RECENT TRENDS IN NANOMATERIAL'S DEVELOPMENT FOR WASTEWATER TREATMENT

Abstract

The industrial sector produces a significant amount of contaminated effluent with organic, inorganic and biological pollutants. Such pollutants in wastewater show numerous adverse effects on living beings and the environment. Moreover, the domestic and agricultural sectors are also responsible for contaminating fresh water due to the application of different chemicals in daily life and in agriculture. To ensure contamination-free water, the elimination of toxic contaminants, and to boost of industrial production processes, innovative and advanced water treatment technologies are used. Nanotechnology-based research emerges as a new field to provide feasible alternative methods to treat wastewater and is the biggest development of twenty-first century. Nanomaterials (NMs) and nanoscale molecules assure for prevention, detecting, tracking, and removal of contaminants from waste water. Different categories of nanomaterials like nano adsorbents, nanocatalysts, and nanomembranes are widely used nowadays. Carbon nanotubes, graphene oxide, titania, zinc, silver nanoparticles types are popularly being used in industrial sector, developed as a solution after innovative research and development-based processes.Several aspects including the efficiency and potential of nanomaterials are considering the future perspectives that have been discussed in the paper.

Keyword: Waste Water, Treatment, Nanotechnology, Nanomaterial

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I. INTRODUCTION

The volume of water consumed worldwide has increased by half since a few decades ago. Water is fast turning into a limited resource due to its extensive usage in agriculture, industry, the household and transportation, which is exacerbated by problems with climate change (1). Nowadays, a number of contaminants and their derivatives are released into the aquatic environment as a result of urbanisation and industrialisation (2). Water pollution is the accumulation of hazardous substances such as biological contaminants and toxic compounds above background values. Chemical contaminants such as heavy metals, organic and inorganic particles, poisons, medicines, hormones, and other dangerous compounds are only a few examples of the pollutants that may be found in wastewater (3). The ecology and human health may be seriously threatened by the impact of these pollutants. Long-lasting mutagens and carcinogens, which degrade slowly and persist in the environment for a long time, may arise as a result of prolonged exposure (4).The task of delivering high purity drinking water is challenging, hence the development of affordable and reliable materials is of the highest importance (5). Techniques such as distillation, chemical treatments, coagulation and flocculation, biological treatment, UV, RO, ultrafiltration, nanofiltration, microfiltration and carbon nanofiber methods have been in practise from a long period of time as a solution to waste water treatment but these conventional techniques did not prove to be effective in terms of providing potable water (6).The development of modern technology in the twenty-first century is greatly impacted by nanoparticles with a particle size of one billionth (10^{-9}) of a metre.The term "enabling technology" is frequently used to describe nanotechnology. Exploitation of properties and occurrences at nanoscale is done by nanoparticles (7). Due to their special size-dependent characteristics like large surface area, short intra-particle diffusion distance, compressibility with negligible decrease in surface area, excellent stability, notable reusability and recyclability, the use of nanostructured materials for scavenging and deterioration of toxic water pollutants is acquiring huge significance (5).

According to the nature of the nanomaterials, nanotechnology may be divided into three primary categories: Nano-adsorbents, Nano-catalysts, and Nano-membranes (8). Atoms of those elements with strong chemical activity and adsorption capacity can be used to create Nano-adsorbents by attaching them to the surface of nanomaterials (9). Different kinds of Nano-catalysts, such as electrocatalysts, Fenton-based catalysts for enhancing chemical oxidation of organic pollutants, and catalysts with antimicrobial capabilities, are used to degrade contaminants in wastewater.Because of its tiny pore sizes, cheap cost, high efficiency, and user-friendliness among the several forms of membrane filtration, nano-filtration (NF) is widely used for the treatment of wastewater in industries (7). Ground and surface water may be contaminated by bacteria, naturally occurring organic chemicals, biological toxins, human pathogens, and free-living microbes. Toxic disinfection by-products (DBPs), such as halogenated disinfection byproducts, carcinogenic nitrosamines, bromate, and others, can be produced by traditional disinfectants such chlorine disinfectants and ozone. Numerous nanomaterials, such as nano-TiO_2, nano-Ag, nano-ZnO, CNTs, and fullerenes, shown antibacterial capabilities while having a decreased propensity to generate DBPs and without experiencing significant oxidation (6).

II. EMERGENCE OF NANOTECHNOLOGY

Methods based on nanotechnology are utilised to treat wastewater that contains organic, An issue that is now receiving a lot of attention is that of inorganic and pathogenic pollutants (10). Nanostructured materials, such as nanoparticles (Pd, Au, Ag, Cu, Fe3O4, TiO2, etc.), nanocatalytic membrane systems, and nanosorbents, are more effective, take less time, are favourable to the environment, and are low energy techniques (11).This primary subject includes a wide range of processes, including extractions, cavitations, oxidations, separation reactions, and flocculation/coagulation. Ion exchange is a step in the separation process, and adsorption is a physicochemical way of therapy for using surface forces or electrostatic attraction. Membrane separation techniques such as ion exchange, coagulation, and adsorption fall under the category of charge-based separations, where the removal process is often polluted under charge neutralisation and is especially useful for removing charged particles or ions from solutions. In order to achieve the final objectives of water reuse or discharge, at least one separation procedure is required, according to the profluent theory (12)

Various forms of Nanomaterials	Nanotubes
	Nanocomposites
	Metallic Oxides
	Nanoadsorbents
	Nanoflowers
	Bimetallic Oxides
	Nanosheets

III. NANOMATERIAL TECHNOLOGY USED IN WASTEWATER TREATMENT

1. **Nano-Photocatalyst:** Photocatalysts, on activation from photons received from light energy, modifies the rate of reaction during the chemical transformation process of a substancewithout being directly involved, making use of different forms of light. The capacity of nanophotocatalysts to increase oxidation has been demonstrated owing to their efficient synthesis of oxidising species at material surfaces, which aids in the efficient breakdown of contaminants from contaminated water (13). Majority of the photocatalysis has been carried out on semiconductors but factors such as significant charge carrier recombination and a limited area of light absorption led to decreased efficiency. Modifications in semiconductors that help in altering the band gap of the material such that it has a large spectra to support higher absorption of light or the recombining of the charge carriers play an important role in increasing the efficiency of the process (14). Titanium dioxide (TiO_2) is a vastly used nanophotocatalyst due to it being inexpensive, highly available, oxidation efficient and non- toxic in nature but to overcome its drawbacks various alternatives has been proposed such as creation of composite catalyst with metals, metallic ions, carbon nanotubes etc, which can enhance the photolytic activity of the material (13). Development of microfluidic reactors has played a pivotal role by providing large surface-to-volume ratio, enhanced diffusion effect, high mass transfer coefficient, and very stable hydrodynamics. A number of technical hindrances still prevail in waste water treatment by photocatalysis which need to be addressed to obtain a highly efficient system (15).

2. **Nanomateials based Membranes:** It is a conventional technique in purifying water and has been used over a long period of time. This technique has been used with inorganic as well as organic membranes (ceramic and polymeric) but it is accompanied with problem like fouling. Advancement in technology led to the formulation of nanomaterials based membranes which yielded positive results. These ceramic and polymeric membranes are used with carbon-based, nanofibers or metal-oxides based materials or CNTs, forming composite membranes that enhance its performance (16). The two-dimensional membrane materials known as freestanding ultrathin nano-membranes (FUN-membranes) have a nanoscale thickness of around 100 nm and need little to no substrate support.High water permeability and selectivity against the target organic contaminants are two characteristics of the nano porous graphene (NPG) membranes. Consequently, it is a viable option for removing organic pollutants from water.The oil-water separation studies with the GO/HNTs(graphene oxide/halloysite nanotubes) and synthesized hybrid nanofiber membrane (FHNM) containing SiO2/polyvinylidene fluoride (PVDF) microspheres composite membranes were found to be successful. As a result, the membrane is an excellent choice for operations that separate oil from water (17). Particularly the nanowire membrane in oil-water separation and the graphene-related membrane in dye wastewater treatment and desalination, the nanomaterial-based membrane with diverse forms and combinations has showed the enormous potential applicability in water purification. Additionally, combining nanomaterials with commercial membranes is a powerful way to give them new properties like anti-bacterial and photo-degradation while also improving the separation performance of commercial membranes in terms of permeability, selectivity, structure robustness, and antifouling (18). The ability to produce fibres that are orders of magnitude thinner than those produced by traditional nanofiber spinning methods makes electrospinning more beneficial. Membrane porosity is governed by fibre diameter, which also controls the surface area to volume ratio. Nearly 100% of the Escherichia coli germs may be removed from water using electrospun nanofiber membranes (ENMs). According to reports, harmful heavy metals including nickel, cadmium, copper, and chromium among others may be removed using electrospun membranes (8).

3. **Nanotechnology Bioremediation:** As non-invasive, affordable, and eco-friendly methods to clean up pollution areas, the use of microorganisms and plants for remediation has been investigated. As a result of their high surface-to-volume ratio, which makes them particularly sensitive to detection and allows for fast remediation of pollution with a little amount of harmful byproducts, nanoparticles typically have distinctive secondary features (4). These features make them energy efficient and effective in the removal of even low concentrations of heavy metal present and other water contaminants. Carbon nanotubes with one or more walls are created using graphene sheets (CNT). Some disadvantages of carbon nanotubes include poor dispersion, separation issues, and small particle size. Researchers created multiwall carbon nanotubes (MWCNT), which may be used to remove metals like manganese, lead, and copper, as a remedy by modifying regular CNT (19). The dry microalga Chlamydomonas microsphaera and polyaluminum chloride combination flocculated. Cu^{2+} could be successfully eliminated from aqueous solution by powder. Newer strategies, including using nanocomposite design which make use of ligands derived from microalgaematerials might be a useful strategy for creating an environmentally benign, economically viable, and long-lasting system for heavy metals from wastewater removal (20).

4. **Fenton Process:** Nanoparticles exhibit properties that make them efficient heterogeneous Fenton catalyst. Adsorption of reactant molecules takes place at the active areas of the catalyst surface in addition to Fenton chemistry. When the reaction is finished, the product molecules are desorbed, leaving the active sites open for future reactant molecules to attach to.Common ways for creating nanoparticles include chemical coprecipitation, hydrothermal treatment, and other physical-assisted techniques includes gamma-ray radiation, the Langmuir-Blodgett method, and radiowave exposure. Catalyst that show more than 50% COD removal from wastewater have been prepared by researchersby crushing olive stones and coating, first with nano-ZVI (using $FeSO_4$ and the borohydride reduction process), and then with nano-magnetite (dissolving the nano-ZVI-coated particles in a Fe^{2+}-Fe^{3+} solution). After regeneration using solutions of NaOH and $C_2H_2O_4$ increased its usage time upto five lifecycles (21).

5. **Nanobiocides:** When NPs, such as metal oxides, are placed into nanofibers constructed of polymer templates, such as poly(vinyl pyrrolidone) (PVP), poly(vinyl acetate), and poly(ethylene oxide), they take on the function of nanobiocides and increase their effectiveness. In order to filter and destroy microorganisms, Ag NPs are great materials to utilise in water filters and membranes. Antimicrobial agents are delivered or scaffolded using poly(amidoamine) dendrimer (PAMAM)-based silver complex and nanocomposites in water filtration applications. In water treatment applications, immobilised TiO2 nanoparticle films, TiO2 nanoparticles embedded in isotactic polypropylene polymeric matrix, and nanocomposite water membranes containing TiO_2 NPs are employed (22). When tap water with a high concentration of E. coli and Legionella Pneumophila (LP) was filtered via a carbon column with attached silver nanoparticles, the biocidal activity of silver nanoparticles after application on a surface of carbonic materials, employed in water filtering devices, was shown. In contrast to the control column, the modified column significantly reduced the amount of bacteria by twofold. Numerous articles have examined the antimicrobial properties of nanoparticles like nAg, TiO_2, ZnO, and C_60. These nanoparticles are appealing for application in water filtration due to their wide availability, inexpensive price, and strong antibacterial activity. There are many ways to fix nanobiocides to nanofibers, preventing leaking from the membrane and lowering potential toxicity and expense (23).

IV. NANOMATERIALS FOR WASTEWATER TREATMENT

1. Carbon nano tubes (CNTs)

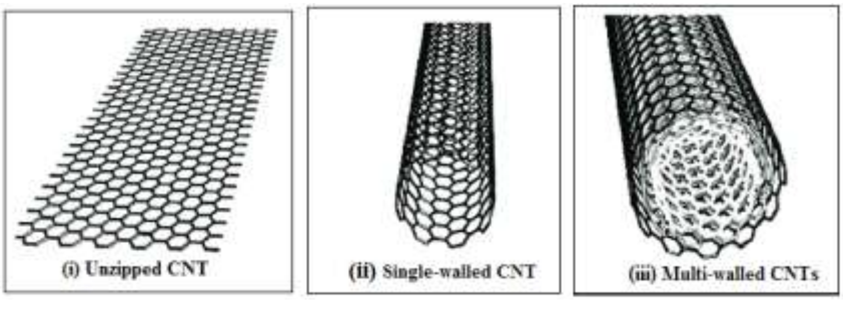

Figure 1: Structures of (i) unzipped CNT (ii) single-walled CNT and (iii) multi-walled CNTs (24).

Even better than activated carbon, CNTs are more efficient in reducing organic pollutants. CNTs' outside surfaces serve as adsorption sites. The adsorption kinetics are fast because the interparticle distance is tiny. Nitric acid, $KMNO_4$, and CNTs all aid in the removal of Cd^{+2} ions from aqueous solutions (25). Many businesses have used CNTs extensively as adsorbents for the treatment of wastewater. High selectivity, excellent physicochemical stability, and structural variety are all characteristics of CNTs. Only in the past ten years has extensive research on CNTs for wastewater treatment started. Due to their high removal efficiencies, CNTs are potential adsorbents for the treatment of significant polluting heavy metals, such as Cd(II), Zn(II), and Pb(II) (26).

Table 1: CNTs produced on a large scale by various methods

Technology	**Methods**	
Arc Discharge	The device consists of a sealed vacuum chamber where nanotubes are created by positioning two carbon rods at a spacing of around 1-2 mm from one another.	
	Helium Arc Discharge	Using a C cathode with a cooled-water mechanism, an unstructured C rod is purported to have generated nanotubes by vaporising it. This method results in rope- or bundle-shaped CNT (27, 28).
	Hydrogen Arc Discharge	After being nucleated, carbon vapour is sent out by inert gas, which then passes through supersaturation and produces carbon nanotubes. Characteristic of hydrogen being the lightest due to its high thermal conductivity works as a more effective extinguisher for condensing carbon vapour and produces nanotubes (29).
Laser Ablation	When a graphite rod is struck by a continuous or pulsed laser beam (from a Yttrium, Aluminum, Garnet, or CO2 laser), the pressure (500 Torr) is kept constant by the use of a combination of Argon and Helium buffer gas. Tiny carbon atoms soon condense into massive clusters called fullerenes when the vapour is cooled (30, 31).	
Chemical vapor deposition	Thermocatalytic chemical vapour deposition (CVD) synthesis is created by diluting a carbon source with a stream of flowing noble gases and allowing it to decompose at a higher temperature between 500 and 1200 °C until a supersaturated condition is reached. When carbon precipitates as fullerene, disintegrated carbon dissolves the metal particle (32, 33).	
High-Pressure Carbon Monoxide Reaction (HiPco)	After the catalytic reaction has occurred in the gaseous stage, the catalyst and hydrocarbon gas are fed into the furnace. SWCNT is made using CO, a hydrocarbon gas, in reaction with iron pentacarbonyl $Fe(CO)_5$ (34).	

CoMoCAT Process	This process includesdisproportionating CO into C and CO2 in the presence of a CoMo catalyst at temperatures between 700 and 950 °C and pressures between 1 and 10 atm. This method yields a sizable quantity of SWCNT in the minimum period of time. The process is sped up by Co and Mo's complementary effects (35).

2. **Graphene Oxide (GO):** Chen and Chen (2016) studied the Graphene Oxide nanosheets (36). A two-dimensional carbon nanomaterial called graphene oxide (GO) is created by chemically oxidising a graphite layer. The adsorption of heavy metals is facilitated by the functional groups hydroxyl and carboxyl present in GO. A single layer GO has two dimensional basal planes that are available for the most effective heavy metal adsorption, and it has a straightforward synthesis process that can be completed by chemically exfoliating graphite without the use of complicated machinery or a metallic catalyst (8). As chemical functionalization of graphene oxide may be one of the best methods for heavy metal removal, graphene oxide produced using the enhanced Hummers technique is prepared for further functionalization. Adsorption isotherms, adsorption kinetics, and adsorption thermodynamics are the three basic categories into which the adsorption processes of graphene oxide-based nanomaterials may be classified (37).

3. **Zero-valent iron (ZVI) nanoparticle:** Li et al. (2014) studied the Zero-valent iron nanoparticles (nZVI) for the treatment of smelting wastewater under a pilot-scale demonstration. Due to their nanoscale size, high surface area to volume ratios, and superparamagnetism, iron-based nanomaterials with unique features and functionalities have been extensively explored in terms of their production and use. One of the most often used metallic reducing agents for the treatment of harmful contaminants from wastewater as well as for the rehabilitation of polluted land and groundwater is zero-valent iron (ZVI) nanoparticle. Several heavy metal ions may be quickly and simultaneously eliminated by the ZVI nanoparticle. Batch investigations shown that ZVI nanoparticles can remove different heavy metals and arsenic simultaneously. With more than 12 months of operation, more than 99.5% of arsenic, copper, and many other harmful ions were removed (39). In the globe, this nanotechnology has already attained the commercial level of application and has found considerable use in the remediation of contaminated groundwater. Additionally, it has previously demonstrated to be a highly effective method for eliminating a wide range of organic and inorganic contaminants, such as pesticides, chlorinated solvents, nitroamines and nitroaromatics, organophosphates, inorganic anions, arsenic, uranium, and a variety of metals (40).

4. **Silver Nanoparticles:** Kyrychenko and co workers (2020) studied the Protonation-dependent adsorption of polyarginine onto silver nanoparticles (41). Silver nanoparticles were most frequently used in water treatment because of their low toxicity and potent, broad-spectrum antimicrobial activity in water. Ag nanoparticles are also employed in water filtration membranes. For instance, poly sulfone membranes use them to reduce biofouling and they have excellent antibacterial effects against a wide range of bacteria and viruses, including E. coli, Pseudomonas, and others (6). According to various research, mercaptosuccinic acid is employed in silver nanoparticles supported by activated alumina for the removal of mercury ions from polluted water. It was discovered that the mercuric ion absorption efficiency of silver nanoparticles was higher. To effectively remove cadmium, Ficus Benjamina leaf extract may be used to create zero-

valent Ag nanoparticles. When the concentration of nanoparticles rose, the removal efficiency improved as well. Ag nanoparticles were created in a similar way using Prosopis julifora leaf extract and were then enclosed in chitosan. Copper ion absorption by silver nanoparticles enclosed in chitosan was 81% (19).

5. **Titania:** Abd Elkodous et al. (2020) reported thr C-dots dispersed macro-mesoporous TiO2 phtocatalyst for effective waste water treatment. Due to its strong photocatalytic activity, redox characteristics, thermal and photochemical stability, and low cost, titania (also known as titanium(IV) dioxide, or TiO2) has been one of the most researched photocatalysts over the past several decades. The metal NPs' alteration of TiO2 causes a rise in the photocatalytic activity under UV-visible light. Bimetallic Au-Cu/TiO2 produced the highest photocatalytic activity.(43)TiO2 nanoparticles are also employed for the treatment of wastewater containing dormant microorganisms. A five weight percent addition of nano-TiO2 to the TFC active membrane layer modestly enhances permeability. The efficiency of absorption is also improved by the conjugation of MgO and TiO2. The features of the membranes, such as mechanical permeability, fouling resistance, thermal stability, and the creation of novel functional groups for eliminating impurities and self-cleaning membranes, will be considerably improved by incorporating the functional Nanomaterials into the membranes (25). As a photocatalyst to degrade dye under UV light, nano-TiO2 is frequently utilised.When nano-TiO2 is exposed to UV light, hydroxyl radicals emerge on its surface. These radicals have the power to oxidise toxic substances like dye molecules into harmless ones (26).

6. **ZnO nanoparticles:** Weldegebrieal (2020) reviewed the Synthesis method, antibacterial and photocatalytic activity of ZnO nanoparticles for azo dyes in wastewater treatment (44). When degrading dyes, nano zinc oxide (nano-ZnO) is frequently used as a photocatalytic nanomaterial. Electrostatic attraction is the key adsorption mechanism for nano-ZnO on dyes.(26)For the adsorption of heavy metals, zinc oxide (ZnO) possesses a porous micro/nanostructure with a high BET surface area. For the removal of heavy metals from wastewater, nano assembly, nanoplates, microspheres with nanosheets, and hierarchical ZnO nanorods are often utilised as nano-adsorbents. Due to their distinctive micro/nanostructure, modified ZnO nano-adsorbent exhibits remarkable Cu (II) removal efficiency. It is demonstrated that mesoporous hierarchical ZnO nano-rods can remove Pb (II) and Cd (II) from wastewater with a high removal efficiency (8). One of the potential photocatalysts used to break down azo dyes in waste water is zinc oxide (ZnO). Its low price, photostability, biological and chemical inertness, and strong photoactivity in the UV region made it an ideal photocatalyst for the azo dye degradation process (45).

7. **Manganese oxides (MnO) nano-particles:** Jamil et al. (2018) reported the Synthesis of saucer shaped manganese oxide nanoparticles by co-precipitation method and the application as fuel additive (46). Due to their large BET surface area and polymorphism structure, manganese oxide (MnOs) nanoparticles have significant adsorption capacity. The creation of inner spheres, which may be described by the ion-exchange process, is generally what causes the adsorption of different heavy metals on HMOs, such as Pb (II), Cd (II), and Zn (II). The two types of modified MnOs that are most often employed are hydrous manganese oxide and nanoporous/nanotunnel manganese oxide (HMO) (8). Due to its intriguing physicochemical features, manganese dioxide (MnO2) and its many allotropes have attracted a lot of study interest in the field of wastewater treatment

throughout time.Tetramethylamine, H2O2, and MnCl24H2O were utilised to create (MnO2) nano-sheets, and these sheets were then used to remediate water tainted with methylene blue (MB) (47).

Table 2: Nano-materials used for Water Treatment

Contaminant		Nanomaterials employed for treatment	Reference
Heavy Metals	Copper (Cu^{2+})	Mesostructured silica magnetite m-PAA-Na-coated MNPs Nanocomposite of ZnO with montmorillonite	(48) (49) (50)
	Lead (Pb^{2+})	Fe3O4–silica m-PAA-Na-coated MNPs	(51) (49)
	Mercury (Hg^{2+})	Fe3O4–silica Au NP– Al_2O_3	(51)
	Arsenic (As^{5+})	Flower-like iron oxides Hydrous iron oxide MNPs Cobalt (10-20 nm) and manganese (10-50 nm) ferrite	(52) (53) (54)
	Chromium [Cr(VI)]	Montmorillonite-supported MNPs PEI-coated Fe3O4 MNPs δ-FeOOH-coated γ-Fe2O3 MNPs Magnetic iron–nickel oxide Graphene oxide-Cobalt oxide	(55) (56) (57) (58) (59)
	Cadmium [Cd(II)]	Nanoscale zerovalent iron particles supported on reduced graphene oxide Ascorbic acid-stabilized zero valent iron nanoparticles γ-Al_2O_3 NPs	(60) (61) (62)
Dyes	Methylene Blue	CeO_2/V_2O_5 and CeO_2/CuO polyacrylic acid (PAA)-bound iron oxide magnetic NPs TiO_2 nanotube Encapsulated nano-Fe3O4 Graphene Oxide	(63) (64) (65) (66) (67)
	Methyl Orange	Quaternary ammonium polyethylenimine (PEI) modified to silica NPs (QPEI/SiO_2) nano-TiO_2 nano-MgO	(68) (69) (70)
	Rhodamine B (Rh B)	cobalt nano-particles embedded magnetic ordered mesoporous carbon (Co/OMC)	(71)
	Direct Red 23	Fe3–C	(72)
	Reactive blue 19, Reactive red 198	nano-MgO	(73)

Oil	SAM modified Pt micro engines Polymer capsule motors	(74) (75)
Pesticides	TiO2 nanophotocatalyst	(76)
Diclofenac (DCF)	Fe3O4 /MWCNT CQDs modified g-C3N4 Ti/RuO2–TiO2 /MWCNTs	(77) (78) (79)
Antibiotics (amoxicillin-AMX)	Ni−Ti Layered Double Hydroxide@Graphitic Carbon Nitride Nanosheet	(80)
Fluazaindolizine (FZDL)	Graphitic carbon nitride nanosheets	(81)
Ciprofloxacin	Fe(VI)-Fe3O4 /GE system nano zinc oxide incorporated graphene oxide/nanocellulose (ZnO-GO/NC) nano composite	(82) (83)
Tetracyclin (TC)	MWCNT/TiO2 MIL-101(Fe)@TiO2 core–shell In2S3@MIL-125(Ti) (MLS) photocatalytic adsorbent	(84) (85) (86)
Escherichia coli	silver decorated grapheme oxide (Ag/GO) composite SnO2 -doped nanocomposites (SnO2 used as a dopant in sulphonated GO and CNT) Ag NPs/GA composite homogenously loaded on graphene aerogel (GA)	(87) (88) (89)

V. CONCLUSION

The world is transforming into a technologically advanced one in a fast pace and one of the key aspects is development of the various industrial sectors. But the most important factor that requires attention in this transformation is sustainability of the environment and our ecosystem. With water being a chief resource and its high usage and availability, wastewater is a major by-product and requires immediate and effective measures to be taken for its treatment. Various research gave rise to techniques that became conventional and provided with effective solutions but there was exposure to various other pollutants and toxicities, for which the conventional techniques were ineffective. Heavy metal ions, which are very poisonous and non-bio degradable became a major pollutant. It has the potential to seriously harm both animals and people's health. Advancement led to nanomaterials which then became a major turning point in the field of wastewater treatment because of their unique characteristics, both physical and chemical. Research provided with the various ways in which they can be used as nano-adsorbents or nanomembranes or nanocatalysts accommodated with various technique for the removal of contaminants from wastewater such as heavy metals, organic and inorganic pollutants. The most appealing and effective applications involve using iron oxide NMs to absorb heavy metals and organic contaminants. In order to effectively remove heavy metals at very low concentrations, fullerene and graphene have been manufactured using carbon nanotubes. Inorganic ions, organic pollutants, nanoparticles, viruses, and other contaminants are separated from water resources using nanomembranes employing diffusion and size exclusion. However, there are still a number of issues that need to be resolved before producing efficient and affordable nanomembranes for the treatment of water. Nano-engineered materials provide enormous potential for point-of-use techniques, significantly biodegradable contaminants, and decentralised water treatment technologies. Additionally, there is a critical need to create modified nanomaterials that are efficient, effective, manageable, and environmentally acceptable.

The difficulties associated with affordability and the commercialization of these technologies for wastewater treatment must also be considered.Water supply development and recovery from unconventional water resources can be made economically possible by novel wastewater treatment methods enabled by nanotechnology. Future studies ought to concentrate on improving the economic feasibility of these nanomaterials and evaluating their interaction mechanisms in water treatment systems because low manufacturing costs are essential for their wider applicability in wastewater treatment.Risk assessment, management, and modelling are crucial components to address the incidence, destiny, and harmful potential of new contaminants. These components are also crucial for the treatment of various water pollutants. Following a sharp increase over the past ten years, advanced oxidation technologies will find larger applications at the full scale level, offering solutions that are both technically and financially practical for the reduction of developing pollutants. When safety concerns about the recovery of nanoparticles from treatment reactors are resolved, a holistic approach for the simultaneous removal of numerous contaminants from water/wastewater matrices using multifunctional nanotechnology will likely prevail in the future.

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