An overview of nanoscale materials on the removal of wastewater contaminants

Ramendra Soni1 · Arun Kumar Pal1 · Pooja Tripathi2,4 · Jonathan A. Lal1 · Kavindra Kesari3 · Vijay Tripathi1

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Abstract
Growing population and climate change are increasing the challenges to the global water situation. Due to a continuous elevating level of pollution, there is the requirement of novel innovative water technologies to ensure the good supply of drinking water. This review is mainly focused on the recent advances in nanotechnology aspects for water and wastewater treatment that include nano-based materials such as nanosorbents, metal oxides of nanoscale materials, polymer-based nanosorbents, membranes of nanoscale materials (nanomembranes), carbon nanotubes (CNTs) and silver nanoparticles (AgNPs). These nanomaterials are beneficial when the properties and specific characteristics of these materials are compared with conventional processes of the wastewater treatment. The aim and objective of this review are to provide an overview of different types of nanomaterials and their applicability in the removal of heavy metals and bacterial pathogens from wastewater during the treatment process.

Keywords Nanotechnology · Nanoparticle · Wastewater treatment · Heavy metal

Introduction

Water is a precious and finite resource for the existence of life on earth. Extensive withdrawal of water in different sectors such as agriculture, industries and for domestic purpose is responsible for the depletion of groundwater at an alarming rate (Boretti and Rosa 2019). The water scarcity and contamination are the major challenges for all around the globe, and almost one billion people are currently facing these challenges. Therefore, it is important to develop various advanced technologies to clean the wastewater and reuse in many sectors. Wastewater is the result of the discharge of untreated sewage sludge, toxic heavy metals, radio-nucleosides, organic & inorganic solutes, fertilizers and microbial contamination which is inappropriate for consumption. The major sectors for wastewater generation are municipal corporations, industries, clinical laboratories, hospitals and household wastes. Wastewater causes numerous bacterial, viral and parasitic diseases like typhoid, cholera, hepatitis, encephalitis, gastrointestinal, skin infection, diarrhoea, etc. The accumulation of heavy metals in wastewater can cause genetic alteration and can affect hormone metabolism which leads to cancer and foetal growth restriction (Cebi et al. 2011). It is largely observed that the people residing near the heavy metal-contaminated sites are suffering from the spine and other bone-related diseases (Rodríguez and Mandalunis 2018). Cadmium is most widely known for causing musculoskeletal diseases (Fukushima et al. 1970). Mercury and lead are commonly known toxic and hazardous heavy metals; exposure to the mercury directly affects the nervous system of humans, especially who are actively associated in drinking and smoking, while lead contamination may be a serious risk factor for osteopenia or osteoporosis (Houston 2007). It is also important to discuss the harmful effects of arsenic (As) because it is a human carcinogen,
and according to the studies, it may cause bone and kidney cancer (Jarup 2003). As per the recommendation of WHO (1984) and Indian standard drinking water specification 1991, the permissible limit of fluoride content in the drinking water is 1.5–1.0 ppm and it will be beneficial for normal human health, but a slight increase in the permissible limit of fluoride content in drinking water can cause detrimental effects leading to dental and brittle bones, osteoporosis, skeletal fluorosis and arthritis (Kumar and Puri 2012). In previous years, enormous conventional techniques such as activated carbon, sedimentation, flocculation, coagulation and membrane filtration were involved in wastewater treatment. However, these traditional techniques were not effective to treat complex polluted materials like pharmaceuticals, surfactants, beauty care products and numerous hazardous chemicals (Amin et al. 2014). These conventional methods are also not able to dislodge the toxic chemicals as well as microorganisms present in water (Ruzhitskaya and Gogina 2017; Awaleh and Soubaneh 2014). In this perspective, nanotechnology has attracted many researchers towards the treatment of wastewater using nanomaterials. Nanotechnology facilitates the observation and manipulation of the things at a nanometre scale (Cloete et al. 2010). On the nanoscale, any material exhibits completely different properties like colour, tensile strength, surface area, magnetic property, catalytic activity, etc. than their original size. Nanotechnology has been established as an auspicious and effective technology to solve water-related problems (Obare and Meyer 2004). It comes with the introduction of various nanoscale materials like carbon nanotube (CNT), metal nanoparticles, nanoclusters, dendrimers, quantum dots, nanowires and zeolites (Liu et al. 2013). Nanomaterials are also called a wonder of modern medicine (Khan and Rehman 2016). Moreover, nanoparticles have been proved as a very effective antibacterial agent rather than conventionally used antibiotics (Wang et al. 2017). The high surface area, actively strong adsorption sites, extensive antimicrobial activity, low toxicity makes CNTs, AgNPs and other nanoscale metal oxides are widely acceptable for adsorption, disinfection and microbial control (Raghunath and Perumal 2017), whereas fullerene derivatives, TiO2 nanoparticle, are extensively used as photocatalysts because of their photocatalytic activity, high stability and low cost (Ratan and Bansal 2013). Zeolites and nanofibres are applied in membrane filtration as they possess the properties of molecular sieving, hydrophilicity and comparatively short internal diffusion distance. Quantum dots are also used for sensing due to its broad absorption spectrum and high conductivity.

In this review, we briefly discussed the applications of different nanomaterials which are effectively used in the removal of different pollutants, especially heavy metals and microbes from effluent water, because the discharge of heavy metals (Cd, As, Co, Cu, Zn, Pb, Cr) and pathogenic bacteria in wastewater can contaminate the aquatic environment. Therefore, it is very much essential to treat the wastewater before discharge into the river or other downstream environments.

### Application of nanomaterials in heavy metals removal

A broad range of heavy metals generally present in different industrial wastewater, which is toxic to human health and also responsible for the contamination of other environments (Jaishankar et al. 2014). Apart from many conventional treatment methods, various nanomaterials are also applied for the removal of heavy metals (Kahrizi et al. 2016, Baby et al. 2019). Nanomaterials are considered to be very efficient and prominent in the elimination of environmental contaminants (Selvi et al. 2019). In this regard, here we briefly discussed the few applications and examples of these nanomaterials.

### Nanoscale materials as sorbents

Industrialization is the major cause for the release of different contaminations in the wastewater. These contaminants include different inorganic and organic wastes including heavy metal ions such as Pb^{2+}, Cd^{2+}, Zn^{2+}, Ni^{2+}, Hg^{2+}, Cu^{2+}, Cr^{3+} and Co^{2+}. These heavy metals are toxic and non-biodegradable; therefore, these are responsible for the many serious diseases and hazardous for environmental health (He et al. 2005). These heavy metals are usually introduced into the environment through chemical manufacturing industries, battery manufacturing industries, leather industries, mining and metallurgical industries, and these are usually discharged directly to the water bodies. Untreated industrial wastewater can cause a severe risk to the aquatic species, and it will also affect the food chain through its absorbance and accumulation (Drozdova et al. 2019). It is very important to consider the various damages caused by these heavy metals; it became crucial to deal with these toxins. Traditionally, many methods are being adopted for the removal of pollutants from different types of wastewater such as reverse osmosis, electrochemical treatment, ion exchange techniques, coagulation, extraction, adsorption and irradiation. Although there have been many traditionally adaptive techniques to remove these toxins from wastewater, it is always expected to come up with such a technique which should be cost-effective, highly efficient and simple to operate. Among many techniques, the adsorption comes up with the most favourable approach for the removal of heavy metals from wastewater. Adsorption techniques have been providing benefits to adsorbed heavy metal on the solid surface, and
they established stability when the concentration of heavy metal is adsorbed, but it has some limitations such as low sorption capacities and efficiency. To solve these defects, nanoscale materials are used for the removal of heavy metals from the wastewater. There is a wide range of nanoscale sorbents such as CNT, carbon-based materials composites, graphene, nanomaterials, or metal oxides and polymeric sorbents with high adsorption capacities (Wang et al. 2011). They are briefly discussed below:

1 Nanoscale materials based on carbon.

Nanomaterials based on carbon are used widely to remove heavy metals from the wastewater as it shows the high sorption capacity and it is non-toxic. Carbon-based nanomaterials are firstly used as biosorbents, but they show difficulties to reach ppb levels while removal of heavy metals. So these carbon-based nanomaterials are used in the formation of CNT, fullerene, and graphene. These synthesized CNT, fullerene, and graphene are used as biosorbents.

- CNTs are the macromolecules, which are shaped like a cylinder and arranged in hexagonal fashion. They are carbon-based materials composites, which are synthesized by hydrothermal treatment of anatase nanoparticles. They exhibit unique structural, chemical, and mechanical properties. These CNTs have abundant variability to remove contaminants from wastewater, as they are also used as remarkable biosorbents as they come up with high sorption efficiency. SWCNTs have diameters ranging from 0.3 to 3 nm, whereas the MWCNTs consist of concentric arrangements of many cylinders, and its size can range up to 100 nm (Iijima and Ichihashi 1993). According to these studies, CNTs will be a promising adsorbent material due to its large surface area and tubular structure. To enhance the capacities of sorption, these CNTs are modified by oxidation, combining with other metal ions or metal oxides; also, they can be coupled with organic compounds. By various combinations of CNTs with metal oxides, organic compounds, it is found that carboxyl-carbon sites are over 20 times more promising for the sorption of zinc other than unoxidized carbon sites. The adsorption parameters of such carbon nanotubes can be optimized by the variation in temperature, pH, ionic strength, and metal ion concentration. Many evaluations of CNTs to improve the sorption were reported (Srivastava et al. 2004). For the sorption of 1,2-dichlorobenzene (DCB), CNTs show a wide range in pH of 3–10 and this sorption of DCB on to CNTS shows maximum sorption capacity of 30.8 mg/g by taking 40 min to reach to the equilibrium. Apart from these, CeO$_2$-based carbon nanotubes (CeO$_2$-CNT) or on aligned carbon nanotubes (CeO$_2$-ACNTS) are developed which claims high surface areas (over 189 m$^2$/g). Though the CeO$_2$-CNTS are active sorbents for As (V), its efficiency was enhanced from 10 to 82 mg/g when incorporated with divalent cations Ca(II) and Mg(II) at concentrations stretch between 1 and 10 mg/L. (Peng et al. 2005). Another study revealed the potential of CeO$_2$-ACNTS for Cr(VI) adsorption from drinking water. The maximum Cr(VI) adsorption ability achieved was 30.2 mg/g at pH 7.0, which was two times greater than that of activated carbon and Al$_2$O$_3$ (Khaydarov et al. 2010). Therefore, the capacity of adsorption of metal ions or any other functional contaminant dependent on wastewater can be enhanced by increasing the electrostatic interaction between the ions and nanoscale sorbents. This strategy also enhances the tendency of adsorption of organic compounds by nanosorbents.

- Graphene is the biosorbent which is formed by synthesizing some layers of graphene oxide and converted into nanosheets. These atomic layered graphites have good mechanical and thermal properties with two-dimensional (2D) structures. These graphene nanosheets are good biosorbents to remove Cd$^{2+}$ and Co$^{2+}$ ions from aqueous solution. The adsorption of heavy metals contaminants from the wastewater depends on ionic strength, pH, and the functional groups containing oxygen. Graphene biosorbents show good adsorption results for As$^{3+}$ with a particle size of 10 nm to give high binding capacity.

2 Nanoscale particles synthesized from oxides of metals.

Nanoscale materials synthesized by oxides of metals are the type of inorganic nanomaterials. These metal oxides nanomaterials extensively used nanoparticles for the removal of heavy metal ions from wastewater (Ray and Shipley 2015; Shukla and Iravani 2017). There are few examples of these nanomaterials such as ferric oxides, silver nanoparticles, manganese oxides, titanium oxides, magnesium oxides, copper oxides, cerium oxides. They remove heavy metals from wastewater by providing high surface area and specific affinity. Metal oxide nanoparticles show a good capacity to remove arsenate (Hristovski et al. 2007). Studies reveal that nanopowders of TiO$_2$, Fe$_3$O$_4$, ZnO$_2$, and NiO have high efficiency and they exhibit the highest amount of removal of arsenate from the water (Hristovski et al. 2007). Another type of nanopowder is introduced called titanate nanoflowers. They are synthesized by hydothermal treatment of anatase nanopowders with a concentrated solution of NaOH. These nanoflowers have a good capacity of removal of heavy metal ions...
due to their large and specific surface area. Titanate nanoflowers are highly selective and show larger absorption of heavy metal ions from highly toxic to less toxic metal ions. Some examples of these metal ions are Cd$^{2+}$, Zn$^{2+}$, Ni$^{2+}$, etc., and they are efficiently removed by titanate nanoflowers (Huang et al. 2012). Although nanoscale metal oxides are a great source of removal of heavy metal ions because of high surface energy and nanosize, they show some difficulties in separation of them from wastewater. With this problem, another approach was introduced to prepare nanosorbents with polymers, usually called as polymer-based nanosorbents.

(3) Polymer-based nanosorbents.

Polymer-based nanosorbents are highly efficient sorbents due to the main characteristic feature of having a high capacity of having high capacity and fast rate of adsorption. This characteristic is due to the main feature of having a large surface area with an additional functional group. There is a presence of both types of sorbents like inorganic sorbents and organic sorbents (Zhao et al. 2018). Most of the organic sorbents possess high surface area but lacking the adsorbing functional group. Unlike organic sorbents show the presence of a functional group to adsorb heavy metal ions, but the absence of a specific area limits their adsorption rate. Therefore, there comes the need of having such sorbents which possess both the features of having specificity and polyfunctional groups to increase the rate of adsorption of heavy metal ions. To meet these requirements, new hybrid sorbents has introduced to provide the application of deep removal of heavy metal ions from wastewater. For example, hybrid polymer of pyromellitic acid dianhydride (PMDA) and phenylaminomethyl trimethoxysilane (PAMTMS), this hybrid polymer adsorbs Cu$^{2+}$ and Pb$^{2+}$ efficiently (Liu et al. 2010). Therefore, the hybridized inorganic and organic nanosorbents are efficient sorbents to remove heavy metal ions from wastewater (Table 1, Fig. 1).

**Advantages of nanoscale materials for adsorption**

- Nanosorbents themselves are non-toxic.
- Nanosorbents show high sorption capacities.

**Table 1 The hazardous heavy metal, their harmful effect and treatment through different nanomaterials**

| S. no. | Heavy metals | Associated problems                                                                 | References                          | Nanomaterials used for treatment                                      | References             |
|--------|--------------|-------------------------------------------------------------------------------------|------------------------------------|------------------------------------------------------------------------|------------------------|
| 1.     | Copper       | Liver cirrhosis in patients, anaemia, liver and kidney damage, abdominal pain, vomiting, headache and nausea in children | Madsen et al. (1990), Bent and Bohm (1995), Salem et al. (2000) | Carbon nanotubes, pyromellitic acid dianhydride (PMDA) and phenylaminomethyl trimethoxysilane (PAMTMS) | Liu et al. (2010)      |
| 2.     | Zinc         | Diarrhoea, vomiting, icterus (yellow mucous membrane), bloody urine, anaemia, kidney failure and liver failure | Nolan (2003), Duruibe et al. (2007) | Carbon nanotubes                                                       | Lu et al. (2006)       |
| 3.     | Nickel       | Eczema, weight loss and hair loss                                                    | Kaaber et al. (1978), Ambrose et al. (1976) | Graphite oxide                                                        | Sheet et al. (2014), Lu and Liu (2006) |
| 4.     | Arsenic      | Bone and kidney cancer                                                               | Jarup (2003)                        | Metal oxide nanoparticles of TiO$_2$, FeO$_3$, ZnO$_2$ and NiO          | Kocabas et al. (2012)  |
|        |              |                                                                                      |                                     | CeO$_2$-CNT$_S$                                                        | Peng et al. (2005)     |
| 5.     | Fluoride     | Dental and skeletal fluorosis, brittle bones, osteoporosis and arthritis              | Kumar and Puri (2012)               | Iron oxide-hydroxide nanoparticle                                       | Raul et al. (2012)     |
| 6.     | Cadmium      | Musculoskeletal diseases                                                             | Fukushima et al. (1970)             | MgO nanoparticles                                                      | Devi et al. (2014)     |
|        |              |                                                                                      |                                     | ZnO nanoparticles                                                      | Kumar and Chawla (2014) |
|        |              |                                                                                      |                                     | Titanate nanoflowers                                                  | Kocabas et al. (2012)  |
| 7.     | Lead         | Osteopenia or osteoporosis                                                            | Puzas et al. (2004)                 | Nanomaterial of calcium hydroxyapatite (n-CaHAP)                       | Mousa et al. (2016)    |
| 8.     | Mercury      | Affects nervous system, fatigue, tremors, headaches, hearing and cognitive loss, hallucinations | Azevedo et al. (2014)               | Carbon nanotubes                                                       | Li et al. (2002)       |
|        |              |                                                                                      |                                     | Iron oxide nanoparticles                                               | Vélez et al. (2016)    |
• The adsorbed nanomaterials can be easily removed from the surface of nanoscale adsorbents.
• These nanosorbents can be recycled also.

Removal of bacterial pathogens from wastewater using different nanomaterials

Wastewater consisted of many pollutants from different sources like municipal corporations, clinics, hospitals and pharma industries gives rise to numerous bacteria, viruses, fungi and pathogens. Waterborne pathogens, Salmonella species, Vibrio Species and protozoa contamination are responsible for various diseases like diarrhoea, gastrointestinal illness dysentery, etc. (Lukhele et al. 2010). According to the WHO, any water is only considered as safe for drinking purpose, if it is free from faecal contamination and coliform counts. Availability of pure water is the uttermost demand of humanity, but increasing pollution makes this demand on very high priority. Microorganisms are of the major pollutant in the water bodies as they participate in the process of removing nutrients and adding toxic metabolites in the wastewater. Sources
of water availability are very limited so as to meet the high demand for pure and drinking water; it is important to have a check on some unconventional sources of water. In an attempt to remove the bacterial pathogens from wastewater, nanoscale technology is another big approach. There are several categories of the nanoscale materials which remove the microbes in the wastewater. High permselectivity and higher hydrophilicity of nanosized composite membrane integrated with inorganic materials enable it as an efficient tool for the enhanced treatment of contaminated water (Khaydarov et al. 2010). In many previous studies, the efficacy of metal ions has been displayed in the term to disinfect the water (Yang et al. 2007). These metal ions have their changed capacity which makes them antibacterial. There are many types of nanoscale materials present which can disinfect waterborne disease caused by microorganisms such as silver, titanium and zinc. Implementation of nanotechnology can be very useful for the detection and removal of bacteria, viruses and other pathogenic microorganisms. Nanoparticles can be used as biosensors for the in situ detection of waterborne microbes (Rainbow et al. 2020). Studies have shown that nanosensors are highly sensitive and selective for the detection of a very amount of E. coli (Zhu et al. 2005, Kumar et al. 2019). The implication of Nanoparticles as nanosensors is a rapid procedure and easy to execute.

Nanoscale particles of ZnO

After the remarkable development of science and nanotechnology, it is very obvious to rely on the antibacterial characteristics of nanoparticles of various metals. These metal nanoparticles are capable option to disinfect the water and wastewater systems. Various studies have been carried out with the ZnO nanoparticle and concluded that it has the potential to remove the total coliforms from the municipal wastewater treatment plant (Hozyen et al. 2019). These ZnO nanoparticles are working by their enhanced time to contact in the water because, at the time of attachment increased, the removal percentage of coliforms will also increase in the wastewater. These ZnO nanoparticles attached the membrane cells of bacteria ensures the inhibition rate of coliforms in the wastewater to a high level. Bacterial growth will be inhibited by the aggregation of ZnO nanoparticles in the membrane and cytoplasm of bacteria. ZnO nanoparticles penetrate the membrane and cytoplasm of bacteria easily, and when their penetration time is being increased, there will be more secretion of H₂O₂ which help in increasing toxic effects to the bacteria.

TiO₂ nanoparticles

TiO₂ nanoparticles are found to be an appealing substance due to their optical, dielectric and photocatalytic characteristics. These properties enable it with the capability to remove bacteria and harmful organic materials from water and air (Pişkin et al. 2013). TiO₂ is a photocatalyst, widely applied as a self-cleaning and self-sanitizing material for surface coating in many applications, as it is non-toxic and exhibits photoinduced super-hydrophobicity and extensively used as an antifogging agent and performs a key role in our environmental decontamination.

Carbon nanotubes

CNTs are very effective to remove bacterial pathogens from water. It possesses antimicrobial characteristic against a wide range of microorganisms including bacteria such as E. coli, Salmonella and viruses (Deng et al. 2008; Upadhyay et al. 2008a, b; Nepal et al. 2008; Akasaka and Watari 2009). Researchers have studied the antimicrobial effects of carbon nanotubes as they remove impurities from water. CNTs possess structure like cylindrical and exist in a honeycomb lattice structure which looks like crystalline graphite. Apart from their two types (1) single-walled carbon nanotubes (SWNT) and (2) multi-walled carbon nanotubes (MWNT), they contain a unique property which is suitable to capture microbial agents strong and stable membranous. A novel approach, continuous spray pyrolysis can also be adopted for the synthesis of carbon nanotubes structures. By using this method, CNTs can be fabricated with 10–12 nm inner diameter and 20–40 nm outer diameter, several cm in length and can withstand the fracture load up to 2 N. These CNTs were successfully tested against Escherichia coli and Staphylococcus aureus and also found to be very efficient for the elimination of even the smallest poliovirus from saline suspensions (Rojas-Chapana et al. 2004). Unique characteristics of size, cytotoxicity and surface functionalizing properties, their fibrous shape, and length of the tubes and membrane of layers made carbon nanotubes a potent antimicrobial agent. CNTs are having a mechanism to kill microorganisms by initiating oxidative stress and disturbance to cell membrane, etc. Single-walled carbon nanotubes are much potent antimicrobial than multiwalled carbon nanotubes by dispersivity of CNTs against microorganisms. Not only bacteria, even viruses can be effectively eliminated from water using filtration membrane containing radically ACNTs in a very short time due to size exclusion and depth filtration which enables these
filters to be more widely applicable disinfection devices for wastewater treatment and cost-effective at the same time (Brady-Estevez et al. 2010; Vecitis et al. 2011; Rahaman et al. 2012). Various studies proved their high potential in CNTs to remove bacteria and serve as an effective aquatic bacterial removal. These carbon nanotubes are not only effective bacterial absorbents but also they serve as effective magnetic separation agent. Supermagnetism and excellent electronic properties enable magnetic nanoparticles for sensing and monitoring of heavy metals and microbes in wastewater.

**Silver nanoscale materials**

Silver is the extensively used material for nanoparticles synthesis due to its low toxicity and microbial inactivation in water (Spadaro et al. 1974; Zhao and Stevens 1998; Inoue et al. 2002) with well-reported antibacterial mechanism (Feng et al. 2000; Yamanaka et al. 2005). In nanoscale materials, silver nanoparticles are having very prominent results against the microorganisms present in wastewater. These silver nanoparticles can be obtained from the salts of silver like silver nitrate, silver chloride, etc. The antibacterial effects of these silver nanoparticles are because of their size and shape which make them capable to inactivate the microorganisms in wastewater. The main active principle of these antibacterial silver nanoparticles is their efficiency to damage the bacterial membranes, altering the membrane properties of bacterial, damaging the active enzyme, alters the interaction with silver nanoparticles gained the interest of being a high antimicrobial agent because they have reported with robust killing effect against Gram-positive as well as Gram-negative bacteria. Son et al. (2004) integrated the cellulose acetate fibres embedded with Ag nanoparticles by direct electrospinning method and achieved good efficacy against both types of bacteria. As their wide range of applicability, silver nanoparticles are also being integrated with various polymers for the fabrication of antimicrobial nanofibres and nanocomposites (Balogh et al. 2001; Chen et al. 2003; Botes and Cloete 2010). Poly(e-caprolactone)-based polyurethane nanofibre mats containing Ag nanoparticles can be used as antimicrobial nanofilter (Jeon et al. 2008). Likewise, various other nanofibres, assimilated with Ag nanoparticles, can be used as an unconventional tool in the antimicrobial application and exhibit excellent antimicrobial properties (Lala et al. 2007; Chen and Chang 2008; Vimala et al. 2009). Water filters prepared by polyurethane’s foam coated with Ag nanofibre can act as an efficient barrier for the growth of *Escherichia coli* (Jain and Pradeep 2005).

**Conclusion**

The adaptation of vastly cutting-edge nanotechnology evolves novel prospects for the expansion of advanced water and wastewater technology processes. Here the applications of various nanomaterials like silver nanoparticles, carbon-based nanoparticles, polymer-based nanoparticles and oxide metal nanoparticles were reported for the removal of heavy metal and microbial pathogens from wastewater. These materials show a great impact on the removal of wastewater contaminants. Nanotechnology has been considered effective in solving water-related problems of quality and quantity (Bottero et al. 2006). However, there are few studies also reported the toxic nature of nanoparticles which are harmful to the human and environmental health and it should be further investigated and regulated. Overall, the use of nanomaterials in the removal of heavy metal and microbial pathogens from wastewater has very much importance in the respect of human and environmental health, but the risk associated with the nanoparticles should not be ignored. Based on previous and current studies, nanotechnology and application of nanomaterials can be recommended for various sewage treatment plants and wastewater treatment plants.

**Compliance with ethical standards**

**Conflict of interest** The authors declare that there is no conflict of interests regarding the publication of this paper.

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