads can be regenerated easily by simply cleaning the beads with hexane. In other studies, it has been shown that the use of triolein embedded biosorbents can eliminate organic contaminants from water [28, 29]. Triolein has shown a remarkable ability to accumulate trace number of organic contaminants in water [30] and the low solubility and permeability of the membrane are due to the high molecular weight of 885.45 Da [31]. The removal of heavy metal ions form water has been achieved through the use of biosorbents. A biosorbent derived from black liquor, a waste material from paper industries, was developed by Guo et al. to investigate the sorption capacity of heavy metals [32]. The reported order of sorption affinity of this biosorbent towards different heavy metal ions is as follows: Pb(II) > Cu(II) > Cd(II) > Zn(II) > Ni(II). Biosorbents prepared from various agriculture and waste materials have been used for the removal of heavy metals from water [33-35].

3.3.3. Metal based nanoadsorbents:

Recently, there has been a growing interest among researchers in utilizing metal-based nanomaterials as adsorbents [36]. Metal oxides like Fe_3O_4, TiO_2, MnO_2, MgO, ZnO, and CdO are extensively used for the removal of heavy metals, ions and organic dyes from wastewater [37]. Metal oxide nanomaterials exhibit more effectiveness as an adsorbent in removing heavy and radioactive metals than activated carbon. Due to their small size and large surface area, these particles exhibit a reduce intraparticle diffusion distance, enabling compression without affecting their surface area. The sorption process is predominantly controlled by the interaction between dissolved metals and the oxygen present in metal oxides [38, 39].

Various metal ions, like calcium (Ca^{2+}) and copper (Cu^{2+}) are present in the wastewater that comes from oil refineries. He et al. has successfully developed a reusable nano-adsorbents using Fe_3O_4/carboxylate graphene oxide (GO-COOH). This nanocomposite was synthesized through magnetization and carboxylation of graphene oxide (GO). This nano-adsorbents removed 78.4% of Ca^{2+} and 51% of Cu^{2+} ions after 60 min. Upon completion of five consecutive adsorption-desorption cycles, the nano-adsorbent maintained exceptional high recovery rates (82.1% for Ca^{2+} and 91.8% for Cu^{2+}) and achieved significant removal percentages (72% for Ca^{2+} and 49.33% for Cu^{2+}) [40]. Sadak et al. synthesized magnetic nano-adsorbent by conjugating polyacrylic acid (PAA) with ferric oxide (Fe_3O_4) nanoparticles (MNPs). This magnetic nanocomposite was then functionalized with an azo dye Congo Red (CR) resulting in (PAA-CR/MNPs). PAA-CR/MNPs exhibited a strong binding strength towards several cations like Fe^{2+}, Fe^{3+}, Cd^{2+}, Cu^{2+}, and Pb^{2+}. The removal efficiency of heavy metals, specifically Pb^{2+}, was examined by analyzing the PAA-CR/MNPs under different pH, temperatures, reaction conditions, and contact times. PAA-

CR/MNPs exhibited the best removal efficiency and adsorption capacity for Pb^{2+} were at a pH 6.5 and a reaction time of 45 min [41].

Arshadi et al. developed an adsorbent using sineguelas waste (S-NaOH) which was derived from agricultural biomass. This waste was then modified by incorporating nanoscale zerovalent iron particles (NZVIPs). The above designed composite was utilized to study the adsorption and reduction of inorganic pollutants like Pb^{2+} ions. The NZVIPs have shown proper dispersion throughout the surface of the sineguelas waste [42]. Using lead-doped zinc-aluminium oxide nanoparticles, Jethave et al. developed an effective nano-adsorbent for the adsorption of anionic dyes like methyl orange (MO). After 30 min, the above system has shown an impressive MO removal efficiency of 99.6%, additionally it exhibited a maximum adsorption capacity of 200 mg/g for MO [43].

3.3.4. Polymer based nano-adsorbents:

In recent years, a numerous studies have been conducted to develop various polymer nanocomposites in order to investigate their potential applications in environmental sustainability and in the process of wastewater treatment. Their high surface area, notable stability, enhanced processability, cost effectiveness, and selectivity to remove various pollutants from water make them suitable for the treatment of wastewater [44, 45]. Nanocelluloses, derived from cellulose, possess a wide range of advantages and their surface can be effectively modified which make them a suitable candidate for wastewater treatment. The study of lignin derived nanomaterials has explored their potential in the field of wastewater treatment. The efficiency of this material has been confirmed in the catalytic decomposition of dyes, nitroarenes, and in the elimination of heavy metals [46].

Abdi and Abedini established a composite material by incorporating a metal organic framework, specially zeolitic imidazolate framework (ZIF), into polyether sulfone (PES) nanocomposite beads for removal of malachite green (MG) from wastewater [47]. Moharrami and Motamedi have developed a biologically derived nanocomposite hydrogel by using starch grafted copolymers consisting of 2-acrylamido-2-methyl propene sulfonate and acrylic acid. Its properties can be further enhanced by incorporating cellulose nanocrystals modified with magnetic properties (M-CNCs). This hydrogel demonstrated excellent adsorption capabilities for cationic dyes such as crystal violet (CV) and methylene blue (MB). For CV, the adsorption capacity of this hydrogel is 2500 mg/g, while for MB it is 1428.6 mg/g [48].

The preparation of nano-adsorbents for arsenic (As) removal was reported by Priya et al. These nano-adsorbents were based on iron-aluminium (Fe-Al) layered dual hydroxide/reduced GO (rGO) coated with sodium alginate (SA). The resulting nano-adsorbents were denoted as FAH-rGO/SA. It was determined that the FAH-rGO/SA-4, FAH-rGO/SA-1, and FAH-rGO samples exhibited maximum adsorption capabilities of 190.84 mg/g, 151.29 mg/g, and 115.39 mg/g, respectively. The study demonstrated that a high weight percentage of SA played a key role in the excellent removal efficiency (> 98%) of FAH-rGO for As(V) [49]. Oilfield produced water is highly salinized because it contains metal like Ca^{2+} and Mg^{2+}. He et al. created nano-adsorbents composed of polyethylene glycol (PEG), aminated GO (NH_2-GO), and magnetic Fe_3O_4 nanoparticles. This prepared system showed removal rates 69.8% for Ca^{2+} and 61.1% for Mg^{2+} at 10 min. Overall results indicated that it was stable and reusable for treating oilfield wastewater [50].

3.3.5. Zeolites:

Zeolites have crystalline three-dimensional microporous structure. They possess well defined voids and channels of distinct sizes. These materials are easily accessible through pores with precise molecular sizes. These pores can retain aluminium, silicon and oxygen within their normal framework [51, 52]. With its high specific surface area and notable ion exchange capacity, zeolites prove to be highly attractive adsorbent for wastewater treatment. Dong et al. developed a modified zeolite known as hexadecyltrimethylammonium (HDTMA) [53], which was utilized to eliminate phenol derivatives from water. The bilayer micelle formed by the HDTMA on the zeolite surface enhances the adsorption efficiency of the nano-adsorbents. Bai et al. studied the deterioration of pyridine and quinoline in wastewater utilizing zeolite [54]. The researchers created a biological modified zeolite containing a combination of bacteria for the decomposition of pyridine and quinoline. Zeolites effectively adsorb ammonium ions that are generated during the biodegradation of pyridine and quinoline in water.

Zeolites have been employed for the adsorption of heavy metal ions. Perry et al. investigated the adsorption of lead and cadmium using two natural zeolites, chabazite and clinoptilolite [55]. The author showed exceptional adsorption capabilities for Pb and Cd using two naturally occurring zeolites treated with NaOH and achieved a metal removal efficiency of more than 99%. Zeolite exhibits higher adsorption capabilities as a result of its exceptional porosity. Moreover, the photocatalytic reduction property of zeolite facilitates the transformation of high valence metal ions to lower valence metal ions and effectively reducing their toxicity.

4. LIMITATIONS AND RISKS ASSOCIATED WITH NANOTECNOLOGY

Nanotechnology has demonstrated encouraging results in the treatment of wastewater; however, there are considerable limitations in the way of these successful outcomes. The primary limitations involve nanomaterial toxicity, cost effectiveness, and social acceptability. Risks may arise from nanomaterials transformation, ecotoxicity linked to engineered nanomaterials, and water pollutions.

4.1. Nanomaterial toxicity:

Several past wastewater treatment methods have produced adverse effects. Chlorination, a traditional method of wastewater treatment, was initially believed to have a positive impact on global life. However, further research found that it actually generates harmful by-products, such as N-nitrosodimethylamine and trihalomethanes. The characteristics properties that contribute to the effectiveness of nanomaterials are also the ones that make them prone to toxicity. Toxicity level is influenced by the molecular structure of the components, which then affects the toxicity endpoint, while the size of the nanomaterials regulates their uptake by cells. Due to their small size, nanoparticles can infiltrate epithelial and endothelial barriers, enable to enter the lymph and blood. They can distribute to various organs and tissues, such as the brain, heart, kidneys, liver, spleen, bone marrow and nervous system [56]. It has been observed that the toxicity of Ag nanoparticles, carbon nanotubes, and various metal nanoparticles is dependent on their size and shape. Nanoparticles, with a size range of 1 to 100 nm, have dimensions comparable to protein globules (2-10 nm), DNA helix (2 nm) and cell membranes thicknesses (10 nm), which facilitate their easy penetration into cells and cell organs [57]. Huo et al. found that gold nanoparticles with a size smaller than 6 nm can effectively enter the nucleus, while larger nanoparticles, with a size ranging from 10 to 16 nm, are able of penetrate the cell membrane and are situated in the cytoplasm [58]. According to the reports, TiO_2 nanoparticles induce a conformational change in tubulin, leading to the inhibition of its polymerization. Consequently, this has a significant impact on intracellular transport, cell migration and cell division. Spherical nanoparticles exhibit a higher susceptibility to endocytosis compared to nanotubes and nanofibers. Studies have indicated that single-walled CNTs have proven to be more efficient in blocking calcium channels than spherical nanoparticles. Plate, rod, needle, and spherical hydroxyapatite nanoparticles were used for toxicity testing, also their impact on nontumorigenic lung epithelial cells was evaluated. The results showed that plate and needle-like nanoparticles killed a higher percentage of nontumorigenic lung epithelial cells than spherical or rod like nanoparticles.

4.2. Cost effectiveness:

The acceptability of nanotechnology is directly depending on its effectiveness and affordability in wastewater treatment. In developing countries, advanced technologies are employed to remove various pollutants in wastewater treatment, while in underdeveloped countries, the primary emphasis is on fulfilling basic requirements such as disinfectant. The treatment of increasingly complex pollutant mixtures is utilized in both cases to attain a superior water quality at a reduced cost. This approach forces the limits of recent wastewater treatment models. The production cost of nanomaterials is directly linked to the methods of separation and purification. Lowering the purity levels of nanomaterials can enhance their applicability for wastewater treatment purposes. A significant cost reduction of approximately 90% can be achieved by substituting ultrapure C60 with fullerene soot in the production of amino-fullerene [59]. However, this replacement leads to a decrease in its effectiveness. The long-term responsibility of nanomaterials can also improve their cost effectiveness. The given example showed that the application of photocatalysis retains its functionality by regenerating nano-adsorbents. Additionally, it involves multifunctional nanomaterials that can be separated magnetically and their multiple recycles [60].

4.3. Transformation of nanomaterials risk in water:

Compared to larger particles, nanoparticles have a slower settling rate. However, owing to their significant surface area, they have the ability to adsorb a great number of sediment particles and soil. Carbon nanotubes and fullerenes, due to their insolubility in water, can be effectively removed from water columns. Designed nanomaterials are occasionally utilized for specific purposes, pristine-engineered nanomaterials that have the potential to transform into different forms such as product-modified, product-weathered, and environmentally transferred engineered nanomaterials. Light can sometimes enhance the oxidation-reduction process, leading to photochemical transformations. The interactions of nanoparticles with the environment led to subsequent transformations, ultimately governing the adsorption and release of pollutants in water [61].

4.4. Ecotoxicity associated with nanomaterials:

The concept of ecotoxicity involves the risk of chemical, physical or biological substances which cause disturbance within an ecosystem. There is a possibility of nanomaterials leaching into the treated water during production, usage, and disposal of nanoparticle containing products. Currently developing metal nanoparticles such as Ag and TiO_2 have a higher production rate per year [62]. These rising nanomaterials are raising serious concern for the aquatic environment, as shown in research how Ag and TiO_2 nanoparticles can inhibit the growth of duckweed, an aquatic plant [63]. Concentrations of nanoparticle in certain natural surface waters are calculated to be within the nano or micro g/L range. These concentrations are expected to increase with the growing productions of nanoparticles. Most developing countries use silver, titanium, and zinc oxide nanoparticles to disinfect water and replace chemical disinfectants due to their antibacterial properties [64]. Ceramic filters containing Ag nanoparticles impregnated are utilized for water filtration. Upon filtration through filter papers coated with nano-Ag, detectable amounts of Ag nanoparticles were observed in the filtered water, significantly lower than the WHO's established threshold [65]. Some studies have reported significant organ damage in rats that consumed TiO_2 nanoparticles in contaminated water. Similarly, engineered nanoparticles have been linked to various health issues such as pulmonary inflammation, genotoxicity, carcinogenicity, and circulatory effects [66].

4.5. Water pollutions:

Numerous research works have been carried out to examine the harmful impacts of water contaminated with nanomaterials. The toxic effect of MWCNTs on Astyanax altiparanae and Danio rerio fish species was investigated by Cimbaluk et al. They found evidence of CNTs-DNA crosslinking, the occurrence of oxidative stress, and acute and subchronic nanotoxicity in these species [67]. Khan et al. investigated the impacts of Ag nanoparticle treated water on freshwater fish, and noted an increase in oxidative stress and genotoxicity [68]. Due to the limited solubility of nanomaterials in water, it has been suggested that their toxicity is attributed to the dispersant employed to disperse them. For instance, tetrahydrofuran is an excellent dispersant for CNTs and C60 fullerenes, leading to worries regarding its potential toxicity [69]. The possible biological and ecological toxicity of using nanotechnology in wastewater treatment is systematically investigated. One such possibility has been ruled out, the applications of nanotechnology could yield favorable results in this field, researchers are exploring different approaches to lower the costs related to nanomaterials. But preliminary findings shows that nanotechnology can effectively clean wastewater and the development is expected to enhance their safety threshold.

Conclusion

The current wastewater treatment process is capable of managing both inorganic and organic waste found in water. However, these techniques require a significant amount of energy and are not cost-effective due to the challenges to fully purifying water and reusing the remaining substances. Wastewater treatment is expected to undergo significant advancements with the integration of nanotechnology in the near future. Due to their exceptional qualities, nanomaterials are highly suitable for water treatment. Their high surface to volume ratio, reactivity, sensitivity, and adsorption capabilities allow for efficient removal of diverse organic and inorganic pollutants, heavy metal and harmful microbes that contaminate water sources. The design of nanomaterials allows for the efficient utilization of solar energy, a readily available resource. These nanomaterials can serve as visible light photocatalysts, offering a cost-effective solution for treating contaminated water. The future of wastewater treatment will see nanomaterials taking on a vital role, thanks to ongoing developments in economically efficient and eco-friendly technology. Nanoengineered materials hold immense promise for water treatment in the forthcoming decades, particularly in the realm of decentralized treatment system, point-of-use devices, and highly degradable pollutants.

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