Chapter 3
Emerging Nano-Bio Material for Pollutant Removal from Wastewater

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Abstract Industrial and domestic processes are generating huge quantity of organic and inorganic pollutants into the environment through releasing wastewater into the environment. The unimpeded dumping of these pollutants not only risks the human and animal health but also deteriorates land and water quality. This generates demand to remove/utilize these pollutants in sustainable manner before releasing wastewater into the environment. Several physical–chemical and biological technologies are available to remove the organic and inorganic pollutants from wastewater. However, some of these technologies are not so efficient in removing the pollutants from wastewater, whereas other technologies either not economically viable or not too suitable to the environment. Development of nanotechnology has provided new paradigm to the several fields including wastewater treatment technologies due to its unique and exceptional characteristics such a superhydrophilicity, high surface area, surface functionalities. Nanomaterials showed a great potential to address all the flaws in removal of pollutants from wastewater. The present chapter enlightens the applicability of bionanomaterials for removal of organic pollutants from wastewater and its sustainability.

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3.1 Introduction

Freshwater is a fundamental necessity for existence of the life on the earth and sustainable development of society (Sajid et al. 2018). The accessibility to clean water is a global environmental problem since it becomes serious confutation to supply clean and inexpensive drinking water to all (Sharabati et al. 2021). The proliferation of industries and urbanization has created inevitable effects on the environment (Singh et al. 2002) as a consequence of amplified contamination with hazardous materials such as acidic and basic pollutants including persistent inorganic and organic compounds and heavy metals (Singh and Rathore 2019, 2021; Chung et al. 2022), which directly and indirectly harms the water quality. The potential hazards caused due to unchecked disposal of industrial effluent have prompted to limit the untreated effluent discharge in the environment (Singh and Rathore 2018, 2020). The availability of clean/potable water is a challenge for all water supply practices and the regularization in standards to maintain the water quality has developed new paradigm for current water treatment and distribution system (Mehta et al. 2021).

Available traditional wastewater treatment regime is confined to three-step process viz. primary, secondary, and tertiary treatment. Prior to primary treatment screening of the wastewater is required to prepare the wastewater for primary anaerobic treatment by maintaining pH or temperature and to filter out the larger sized particles which can go for further treatment at other facility or land filling. Primary treatment process involves microbial degradation of organic waste material under anaerobic condition, while secondary treatment process depends on the microbial decomposition process that removes suspended solids from the wastewater under aerobic condition. Tertiary treatment was carried out to further improve the water quality by microbial activity before discharging into the environment or recycled for utilization to other purposes such as agriculture, industrial, or household purpose (Singh 2021). Advanced oxidation, biodegradation, flocculation, use of bioadsorbents or activated carbon adsorption, coagulation, ion exchange, membrane separation, etc. are some of the widely used processes (Abhinav et al. 2021).

Current available techniques used for treatment of wastewater have limitation to offer potable or palatable class of water that can be used for different domestic or industrial uses to reduce the burden on natural water resource and reduced commotion to environment. Advancement on the traditional wastewater treatment technologies is a continuous process to get an improved and efficient treatment technology (Mehta et al. 2021). Being environmental friendly, low cost, simple in design, operational fluidity and higher effectiveness for removal of pollutants from the wastewater streams (Kubra et al. 2021) made adsorption process highly promising and sustainable way for wastewater treatment (Zhao et al. 2019; Sharabati et al. 2021). The pollutants present on the wastewater streams adsorb on the surface of the adsorbing material and thus removed from the wastewater stream. Several absorbent materials such as activated carbon, zeolite, clay minerals, chitosan, etc. are actively in use for treatment of wastewater (Yu and Han 2015; Al Bsoul et al. 2021). Among these, the activated carbon is oldest known and the most popular and commonly used absorbent. Its large surface area and porous structure is highly efficient to remove the pollutants (Yu and Han 2015; Al Bsoul et al. 2021). Its surface area can reach 500–2000 $m^2\ g^{-1}$ and is efficient to adsorb various heavy metals present in wastewater (Carrott et al., 1997; Gabaldon et al. 2006). However, higher cost, low competency for several other metals and poor removal of hydrophilic organic pollutants, etc. restrict its industrial use for wastewater treatment (Alsbaiee et al. 2016; Sharabati et al. 2021). Similarly, low permeability and pretreatment requirement of zeolite and lower efficiency of clay particles restrict its industrial use (Stojakovic et al. 2011; Yu and Han 2015). Therefore, the researchers are focusing on the developing absorbent with improved performance with low cost and wider availability to improve the effectiveness of water treatment (Kurniawan et al. 2006; Sharabati et al. 2021). A superlative adsorbent ought to have multiple characteristics, e.g., large surface area that increases the adsorption capacity, economical, environmental friendly, reusable, well-suited, and high selectivity toward water pollutants (Nasar and Mashkoor 2019) which increase the efficiency of water treatment and thus improve its industrial application. Nanotechnology is expected to provide the highly efficient techno-economical elucidation for wastewater treatment problems (Mehta et al. 2021).

3.2 Extraordinary Properties

Nanomaterials have gained prominence in research and development due to their exceptional tunable properties (Sadegh and Ali 2018). The importance of this class of materials was realized when scientist found that the size can influence the physic-chemical properties of material (Khan et al., 2019). The unique characteristics of nanomaterials, i.e., size in nm, exceptionally large surface to volume ratio, higher capacity and efficiency than the material itself, simplicity of fictionalization, stability, reuse potential, and antimicrobial structure make them attractive substances to be used in different industrial and engineering applications including wastewater treatment (Ponnusamy and Saththasivam 2021; Sharabati et al. 2021). The efforts have been made in this chapter to summarize the recent advancements in nano-bio materials for wastewater treatment in sustainable way.

3.3 Nano-Bio Materials

Focus of the nanotechnology is on the design of new materials, structures, and devices that having minimum one dimension fitting the nanoscale, i.e., less than 100 nm (Mohmood et al. 2013; Rienzie et al. 2019), which could be an effective means to treat wastewater contaminated with pollutant ranging from metallic ions to organic and inorganic solutes, and microbial pathogens (Aguilar-Perez et al. 2020), because nanomaterials contains unique physical and chemical properties due to their nanoscale size. Unique physic-chemical properties of nanomaterial included large surface to aspect ratio, topography, aggregation state, strong solution mobility, surface chemistry such as optical property, reactivity, catalytic potential, porosity, strong adsorption, dispersibility, and enhanced redox ratio (Mohmood et al. 2013; Yaqoob et al. 2020), which enables them to interact with the pollutants through increased binding sites causing them inactive or degrade (Saharan et al. 2014; Aguilar-Perez et al. 2020). The nanomaterial-based water treatment applications of nanotechnology can be grouped in to three categories, viz. water filtration, water remediation, and purification or disinfection of water (Fig. 3.1). Water filtration is mainly based on the use of semi-permeable nanoporous membranes to remove the organic and micropollutants. Membrane used for this technology is highly stable, easy in operation, and low cost and low energy consuming (Santhosh et al. 2016; Ali et al. 2019a). In recent years fullerene, carbon nanotubes and graphene-based material is gaining attention for water filtration and desalination (Bodzek et al. 2019). Focus of the water remediation is on the adsorption phenomenon of the nanosorbents to remove a broad range of pollutant from the wastewater streams with high compatibility to

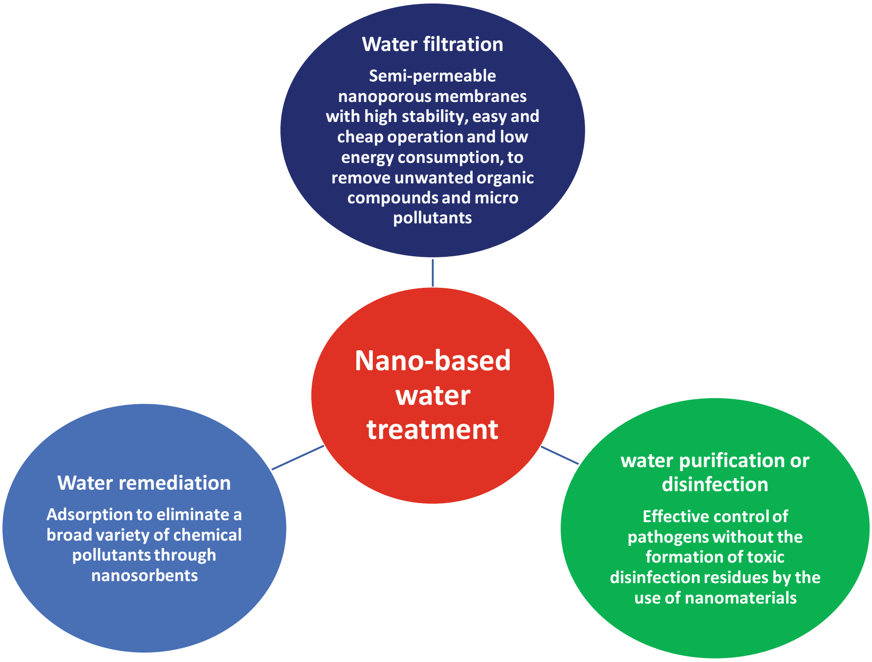

Fig. 3.1 Classification of nanotechnology-based water treatment application (adopted from Aguilar-Perez et al., 2020)

specific organic or inorganic pollutants (Cincinelli et al. 2015; Santhosh et al. 2016). Recently, numerous studies reported promising results for zeolites, carbon-based, bio-based, and metal oxide-based materials (El-Sayed 2020). Water purification or disinfection targeted on the effective control of microbial pathogens without generation of harmful residues by the use of nanomaterials with antimicrobial activity as graphene-based materials, metallic, and bioactive composites (Mohmood et al. 2013; Morsi et al. 2017; Aguilar-Perez et al. 2020).

Synthesis of metallic nanoparticles can be exercised using physical processes such as evaporation–condensation, laser ablation, electrolysis, pyrolysis, diffusion plasma arcing, sputter deposition, and high energy balling, chemical processes such as chemical reduction, microemulsion, electrochemical, thermal decomposition, sol–gel process and coprecipitation, and biological processes such as exploitation of biological mass, e.g., plant, fungi, microbes, etc. (Aguilar-Perez et al. 2020). Number of metallic nanoparticles-based nanosorbent materials is being produced through physical and chemical methods to remove dyes and antibiotics such as Rhodamine, amoxicillin, doxorubicin (Aguilar-Perez et al. 2020). However, biological methods are preferred over other methods because these methods are easy, cost-effective, ecofriendly, and convenient. Further, due to slow kinetic reaction, it is convenient to control the growth and stabilization (Singh et al. 2021).

The investigation of biomaterials up to the nanoscale turn out to be practicable due to the methodical improvement in sophisticated instrumentation technologies, especially on neutron, X-ray, light scattering, diffraction methods, and spectroscopic techniques, including atomic force microscopy/spectroscopy, or Raman spectroscopy (Gadomski 2008). Bionanomaterials are molecular material composed partially or completely from biological active molecules (Honek 2013), are multifaceted and generally nonlinear viscoelastic and stochastic structure (Gadomski 2008) obtained from plants, animals, fungi, peptide, nucleic acid, agricultural waste, etc. (Singh et al. 2021; Barhoum et al. 2022).

The formation of nanoparticles from or with the presence of bioactive molecules such as peptides, enzymes, vitamins, alkaloids, phenolics, along with others derived from variable biological sources (e.g., plants, bacteria, fungi, etc.) is depending on the character of the precursor material and the end use (Ali et al. 2019b). Debnath et al. (2020) have successfully synthesized zirconia nanoparticles using microbial green technology which can be used for remediation of tetracycline from wastewater. They reported that bacteria *Pseudomonas aeruginosa* enable the production of secondary metabolites during the bacterial growth in the synthesis activity, that bestowed the capping and stabilizing agents for the development of zinconia nanoparticle, which showed high adsorption capacity for tetracycline and enable them suitable for practical applications.

3.4 Utilizations of Nano-Bio Materials in Wastewater Treatment

Manna et al. (2019) synthesized a value-added nanomaterial from carbonaceous industrial waste. They coated the carbonaceous industrial waste with graphene oxide and activated it at 800 °C and characterized the graphene oxide and graphene oxide-coated biochar with various microscopy, spectroscopy, and x-ray diffraction methods. This graphene oxide-coated biochar was tested for phenol removal capacity in wastewater. They reported that the graphene oxide-coated biochar (nanocomposites) showed improved separation potential than that for the graphene oxide. They also claimed that the availability of salt showed positive effect on phenol severance by the nanocomposites process. They concluded that the nanocomposites have promising separation capacity for wide range of sorption parameters.

Goswami et al. (2020) assessed the potential of an up-flow packed bed bioreactor (UFPBBR) with immobilized bacteria *Rhodococcus opacus* onto biochar loaded polyurethane foam (PUF) as the packing material for treating biomass gasification wastewater. They reported that a maximum 81 ± 2.65% COD removal was obtained with 1820 mg L^{-1} of influent COD concentration in 24 h of HRT when the bioreactor was operated with PUF only as the support material, while more than 95 ± 1.27% COD removal was obtained when biochar loaded PUF was used as the support material. They also concluded 96.2% detoxification by the application of novel biochar-based bionanomaterial for biomass gasification wastewater remediation.

During his research Zheng et al (2021) recently explained functional microbiome linkages and method implicated in aromatic ring breakdown on coke enhanced nano-Fe_3O_4 activated bio-system (FEBS) under limited-oxygen state for proficient remediation of aromatic organic compounds in coal pyrolysis wastewater. They also identified that the efficiency of biodegradation with the FEBS supplementation presented excellent organic removal (average 92.29%) and biodegradability continuance (>40%) then control reactors. They concluded that the enhanced biodegradation in the FEBS is principally due to enriched functional species. Another study by Muthukumar et al. (2020) found photocatalytic dilapidation of caffeine in synthetically produced wastewater of coffee industry by silver ferrite nanoparticles produced with extract of *Amaranthus blitum* leaf. Furthermore, Abbasi et al. (2020) found effective cationic dye remediation of crystal violet from aqueous solution using Keratine nanoparticles obtained from human hair. This could also be a suitable use of wasted hairs.

In a recent study, Deng et al. (2022) designed a highly efficient and stable microsphere-immobilized bacterial strain of *Bacillus velezensis* to remediate organic substance and suppress the growth of unsafe microorganism the course of slaughter wastewater treatment. Immobilization of *Bacillus velezensis* was done at the surface of sodium alginate (SA)/Polyvinyl alcohol (PVA)/Nano-Zinc Oxide (Nano-ZnO) microsphere. Adhesion of the bacterial strain was managed by direct physical adsorption. The researchers reported inhibition of *Escherichia coli* on SA/PVA/ZnO and SA/ZnO microspheres with addition of 0.15 g/L nano-ZnO without affecting *Bacillus velezensis* strain. Process reported 16.99% removal rate of the chemical oxygen demand (COD) of SA/PVA/ZnO microsphere-immobilized cells, followed by 13.69% COD removal rate of SA/ZnO and free bacteria (7.61%) from 50% concentration slaughter wastewater within 24 h on 37 ∘C temperature and 7.0 pH at 120 rpm. From the results of the study, Deng et al. (2022) also reported that the strategy design could enhance the degradation potential to a greater extent, inhibit the growth of other bacteria without affecting the activity of protease in slaughter wastewater. Thus it was concluded that the wastewater treatment system of nano-ZnO hydrogel immobilization *Bacillus velezensis* is an imperative alternative technique to remediate pollutants from slaughter wastewater with a novel and ecofriendly and low-priced investment.

3.5 Sustainability and Future Perspectives

Nanotechnology is an economical, efficient, and trustworthy approach to improve the eminence and reliability of wastewater treatment. Nanomaterials have already been successfully utilized in several area, like medical, catalysis, agriculture, etc. owing to their exceptional attributes like nano in size, increased surface area than mass, higher reactivity, mobility, sturdy mechanical strength, highly porous surface, hydrophilic and dispersible nature (Khan et al. 2018; Yaqoob and Ibrahim 2019; Wu et al. 2019). Environmental experts have designated application of nanomaterials for wastewater remediation as a superior strategy than the other individual classical wastewater treatment techniques due to its potential to eradicate hazardous elements like Pb, Mo, Co, other organic and inorganic contaminants, and pathogenic microorganisms harmful for human health, present in water (Umar, 2018, Mohammad et al., 2019, Sekoai et al. 2019; Khan et al. 2021). Nanotechnology sector is expected to expand further with the increase in its application for domestic and industrial purposes due to lower energy consumption and reduced production cost, boosting quality, and better environmental control (Patil 2015).

Nanotechnology is established its success in a variety of manufacturing applications including wastewater treatment, and it has capability to enhance wastewater treatment as the materials may be controlled and altered at the nanoscale. Further the nanomaterial obtained through biological sources could be controlled and stabilized. It also has several unique qualities, e. g., low size-specific surface energy, affinity and reactivity with other material, stability, and transferrable atomicity. These features are peculiar for decontamination of drinking water and improved wastewater treatment technologies (Khan and Sengül 2016, Samanta et al. 2016, Khan et al. 2018, Khan et al. 2021). Further, the nanoscale bioadsorbents obtained from waste biomass sources are renewable, sustainable, cost-effective, and environmental friendly material for wastewater treatment (Solangi et al. 2021). Potential to increase efficiency of wastewater treatment plant contribute in development of nanotechnology sector and its application and research for domestic and industrial use.

Bionanomaterials may composed of proteins, DNA, or other biological origin material, and although these biomolecules are "natural" compounds, they may have harmful effects ranging from no toxicity to high toxicity (Honek 2013). Although nanoparticles in water have no instantaneous consequence on human health but there is a possibility of nanoparticle ingestion through bio-magnification, hence the effect of nanomaterials on aquatic organisms is essential to address (Khan et al. 2021). Pernicious effects of nanomaterials in biological world are by the fact that such exposed nanomaterials are contemplated as the potential body "invaders" alike viruses or bacteria, nonetheless, their baneful effects depends on the interactions to immune cells. Interactions of the nanomaterials with biomolecules may lead to inflammation. However, no mandatory guidelines were specified by the regulatory agencies specifically for nanomaterials, its abrupt use could pretense threat to the environment and society. Thus the sustainable nanotechnological development may be ensured by compelling different regulatory guidelines suggested by Environmental Protection Agency (EPA), Toxic Substances Control Act (TSCA), and Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). The commercialization of nanomaterials requires an inclusive considerate on Ecological and societal, effects of the exposed engineered materials predominantly at bio-nanointerface (Karak 2019; Goodman et al. 2004).

Aguilar-Perez et al. (2020) concluded that nanotechnology is attracting the researchers for wastewater treatment because of its imperative properties like small size and large surface area, which changed the physic-chemical property of the material including chemical reactivity, catalytic property, adsorption capacity, etc., that enables them to potentially decontaminate wastewater from several common and specific organic and inorganic pollutants. The biogenic nanomaterials are considered as ecofriendly and they can also be produced from waste. There is an inevitability to evaluate the performance of bionanomaterials under controlled environments. Further, more thorough and careful research ventures are also require to optimize its contrive. The challenges and issues with the bionanomaterials are to address the fate and its toxicity in the environment and the administrating policies and protocols for appropriate disposing or recycling.

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