Need of wastewater purification for sustainability: A mini review

Agnishwar Girigoswami and Poornima Govindharaj
Medical Bionanotechnology, Faculty of Allied Health Sciences, Chettinad Hospital and Research Institute, Chettinad Academy of Research and Education, Kelambakkam, India
Mahashweta Mitra Ghosh
Department of Microbiology, St. Xaviers College, Kolkata, India, and
Koyeli Girigoswami
Medical Bionanotechnology, Faculty of Allied Health Sciences, Chettinad Hospital and Research Institute, Chettinad Academy of Research and Education, Kelambakkam, India

Received 20 February 2023
Revised 8 May 2023
Accepted 30 May 2023

Abstract

Abstract –

Purpose – In addition to agriculture, energy production, and industries, potable water plays a significant role in many fields, further increasing the demand for potable water. Purification and desalination play a major role in meeting the need for clean drinking water. Clean water is necessary in different areas, such as agriculture, industry, food industries, energy generation and in everyday chores.

Design/methodology/approach – The authors have used the different search engines like Google Scholar, Web of Science, Scopus and PubMed to find the relevant articles and prepared this mini review.

Findings – The various stages of water purification include coagulation and flocculation, coagulation, sedimentation and disinfection, which have been discussed in this mini review. Using nanotechnology in wastewater purification plants can minimize the cost of wastewater treatment plants by combining several conventional procedures into a single package.

Social implications – In society, we need to avail clean water to meet our everyday, industrial and agricultural needs. Purification of grey water can meet the clean water scarcity and make the environment sustainable.

Originality/value – This mini review will encourage the researchers to find out ways in water remediation to meet the need of pure water in our planet and maintain sustainability.

Keywords Water purification, Potable water, Nanotechnology, Wastewater remediation, Disinfection of water

Paper type Literature review

1. Introduction

Water is life and it is known that all living beings are dependent on water. Some require brackish water and many need fresh water for their survival and sustenance. As fresh water supplies are being exhausted, there has been a greater need to develop renewable water resources. Many efforts were made to get safe drinking water as an outcome and a scientific innovation as a competent replacement of conventional approaches is warranted.

The authors acknowledge Chettinad Academy of Research and Education for providing the CARE Seed Grant (No. Grant Number-Ref No. 004/Regr./AR-Research/2022-06).

Conflict of interest: The authors declare no conflict of interest.

Arab Gulf Journal of Scientific Research
Emerald Publishing Limited
e-ISSN: 2536-0051
p-ISSN: 1985-9899
DOI 10.1108/AGJSR-02-2023-0069

Nanotechnology has emerged as a boon for resolving several issues in the field of biomedical science as well as environmental sustainability (Sudhaik *et al.*, 2022). Clean water is becoming exhausted from our planet necessitating the remediation of wastewater to meet our requirements. Remediation of wastewater can take place by using different types of nanoparticles (NPs), nanocomposites and functionalized nanostructures, which can be used for designing efficient membranes for desalination and purification, antimicrobial agents to decontaminate water, photocatalysts to remove harmful dyes and pigments from wastewater, nano-absorbents to remove heavy metals from polluted water, highly active NPs to chelate heavy metals, etc. These versatile applications of nanotechnology also require the stringent testing for biocompatibility and the residues these technologies will leave on our planet. In this review, we shall discuss about the need of water in different sectors, conventional method of water remediation, nanotechnology and nanostructures derived from natural substances for remediation of wastewater.

2. Water needs and purification

Water requirements may be divided into four categories: water for basic necessities, industries and services, water for agriculture and nature, and water for energy generation. Many rapidly growing urban and industrial areas in the developing world face water problems, which are comparable to those faced by industrialized countries (protection of surface- and groundwater quality) despite limiting the capital to maintain even to the most basic water requirements (access to adequate water and sanitation facilities). Although current global water consumption has not yet reached the limit of available freshwater resources, uneven resource distribution has led to an increased region of the globe encountering severe water scarcity (Ashton, 2002). Water consumption for human needs increased six-fold and is attributed to mostly excessive water utilization for agricultural, industrial and household activities. With the increasing population of the world, increased industrial production and shifting consumer patterns, the overall amount of freshwater required for human activities is gradually reaching a point when water shortage would become a worldwide concern. Importing "virtual water" may not be an affordable option for these nations to deal with water crisis. Water requirements must be stated in terms of their uses, quality standards, economic sensitivity and volumetric requirements. A considerable proportion of effluents discharged into water bodies is inadequately or not treated at all, thereby contaminating water bodies and reducing their viability as freshwater resources (Okoh, Odjadjare, Igbinosa, & Osode, 2007). This in turn intensifies the water scarcity for a growing number of individuals, since many of the nations are already experiencing serious water shortage at present. Furthermore, the ecological water problems in the rapidly industrialized countries are becoming increasingly severe and increased water consumption has resulted in increased amount of wastewater also.

2.1 Water for basic necessity

When cooling water and energy generation are not taken into consideration, industries require the volume of water between 8 and 140 m^3 per capita per year. Water is being used extensively in hospitals, restaurants, hotels and other public organization for providing high-quality hygiene and cleanliness (Dziegielewski, 2000). As a result, each individual requires between 1 and 3 m^3 of high-quality water each year. The quantity actually consumed now ranges from 5 to 120 L per person per day, depending on whether water is scarce and/or people are flushing toilets. Watering the lawn, washing the car, filling the swimming pool and flushing the toilet are all examples of home water demands (Kurunthachalam, 2014). This water is generally polluted and must be treated before reusing them.

2.2 Water for agriculture

Water conservation methods, such as improved management, the use of water-saving technology and the deployment of market-based incentives, can reduce the agricultural water consumption significantly. The water consumption efficiency in crop production varies depending on how the water is delivered to the plant and the fertilizers used. Most parts of life are influenced by agricultural goods, including common commodities such as fuels, textiles, furniture and feedstock for bio-based goods such as food and feed. Water is a key essential in farming, and the largest amount of water is drawn from natural sources (Kurunthachalam, 2014). The efficiency of water usage varies from plant to plant. Water consumption might be reduced even more by using micro-irrigation or a similar effective technology. According to Food and Agriculture Organization (FAO), crops utilize just 45% of irrigation water on an average. Food production requires far more water than is often presumed. Hydroponics and drip irrigation can reduce the consumption of water used for farming few types of crops (Dahan, Babad, Lazarovitch, Russak, & Kurtzman, 2014).

2.3 Water for nature

Although it is commonly understood that water must be reserved for ecosystems, there is little regard for their benefits, functions and services. Water quality data presented by different nations are plenty; however, the water quality appears to be impaired in nearly all places with heavy agriculture, industrialization and increasing urbanization. Freshwater systems, such as lakes, rivers, wetlands and aquifers, provide the supply of water for people and food production, and can be considered ecosystems. Wetlands and aquifers play an important role in water quality maintenance by eliminating hazardous microbes, chemical pollutants, excessive nutrients and organic wastes. Ecosystems perform at least four distinct tasks: control, habitat, production and resource functions, and information functions. Plundering natural ecosystems typically has no immediate disastrous impact; instead, they are stealthy and enduring until the point of crisis is reached. At the onset of fertilization, the impacts appear to be good, with increased primary production and improved fish development. As a result, a number of fish species' reproduction is impeded since their eggs hatch in deeper waters. Nitrogen and phosphorus pollution of rivers and lakes has a significant impact on the ecosystem (Chislock, Doster, Zitomer, & Wilson, 2013).

2.4 Water for energy generation

Throughout the power generating cycle, water is used at several stages, comprising fuel extraction and production. According to research, in addition to the water used in hydrothermal energy, a two-fold quantity of water was utilized in the cooling system of thermal energy generation (Luqman & Al-Ansari, 2020). According to the previous studies, the energy mix in 2030 will be more water-intensive because the use of coal, oil, nuclear and hydropower will decrease, and the use of biogas, wind and solar energies will grow. The use of biomass for the production of biogas is water-intensive, which will also grow. Water distribution demands a lot of energy, but energy generation requires a lot of water in operations like thermal plant cooling systems or raw material extraction. Large dams presently provide around 19 % of the world's power. In accordance with the model research, the energy sector drained approximately 8 km^3 of freshwater in 2005, of which 6.8 km^3 were utilized for the cooling of thermal power plant and nuclear power plant facilities.

3. Need for purification

The water usage of ecosystems is a rough estimate, and the figures given may vary by up to 25 %. The overall volume of water for ecosystems will remain constant, as will the yearly per capita demands for ecosystems. As saltwater can provide a large amount of fresh water after purification, desalination of saltwater has received a lot of interest as a solution to the growing worldwide need for fresh water (Shatat & Riffat, 2014). The dynamic research of water purification involves the process of removing undesired chemical or biological contaminants that affect our use of fresh, consumable water. Desalination can satisfy the need for water by breaking down the functions of water usage and their importance to people's well-being. Water purification could be a costly process considering the long-term maintenance of the purification plant, time-intensiveness and possible environmental impact.

4. Conventional applications for water treatment

The optimization of standard potable treatment plant suggests that "to attain the foremost economical or effective use of" the water treatment plant, certain principles should be followed. These include the consistent production of high-quality finished water on a continuous basis and the importance of focusing on the overall process. As a "treatment train," a conventional water treatment plant contains many series steps and units (coagulation–flocculation, sedimentation, filtration and disinfection). Every stage ought to be optimized in terms of design, method and operation (Howe, Hand, Crittenden, Trussell, & Tchobanoglous, 2012). As a result of additional demanding regulations, the plants ought to manufacture water of a stronger quality and, therefore, totally different treatment processes are placed asynchronous to satisfy the guidelines. Water treatment plants are already functioning for quite a century and has become cumbersome. Some treatment processes involve particle exchange and absorption water utilities, which is a combination of treatment method and foremost acceptable to treat the contaminants found in raw water. Among the many desalinization processes are multi-stage flash distillation, multiple-effect distillation, membrane distillation and reverse osmosis. Conventional drinking water treatment plant consists of the following stages:

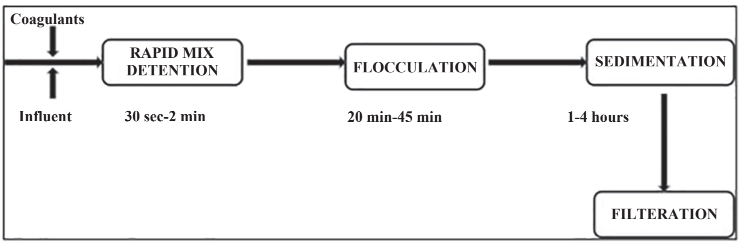
(1) Coagulation and flocculation

(2) Sedimentation

(3) Filtration

(4) Disinfection

(1) **Coagulation and flocculation:** There are a number of conditions that should be monitored to ensure that the clarifier is operating at or below the design capacity, including the loading rate and flow per unit area (m/m/h or m/h), typical loading rates, traditional sedimentation (up to 4 m/h), conventional inadequate air loading (up to 20 m/h), high-rate insufficient air loading (30–45 m/h) and ActiFlo (40–60 m/h). Frequent currents caused by variations in temperature inside the containers, excessive loading levels, poor air flow and weak equipment due to uneven flow of inlet or circulation patterns can result in sudden changes in water conditions, substandard or excessive doses, mud and insufficient air quality. These are common causes of misalignment. The different stages of flocculation are shown in Figure 1.



Source(s): Author's Work

Figure 1. Steps involved in flocculation

This particle conglomerate is removed from the water prior to filtration so that the improvement of sedimentation/clarifier should be presented by many modalities. If there are consistent results of <2 NTU (Nephelometric Turbidity Unit), it is stable, but when faced with rapidly changing water quality conditions, it produces a consistent quality sludge with sedimentation of 0.5–1% of total solids. Bulk circulation occurs in poorly constructed flocculation basins, resulting in high localized entry velocities. Coagulation and sedimentation are combined in certain designs (either upflow solids contact units or sludge blanket units). Inlet flow mal-distribution is generally caused by poor inlet channel design, and sometimes it can be caused by uneven inlet weirs. To neutralize the negative charges on non-settleable particles, coagulant chemicals with charges opposite to those of the suspended solids are introduced to the water (such as clay and color-producing organic substances). In both form of units, the cross-sectional surface of the basin increases as it goes from bottom to upward, causing the water flow to slow down as it rises. This allows floc to settle and sediment. Most upflow solid contact units employ recirculation of previously produced flocs to improve floc development and maximize the use of treatment chemicals. Better flow distribution typically necessitates the introduction of head loss, which can be difficult to mitigate without causing floc damage. Due to surface warming, density currents are worse in the big sedimentation basins (Howe *et al.*, 2012).

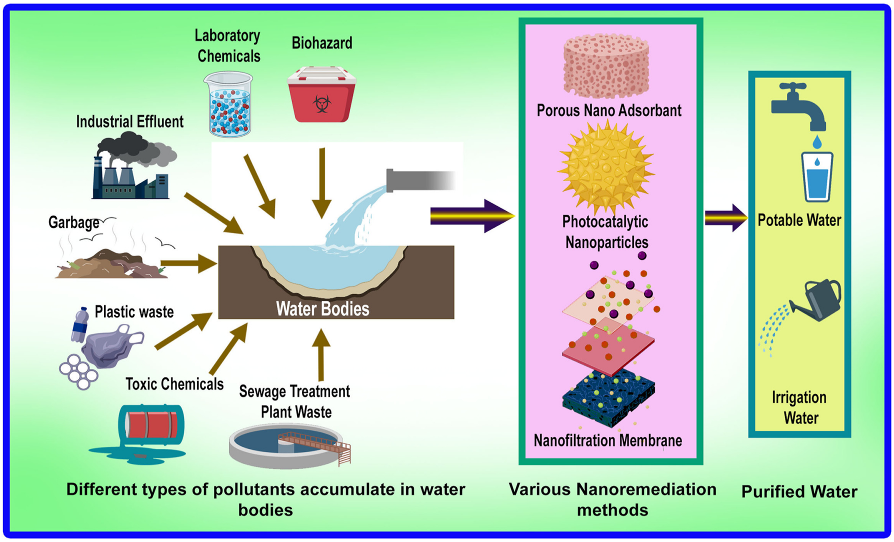
(2) **Sedimentation:** Coagulation, flocculation and sedimentation are all included in certain designs (either upflow solids contact units or sludge blanket units). To improve floc development and make use of the most of treatment chemicals, most upflow solid contact units recirculate previously produced flocs as we discussed earlier. In comparison to traditional therapy, combination units have greater rise rates and shorter detention times. Prior to design, an onsite pilot plant evaluation by a trained engineer familiar with the water quality is advised. These units are smaller and require less land for installation of the plant.

(3) **Filtration:** Visual inspections should include "cracking" at the media substrate, sand detachment at the filter walls, visible algae growth, filter media in troughs, monitoring whether scaling or fouling has changed the aftermath characteristics of the media, depth uniformity of media, level of wash water troughs, freeboard-top of media to underside of the trough and effectiveness of surface materials reaching the corners. There are several essential aspects of filter appraisal safety to consider. These include never walking directly on permeate, ensuring that the filter is completely drained before entering the filter box, being aware of filter appurtenances, and using a safety harness where appropriate, especially during bed liquidation testing. There are a variety of options for preventing poor filter performance, including optimizing filter backwashing, adding filter-to-waste, using filter assist polymers and adding coagulant or other chemicals during backwashing of the water. Backwashing instantly re-classifies bed to position the finest grains at the surface, thus utilizes multi-media (Piri, Homayoonnezhad, & Amirian, 2010), backwash waste characterization, floc retention and profiling to create a "good" filter design. The most efficient media design includes the biggest media at the top and the finest at the bottom. The increased flow of material and bacteria through coarse-grained media filters immediately following by-product formation is a common issue known to the water purification community as filter developing or maturation. According to another study by James *et al.*, many parameters, such as continuously <0.3 NTU, particle counts 50 particles/ml, lengthy and predictable filter runs (24+ h), and low premature particle breakout are touted as "good" filter performance.

(4) **Disinfection:** The production potential of disinfection by-products (DBPs) was determined in samples from various locations of water resources for supplying drinking water treatment facilities using improved analytical techniques. The development and refinement of analytical techniques for determining DBPs in water are critical steps in estimating human exposure after water treatment. The procedures were applied to water samples from two different sources to assess the formation potential of the DBPs investigated during chlorination. Chlorine, chloramines and chlorine dioxide are the most often utilized disinfectants, not just at the treatment plant but also in the pipes that transport water to our houses. DBPs are formed when disinfection procedures are used during water treatment. The undesirable side effect of using ozone in drinking water treatment is the development of chlorinated and brominated by-products. Although ozone is a potent disinfectant and UV radiation is an efficient disinfectant and treatment for reasonably clean source waters, neither of these disinfectants or treatments are successful in controlling biological pollutants in distribution pipes. To prevent tooth decay, fluoride is added, and a rust inhibitor is added to protect the pipes that transport water to houses and business places. According to the previous studies, the presence of DBPs in drinking water is a major source of worry. To destroy and/or inactivate any residual germs, chlorine is added to the water. To guarantee that potentially harmful bacteria are eliminated, water is often disinfected before entering the distribution system (Howe *et al.*, 2012).

5. Nanotechnology in wastewater remediation

Nanotechnology has been used in biomedical science, environmental applications, biosensors, nanomedicine, targeted drug delivery, imaging and theranostics (Agraharam, Saravanan, Girigoswami, & Girigoswami, 2022; Balasubramanian, Girigoswami, & Girigoswami, 2023; Deepika, Gopikrishna, Girigoswami, Banu, & Girigoswami, 2022; Girigoswami, Girigoswami, 2021; Haribabu, Girigoswami, & Girigoswami, 2021; Jagannathan, 2022; Keerthana *et al.*, 2022; Vedhantham, Girigoswami, Harini, & Girigoswami, 2021). The use of nanotechnology and natural compounds has been used recently for the treatment of wastewater (Abdelghaffar, Abdelghaffar, Mahmoud, & Youssef, 2019; Ilame and Ghosh, 2022). By reducing the cumulative energy consumed during the synthesis or production process, nanomaterials have been used to solve water pollution. It has already been discussed how nanomaterials can be recycled and manufactured, as well as their use in water/wastewater remediation by previous researchers. Various methods of NP synthesis have been discussed along with the summary of sorption capacities of different nanomaterial-based sorbents for different types of water pollutants. Nano adsorbents, nano catalysts, electrochemical advanced oxidation process and water nanofiltration have been explained elaborately (Elgarahy, Elwakeel, Akhdhar, & Hamza, 2021). Yadav *et al.* described the different types of pollutants that contaminate water bodies including persistent organic pollutants, surfactants, dyes, phenolic resins, pesticides and heavy metals. The book chapter discusses about bioremediation, chemical wastewater treatment, NP-assisted remediation of wastewater photochemical, sonochemical and electrochemical methods. The role of magnetic NPs was focused because of its application toward nanoadsorbent (Yadav, Gupta, & Sharma, 2019). Several publications have summarized the role of nanobiotechnology in the remediation of wastewater (Kamali, Persson, Costa, & Capela, 2019; Khan *et al.*, 2019; Sahu, Zabed, Karri, Shams, & Qi, 2019; Werkneh and Rene, 2019). Figure 2 shows the different sources of water pollutants and remediation of wastewater using nanotechnology.



Source(s): Author's Work

Figure 2. The schematic representation of the various sources of water pollutants and the kinds of nanoremediation methods using nanoadsorption, photocatalytic degradation and anno-assisted membrane filtration to yield clean water

Table 1 summarizes the different research reports, including review papers and original research on the topic of green sustainable wastewater remediation using nanotechnology.

Titanium dioxide (TiO_2) and zinc oxide (ZnO) NPs have been widely used as photocatalysts for the remediation of wastewater (Bognár, Putnik, and Šojić Merkulov, 2022). But their band gaps are too high, which makes to execute photocatalysis using UV light portion of the sunlight, which is only 3–4%. To decrease the band gap, many innovative combinations are used with TiO_2 and ZnO NPs so that they can be more effective in photocatalysis in the presence of sunlight (Nam, Lim, Ko, & Lee, 2019). In the removal of hazardous pollutants from wastewater, nanomaterials made of metals and non-metals oxides are extensively used (Saikia, Gogoi, & Baruah, 2019). Since iron is abundant in nature and the synthesis process of ferric oxide NPs is cost-effective, it has been widely utilized for a variety of purposes. As a result of their large surface charge, redox potential and reusability, iron-based NPs are mainly used for removing dyes and heavy metals from water. For adsorption to occur, several factors, such as pH, adsorbent dose, temperature and incubation time, must be considered. A variety of additives, such as aminopropyltrimethoxysilane, can be used to increase the adsorption of Fe_2O_3 NPs (Palimi, Rostami, Mahdavian, & Ramezanzadeh, 2014). In addition to its zero-valent properties, nanoscale zero-valent iron (nZVI) can catalyze the reduction of heavy metal ions, for example, hexavalent chromium, to trivalent forms, which causes Cr to be separated as insoluble hydroxides. The magnetic properties of nZVI and its quick oxidation cause it to coalesce into large aggregates. Thus, surface active sites are blocked, reaction rates are decreased, and inactivation often occurs quickly. ZVI NPs coated with chitosan have been shown to be effective at removing Cr(VI) from water by reducing it to Cr(III) and precipitating it together with Fe(III) (Qiu *et al.*, 2020). On the other hand, Fe_3O_4 and γ-Fe_2O_3 are popular owing to their high abundance, reactivity, low-cost, ease of reusing, separating and environmental friendliness. Since the magnetic NPs are highly reactive in an aquatic environment, they are susceptible to corrosion, which reduces their life expectancy. Most of them are thus coated with porous carbon, mesoporous silica and thiosalicylhydrazide. Other than iron oxides, zinc oxide (ZnO), manganese oxide (MnO)

Table 1.
The different kinds of nanomaterials used for remediation of water

S No.	Nanomaterials used	Outcome of the study	References
1	Functionalized CNTs	Researchers have summarized recent developments and adsorption behavior of CNTs for removing organics or heavy metal ions from contaminated waters. The synthesis of CNTs, purification, surface modification or functionalization, as well as their characterization and the effects of water chemistry on their adsorption capacities were discussed	Aslam *et al.* (2021)
2	Zero-valent metal NPs (nZVIs), metal oxide NPs, CNTs and nanocomposites	nZVI serves as an electron subscriber, allowing toxic metals to be converted into safe forms (chromium is reduced from hexavalent to trivalent form), as well as allowing for adsorption and co-precipitation processes. The polychlorinated compounds, nitrates, phosphates, perchlorates, nitroaromatic compounds, organic dyes, phenols, metalloids and radioactive elements can be eliminated through the nZVI. Besides silver (Ag), titanium oxides (TiO_2), zinc oxides (ZnO), iron oxides and CNTs, other NPs are also used in water treatment technology. As silver nanoparticles (AgNPs) are very toxic to bacteria, viruses and fungi, they have excellent antibacterial properties. They have discussed about the different conventional methods of water purification	Beyene and Ambaye (2019)
3	Nitrogen-doped porous carbon microtubes	In capacitive deionization, new nitrogen-doped porous carbon microtubes generated from waste biomass are being explored over existing ACs. In comparison to undoped samples, the N-CMTs (Nitrogen-doped porous carbon microtubes) show enhanced desalination performance. Langmuir isotherm prediction of 16.78 mg g^{-1} deionization capacity is observed over ten cycles combined with stable cycling performance	Sheng *et al.* (2021)

(*continued*)

S No.	Nanomaterials used	Outcome of the study	References
4	Chitosan (CH)–Carbon Dots (CDs) hybrid hydrogel nanocomposite film	A CH–CD hybrid hydrogel nanocomposite film was prepared from CH and CDs. The photoluminescent CDs were able to remove Cd^{2+} four times faster under UV light illuminations. According to the study at pH 8, the maximum adsorption capacity was 112.4 mg g^{-1} at 25 °C. Thus, CH–CDs could be used for a variety of water treatment applications in the future	Jlassi *et al.* (2020)
5	B-S-Calix	Using a fast photo-induced radical-mediated thiol-yne addition between a thiolated clay and an alkynylated calix[4]arene, a novel type of hybrid clay/calix[4]arene has been prepared. This was known as B-S-Calix, and was compared to mercaptosilanized bentonite (B-S) at room temperature as an adsorbent for toxic Cd(II) metal from wastewater. At room temperature and pH 8, this composite demonstrated a removal efficiency of 92.8% and an adsorption capacity of 114 mg g^{-1} within only 1.5 min	Jlassi, Eid, Sliem, Abdullah, and Chehimi (2020)
6	Polymeric NPs, carbon-based nanomaterials, metal NPs, zeolite, biopolymers and self-assembled monolayer on mesoporous supports	For the development of a better technology for wastewater treatment, researchers have reviewed methods based on adsorption and biosorption, nanofiltration, photocatalysis, disinfection and sensor technology that are being studied in relation to wastewater treatment using nanotechnology	Jain, Patel, Pardhi, and Flora (2021)
7	Different types of nanoadsorbants: carbon based, metal and metal oxides, nanocomposites	Process of adsorption and NPs in wastewater treatment was discussed. The carbon-based adsorbants, as well as metal-based and metal oxide-based adsorbants including iron oxides, manganese oxides and aluminium oxides, have been extensively elaborated upon. The role of nanocomposites has been emphasized in this review for purification of wastewater. The different types of pollutants including inorganic (As, Cr, Cd, Pb, Cu, Ni and miscellaneous metals), organic and biological pollutants have been elaborated. The regeneration of nanoadsorbants has also been discussed	Kumari, Alam, and Siddiqi (2019)

(*continued*)

Table 1.

Table 1.

S No.	Nanomaterials used	Outcome of the study	References
8	NPs used in desalination	The use of nanotechnology-driven solutions has been presented by the researchers, along with the large disparities that exist in terms of ensuring their implementation. Desalination (thermal and chemical), atmospheric water harvesting, affordable nanosensors and catalysts for clean water, toxicity concern of the nanomaterials used, commercialization, business and incubation, and opportunities in sustainable and affordable clean water have been discussed in detail	Nagar and Pradeep (2020)
9	CNTs, graphene and GO, carbon and graphene quantum dots	Nanomaterials derived from graphene and GO, and from carbon and graphene quantum dots, have shown significant promise for the treatment and purification of water and wastewater, particularly for pharmaceutical and industrial wastes. Nanosorbents for wastewater, drinking and ground water treatment are included in this review, as well as advanced carbonaceous nanomaterials and methodologies	Nasrollahzadeh, Sajjadi, Iravani, and Varma (2021)
10	Nanomaterials	They examined nanomaterials, including NPs, and their interactions with environmental matrixes to analyze the principles of bioremediation assisted by nanomaterials. They discussed about the response of living beings to nanomaterials, and how these technologies contribute to sustainability and the international regulatory framework applicable to them. Nanocrystals, NPs, nanopowders, nanomembranes, nanocomposites, nanotubes and nanosponges were explored for their capacity to remove pollutants from water and their removal efficiency was tabularized	Vázquez-Núñez, Molina-Guerrero, Peña-Castro, Fernández-Luqueño, and de la Rosa-Álvarez (2020)

(*continued*)

Table 1.

S No.	Nanomaterials used	Outcome of the study	References
11	Magnetic NPs	By combining microbes with magnetic nanocomposites, this review addressed the treatment of wastewater by removing heavy metals. The introduction of microbes into wastewater detoxification has proven to be beneficial to society, which is why the emphasis is placed on biomineralizations, oxidation–reductions, bioprecipitations, bioaccumulations, biosurfactant technologies, bioleaching, biovolatilization and biosorptions with their advantages and disadvantages. Bacillus, Microbacterium, Micrococcus, Shinella, Arthrobacter, Bacillus and Serratia are all capable of compartmentalizing heavy metals, such as lead, zinc, copper, cobalt and copper. Researchers used nanocomposites (CuFeO, FeO, Co_3O_4@SiO_2, Fe_3O_4, etc.) to treat wastewater efficiently because they are unique in nature	Sharma, Dutta, Udayan, and Kumar (2021)
12	Electrospun nanofibrous membranes	Various polymeric nanofibrous membranes are used for water purification because they are sustainable, affordable, efficient, nanoporous, durable, have a large surface area and do not accumulate chemicals. Recent updates on electrospun nanofibrous membrane sustainability, prerequisites, manufacturing techniques, merits and limitations of nanofibrous membranes, and solutions to overcome the problem faced by electrospun nanofibrous membranes are discussed in this study. The advantages and limitations of membrane technology are also discussed	Uddin *et al.* (2022)
13	MXene-coated cellulose membrane	A new method for fabricating a flexible antibiofouling fibrous photothermal membrane containing a MXene-coated cellulose membrane is described herein for highly efficient solar-driven steam evaporation for water purification. The MXene/cellulose exhibited 94% light absorption efficiency with rate of evaporation 1.44 kg/m^2 per hour of solar illumination. The MXene coating had high antibacterial efficiency (above 99.9%) with bacteriostatic activity	Zha *et al.* (2019)

Source(s): Author's Work

and magnesium oxide (MgO) are also effective in the removal of heavy metals like arsenic, cadmium and zinc (Saikia *et al.*, 2019).

The carbon nanotubes (CNTs) are also extremely effective at absorbing organic pollutants due to their high surface area and the ability to interact with them through a variety of interactions including hydrophobic, π-π, hydrogen bonding, covalent and electrostatic interactions. Adsorption on CNTs can occur at four different sites: the inner site, the interstitial channel, the external surface and the peripheral groove (Das *et al.*, 2017). Graphene oxide (GO) nanosheets, however, have emerged as alternatives to CNTs due to their higher cost. To increase heavy metal adsorption, GO contains selective hydrophilic groups like carboxylic acids and hydroxyl groups (Reynosa-Martínez *et al.*, 2020). Dendrimers and nanocellulose are also investigated as adsorbents for wastewater treatment. The best characteristics of nanocellulose are its biocompatibility, biodegradability and cost-effectiveness. As an adsorbent, dendrimers are effective for both inorganic and organic pollutants. Adsorption of hydrophobic organic compounds occurs on the hydrophobic core of dendrimers while electrostatic and/or hydrogen bonding can draw metals and/or ions to the interior and exterior branches. Furthermore, dendrimers can be desorbed from solutions by merely changing pH (Wazir, Daud, Ali, & Al-Harthi, 2020). Overall, nanoadsorbents are easy to synthesize, have high adsorption capacities, and are regenerated and reused effectively (after contaminants desorption).

Due to their 2D multilayered structures, photocatalytic properties, diverse chemical compositions and activated metallic hydroxide sites, MXenes are emerging as a superior water purification technology. MXene-based membranes, composites, photocatalysts, sorbents and electrodes are discussed for the adsorption, removal or degradation of dyes using several mechanism-based approaches. Additionally, MXenes are compared with other materials for developing a sustainable water purification system along with their cytotoxicity and potential for large-scale application. The MXenes (Ti_3AlC_2) structure consists of five hexagonal-like atomic layers, with three Ti sublayers (Ti1, Ti2 and Ti3) bonded to carbon at octahedral interstitial sites and two more reactive Al layers between them. As a result of its simplicity, feasibility, environmental friendliness and high efficiency, adsorption is widely used to sequester dyes from wastewater. Three types of interactions (i.e. chemical binding, electrostatic force and ion exchange) occur between pollutants and MXenes. As a result of their large surface area and surface terminations, MXenes can facilitate direct ion exchange in addition to being reductive/adsorptive to dyes and cations, which is advantageous (Ibrahim *et al.*, 2022). There was a previous report that provided a very detailed overview of the removal of toxic metals, including fabrication methods, characterization techniques, and advantages and limitations of MXenes for the adsorption of toxic metals (i.e. Pb, Zn, Cu and Cr). Moreover, based on some representative paradigms, MXene fundamentals and adsorption mechanisms are discussed along with their limitations and their implications for wastewater treatment research in the future (Ibrahim *et al.*, 2020).

For treating domestic wastewater, several conventional techniques have been used, but they are ineffective for removing pharmaceuticals. A critical evaluation of the performance of sustainable green nanoadsorbents for the remediation of pharmaceutical pollutants from water has been conducted by researchers. As part of the discussion, they also discussed the influential sorption parameters as well as the interaction mechanism (Khan *et al.*, 2022). Nanotechnology-based removal of pharmaceutical pollutants from wastewater effluents, such as antibiotics, hormones, pesticides, toxic dyes, antiviral drugs, among others, from respective wastewater effluents was discussed. The unique properties of nanosorbent materials, such as their immense affinity for organic and inorganic compounds, high absorption capabilities, large surface areas and eco-friendly fabrication are fascinating. An overview of some of the current nanotechnology applications for treating pharmaceutical-based wastewater effluents has been provided for researchers in recent reports. Carbon-based sorbent materials, CNTs-based sorbent materials, graphene-based sorbent materials, biogenic NPs-based sorbent materials and the different nanofiltration membranes has been discussed elaborately in this review (Aguilar-Pérez, Avilés-Castrillo, and Ruiz-Pulido, 2020).

6. Natural compounds and their derivatives for wastewater purification

In comparison to synthetic polymers, natural biopolymers are greener, sustainable and eco-friendly materials that come from living organisms and/or renewable resources. Due to their outstanding structural features, abundant availability, nontoxicity, ease of modification, biocompatibility and promising potential, natural polysaccharides such as chitin/chitosan, cellulose, starch, alginate, gum and pectin are environmentally sustainable materials. In recent years, polysaccharides have been utilized for producing various (nano)catalysts, with polysaccharide-supported metal/metal oxide (nano)material fabrication emerging as an effective nanotechnology approach. A variety of aqueous pollutants, including ionic metals and organic/inorganic pollutants, have been eliminated from wastewater using nanomaterial-adorned polysaccharide-based entities. Several natural biopolymers were used in the production of cellulose, chitin, starch, pectin, alginate, gum and chitosan-derived (nano)materials based on renewable resources. A recent report summarizes recent advances, trends and challenges associated with these biopolymers for wastewater purification (Nasrollahzadeh, Sajjadi, Iravani, and Varma, 2021). Remazol red dye was efficiently removed from the aqueous environment using activated coconut husk (Mustapha, Harun, Manas, Ali, & Hamzah, 2020). The same group of researchers has used low-cost oil palm empty fruit bunch for the efficient removal of malachite green dye. The treated and untreated empty palm fruit bunch was used, which has yielded adsorptive removal of 88.3% and 94.5% of the concentration of the dye taken initially (Mustapha *et al.*, 2021). In another study, a stink bean pod (*Parkia speciosa*) was used for the adsorption of harmful dyes from an aqueous solution such as Remazol Brilliant Blue R (RBBR) and RBV5. There was a removal of 83.35% of RBBR showing the adsorption capacity of 1.23 mg/g, which was removed by using a 3 g stink bean pod (Chang, Hadibarata, & Syafrudin, 2020). A partial simulation-based study was done for the removal of 2-naphthol orange dye known as Acid Orange 7 (AO7) dye using treated wheat bran. The laboratory studies corroborated with the *in silico* studies showing the high efficiency of dye removal of wheat bran (Mohammadi, Baniasadi, Rahdar, & Kyzas, 2021). Low-cost activated carbon (AC) was prepared from agricultural waste material: Cucumis melo was utilized to adsorb the dyes methylene blue and AO7. The efficient AO7 removal of 94.20% was achieved at 3 hours – activation time, temperature for activation (500°C), 1.5 mol/L – H_3PO_4 concentration along with a contact time of 90 min (El Kassimi, Achour, El Himri, Laamari, and El Haddad, 2021). In another study, chitosan/hyperbranched polyester (HBPE)/cobalt composite was synthesized by emulsion technique with ratio (1:1:0.5 wt %, respectively) for the remediation of the dye acid blue 277 dye (AB277) in an aqueous environment. The composite could adsorb the dye with an adsorption capacity of 26.74 mg/g compared to only chitosan/HBPE, which was 3.19 mg/g (Haroun, Abdelghaffar, & Hakeim, 2021). The dyeability and antimicrobial efficacy of the dyed fabric were improved by using cotton fabrics that were modified using Quat-188. This method was used to change the negative charges and incorporate the cationic sites for improving the affinity of acid dyes toward these fibers. A step forward, these fabrics were eventually treated with silver nanoparticles (AgNPs) for enhanced antibacterial activity (Ghazal, El-Masry, & Mosaad, 2021). Watermelon peel (*Citrullus lanatus*) and the peel of corn (*Zea Mays*) are quite common agricultural wastes and were used to remove the synthetics dyes: Remazol Brilliant Violet 5R (RBV5) and RBBR. The water melon peel was able to reduce 44.8% of color, while the corn peel removed 18.89% of the color (Kanthasamy, Hadibarata, Hidayat, Alamri, & Al-Ghamdi, 2020). By utilizing (nano)materials adorned with lignin, organic/inorganic contaminants can be efficiently and cost-effectively removed from aqueous media. To make lignin-derived (nano)materials economically viable, the production of functionalized lignin, metal oxide/lignin nanocomposites or hydrogels was suggested. Several recent advances, trends, challenges and future prospects of lignin-derived (nano)materials in wastewater treatment and purification were discussed, with an emphasis on adsorption and/or catalytic reduction or (photo)degradation of pollutants (Sajjadi, Ahmadpoor, Nasrollahzadeh, & Ghafuri, 2021). Recent reports demonstrate how agro-waste can be used to generate and store energy in nanoscale ways. The transformation of agro-waste into renewable energy resources in the forms of biofuels, green nanomaterials, biogas, solar energy, thermal energy, green hydrogen, triboelectricity, and battery and supercapacitor energy storage modules were discussed (Rani *et al.*, 2023).

7. Conclusion

Environment sustainability is the only choice for humans to save this planet and make it inhabitable for a longer period. Fresh water is necessary for every human activity and contribute for the various life forces. This mini review discusses about the requirement of fresh water and the different steps involved in its purification. Grey water remediation and desalination are the two major steps in fulfilling the increasing demand for fresh water. The different conventional method for the remediation of wastewater has been included in this review. Nanotechnology-based wastewater remediation methods have developed enormously to remediate grey water, which has been mentioned. Organic and inorganic NPs and composites, which are used for either development of membrane filtration or for photocatalysis or adsorption of heavy metals and other uses, have been included in this mini review. The natural compounds and their derivatives are researched for their role in purification of grey water. In our opinion, we all need to contribute for saving the clean water for our everyday usage, such as making rain water harvesting compulsory in all houses, reusing the water released from the air conditioner as well as RO plants for washing and mopping, reduce the planting of trees which are deep rooted and can exhaust the ground water, such as *Prosopis juliflora* plant. We can also inculcate the practice of groundwater replenishment through a mandatory schedule by the local government. These all measures will further add value to the effort of wastewater remediation. Further research is necessary to improve the efficiency of wastewater remediation using bio routes considering the safety concerns for human and animal consumption.

References

Abdelghaffar, F., Abdelghaffar, R. A., Mahmoud, S. A., & Youssef, B. M. (2019). Modified sugarcane bagasse for the removal of anionic dyes from aqueous solution. *Pigment and Resin Technology*, *48*(5), 464–471. doi:10.1108/PRT-01-2019-0003.

Agraharam, G., Saravanan, N., Girigoswami, A., & Girigoswami, K. (2022). Future of Alzheimer's disease: Nanotechnology-based diagnostics and therapeutic approach. *BioNanoScience*, *12*(3), 1002–1017.

Aguilar-Pérez, K., Avilés-Castrillo, J., & Ruiz-Pulido, G. (2020). Nano-sorbent materials for pharmaceutical-based wastewater effluents-An overview. *Case Studies in Chemical and Environmental Engineering*, *2*, 100028.

Ashton, P. J. (2002). Avoiding conflicts over Africa's water resources. *AMBIO: A Journal of the Human Environment*, *31*(3), 236–242.

Aslam, M. M. -A., Kuo, H. -W., Den, W., Usman, M., Sultan, M., & Ashraf, H. (2021). Functionalized carbon nanotubes (Cnts) for water and wastewater treatment: Preparation to application. *Sustainability*, *13*(10), 5717.

Balasubramanian, D., Girigoswami, A., & Girigoswami, K. (2023). Nano resveratrol and its anticancer activity. *Current Applied Science and Technology*, doi: 10.55003/cast.52022.55003, 55023.55010 (55016 pages)-55010.55003/cast. 52022.55003. 55023.55010 (55016 pages).

Beyene, H. D., & Ambaye, T. G. (2019). Application of sustainable nanocomposites for water purification process. In Inamuddin, S. Thomas, R. Kumar Mishra, & A. Asiri (Eds) Sustainable polymer composites and nanocomposites, Cham: Springer, pp. 387-412, doi: 10.1007/978-3-030-05399-4_14.

Bognár, S., Putnik, P., & Šojić Merkulov, D. (2022). Sustainable green nanotechnologies for innovative purifications of water: Synthesis of the nanoparticles from renewable sources. *Nanomaterials*, *12*(2), 263.

Chang, T. W., Hadibarata, T., & Syafrudin, M. (2020). Functionalized stink bean pod (*Parkia speciosa*) powder for adsorption of reactive dye. *Biointerface Research in Applied Chemistry*, *11*, 11616.

Chislock, M. F., Doster, E., Zitomer, R. A., & Wilson, A. E. (2013). Eutrophication: Causes, consequences, and controls in aquatic ecosystems. *Nature Education Knowledge*, *4*(4), 10.

Dahan, O., Babad, A., Lazarovitch, N., Russak, E. E., & Kurtzman, D. (2014). Nitrate leaching from intensive organic farms to groundwater. *Hydrology and Earth System Sciences*, *18*(1), 333–341.

Das, R., Vecitis, C. D., Schulze, A., Cao, B., Ismail, A. F., Lu, X., . . . Ramakrishna, S. (2017). Recent advances in nanomaterials for water protection and monitoring. *Chemical Society Reviews*, *46*(22), 6946–7020.

Deepika, B., Gopikrishna, A., Girigoswami, A., Banu, M. N., & Girigoswami, K. (2022). Applications of nanoscaffolds in tissue engineering. *Current Pharmacology Reports*, *8*(3), 171–187.

Dziegielewski, B., Kiefer, J. C., Opitz, E. M., Porter, G. A., Lantz, G. L., DeOreo, W. B,. . . Olaf Nelson, J. (2000). *Commercial and institutional end uses of water*. Denver: American Water Works Association.

El Kassimi, A., Achour, Y., El Himri, M., Laamari, M. R., & El Haddad, M. (2021). Process optimization of high surface area activated carbon prepared from Cucumis Melo by H3PO4 activation for the removal of cationic and anionic dyes using full factorial design. *Biointerface Research in Applied Chemistry*, *11*, 12662–12679.

Elgarahy, A. M., Elwakeel, K. Z., Akhdhar, A., & Hamza, M. F. (2021). Recent advances in greenly synthesized nanoengineered materials for water/wastewater remediation: An overview. *Nanotechnology for Environmental Engineering*, *6*, 1–24.

Ghazal, H. A., El-Masry, A. A., & Mosaad, R. M. (2021). Multifunction finishing of cellulose based fabrics via 3-Chloro-2-hydroxypropyl trimethyl ammonium chloride (Quat-188) and silver nanoparticles (AgNPs) to improve its dyeability and antibacterial. *Biointerface Research in Applied Chemistry*, *11*(4), 11666–11678.

Girigoswami, K., Girigoswami, A. (2021). A review on the role of nanosensors in detecting cellular miRNA expression in colorectal cancer. *Endocr Metab Immune Disord Drug Targets*, *21*(1), 12-26.

Haribabu, V., Girigoswami, K., & Girigoswami, A. J. N. -S. (2021). Magneto-silver core–shell nanohybrids for theragnosis. *Nano-Structures and Nano-Objects*, *25*, 100636.

Haroun, A. A., Abdelghaffar, F., & Hakeim, O. A. (2021). Preparation of chitosan/hyperbranched polyester/cobalt composite for Acid Blue 277 dye adsorption. *Biointerface Research in Applied Chemistry*, *11*, 11653–11665.

Howe, K. J., Hand, D. W., Crittenden, J. C., Trussell, R. R., & Tchobanoglous, G. (2012). *Principles of water treatment*. John Wiley & Sons.

Ibrahim, Y., Kassab, A., Eid, K., Abdullah, A. M., Ozoemena, K. I., & Elzatahry, A. (2020). Unveiling fabrication and environmental remediation of MXene-based nanoarchitectures in toxic metals removal from wastewater: Strategy and mechanism. *Nanomaterials*, *10*(5), 885.

Ibrahim, Y., Meslam, M., Eid, K., Salah, B., Abdullah, A. M., Ozoemena, K. I., . . . Sillanpää, M. (2022). A review of MXenes as emergent materials for dye removal from wastewater. *Separation and Purification Technology*, *282*, 120083.

Ilame, T., & Ghosh, A. (2022). The promising applications of nanoparticles for synthetic dyes removal from wastewater: Recent review. *Management of Environmental Quality: An International Journal*, *33*(2), 451–477.

Jagannathan, N. R. (2022). Potential of magnetic resonance (MR) methods in clinical cancer research. *Biomedical Translational Research* (pp. 339–360). Springer.

Jain, K., Patel, A. S., Pardhi, V. P., & Flora, S. J. S. (2021). Nanotechnology in wastewater management: A new paradigm towards wastewater treatment. *Molecules*, *26*(6), 1797.

Jlassi, K., Eid, K., Sliem, M. H., Abdullah, A. M., & Chehimi, M. M. (2020). Calix [4] arene-clicked clay through thiol-yne addition for the molecular recognition and removal of Cd (II) from wastewater. *Separation and Purification Technology*, *251*, 117383.

Jlassi, K., Eid, K., Sliem, M. H., Abdullah, A. M., Chehimi, M. M., & Krupa, I. (2020). Rational synthesis, characterization, and application of environmentally friendly (polymer–carbon dot) hybrid composite film for fast and efficient UV-assisted Cd2+ removal from water. *Environmental Sciences Europe*, *32*(1), 1–13.

Kamali, M., Persson, K. M., Costa, M. E., & Capela, I. (2019). Sustainability criteria for assessing nanotechnology applicability in industrial wastewater treatment: Current status and future outlook. *Environment International*, *125*, 261–276.

Kanthasamy, S., Hadibarata, T., Hidayat, T., Alamri, S., & Al-Ghamdi, A. (2020). Adsorption of azo and anthraquinone dye by using watermelon peel powder and corn peel powder: Equilibrium and kinetic studies. *Biointerface Research in Applied Chemistry*, *10*(1), 4706–4713.

Keerthana, V., Girigoswami, A., Jothika, S., Kavitha, D., Gopikrishna, A., Somanathan, T., & Girigoswami, K. (2022). Synthesis, characterization and applications of GO–TiO2 nanocomposites in textile dye remediation. *Iranian Journal of Science and Technology, Transactions A: Science*, *46*(4), 1149–1161.

Khan, N. A., Khan, S. U., Ahmed, S., Farooqi, I. H., Dhingra, A., Hussain, A., & Changani, F. (2019). Applications of nanotechnology in water and wastewater treatment: A review. *Asian Journal of Water, Environment and Pollution*, *16*(4), 81–86.

Khan, A. H., Khan, N. A., Zubair, M., Shaida, M. A., Manzar, M. S., Abutaleb, A., . . . Iqbal, J. (2022). Sustainable green nanoadsorbents for remediation of pharmaceuticals from water and wastewater: A critical review. *Environmental Research*, *204*, 112243.

Kumari, P., Alam, M., & Siddiqi, W. A. (2019). Usage of nanoparticles as adsorbents for waste water treatment: An emerging trend. *Sustainable Materials and Technologies*, *22*, e00128.

Kurunthachalam, S. K. (2014). Water conservation and sustainability: An utmost importance. *Hydrology: Current Research*, *5*(2), 1.

Luqman, M., & Al-Ansari, T. (2020). Thermodynamic analysis of an Energy-Water-Food (Ewf) nexus driven polygeneration system applied to coastal communities. *Energy Conversion and Management*, *205*, 112432.

Mohammadi, L., Baniasadi, M., Rahdar, A., & Kyzas, G. Z. (2021). Removal of acid dye from aqueous solutions with adsorption onto modified wheat bran–modeling with artificial neural networks. *Biointerface Research in Applied Chemistry*, *11*(6), 14044–14056.

Mustapha, R., Harun, M. H. C., Manas, A., Ali, A., & Hamzah, S. (2020). Preparation and characterization of Bio-Adsorbent from coconut husk for remazol red dye removal. *Biointerface Research in Applied Chemistry*, *11*(3), 10006–10015.

Mustapha, R., Ali, A., Subramaniam, G., Zuki, A. A. A., Awang, M., Harun, M. H. C., & Hamzah, S. (2021). Removal of malachite green dye using oil palm empty fruit bunch as a low-cost adsorbent. *Biointerface Research in Applied Chemistry*, *11*(6), 14998–15008.

Nagar, A., & Pradeep, T. (2020). Clean water through nanotechnology: Needs, gaps, and fulfillment. *ACS Nano*, *14*(6), 6420–6435.

Nam, Y., Lim, J. H., Ko, K. C., & Lee, J. Y. (2019). Photocatalytic activity of TiO 2 nanoparticles: A theoretical aspect. *Journal of Materials Chemistry A*, *7*(23), 13833–13859.

Nasrollahzadeh, M., Sajjadi, M., Iravani, S., & Varma, R. S. (2021). Carbon-based sustainable nanomaterials for water treatment: State-of-art and future perspectives. *Chemosphere*, *263*, 128005.

Nasrollahzadeh, M., Sajjadi, M., Iravani, S., & Varma, R. S. (2021). Starch, cellulose, pectin, gum, alginate, chitin and chitosan derived (nano) materials for sustainable water treatment: A review. *Carbohydrate Polymers*, *251*, 116986.

Okoh, A. I., Odjadjare, E. E., Igbinosa, E. O., & Osode, A. N. (2007). Wastewater treatment plants as a source of microbial pathogens in receiving watersheds. *African Journal of Biotechnology*, *6*(25). doi:10.5897/AJB2007.000-2462.

Palimi, M., Rostami, M., Mahdavian, M., & Ramezanzadeh, B. (2014). Surface modification of Fe2O3 nanoparticles with 3-aminopropyltrimethoxysilane (APTMS): An attempt to investigate surface treatment on surface chemistry and mechanical properties of polyurethane/Fe2O3 nanocomposites. *Applied Surface Science*, *320*, 60–72.

Piri, I., Homayoonnezhad, I., & Amirian, P. (2010). Investigation on optimization of conventional drinking water treatment plant. In *Paper presented at the 2010 2nd International Conference on Chemical, Biological and Environmental Engineering*.

Qiu, Y., Zhang, Q., Gao, B., Li, M., Fan, Z., Sang, W., . . . Wei, X. (2020). Removal mechanisms of Cr (VI) and Cr (III) by biochar supported nanosized zero-valent iron: Synergy of adsorption, reduction and transformation. *Environmental Pollution*, *265*, 115018.

Rani, G. M., Pathania, D., Umapathi, R., Rustagi, S., Huh, Y. S., Gupta, V. K., . . . Chaudhary, V. (2023). Agro-waste to sustainable energy: A green strategy of converting agricultural waste to nano-enabled energy applications. *Science of The Total Environment*, *875*, 162667.

Reynosa-Martínez, A., Tovar, G. N., Gallegos, W., Rodríguez-Meléndez, H., Torres-Cadena, R., Mondragón-Solórzano, G., . . . López-Honorato, E. (2020). Effect of the degree of oxidation of graphene oxide on as (III) adsorption. *Journal of Hazardous Materials*, *384*, 121440.

Sahu, J., Zabed, H., Karri, R. R., Shams, S., & Qi, X. (2019). Applications of nano-biotechnology for sustainable water purification. *Industrial Applications of Nanomaterials* (pp. 313–340). Elsevier.

Saikia, J., Gogoi, A., & Baruah, S. (2019). Nanotechnology for water remediation. *Environmental Nanotechnology*, *2*, 195–211.

Sajjadi, M., Ahmadpoor, F., Nasrollahzadeh, M., & Ghafuri, H. (2021). Lignin-derived (nano) materials for environmental pollution remediation: Current challenges and future perspectives. *International Journal of Biological Macromolecules*, *178*, 394–423.

Sharma, P., Dutta, D., Udayan, A., & Kumar, S. (2021). Industrial wastewater purification through metal pollution reduction employing microbes and magnetic nanocomposites. *Journal of Environmental Chemical Engineering*, *9*(6), 106673.

Shatat, M., & Riffat, S. B. (2014). Water desalination technologies utilizing conventional and renewable energy sources. *International Journal of Low-Carbon Technologies*, *9*(1), 1–19.

Sheng, X., Xu, X., Wu, Y., Zhang, X., Lin, P., Eid, K., . . . Nanjundan, A. K. (2021). Nitrogenization of biomass-derived porous carbon microtubes promotes capacitive deionization performance. *Bulletin of the Chemical Society of Japan*, *94*(5), 1645–1650.

Sudhaik, A., Raizada, P., Rangabhashiyam, S., Singh, A., Nguyen, V. -H., Van Le, Q., . . . Ahamad, T. (2022). Copper sulfides based photocatalysts for degradation of environmental pollution hazards: A review on the recent catalyst design concepts and future perspectives. *Surfaces and Interfaces*, 102182.

Uddin, Z., Ahmad, F., Ullan, T., Nawab, Y., Ahmad, S., Azam, F., . . . Zafar, M. (2022). Recent trends in water purification using electrospun nanofibrous membranes. *International Journal of Environmental Science and Technology*, *19*(9), 9149–9176.

Vázquez-Núñez, E., Molina-Guerrero, C. E., Peña-Castro, J. M., Fernández-Luqueño, F., & de la Rosa-Álvarez, M. G. (2020). Use of nanotechnology for the bioremediation of contaminants: A review. *Processes*, *8*(7), 826.

Vedhantham, K., Girigoswami, A., Harini, A., & Girigoswami, K. (2021). Waste water remediation using nanotechnology-A review. *Biointerface Research in Applied Chemistry*, *12*(4), 4476-4495.

Wazir, M. B., Daud, M., Ali, F., & Al-Harthi, M. A. (2020). Dendrimer assisted dye-removal: A critical review of adsorption and catalytic degradation for wastewater treatment. *Journal of Molecular Liquids*, *315*, 113775.

Werkneh, A. A., & Rene, E. R. (2019). Applications of nanotechnology and biotechnology for sustainable water and wastewater treatment. *Water and Wastewater Treatment Technologies*, 405–430.

Yadav, M., Gupta, R., & Sharma, R. K. (2019). Green and sustainable pathways for wastewater purification. *Advances in water purification techniques* (pp. 355–383). Elsevier.

Zha, X. -J., Zhao, X., Pu, J. -H., Tang, L. -S., Ke, K., Bao, R. -Y., . . . Yang, W. (2019). Flexible anti-biofouling MXene/cellulose fibrous membrane for sustainable solar-driven water purification. *ACS Applied Materials & Interfaces*, *11*(40), 36589–36597.

Corresponding author
Koyeli Girigoswami can be contacted at: koyelig@gmail.com