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Nanotechnology for Clean and Safe Water: (A Review)

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ABSTRACT

The demand for clean and safe water together with increasingly strict environmental regulations in both developed and developing countries has necessitated the need for a highly efficient yet low-cost water treatment technology to prevent the negative effects of pollutants on the human health and the environment. Nanotechnology holds great potential as a novel and promising field in water treatment. This review presents the recent development in nanotechnology for water and wastewater treatment. The review includes discussion on the nanomaterials- its properties and mechanism that allows its use in the remediation of pollutants in both water and waste water.

Keywords: Nanotechnology, Nanomaterials, Water quality, Waste water, Remediation.

INTRODUCTION

The Philippines is endowed with abundant source of freshwater with about 479 billion m^3 of it can be obtained from ground water and surface water sources[1]. Fresh water supply, which can be obtained from different sources such as river, lakes, reservoirs, and groundwater sources, is continuously replenished by rainfall and assures an adequate amount intended for agricultural, industrial and domestic use[2]. Nowadays, the country's water resources are experiencing major problems due to increased demand brought upon by rapid population growth; high usage intended for food production, urbanization and the worst, water pollution[1]. Water pollution has greatly altered the water quality thus affecting the livelihood of the people depending on it. Water discharges or spills from different sources such as domestic source, solid waste landfills, industrial source (pharmaceutical waste, mining) and agricultural runoff may contain different entities like solid wastes, nutrients, heavy metals, pesticides, fertilizers, and pharmaceuticals which contributes to worsening of water quality[3].

To ensure that the future generation will still avail of fresh, clean and adequate supply of fresh water, water resources must be protected by conducting regular water quality monitoring, effective provisions of prevailing water supplies and through development and upgrade of catchment areas such as dams, rivers, and lakes and most importantly watershed protection[1].

Presence of microcontaminants such as PAH, PCB and endocrine disrupting compounds

(EDC), heavy metals and dyes in polluted waters and wastewater has brought scrutiny to the current water and wastewater treatment plants[4]. There have been great concerns on the proliferation of antibiotic wastes in the water. Studies show that residual antibiotics in environment can induce the antibiotic resistance of microorganisms. Even at low amounts, these pharmaceutical wastes can pose serious environment and health threats when released in aqueous systems[5,6]. Organochlorine compounds from pesticides, on the other hand, have adverse effects on children and pregnant women and tends to accumulate in the lipids over time due to slow degradation[7].

Rising demand for clean and fresh water, growing pressure on the use of unconventional water resources (e.g. storm water, polluted water, waste water and seawater) in water-stressed regions, together with increasingly strict environmental regulations in both developed and developing countries have brought challenges to the existing infrastructure for the treatment of water and waste water[8-11] Current water treatment technology like flocculation, oxidation, coagulation, membrane separation, ion exchange, electroprecipitation, evaporation and floatation are no longer sustainable, not capable to address the complete removal of complex impurities and entails high price[4,9,11-13]. Hence, an urgent requisite for an effective yet low cost water treatment technology to prevent the negative effects on human health and the environment is necessary[9,11,14,15]. Nanomaterials have become the center of attention in recent years as a novel and promising field in water treatment[4,12].

According to National Nanotechnology Initiative[16], nanotechnology is "*the understanding and control of matter at dimensions of roughly 1 to 100 nanometers, where unique phenomena enable novel applications*." Nanomaterials are structures with dimensions lesser than 100 nm wherein novel application can be derived owing to its size-dependent properties. Owing to its very, very small particle size, nanomaterials possesses unique physical and chemical characteristics and properties that is very useful in water and waste water treatment[8,11,17,18]. Well-defined characteristics of nanomaterials which includes the size, surface area, surface charge, surface chemical composition and solubility are often investigated in environmental studies[4,8,11,19]. Recent developments in the field of nanotechnology have provided opportunities on the exploration of cutting-edge water treatment technology. Nanomaterials like cellulose and chitosan nanoparticles have become a material of choice in the manufacture of membrane and adsorbents[13]. On the other hand, silver nanoparticle (AgNP)-alginate composite beads were utilized as materials in packed columns for the simultaneous filtration-disinfection of drinking water[20]. The use of nanomaterials could overcome the challenges experienced by current treatment methods and could significantly save resources by cutting the production of waste product and consumption of nonrenewable resources[8,21].

Nanomaterials in Membrane Technology

Membrane water treatment has become an important development in water treatment technologies. A membrane is defined as the interphase between two phases acting as a selective barrier. The use of nanomaterials in the manufacture of next generation water filtration membrane has become promising owing to its inherent fibrous nature, outstanding mechanical properties, low operation cost, biocompatibility, sustainable source and compliance with environmental regulations[19,22,23]. Membrane technology, nowadays, is currently focused on the addition of inorganic and organic nanomaterials such as 2D-montmorillonite[24], zeolites[25,26], silica[27], cellulose[28], carbon nanotubes with thin film of nanosilver (AgNP) particles[22], graphene oxide[29,30], graphene oxide with silver nanoparticles (GO-AgNP)[31,32], polyethersulfone (PES) and self-produced polyaniline/iron(II, III) oxide ($PANI/Fe_3O_4$) nanoparticles[33], polyvinylchloride-blend-cellulose acetate/iron oxide nanoparticles[34], polyvinylchloride with zinc oxide (ZnO) nanoparticles[35], polyvinylchloride with TiO_2 nanoparticles[36], carbon nanotubes (MWCNTs) coated by zinc oxide nanoparticle (ZnO NP)[37], polysulfone (PSf)-based membranes modified with inorganic hydrous aluminum oxide (HAO) nanoparticles[38], nano-sized ZrO_2[39], to increase membrane selectivity and permeability, improve flux and antibacterial activity, improved mechanical or thermal stability, porosity and hydrophilicity, remove oil in water solution, removal of some heavy metals and reduce the incidence of biofouling. Surface modification is also considered in order to address some limitation on the use of other polymer as material for membrane modification such in the case of thin-film nanocomposite (TFN) membrane

described in the study of Valamohammadi *et al.,*[40]. TFN membrane was fabricated by assembling hyperbranched polyethyleneimine (HPEI) followed by cross-linking using glutaraldehyde onto hydrolyzed polyacrylonitrile (PAN) support layer containing MWCNTs or GO to obtain a positively charged membrane with improved water permeability.

To achieve stable fluxes, the pore size, nature and availability of the functional groups in nanomaterials acting as adsorption sites must be determined. Removal of contaminants by nanomaterial is possible owing to the high permeability, relatively small size and very active surface. However very small pore size is not suitable for a nanomaterial since it requires higher pressure to allow permeation. The pore size must be suitable for the purpose of the separation since economic efficiency is also taken into consideration when choosing the right material for the membrane[9,28,41]. Several studies on the research and development of membrane technology for water and waste water treatment were conducted which prove the efficiency of performance of nanomaterials.

Zeolithic imidazolate framework-8-based thin film nanocomposite (ZIF-8 TFN) membrane, which is highly permeable to water and exhibited resistance to swelling, was developed by Beh and coworkers[26] for forward osmosis treatment of high salinity oil emulsion wastewater. The fabricated TNF membrane exhibited significantly improved pure H_2O permeability upon the addition of poly(sodium 4-styrenesulfonate) (PSS) coating onto the ZIF-8 particle surface. Furthermore, addition of triethanolamine (TEA) as acid acceptor during interfacial polymerization resulted to an increase in pure water permeability with minimum loss in NaCl rejection.

An electroneutral nanofiltration (NF) thin film composite (TFC) for the removal and purification of dyes was fabricated by the team of Soyekwo[42]. The composite membrane is developed by depositing a layer of Zn cations in a layer within the crosslinked polyvinyl alcohol-polyethyleneimine onto the layer of polydopamine -wrapped carbon nanotubes. The fabricated membrane exhibited electroneutrality over a pH of 5.0 to 8.6 and possessed outstanding rejection of dyes such as congo red, bromothymol blue, and direct yellow dye. Due to the high almost neutral surface of the fabricated membrane, low salt retention was observed with moderately high-water flux at 5 bars. It was noted that the presence of NaCl and Na_2SO_4 at low concentration does not hinder the rejection of congo red even up to 20 h of filtration which indicates it suitability for dye desalination.

Using phase-inversion process, a polysulfone/polyhedral oligomeric silsesquioxanes (PSF/POSS) nanocomposite ultrafiltration membrane was developed by the group of Koutahzadeh[43]. Incorporation of POSS nanoparticles onto the PSF membrane ensued the creation of more pores on the top layer and causing an increase in the hydrophilicity and negative electrical surface charge. This ensures that the fabricated membrane has higher flux, and enhanced antifouling and rejection properties.

An ultrasmooth TFN nanofiltration membrane (NF) was prepared by Zhang and co-workers[44] using conventional interfacial polymerization with low concentration of piperazine and trimesoyl chloride on the polysulfone support membrane surface. The interlayer support membrane was made of PVA-modified GO followed by glutaraldehyde crosslinking and helps to convey a more orderly TFN NF membrane. The interlayer also ensures that the engineered membrane possess a high water permeance, high Na_2SO_4 rejection and excellent high separation factor of Na_2SO_4 to NaCl, enhanced fouling and chlorine resistance. The prepared TFN NF membrane exhibits better characteristics than TFC NF membrane in terms of fouling resistance and separation performance.

An ultrathin nanocomposite membrane was developed by the team of Seyedpour *et al.,*[45] with an end goal of efficient removal of Mn and Fe from ground water. The ultrathin nanocomposite membrane was prepared through dip coating method composed of chitosan (CS) incorporated GO on the surface of polyethersulfone (PES) surface, followed by crosslinking with sodium tripolyphosphate (TPP). Integration of GO nanosheets efficiently enhanced the surface and transport properties of the CS/GO NC membranes, as well as the membrane's water flux. As compared with chitosan NC membrane, the prepared CS/GO NC membrane showed high Fe and Mn removal. Antibacterial assessment of the CS/GO NC membrane revealed that less bacterial attachment

to the membrane surface was noted, enabling the formation of biofilm which may cause fouling. Less flux decline was also observed for the CS/GO NC membrane as compared to pure CS NC.

Nanomaterials for the Remediation of Heavy Metals and Radioactive Nuclides in Water and Waste Water

Heavy metals, such as V,Cr,Co,Ni,Mo,Ag, Cd,Pb, have found their way into the environment as a result of anthropogenic activity such as mining, smelting, petroleum distillate spillage and as leachates from different source like landfills, waste dumps, and many industries. Its toxicity varies and depends on different factors such as the nature and biological role of the metal, the exposed organism and the length or duration of exposure. They can enter the human body by inhalation, ingestion, and through skin contact and can pose a threat not only in humans but also in the environment. Once ingested, heavy metals may interfere normal metabolic processes which may result in cancer, organ damage, and on more serious cases, death[3,46]. Radioactive materials, usually produced as a by-product of nuclear generation or nuclear applications, are considered to be hazardous to all organisms and to the environment due to high quantity of radionuclides which are highly transferable, highly soluble and have long half-lives[47,48]. Radioiodine, I-131, a fission product during U and Pu processing, is hazardous as it may be absorbed in the food and may accumulate in the thyroid further destroying it. Thus, complete removal of I-131 is deemed important[49].

Adsorption is the most commonly used process in the removal of contaminants in water and waste water treatment. The high surface area and surface to volume ratio enables nanomaterials to be often used as adsorbing materials than its conventional counterparts. Due to its tunable pore size and surface chemistry, large surface area, and short intraparticle diffusion distance, adsorption of different chemical species in the active sites is attainable. Owing to its outstanding characteristics, nanoparticles are the new alternative choice in water and waste water treatment[8,9].

Various type of materials has been utilized for the remediation of heavy metals and radionuclides from water and waste water such as activated carbon, zeolites, clay and others. However, inorganic and metal-based nanomaterials are demonstrated to be better in the removal of heavy metals than activated carbon[4]. They were also observed to exhibit some drawbacks such as slow adsorption kinetics, low chemical, thermal or radiation stability and low adsorption yield[47]. Metal based nanomaterials are proven to be advantageous in terms of efficiency and have shown to be a promising alternative than conventional materials because of its high adsorption capacity, cost effectiveness, and simple separation and regeneration[8]. Attallah and coworkers[49] utilized iron oxide nanofiber as adsorption material for the removal of I-131 and Cr(VI) from liquid waste. Adsorption capacity of the synthetic hematite nanofibers (SH1) was 5.98 mg/g at pH1 which contributed to 72.4% and 90% removal of I-131 and Cr(VI), respectively. Utilization of biopolymers such as cellulose, chitin, and chitosan were investigated by Pospêchová *et al.,*[48] to be further utilized for the removal of toxic radionuclides namely ^{60}Co, ^{85}Sr, ^{137}Cs, and $^{152+154}Eu$. Being cost-effective and abundant, the aforementioned biopolymers were surface modified with Ti and Ni to improve its performance and adsorption ability. Result showed that the uptake of radionuclides were fast and pH dependent with the highest maximum adsorption capacity was noted in Ti-modified chitosan (11.83 mg/g). Novel polyfunctional nanocomposite hydrogel (NCHG) based on magnetic composite nanoparticles (MCNP) were developed by the team of Ghazy[50] for the removal of metal ions Co^{2+},Cs^{+}, and Sr^{2+} in simulated radioactive wastewater. The MCNPs were fabricated by the encapsulation of magnetite in a mini emulsion created from polystyrene-co-polymethacrylic acid. The polymerization of co (sodium styrene sulfonate-acrylic acid) utilized MCNPs as crosslinker in the presence of polyacrylamide and gamma (γ) radiation as initiator. Result revealed that the adsorption process in NCHG was endothermic chemisorption.

Some studies on the use of nanomaterial for the removal of heavy and radioactive metals in water and waste water were presented in Table 1.

Table 1: Organic and Metal-based Nanomaterials for the Removal of Some Heavy and Radioactive Metals

Nanomaterial Composition	Adsorption capacity, (mg/g)/Removal (%)	Target Metal	Reference
Graphene oxide/chitosan membrane	99% removal	Fe	
	85% removal	Cr(VI)	(45)
Iron oxide nanofibers	6 mg/g	Cr(VI)	(49)
	27 mg/g	^{131}I	
Novel polyfunctional	53.37 mg/g	Cs^{+}	
nanocomposite	80.69 mg/g	Co^{2+}	
hydrogel (NCHG)	65.35 mg/g	Sr^{2+}	(50)
Nanoscale zero-valent iron particles modified on reduced graphene oxides	425.72 mg/g	Cd(II)	(52)
Nanoscaled zero valent iron/graphene (0FG) composite	65.58 to 134.27 mg/g	Co(II)	(53)
Magnetic nanoparticle adsorbents (Mag-PCMA-T)	2250 mg/kg	Cd(II)	(54)
Fe_3O_4 sulfonated magnetic nanoparticle (Fe_3O_4-SO_3H MNP)	108. 93 mg/g Cd (II)	Cd(II)	(55)
	80.9 mg/g Pb (II)	Pb(II)	
EDTA functionalized Fe_3O_4 nanoparticles	71–169 mg/g	Ag(I), Hg(II),Mn(II), Zn(II), Pb(II),Cd(II)	(56)
Cysteine functionalized Fe_3O_4 magnetic nanoparticles (Cys-Fe_3O_4MNPs)	380 mg/mol	Hg(II)	
Fe_2O_3 NP-Alginate	564 mg/g	Cd(II)	(58)
	158 mg/g	Pb(II)	
	102.2 mg/g	Cu(II)	
		Cr(VI)	
Red mud carbon nanotubes (RMCNT)	193.8 mg/g	Cu(II)	(59)
SnO_2/MWCNT	> 90% removal		(60)
SiO_2@Tea waste nanocomposites	153 mg/g	Pb (II)	(61)
	222 mg/g	Cd (II)	
Zn/Al/gallate layered double hydroxide/ polystyrene nanofibers (Zn/Al/GA LDH/ PSNFs)	190 mg/g	Cu (II)	(62)
Silica-coated amino functionalized magnetic nanoparticles with *Cynodon dactylon* and *Muraya koenigii* extracts	78.24 mg/g	Zn (II)	(63)
	81.76 mg/g	Cu (II)	
SnO_2 nanoparticles	100% removal	Cd	
	99.95% removal	Co	(64)
UiO-66 and UiO-66-NH_2	76.93%	Cr	(65)
	93.73%	Mn	
	88.81%	Fe	
	83.30%	Ni	
	86.11%	As	
Fe_3O_4@SiO_2@graphene quantum dot	68 mg/g	Hg (II)	(66)

Metal-based nanomaterials, due to its large surface areas and high activities caused by the size quantization effects, were considered significantly for the pollutant reduction in many aqueous systems. Zero-valent iron (ZVI or Fe^0) is also becoming popular as a reactive constituent in permeable reactive barrier and chemical reductant for environmental applications. Due to its miniscule size and greater surface area to volume ratio, significant improvement in reactivity and reaction efficacy were achieved[10,14,11,67]. Metal oxide nanoparticles have high affinity to heavy metals sorption which is favorable in its removal in contaminated waters. However, the stability of metal nanoparticles decreases as size is reduced due to increased surface energy and agglomeration of particles when introduced in water flow through systems. To overcome this dilemma, hybrid adsorbents were made by impregnation to porous supports such as carbon nanotubes[68], silica[54], graphene[53,69], reduced graphene oxides[52,67], reduced graphite oxide[51], magnetic substrate[55,56,57,70,71] and synthetic polymer[33,34]. They impart mechanical and thermal strength and possesses tunable porous characteristics and chemically bounded functional

groups[9,11]. Carbon nanotubes (CNTs) and graphene oxides are making waves as it exhibits high removal efficiency for major polluting heavy metals[53,68,69,70].

Nanomaterials for the Remediation of Organic Pollutants in Water and Waste Water

The textiles industry was cited as one of the major contributors to water pollution. Untreated effluents are mostly discharged onto the water system and contained significantly high levels of biochemical oxygen demand (BOD), chemical oxygen demand (COD) and most especially, organic dyes. Dyes are water soluble organic compounds which imparts color to a given substrate due to chromophoric groups in its molecular structure. They possess high water solubility which renders it difficult to remove by just any conventional methods. Ingestion of dyes is dangerous because it is highly toxic, mutagenic and carcinogenic[72].

Pesticides present in water and waste water has always been a great concern due to its persistence in the environment, inherent toxicity, difficulty to degrade and ability to be bioaccumulated, bioconcentrated and biomagnified[7,73,74]. Chronic exposure to herbicides such as atrazine, and oxyfluorfen causes serious physiological problems such as cardiovascular problems, irreversible cell damage, and cancer while azoxystrobin, a broad-spectrum fungicide, is reported to be highly toxic to aquatic organisms. Therefore, complete removal of pesticides from water and waste water is necessitous even so current treatment strategies present limitations not only on the cost but also on the efficiency, reliability, environmental impact and others[75]. A study conducted on the drinking water from Behbahan City, Iran revealed high concentration of organophosphate pesticides (0.87 to 3.229 ug/L) and 1,3-dichloropropene (3.586 ug/L) in raw water. Due to the hydrophobic nature of most pesticides and the use of granular activated carbon treatment, the level of pesticides has been decreased to acceptable amount with the major removal occurred in coagulation-flocculation and rapid sand filtration units[74]. Among the waste water techniques for pesticides removal reviewed by Saleh *et al.,*[75] adsorption presents many advantages including low cost and high efficiency. Comparative analysis of different treatment methods revealed that for methyl parathion, adsorption is the most effective method for its removal while adsorption using wood charcoal and biochar is most effective for atrazine.

Waste water containing antibiotics and other pharmaceutical wastes such as tetracycline, acetaminophen and naproxen which are widely used in livestock farms to increase production, inhibit parasites and prevent disease, enter the water ways in a variety of routes such as in households, hospitals, and pharmaceutical industries. It was reported to induce and spread the increase of antibiotic resistance among the population[76,77]. A comprehensive study in the final effluent of waste water treatment plants in 7 European countries revealed that among the 53 antibiotics monitored, 17 antibiotic compounds were detected with macrolides and fluoroquinolines having the highest loads in all countries studied[78]. Thus, an effective removal of these pollutants from waste water must be ensured before discharging the effluent into the nature. Typically, a wastewater is treated by a variety of methods to address the removal of each pollutant such as electrodegradation, advanced oxidation, photocatalytic degradation, and adsorption. Among these, adsorption is the most popular due to its simplicity and effectiveness[15,79].

Nanomaterials and activated carbons are commonly used in the adsorption process due to its high surface area and active sites. However, activated carbon is outweighed by the use of nanomaterials due to its economic advantage as small amount of adsorbent is needed for adsorption and low cost operation for its synthesis[80]. Multi walled carbon nanotubes (MWCNTs) are added to improve to improve the mechanical properties and to increase the adsorption capacity. However, when compared with single walled carbon nanotubes (SWCNTs), the latter demonstrate better adsorption performance for organic compounds due to higher surface area[81]. 3-dimensional Graphene (3DG) when added as stabilizer in nano-zero valent iron (NVZI) prevents the aggregation of particles and increased the reaction activity with Orange IV than free iron nanoparticles[82]. NVZI are also utilized in the removal of many organochlorine pesticides, organic dyes and other inorganic pollutants. Common to adsorbent nanomaterials, the large specific surface area of NVZI and other nanoparticles provides more active sites for the adsorption and degradation of organic contaminants. It can be bonded with a stabilizer like polymer[5], activated carbon[80,83], graphene[84] and surfactant[85] to prevent particle aggregation due to

Van der Waals and magnetic forces[5]. Biopolymers like cellulose and chitosan were also being considered for the synthesis of composite material which can be incorporated with GO to produce a nanocomposite with improve surface roughness, swelling property and enhanced adsorptive capacity[86]. Similarly, due to its high efficiency owing to its large surface area, metal oxides nanoparticles (MONP) have been considered as adsorbent for waste water treatment[87]. Metal organic frameworks (MOF), due to its excellent adsorptive capacity, have been documented useful in pesticides removal. However, it was reported to pose environmental risks as MOF or its dissociated ions can accumulate in organisms, leading to heavy metal pollution which might harm the health of humans or other aquatic organisms[88]. Some Various factors such as pH, temperature, adsorbate concentration, adsorbent mass, and contact time must be considered to determine the maximum adsorption capacity and removal efficiency of the adsorbent. In addition, the adsorbent's reusability must also be studied and considered to determine the best nanomaterial needed for the removal of such pollutant[89,90]. Table 2 shows some studies on nanomaterials which is used to remove some organic pollutants in water and waste water.

Table 2: Nanomaterials for the Removal of Some Organic Pollutants in Water and Waste Water

Nanomaterial	Adsorption Capacity (mg/g)/ Removal (%)	Target Organic Pollutant	Reference
a.Organic Dyes			
PVA-PEI-Zn (II) TFC	> 99.7% removal	Bromothymol blue, Congo red Direct yellow dye	42
Zn/Al/gallate layered double hydroxide/ polystyrene nanofibers (Zn/Al/GA LDH/ PSNFs)	60.7 mg/g	Malachite Green	62
Magnetic graphene oxide (MGO)	64.23 mg/g 20.85 mg/g	Methylene blue Orange G	70
Zinc oxide nanoparticle loaded on activated carbon (ZnO-NP-AC)	322.58 mg/g for 0.005 g ZnO-NP-AC	Malachite Green	80
Three-dimensional graphene (3DG) on nanoscale zero-valent iron (nZVI) particles	94.5% removal	Orange IV azo dye	82
Pd, Ag and ZnO nanoparticles loaded on activated carbon (Pd-NP-AC, Ag-NP-AC and ZnO-NP-AC)	143 mg/g, 250 mg/g and 200 mg/g for Pd-NP-AC, Ag-NP-AC and ZnO-NR-AC, respectively.	Bromophenol Red	83
CMC/CH/GO nanocomposite	1.8975 mg/g 122.1 mg/g	Brilliant Green Methylene Blue	86
Pb-doped $ZnFe_2O_4$ nanocomposites	1042.86 mg/g	Congo Red	87
Graphene oxide-Ag nanocomposite	72 mg/g 143 mg/g	Ethyl Violet Malachite Green	89
PolyPyrrole/Prussian Red nanocomposite	94% degradation 91% degradation 80% degradation Not reported	Methylene Orange Methylene Blue Rhodamine B Rifampicin Levofloxacin Ampicillin	92
ZnO-SiO_2 nanocomposite	97.8% degradation	Methylene Blue	93
Magnetic hydroxyapatite nanocomposite	43.47 mg/g	Eriochrome Black-T	94
Magnetic Octaminopropyl silsesquioxane (POSS)-grafteD-RAFT agent (MPGR) nanocomposite	435 mg/g	Carmine Dye	95
b. Organic Pesticides			
UiO66-NH2@MPCA	227.3 mg/g	Chipton	88
ZIF-8@MPCA	110.4 mg/g	Alachlor	
UiO66-NH2@MPCA	73.53 mg/g	Chipton	
ZIF-8@MPCA	107.18 mg/g	Alachlor	
Fe3O4/graphene nanocomposite	93.61% 91.34% 88.55% 81.22% 75.24%	Ametryn Prometryn Simazine Simeton Atrazine	96

Chitosan functionalized AgNP	95% efficiency	Imidacloprid	97
f-MWCNTs/PVA nanocomposite film	< 95%	Diazinon	98
	< 99%	Chlorpyrifos	
	< 99%	Pirimiphos-methyl	
	< 99%	Malathion	
Mixed hemimicelle SDS-coated magnetic chitosan	16.58 mg/g	Diazinon	99
nanoparticles	15.53 mg/g	Phosalone	
	13.48 mg/g	Chlorpyrifos	
Fe_3O_4/Biochar nanocomposites	1.02 mg/g	Thiacloprid	100
	0.97 mg/g	Thiamethoxam	
Activated Biochar	0.73 mg/g	Thiacloprid	
	0.40 mg/g	Thiamethoxam	
c. Antibiotics			
$CoFe_2O_4$/rice husk silica nanocomposite	835.47 mg/g (CFS100)	Doxycycline hydrochloride	77
(CFS)	581.44 mg/g (CFS700)		
Zinc oxide coated carbon nanofiber	156 mg/g	Amoxicillin	79
Fe_3O_4/Graphene oxide citrus peel-derived magnetic	283.44 mg/g	Ciprofloxacin	101
bio-nanocomposite	502.37 mg/g	Sparfloxacin	
Iron oxide particles supported on mesoporous MCM-41	25 mg/g	Amoxicillin	102
$MnFe_2O_4$ nanoparticles embedded chitosan-diphenylureaformaldehyde resin (CDF@MF)	168.24 mg/g	Tetracycline	103
Biochar-based nanocomposite g-MoS_2	249.45 mg/g	Tetracycline hydrochloride	104
ZnO nanostructures with nano-cellulose	96.4% degradation efficiency	Tetracycline hydrochloride	105

CONCLUSION

Nanomaterials presents a novel alternative to conventional water and waste water treatment methods. Many nanomaterials are used in conjunction with conventional treatment method due to increased adsorption and substrate specificity. Due to its high porosity, relatively small size and very active surface, nanomaterials are able to remove contaminants of different composition such as dyes, heavy metals, pesticide residues, organic matter and other unwanted impurities in water. The use of nanomaterial presents several advantage including outstanding mechanical properties, low operation cost, biocompatibility and can be produced from sustainable source. Nanomaterials exhibits high capacity, appreciably fast kinetics of reaction, specificity towards contaminants and anti-bacterial activity. In the near future, it is seen that water treatment technology will soon utilize more nanomaterials with better performance than what we have today in the treatment of effluents and drinking water so as to meet increasingly strict environmental and health regulation.

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Conflicts of Interest

The author declares no conflict of interest.

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