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A Research on the Treatment of Pollutants from Water through Different Types of Nano Adsorbents/Materials

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Abstract* – *The potential human health issues resulting from the continuous consumption of drinking water containing low concentration levels of persistent emerging pollutants has raised some concerns. The presence of emerging pollutants in surface water bodies and ground-water in Canada together with absence of proper drinking water treatment processes in remote places has created the need for an effective and simple process for removal of emerging pollutants from drinking water. Low seasonal temperatures in regions such as Saskatchewan demand a removal process that is effective at temperatures lower than room temperature. Adsorption with granular activated carbon is a well-established and effective method for removal of organic compounds from drinking water. There are a large number of reports on removal of organic compounds by activated carbon in literature however, the effectiveness of adsorption of emerging pollutants with granular activated carbon is not clear. Effectiveness of ozone treatment for oxidation of emerging pollutants is reported in literature however, effectiveness of regeneration of adsorbents saturated with emerging pollutants with ozone has not been investigated extensively.

The rapidly increasing population, depleting water resources, and climate change resulting in prolonged droughts and floods have rendered drinking water a competitive resource in many parts of the world. The development of cost-effective and stable materials and methods for providing the fresh water in adequate amounts is the need of the water industry. Traditional water/wastewater treatment technologies remain ineffective for providing adequate safe water due to increasing demand of water coupled with stringent health guidelines and emerging contaminants. Nanotechnology-based multifunctional and highly efficient processes are providing affordable solutions to water/wastewater treatments that do not rely on large infrastructures or centralized systems. The aim of the present study is to review the possible applications of the nanoparticles/fibers for the removal of pollutants from water/wastewater.

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INTRODUCTION

The various chemicals added to food, water and care products play significant roles in influencing human activities. They enable the development of new technologies and improve the standards and quality of life. Chemicals enter the environment because of the widespread industrial activities taking place in our surroundings. These activities can release effluents (liquids or gases) and solid residues that can be harmful to the environment. Some chemicals like pesticides, CO2, CO and CH4 are released deliberately from industrial and manufacturing sector into the environment, although it is unintentional in most cases. When compared to the normal levels defined by environmental legislation, the levels of chemicals are higher, in this case they are known as contaminants or pollutants. Water is a major and significant means by which these chemicals reach the living organisms in the environment, which exert their effects upon consumption, or accumulate in the water bodies such as rivers, lakes and groundwater. Therefore, water carries the imprint of all the activities performed by human beings. The chemicals in the water can be either macro-pollutants or micro-pollutants depending on the concentration of the chemical in the water body. Micro-pollutants and macro-pollutants have significant impacts on the environment depending on the concentration of the chemicals. The increasing amounts of pollutants have raised concerns worldwide regarding the adoption of strategies that will help reduce the consequences associated with the high levels of pollutants in the environment (Altaf, Masood, and Malik, 2008). This study analyzes different emerging contaminants in water, wastewater and drinking water as a result of industrial development, lifestyle, and advancement in technology in today's world. It also focuses on their effects on public health and the environment including the remediation techniques. This is achieved by investigating different methods of removing contaminants in water, wastewater and drinking water. This study also suggests ways of minimizing the contaminants and strengthening the treatment methods.

Water is a fundamental substance whose material existence is secondary compared to the symbolic value as it is manifested in our mind as the symbol of life. Sustainable supplies of clean water are vital to the world's health, environment and economy (Bhattacharya *et al.,* 2013). Water has a broad impact on all aspects of human life including but not limited to health, food, energy and economy (Amin *et al.,* 2014). It is estimated that 10-20 million people die every year due to waterborne and nonfatal infection causes death of more than 200 million people every year.

Every day about 5,000-6,000 children die due to the water-related problem of diarrhea. There are currently more than 0.78 billion people around the world who do not have access to safe water resources (WHO, 2013) resulting in major health problems. It is estimated that more than one billion people in the world lack access to safe water and within couple of decades the current water supply will decrease by one-third. In the present context the recent advancement of nano-scale science and engineering is opening up a hitherto unknown and novel gateway to the development and deployment of water purification processes. Nano-science is the study of phenomenon and manipulation of materials at atomic, molecular and macromolecular scales, where properties differ significantly from those at a larger scale (Shah and Ahmed, 2011). In recent years, a great deal of attention has been focused onto the applicability of nanostructured materials as adsorbents or catalysts in order to remove toxic and harmful substances from. Nano-adsorbents had gained special attention since last decade because the materials of such kind possess unique properties than the bulk materials. Like different nano-materials, single and multi-metal or doped metal oxides are also subject of much interest since that materials possess high surface-to-volume ratio, enhanced magnetic property, special catalytic properties etc (Gupta *et al.,* 2011). Consequently, different methods viz. chemical precipitation, sol-gel, vapour deposition, solvo thermal, solid state reaction etc were adopted for the synthesis of specified oxides by various researchers.

Advances in Nano scale science and engineering suggest that many of the current problems involving water quality could be resolved or greatly diminished by using nano-adsorbents, Nano catalysts, bioactive nanoparticles, nanostructured catalytic membranes, nanotubes, magnetic nanoparticles, granules, flake, high surface area metal particle supra molecular assemblies with characteristic length scales of 9-10 nm including clusters, micro molecules, nanoparticles and colloids have a significant impact on water quality in natural environment. The defining factor which characterizes the capability of nanoparticles as a versatile water remediation tool includes their very small particle sizes (1-100 nm) in comparison to a typical bacterial cell which has a diameter on the order of 1 μm (1000 nm). Hence nanoparticles can be transported effectively by the groundwater flow. As a result, nanoparticles can be anchored onto a solid matrix such as a conventional water treatment material like activated carbon and zeolite for enhanced water treatment.

Nanotechnology has been considered effective in solving water problems related to quality and quantity. Nanomaterials are contributing to the development of more efficient treatment processes among the advanced water systems. There are many aspects of nanotechnology to address the multiple problems of water quality in order to ensure the environmental stability. This study provides a unique perspective on basic research of nanotechnology for water/wastewater treatment and reuse by focusing on challenges of future research.

There is limited possibility of an increase in the supply of fresh water due to competing demands of increasing populations throughout the world; also, water-related problems are expected to increase further due to climate changes and due to population growth over the next two decades. It is estimated that worldwide population will increase by about 2.9 billion people between now and 2050 (according to UN's average projections). Shortage of fresh water supply is also a result of the exploitation of water resources for domestic, industry, and irrigation purposes in many parts of the world. The pressure on freshwater resources due to the increasing world's demand of food, energy, and so forth is increasing more and more due to population growth and threats of climate change. Polluting surface/ground water sources is another cause of reduced fresh water supplies. Aquifers around the world are depleting and being polluted due to multiple problems of saltwater intrusion, soil erosion, inadequate sanitation, contamination of ground/surface waters by algal blooms, detergents, fertilizers, pesticides, chemicals, heavy metals, and so forth.

The occurrence of new/emerging micro contaminants (e.g., endocrine disrupting compounds (EDCs)) in polluted water/wastewater has rendered existing conventional water/wastewater treatment plants ineffective to meet the environmental standards. The discharge of these compounds into the aquatic environment has affected all living organisms. The traditional materials and treatment technologies like activated carbon, oxidation, activated sludge, Nano filtration (NF), and reverse osmosis (RO) membranes are not effective to treat complex and complicated polluted waters comprising pharmaceuticals, personal care products, surfactants, various industrial additives, and numerous chemicals purported. The conventional water treatment processes are not able to address adequately the removal of a wide spectrum of toxic chemicals and pathogenic microorganisms in raw water.

This is the right time to address water problems since aquifers around the world are depleting due to multiple factors such as saltwater intrusion and contamination from surface waters. Using better purification technologies can reduce problems of water shortages, health, energy, and climate change. A considerable saving of potable water can be achieved through reuse of wastewater which, in turn, requires the development materials and methods which are efficient, cost-effective, and reliable. Although dilution of complex wastewater effluents can help decreasing the load of micropollutants downstream, however, much of them pass through conventional water treatment due to occurrence of these substances in micro- or even in nanograms per liter.

Biological treatment systems such as activated sludge and biological trickling filters are unable to remove a wide range of emerging contaminants and most of these compounds remain soluble in the effluent. Physicochemical treatments such as coagulation, flocculation, or lime softening proved to be ineffective for removing different EDCs and pharmaceutical compounds in various studies. Chlorination, though providing residual protection against regrowth of bacteria and pathogens, results in undesirable tastes and odors in addition to the forming of different disinfection by-products (DBPs) in portable drinking water. Ozonation has been considered to be

a less attractive alternative due to expensive costs and short lifetime. Both ultraviolet (UV) photolysis and ion exchange, though being advanced type of treatments, are not feasible alternatives for micro pollutants removal.

Membrane processes like microfiltration, ultrafiltration, NF, and RO, which are pressure-driven filtration processes, are considered as some new highly effective processes. These are considered as alternative methods of removing huge amounts of organic micro pollutants. Water/wastewater treatment by membrane techniques is cost-effective and technically feasible and can be better alternatives for the traditional treatment systems since their high efficiency in removal of pollutants meets the high environmental standards.NF and RO have proved to be quite effective filtration technologies for removal of micro pollutants. RO is relatively more effective than NF but higher energy consumption in RO makes it less attractive than NF where removal of pollutants is caused by different mechanisms including convection, diffusion (sieving), and charge effects. Although NF based membrane processes are quite effective in removing huge loads of micro pollutants, advanced materials and treatment methods are required to treat newly emerging micro pollutants.

Since the water industry is required to produce drinking water of high quality, there is a clear need for the development of cost-effective and stable materials and methods to address the challenges of providing the fresh water in adequate amounts. There are inventions of new treatment methods; however, they need to be stable, economical, and more effective as compared with the already existing techniques. For this, traditional treatment technologies have to be modernized, that is, updated or modified or replaced by developing materials and methods which are efficient, cost-effective, and reliable. This is particularly important to achieve a considerable potable water savings through reuse of wastewater in addition to tackling the day-by-day worsening quality of drinking water.

EMERGING CONTAMINANTS

Emerging contaminants refer to the materials or chemicals in the water, air, soil, or river sediments at relatively low concentration. The contaminants are perceived as actual or potential threat to any living organisms and the environment. They are referred as emerging contaminants because new technologies can easily detect them and they also have a new portal of entry into human beings and the environment. According to Richardson and Ternes (2005), emerging contaminants can be classified as either pharmaceuticals and personal care products (PPCPs), or chemicals that disrupt the endocrine functioning (EDCs), or Nanomaterial. They could also be classified as contaminants of emerging concerns (CECs), persistent organic pollutants (POPs), and Organic wastewater contaminants (OWCs).

Endocrine disrupting compounds (EDCs) interfere with the normal functioning of the endocrine systems of the mammals. The disruption results in conditions such as cancer, birth defects, and developmental disorders. Endocrine disruptors stimulate cell mutation that results in the formation of cancerous cells. The effects will present in forms of learning disabilities, attention deficit hyperactive disorders, and deformities of body parts such as the limbs. Exposing animals to low level of the EDCs causes similar effects as those seen in the human beings. Organisms are exposed to the EDCs when they consume food products containing the compounds. Xenoesstrogens, alkyl phenols, and bisphenol-A are some of the examples of the endocrine disrupting compounds (Richardson and Ternes, 2005). Persistent organic pollutants are organic compounds considered non-biodegradable through the action of biological, photolytic, and or chemical processes. These pollutants persist in the environment and accumulate in the animal and human tissues, thereby, posing a significant threat to the human and animal health. Most of the POPs were used in the past as pesticides. Persistent organic pollutants disrupt the endocrine functioning as the EDCs Richardson (2003). Pharmaceuticals, personal care products (PPCPs) and organic waste contaminants (OWCs) are active compounds that passed through human bodies and also transferred to drinking water and wastewater. These compounds are not removed by conventional treatment methods. They cause a significant environmental threat by promoting the emergence of bacteria resistant to antibiotics, which later combine with other chemicals in the environment resulting in the complex chains (Focazio et al, 2008). Nanomaterials are tiny particles which have significant threat to the environment. Their presence in the environment causes changes of the ecological balance as a result of the change in the hematologic functioning of the aquatic animals and its interaction with other pollutants. This change occurs due to the disturbance of the normal flora and the functioning of the living organisms because of the enhanced toxic effects of the organic compounds.

ASSESSING THE EMERGING CONTAMINANTS IN WASTEWATER AND DRINKING WATER

To Assess the impact of emerging contaminants in drinking water and wastewater it is necessary to identify the source of the contaminant and the seriousness of its effects to the environment. The purpose of this assessment is to determine the amount of contaminants released to the environment and to adopt approaches that aim at minimizing the release and effects of the emerging contaminants. Petrović et al., (2003) stated that risk assessment of the emerging contaminants is very important because it helps in the formulation of goals that assist in protection of the environment. Assessment enables the involved parties to be able to determine the effectiveness of the planned goals. This is important because it will reduce the impacts of the emerging contaminants in the environment. Successful assessment of the emerging contaminants involves evaluating the occurrence of the emerging contaminant, evaluating the exposure of the contaminant and compliance choices for the regulatory alternatives. Furthermore, it requires the assessment of the alternatives available to prevent and reduce occurrences of emergence of contaminants. To facilitate the success of the assessment process it is advised to use epidemiological studies.

REMOVAL OF EMERGING CONTAMINANTS IN DRINKING WATER AND WASTEWATER

According to Mitch et al. (2003), there are various methods of treating water and wastewater alongside removing the emerging contaminants. These techniques include advanced oxidation processes (AOPs), adsorption, Reverse Osmosis (RO), and Nano-filtration (NF). In another study carried out by the US Environmental Protection Agency (EPA), treatment such as reverse osmosis, ozonation, ultrafiltration, ultraviolet disinfection, activated sludge, fixed film biological treatment and biological phosphorus removal among others were reviewed. From this study, data shows that high removal efficiencies were recorded using ozonation process especially for contaminants like Naproxen, Trimethoprim, and Estradiol with removal efficiencies of more than 95%. Reverse osmosis was also performed on the same wastewater with removal efficiency of 100% on contaminants such as Meprobamate, Naproxen, Triclosan. Ultrafiltration and ultraviolet disinfection were also used to treat wastewater the removal efficiencies vary from 69 to 99% while for the ultraviolet infection low removal efficiencies were recorded ranging from 0.85 to 63 %. In the same study drinking water was treated using methods such as chlorine disinfection, granular activated carbon, ozonation and ultraviolet disinfection. Removals efficiencies vary from 5.3 to 99% for contaminants such as polynuclear aromatic hydrocarbons (PAH), PPCP, pesticides, steroids and hormones (SH).

Despite the high removal efficiency recorded for the removal of emerging contaminants using these methods most organizations are still faced with challenges due to the high investment and maintenance costs associated with the methods. Also, the complicated procedure involved in the treatment of emerging contaminants and the massive production of toxic wastes constitute additional challenges associated with the efficiency and implementation of these methods. According to Peabody et al., (2006) physico-chemical treatments are considered effective in the removal of contaminants, except for the removal of endocrine disrupting compounds and pharmaceuticals and personal care products. In another study using membrane filtration carried out by Comerton et al.,(2007), 22 endocrine disrupting and pharmaceutically active compounds were effectively removed through adsorption by ultrafiltration (UF) , nanofiltration (NF) and reverse osmosis(RO).

ROLE OF NANO-ADSORBENTS IN WATER/WASTE WATER TREATMENT

Nano-adsorbents are fast emerging as potent candidates for water/wastewater treatment in place of conventional technologies which, notwithstanding their efficacy, are often very expensive and time consuming (Amin *et al.,* 2014). This would be in particular, immensely beneficial for developing nations like India where cost of implementation of any new removal process could become an important criterion in determining its success. Qualitatively speaking nano-adsorbents can be substituted for conventional materials that require more raw materials, are more energy intensive to produce or are known to be environmentally harmful (Bhattacharya *et al.,* 2013). Employing green chemistry principles for the production of nano-adsorbents can lead to a great reduction in waste generation, less hazardous chemical syntheses, and an inherently safer chemistry in general. There is also a wide debate about the safety of nano-adsorbents and their potential impact on the environment. There is fervent hope that nanotechnology can play a significant role in providing clean water to the developing countries in an efficient, cheap and sustainable way (Gupta *et al.,* 2011).

MECHANISMS OF REMOVING POLLUTANTS FROM WASTEWATER BY NANO-ADSORBENTS

Two vital properties make nanoparticles highly lucrative as adsorbents. On a mass basis, they have much larger surface areas compared to macro particles. They can also be enhanced with various reactor groups to increase their chemical affinity towards target compounds. Many materials have properties dependent on size. Hematite particles with a diameter of 7 nm, for example, adsorbed Cu ions at lower pH values than particles of 25 or 88 nm diameter, indicating the enhanced surface reactivity for iron oxides particles with decreasing diameter.

Manna *et al.,* (2004) investigated the removal of As (III) using a synthesized crystalline hydrous titanium dioxide. They found that 70% of As (III) adsorption occurred within the first 30 minutes of contact time. Nano-agglomerates of mixed oxides such as iron-cerium, iron-manganese, iron-zirconium, iron-titanium, iron-chromium, cerium-manganese etc. have been synthesized and successfully employed for pollutant removal (i.e. arsenic, fluoride etc.) from aqueous solutions. Metals such as zinc and tin possess similar reduction capabilities of iron. Like iron, these metals are converted to metal oxides in the decontamination process. Other metals have been combined with iron as well to produce similar results. Both iron-nickel and iron-copper bimetallic particles have been demonstrated to degrade trichloro-ethane and trichloro-ethene. Bissen *et al.,* (2001) have showed that photo-oxidation of As (III) to As (V) occurs within minutes. No reverse reaction of As (V) to As (III) was observed, and while As (III) was oxidized by UV light in the absence of TiO_2, the reaction was way too slow to be feasible in water treatment.

Carbon is a versatile adsorbent that is heavily used in the removal of various pollutants including heavy metals from aqueous solutions. Graphene is the latest member of the carbon family in research and is believed to be one of the most potential materials for water treatment. Graphene is a flat, sp2-hybridized, two-dimensional honeycomb arrangement of carbon atoms with single carbon atom thickness. Features like large surface area and presence of surface functional groups make them attractive adsorbent candidates for water purification (Sreeprasad *et al.,* 2011). RGO-magnetite and GO-ferric hydroxide composites were used for the removal of arsenic from water (Chandra *et al.,* 2010). Iron based oxides and hydroxides are already proved as effective materials for removing arsenic from drinking water. Interestingly, reduced graphene oxide also has antibacterial property and this property may help in preventing the development of biofilm on the filter surface due to bacterial growth, which can cause unwanted tastes and odors or prematurely clogging of filters.

While nanotechnology is considered to be the new buzzword by many in the scientific community, information regarding the subject remains largely dispersed and fragmented due to the relative novelty of the technology. But the increasing trends of researches which have been discussed so far have made it clear that nanotechnology holds an immense potential to be developed into a very potent water treatment tool of the 21st century. In fact nanomaterials and their various incarnations are the drivers for the nanotechnology revolution. On a positive note, due to their extremely high potential in combination with the high specificity, nano-adsorbents can be developed into ideal candidates for water treatment and may contribute to solving future challenges in the area of water treatment technologies. Thus nanotechnology holds a lot of promise in the remediation of groundwater and for this there is further scope in research and development.

POLLUTANTS REMOVAL USING DIFFERENT NANOMATERIALS

Disinfection- Biological contaminants can be classified into three categories, namely, microorganisms, natural organicmatter (NOM), and biological toxins. Microbial contaminants include human pathogens and free living microbes. The removal of cyanobacterial toxins is an issue in conventional water treatment systems. Many adsorbents including activated carbon have reasonably good removal efficiencies and again a number of factors influence the removal process.

Contamination from bacteria, protozoans, and viruses is possible in both ground and surface water. The toxicity of the standard chlorine chemical disinfection in addition to the carcinogenic and very harmful by-products formation is already mentioned. Chlorine dioxide is expensive and results in the production of hazardous substances like chlorite and chlorate in manufacturing process. Ozone, on the other hand, has no residual effects but produces unknown organic reaction products. For UV disinfection, longer exposure time is required for effectiveness and also there is no residual effect. Despite advances in disinfection technology, outbreaks from waterborne infections are still occurring. So, advanced disinfection technologies must, at least, eliminate the emerging pathogens, in addition to their suitability for large-scale adoption. There are many different types of nanomaterial's such as Ag, titanium, and zinc capable of disinfecting waterborne disease-causing microbes. Due to their charge capacity, they possess antibacterial properties. TiO_2 photo catalysts and metallic and metal-oxide nanoparticles are among the most promising nanomaterials with antimicrobial properties.

Desalination- Desalination is considered an important alternative for obtaining fresh water source. Though expensive, membrane based desalination processes cover most of the desalination capability out of which only RO accounts for 41%. Parameters that control the desalination cost include maximizing the flux of water through membrane to minimize the fouling. Recent developments in membrane technology have resulted in energy efficiency in RO plants. NF has also been evaluated for desalinating seawater.

Nanomaterials are very useful in developing more efficient and cheaper nanostructured and reactive membranes for water/wastewater treatment and desalination such as CNT filters. Nanomaterials offer opportunities to control the cost of desalination and increase its energy efficiency and among these are CNTs, zeolites, and graphene. The controlled synthesis of both the length and diameters of CNTs has enabled themto be used in RO membranes to achieve high water fluxes.

Thin film Nano composite membranes containing Ag and TiO2 nanoparticles exhibited good salt rejection. Membrane permeability and salt rejection are shown to be effected by the number of coatings in TiO2/Al2O3 (aluminiumoxide) composite ceramic membranes coated by iron oxide nanoparticles (Fe2O3). A high sodium chloride rejection was obtained by using alumina ceramic membranes fabricated with silica nanoparticles. Zeolitebased membranes for RO have exhibited high flux with excellent ion rejection characteristics. Studies also have indicated the potential of graphene membranes for water desalination with higher fluxes than polymeric RO membranes.

Removal of Heavy Metals and Ions- Different types of nanomaterials have been introduced for removal of heavy metals from water/wastewater such as Nano sorbents including CNTs, zeolites, and dendrimers and they have exceptional adsorption properties. The ability of CNTs to adsorb heavy metals is reviewed by many researchers such as Cd2+, Cr3+, Pb2+, and Zn2+ and metalloids such as arsenic (As) compounds. Composites of CNTs with Fe and cerium oxide (CeO2) have also been reported to remove heavy metal ions in few studies.

Cerium oxide nanoparticles supported on CNTs are used effectively to adsorb arsenic. Fast adsorption kinetics of CNTs is mainly due to the highly accessible adsorption sites and the short intraparticle diffusion distance. Metal based nanomaterials proved to be better in removing heavy metals than activated carbon, for example, adsorption of arsenic by using TiO2 nanoparticles and nanosized magnetite. The utilization of photo catalysts such as TiO2 nanoparticles has been investigated in detail to reduce toxic metal ions in water. In a study, the effectiveness of nanocrystalline TiO2 in removing different forms of arsenic is elaborated and it has shown to be more effective photocatalyst than commercially available TiO2 nanoparticles with a maximum removal efficiency of arsenic at about neutral pH value. A Nano composite of TiO2 nanoparticles anchored on graphene sheet was also used to reduce Cr(VI) to Cr(III) in sunlight.

Removal of Organic Contaminants- NOM constitutes a diverse group of hydrophobic (humic and fulvic acids) and hydrophilic organic compounds and it contributes significantly towards water contamination. A variety of carbon-based adsorbents have been used for the removal of NOM from raw water and several factors affect this sorption of NOM.

CONCLUSION

Emerging pollutants were previously not listed as a cause for concern, therefore water treatment plants were not (purposely) designed to remove them. This in turn has allowed for emerging pollutants to access our water systems leading them to enter freshwater and drinking water systems. Contaminants of drinking water and wastewater have numerous risks to the environment. The effects of the contaminants range from developmental, growth, and reproductive effects. The causes of these effects can be identified. Adopting the most effective strategies will contribute to the reduction of the incidences of adverse environmental effects brought by drinking water and wastewater contaminants. Therefore, it is highly recommended that interventions aiming at determining the source of contamination and responding to the challenges should be adopted to ensure environmental safety and sustainability. The removal of all the aforementioned “emerging contaminants” through the “wastewater” and the treatment of the drinking water is not as satisfactory as it should be. The improved treatment and the control of this treatment procedure have to be completely noticed so that the elimination of such micro contaminants becomes as high as it could be. Easily available absorbents are being used for the treatment of wastewater that contains pollutants.

Safe water has become a competitive resource in many parts of the world due to increasing population, prolonged droughts, climate change, and so forth. Nanomaterials have unique characteristics, for example, large surface areas, size, shape, and dimensions, that make them particularly attractive for water/wastewater treatment applications such as disinfection, adsorption, and membrane separations. Surface modifications of different nanomaterials like nanoscale TiO2, nZVI by coupling with a second catalytic metal can result in enhanced water/wastewater quality when applied for this purpose by increasing the selectivity and reactivity of the selected materials. Surface modification may lead to the enhanced photo catalytic activity of the selected compounds due to the short lifetime of reactive oxygen species and increase the affinity of modified nanomaterials towards many emerging water contaminants. Bimetallic nanoparticles have also proved effective for remediation of water contaminants. However, further studies are required for understanding the mechanism of degradation on bimetallic nanoparticles responsible for the improved efficiency. For real field applications, however, an improved understanding of the process mechanism is very important for the successful applications of innovative Nano composites for water/wastewater treatment.

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