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REVIEW

Impact of water pollution on flora, fauna and human health

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Abstract: Water has a broad impact on all aspects of human life including but not limited to health, food, energy, and economy. In addition to the environmental, economic, and social impacts of poor water supply and sanitation, the supply of fresh water is essential for the safety of children and the poor.

INTRODUCTION

Environment is a valuable gift of God to all animals whether living or non-living. The regular assets of the earth including air, water, land, flora and fauna agent tests of biological systems must be defended to assist the present and future generations through careful planning and management (Mara, 2003). Water is a fluid of life, as there can be no existence without water. Unadulterated water is an animating liquid while polluted water is a genuine revile for living creatures. Accordingly, causes and effect of water contamination and its unfriendly consequences for wellbeing of individuals will be investigated. Man during course of his development has settled in spots where a lot of water was accessible. Be that as it may, with the expansion of population and in misuse of regular assets for his very own advantage, he has carried on in a wild way by making issues of pollution hazardous not exclusively to oceanic life yet in addition to his very own life. While western nations have turned out to be very touchy to this issue, India is as yet proceeding with, in view of unreliable conduct of its residents, in rendering water increasingly contaminated step by step and the circumstance is breaking down progressively (Moore, 2003). The water assets on the earth are exhausting quick. Out of a few parts of condition, water, being customarily the most advantageous container for the general public in India, has been dirtied to the limit. The water assets are constrained yet the ambush as contaminations is a continuous procedure. Around 70 percent of all accessible water in India is dreaded dirtied. This situation is truly alarming (Johnson et al 2008). Without contamination controls, water would turn out to be horribly dirtied and unusable for a wide scope of human and non human needs (Montgomery and Elimelech, 2007). The issue of water assets isn't less earnest than that of different kinds of pollution (Theron and Cloete,

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2002). "It isn't an issue of an individual or a country however is an issue which 'no country, no landmass, no half of the globe, no race, no framework can deal with alone'. It is an issue of whole human race which requires joint action" (Eshelby, 2007). A sufficient supply of safe drinking water is one of the major pre-imperatives for a solid life. The significance of clean water and connection between debased or rotten water and ailment was perceived in the inaccessible past, despite the fact that the genuine instance of illness was not legitimately comprehended until the last 50% of the nineteenth century (Leonard et al., 2003). During late years there has been expanding familiarity with, and worry about, water contamination everywhere throughout the world, and new methodologies towards accomplishing supportable misuse of water assets have been created internationally (Ashbol, 2004). Water has a broad impact on all aspects of human life including but not limited to health, food, energy, and economy. In addition to the environmental, economic, and social impacts of poor water supply and sanitation, the supply of fresh water is essential for the safety of children and the poor. 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 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.

The portion of total run-off which constitutes stable run-off flow is considered as the freshwater resource upon which humans depend. This stable fresh water flow has been estimated at 12,500–15,000 km^3 per year, from which 4000 km^3 per year is considered to be the total freshwater for irrigation, industry, and domestic purposes, and which is estimated to increase to a range of 4300–5000 km^3 per year in 2025. Alternatively, only accessible fresh water is 0.5% of the world's 1.4 billion Km^3 of water which is furthermore poorly distributed across the globe.

MEANING OF PURE WATER

It can be said that no water is unadulterated or clean inferable from the nearness of a few amounts of gases, minerals and life. However, for every commonsense reason, unadulterated water is viewed as that which has low dissolved and suspended solids and disagreeable gases just as low in natural life. Such a high caliber of water might be required just to drink purposes while for different utilizations like horticulture and industry, the nature of water can be very adaptable and water polluted up to certain degree, all in all sense, and can be viewed as pure.

WATER POLLUTION

According to the Water (Prevention and Control of Pollution) Act, 1974, ―water pollution means suchcontaminationof water or such change of the physical, chemical or natural properties of water or such release of any sewage ortrade effluent or of some other fluid, vaporous or strong substance into water (whether directly or indirectly) as may or is probably going to, make an irritation or render such water destructive or damaging to public health orto domestic, commercial, industrial, agricultural or other real uses, or the life and strength of animals or plants or of aquatic organisms.

WATER POLLUTANT

There are hundreds, perhaps thousands of pollutants whose effects are of actual

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andpotential concern. Their numbers increase annually as new compounds and formulationsare synthesised.Several attempts have been made to group water pollutants into classesor categories. Pollutants have been classified according to their mode of occurrence intophysical, chemical and biological pollutants.

CLASSIFICATION OF WATER POLLUTANTS

OccurrenceNature	Examples	
Physical	Temperature Turbidity Colour Suspended& floating matter	Waste neat from industry. Dyes and pigments Silt, sand, metal pieces,rubber, wood chpis, paper,foam, scum, carcasses,sewage.
Chemical	Inorganic	Nitrites, phosphates, chlorides, fluorides, salts etc.
	Organic	Detergents, tar, plastic, pesticides
Biological	Pathogenic	Bacteria, virus, nematodes, worms, protozoans.
	Nuisance organisms	Slime, mollusc, algae, Ascellus, nematodes

CAUSES OF WATER POLLUTION

Some of the major factors which are responsible for causing water pollution or degradation can be enumerated as growing population, rapid industrialization, urbanisation, use of science and technology and modern agriculture practices.

- ***Growing Population***

Every year we add millions of people to the world population and our country is no exception. Now it is the second largest country of the world after China and the rate of growth still continuous alarmingly. The earth is now overcrowded and consumption habit of the people is on the rise.17 The growth of population gave rise to increase in wants and demands of

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mankind and has succeeded in creating acute problem of water pollution.18

- ***Industrialization***

Rapid industrialization is another cause of worry as far as water pollution is concerned. Immediately after the independence, major steps were taken in our country in its stride for development in order to give its economy a big push. Industrialization was then considered the most important factor that can put the country in the path of progress. But to our utter surprise industrialization along with development brought with it a danger to the human civilization- the problem of environmental pollution.19

- ***Nature of Modern Technology***

The nature of productive technology in recent years is closely related to the environmental crises. This factor has been largely responsible for the generation of synthetic and non biodegradable substances such as plastics, chemical nitrogen fertilizers, synthetic detergents, synthetic fibres, big cares petrochemical and other environmentally injurious industries and disposable culture. Thus, an environmental crisis is the inevitable result of a counter ecological pattern of productive growth21.

- ***Modern Agricultural Practices***

Modern agricultural practices and application of new technological processes in the field of agriculture severely affect the environment. Inorganic fertilizers are being widely used now-a-days. Fertilizers like phosphates and nitrates cause wide spread damage when applied carelessly to crops. The fertilizers can be transmitted to ground water by leaching and to surface waters by natural drainage and storm run-off. In addition to fertilizers various kinds of pesticides and insecticide also applied. Almost all the pesticides those are used are toxic to human and animals22

TYPES OF WATER POLLUTION

Pollution of water can take any one or more of physical, chemical, physiological and biological forms.

1. Physical Pollution

- ***Temperature***

The increase in temperature of water bodies due to the heated discharges like the one from power stations can lead to thermal pollution. As the solubility of oxygen in water is inversely proportional to the temperature, dissolved oxygen (DO) in the water at a higher temperature would be reduced. Higher temperature may also increase the biological activities requiring greater quantities of DO for respirational purposes and affect adversely the growth and survival of aquatic life especially the delicate fishes and bacterial population due to inadequate DO. 23

- ***Turbidity***

It is mainly due to the presence of colloidal or finely divided suspended matter which does not readily settle e.g. river water in monsoon, water polluted with sewage and wastes from ceramic and paper industries. It can also be caused by iron and manganese salts due to their conversion into insoluble hydroxides. Turbidity reduces the penetration of sunlight into the water for green aquatic plants (which give oxygen to water), adversely effecting the photosynthesis resulting in the death of the plants and thus reducing the oxygenation in the stream.24

2. Chemical Pollution

- ***Inorganic Pollution***

Corrosive acids in water give rise to corrosion of metals, concrete structures and pumps etc. coming in its contact. Many industries discharge acids in their wastewater, common one being sulphuric and hydrochloric acids. Certain wastes may contain toxic inorganic substances such as free chlorine, ammonia, hydrogen sulphide, soluble sulphides and salts of many metals like copper, zinc, lead, nickel, chromium, cadmium, silver, mercury, iron, uranium, vanadium and thorium etc.29

- ***Organic pollution***

The most common form of organic pollution is due to the presence of carbohydrates, fats, proteins and similar other organic substances found in sewage and other industrial wastes. Untreated sewage and domestic wastes including wastes from sanatoriums, hospitals and slaughter houses contains complex organic substances in the form of urine, faeces, paper, soap, detergent, scrap of food and grease etc.30

3. **Physiological Pollution**

Taste and odour, although may not pose public health problems, are considered aesthetic pollutants. Several industrial wastes impart odour and unpleasant taste. Salts of iron, manganese and chlorine, H2S, phenols and unsaturated hydrocarbons are some of the examples.31

4. **Biological Pollution**

It is the result of wastes containing pathogenic forms of bacteria, certain fungi, algae, viruses, pathogenic protozoa, parasite worms, helminthic parasites and indeed any plant or animal which multiplies excessively in the water bodies for one reason or the other. This pollution is often a result mainly of the domestic sewage and human excreta and at times certain industrial wastes.32

SOURCES OF WATER POLLUTION

The sources of water pollution are innumerable. Major sources can be found in practically every variety of industrial, municipal and agricultural operations.33 The main sources of water pollution are as under:

1. Domestic wastes ;
2. Industrial wastes ;
3. Agricultural wastes, insecticides and pesticides ;
4. Thermal pollution ;
5. Marine pollution ; and
6. Radioactive wastes.

1. **Domestic Wastes**

Wastes from residential homes, sewage etc. constitutes nearly 70 percent of the water pollution. The residential buildings do have connected sewage treatment system but it is either inadequate or misused. The garbage and sewage discharged from it is flown in drains or sewage lines thereby blocking the free flow of water. Sewage generally includes bio-degraded pollutants such as human excretion, animal waste and many compounds like carbohydrates, proteins, urea, fats etc. as also inorganic nitrates and phosphates of detergents which cause water pollution. The detergent accumulated in water render it unfit for drinking purposes.

According to a recent survey, an average Indian family throws away wastes of about 60 kg per week. About 60 percent of the wastes processed by municipal treatment plants come from domestic sources and around 40 percent from industrial units. The thickly populated areas are more prone to the ill-effects of contaminated water.

The water discharged from untreated or inadequately treated sewage which goes into rivers, lakes, wells etc. causes serious infectious diseases like typhoid, cholera, dysentery and other skin diseases.34

2. **Industrial Wastes**

Industrial waste or trade effluent includes any liquid or solid substance, which is discharged from any premises used for carrying on any industry, operation or process or treatment and disposal system other than the domestic sewage. It is a common practice that a large number of industries, which are located on the banks of rivers, discharge their effluent into the river and thus pollute the river water. Industrial effluents contain, inter alia, mercury, lead, cadmium and copper etc., which are harmful to the aquatic animals.35

3. **Agricultural Wastes, Insecticides and Pesticides**

The main pollutants of agricultural wastes that cause water pollution are pesticides and fertilizers which reach water through run off and leaching. Sediments and farm-animals wastes also cause water pollution. The pesticides and insecticides which are sprinkled in agricultural farms when washed off the lands through irrigation, drainage or rainfall, enter into rivers, streams and even soaked underground and the water gets contaminated. The excessive use of inorganic fertilizers accelerates nitrite contents in water and it gets polluted.36

- ***Effects of Pesticides***

Pesticides have adversely affected human beings all these years. Some of these effects are

(a) Cancer

Many studies have examined the effects of pesticide exposure on the risk of cancer. Associations have been found with: leukemia, llymophoma, brain, kidney, breast, prostate, pancreas, liver, lung and skin cancers. This increased risk occurs with both residential and occupational exposures. Increased rates of cancer have been found among farm workers who apply these chemicals. A mother's occupational exposure to pesticides during pregnancy is associated with an increases in her child's risk of leukemia, wilms‘ tumor and brain cancer.62

(b) Neurological

Strong evidence links pesticide exposure to worsened neurological outcomes. The risk of developing Parkinson‘s disease is 70 percent greater in those exposed to even low levels of pesticides. People with Parkinson's disease were 61percent more likely to report direct pesticide application than were healthy relatives. Both insecticides and herbicides significantly increased the risk of Parkinson's disease.

(c) Fertility

Pesticides study shows that it has an adverse affect on the fertility too. A number ofpesticides including dibromochlorophane and 2,4-D has been associated with impairedfertility in males.

4. Thermal Pollution

Thermal pollution results out of excessive heat generated from the thermal plants whichuse water in the process of cooling their generators. This water due to contact withexcessive heat and high temperature gets polluted because of the decrease in the solubilityof dissolved oxygen. The excessive heat has adverse effect in bio-chemical reactionswhich are detrimental for human health and aquatic organisms.

5. Marine Pollution

Oceans and seas are major water sources which are immensely beneficial to mankind.Wastes from shipping fuel and oil are the main pollutants of sea water. Wastesdischarged from navigable ships cause water pollution which seriously damages the marine resources and organisms. Spilling from ships and off-shore drilling rigs also result in marine pollution. Accidents and collisions between the navigating ship results in discharge of huge amount of oil from the tankers which pollutes the sea-water and causes irreparable damage to marine habitat and vegetation.It has been the general practice that after the oil-tankers deliver the contents, the emptied tanker is filled with sea water to clean it for being refilled again for a return trip. The water used for cleaning is discharged in the sea which contains contaminated oil and the water thus gets polluted.

6. Radioactive Wastes

Today man made sources have begun to add large doses of radionuclides to the already existing radioactive materials in water bodies to which the living organisms are accustomed with various ill effects. Radioactive pollutants enter into water streams from various sources such as nuclear power plants, nuclear reactors, nuclear tests, nuclear installations, operations of power, processing of fission and fusion products etc. actually hazards

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from radioactivity arise because radionuclides deposit in body organs and deliver radiation dose. Extremely toxic radioactive Pu, Np, Cm, Bk, Cs, Zr, Ru etc. are produced from neutron bombardment of atomic fuel. Once they find access into water bodies, they disrupt the ecocycling process, enter into food chain and effect metabolic pathways.71 The main concern with the radioactivity is the fallout of radioactive materials from explosions of nuclear weapons. Besides the nuclear explosions and hazards associated with it, the other source of pollution is dumping of radioactive waste materials from the nuclear power plants, nuclear reactors and waste from medical and research laboratories.72

DISCUSSION OF SOME ASPECTS OF WATER POLLUTION WITH THE HELP OF TABLES

ILL EFFECTS OF WATER POLLUTANTS

S.NO.	POLLUTANT	EFFECTS OF THE POLLUTANT
1	Zinc (Zn)	Zinc is essential element for humans, animal andplants. It is also an important cell component inseveral metalloenzymes. Infants need 3–5mg/day, adult males 15 mg/day, pregnant andlactating females 20–25 mg Zn/day. However,heavy doses of Zn salts (165 mg) for 26 dayscauses vomiting, renal damage, cramps, etc.
2.	Copper (Cu)	Excess of Copper in human body (more than 470 mg) is toxic, may cause hypertension, sporadic fever, uremia, coma. Copper also produces pathological changes in brain tissue. However, Cu is an important cell component in several metalloenzymes. Lack of Cu causes anaemia, growth inhibition and blood circulation problem.
3.	Barium (Ba)	Excess of Barium (more than 100 mg) in human body may cause excessive salivation, colic, vomiting, diarrhoea, tremors, paralysis of muscles or nervous system, damage to heart and blood vessels.
4.	Iron (Fe)	Iron (Fe) is one of the essential mineral for humans and animals. Degree of absorption depends upon solubility and stability of compound. It is a component of blood cells and liveral metalloenzymes. However, more than 10 mg per kg of body weight causes rapid respiration and pulse rates, congestion of blood vessels, hypertension and drowsiness. It increases hazard of pathogenic organisms, as many of them require Fe for their growth.
5.	Cadmium (Cd)	Cadmium is very toxic, 50 mg may cause vomiting, diarrhoea, abdominal pains, loss-of consciousness. It takes 5-10 years for chronic cadmium intoxication.

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		During first phase, discolouration of teeth, loss of sense of smell, mouth dryness occurs. Afterwards it may cause decrease of red blood cells, lumber pains, disturbance in calcium metabolism, softening of bones, fractures, skeletal deformations, damage of kidney, hypertension, tumor formation, heart disease, impaired reproductive function, genetic mutation, etc.
6.	Mercury (Hg)	Mercury is very toxic. Excess mercury in human body (more than 100mg) may cause headache, abdominal pain, diarrhoea, destruction of haemoglobin, tremors, very bad effects on cerebral functions and central nervous system, paralysis, inactivates functional proteins, damage of renal tissues, hyper coagulability of blood, mimamata disease, and even death. It may cause impairment of vision and muscles and even coma. It disturbs reproductive and endocrine system. Also causes insomnia, memory loss, gum inflammation, loosening of teeth, loss of appetite, etc.
7.	Lead (Pb)	More than 400 mg of lead in human body can cause brain damage, vomiting, loss of appetite, convulsions, uncoordinated body movements, helplessly amazed state, and coma. It is retained in liver, kidney, brain, muscle, soft tissues, bones, leads to high rate of miscarriages, affects skin, and respiratory system, damages kidney, liver and brain cells. Disturbs endocrine system, causes anaemia, and long term exposure may cause even death.
8.	Arsenic (As)	Poisonous to fishes, animals and humans. Greater than 25 mg of arsenic causes vomiting, diarrhoea, nausea, irritation of nose and throat, abdominal pain, skin eruptions inflammations and even death. It binds globulin of blood haemoglobin in erythrocytes. May cause cancer of skin, lungs and liver, chromosomal aberration and damage, gangrene, loss of hearing, injury to nerve tissue, liver and kidney damage. Minor symptoms of As poisoning, weight loss, hair loss, nausea, depression, fatigue, white lines across toe nails and finger nails.
9.	Vanadium (V)	It is very toxic, may cause paralysis.
10.	Silver (Ag)	Silver (Ag) causes pathological change in kidney, liver and may even damage kidney. May cause

Argyria (discolouration of skin). Effects mucous membranes and eyes. In high doses, it may be fatal to humans.

METHODS FOR REMOVE POLLUTANT FROM WATER

1. Disinfection

Biological contaminants can be classified into three categories, namely, microorganisms, natural organic matter (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 nanomaterials such as Ag, titanium, and zinc capable of disinfecting waterborne disease-causing microbes. Due to their charge capacity, they possess antibacterial properties. TiO_2 photocatalysts and metallic and metal-oxide nanoparticles are among the most promising nanomaterials with antimicrobial properties. The efficacy of metal ions in water disinfection has been highlighted by many researchers. This part of the paper covers the application of these antimicrobial nanomaterials for water disinfection.

2. *Silver Nanoparticles*

Silver is the most widely used material due to its low toxicity and microbial inactivation in water with well-reported antibacterial mechanism. Silver nanoparticles are derived from its salts like silver nitrate and silver chloride, and their effectiveness as biocides is documented in the literature. Though the antibacterial effect is size dependent, smaller Ag nanoparticles (8 nm) were most effective, while larger particle size (11–23 nm) results in lower bactericidal activity. Also, truncated triangular silver nanoplates exhibited better antibacterial effects than the spherical and rod-shaped nanoparticles indicating their shape dependency. The mechanisms involved during the bactericidal effects of Ag nanoparticles include, for example, the formation of free radicals damaging the bacterial membranes, interactions with DNA, adhesion to cell surface altering the membrane properties, and enzyme damage.

Immobilized nanoparticles have gained importance due to high antimicrobial activity. Embedded Ag nanoparticles have been reported as very effective against both Gram-positive and Gram-negative bacteria. In a study, the cellulose acetate fibers embedded with Ag nanoparticles by direct electrospinning method were shown effective against both types of bacteria. Ag nanoparticles are also incorporated into different types of polymers for the production of antimicrobial nanofibers and nanocomposites. Poly (ε-caprolactone-) based polyurethane nanofiber mats containing Ag nanoparticles were prepared as antimicrobial nanofilters in a study. Different types of nanofibers containing Ag nanoparticles are prepared for antimicrobial application and exhibited very good antimicrobial properties. Water filters prepared by polyurethane's foam coated with Ag nanofibers have shown good antibacterial properties against Escherichia coli (E. coli).

There are other examples of low-cost potable microfilters prepared by incorporating Ag nanoparticles that can be used in remote areas in developing countries. Ag nanoparticles also find their applications in water filtration membranes, for example, in polysulfone membranes, for biofouling reduction and have proved effective against variety of bacteria and viruses. These Ag nanoparticles laden membranes had good antimicrobial activities against E. coli, Pseudomonas, and so forth.

Finally, Ag nanocatalyst alone and incorporate with carbon covered in alumina has been demonstrated as efficient for degradation of microbial contaminants in water. Although Ag nanoparticles have been used efficiently for inactivating bacteria and viruses as well as reducing membrane biofouling, their long-term efficacy against membrane biofouling has not been reported mainly due to loss of silver ions with time. So, further work to reduce this loss of silver ions is required for long-term control of membrane biofouling. Alternatively, doping of Ag nanoparticles with other metallic nanoparticles or its composites with metal-oxide nanoparticles can solve the issue and this could also lead to the parallel removal of inorganic/organic compounds from water/wastewater.

3. 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 them to be used in RO membranes to achieve high water fluxes.

Thin film nanocomposite membranes containing Ag and TiO_2 nanoparticles exhibited good salt rejection. Membrane permeability and salt rejection are shown to be effected by the number of coatings in TiO_2/Al_2O_3 (aluminium oxide) composite ceramic membranes coated by iron oxide nanoparticles (Fe_2O_3). A high sodium chloride rejection was obtained by using alumina ceramic membranes fabricated with silica nanoparticles. Zeolite-based 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.

Other nanostructures such as lyotropic liquid crystals and aquaporins also have exhibited high flux and selective water transportation. Zeolite-polyamide thin film nanocomposite membranes offered new

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ways of designing NF and RO membranes with increased water permeability and high salt rejection. The use of nanozeolites in thin film nanocomposite membranes has resulted in enhanced permeability and salt rejection.

By grafting functional groups, such as carboxyl, at opening of CNTs, membranes have better selective rejection of some components but this has resulted in reduced permeability rendering CNTs incapable for desalination. Hinds concluded a uniform CNT diameter of less than 0.8 nm for high salt rejection. Nanocomposite membranes may serve as ideal membranes for desalination but a basic understanding of transport mechanism along with proper pore size selection by keeping the uniformity is required for economically feasible and commercially acceptable desalination membranes. The effects of real seawater feed on the efficiency of different nanomaterials need to be investigated in terms of long-term operation and maintenance of membrane performance.

4. Removal of Heavy Metals and Ions

Different types of nanomaterials have been introduced for removal of heavy metals from water/wastewater such as nanosorbents 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 Cd^{2+}, Cr^{3+}, Pb^{2+}, and Zn^{2+} and metalloids such as arsenic (As) compounds. Composites of CNTs with Fe and cerium oxide (CeO_2) 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 TiO_2 nanoparticles and nanosized magnetite. The utilization of photocatalysts such as TiO_2 nanoparticles has been investigated in detail to reduce toxic metal ions in water. In a study, the effectiveness of nanocrystalline TiO_2 in removing different forms of arsenic is elaborated and it has shown to bemore effective photocatalyst than commercially available TiO_2 nanoparticles with a maximum removal efficiency of arsenic at about neutral pH value. A nanocomposite of TiO_2nanoparticles anchored on graphene sheet was also used to reduce Cr(VI) to Cr(III) in sunlight. Similar Cr treatment was carried out by using palladium nanoparticles in another study.

The capability of removing heavy metals like As is also investigated by using iron oxide nanomaterials ($Fe_2O_3$and Fe_3O_4) as cost-effective adsorbents by many researchers. Arsenic removal was also investigated by using high specific surface area of Fe_3O_4 nanocrystals.Polymer-grafted Fe_2O_3 nanocomposite was effectively used to remove divalent heavy metal ions for copper,nickel and cobalt over a pH range of 3 to 7.

Bisphosphonate-modified magnetite nanoparticles were also used to remove the radioactive metal toxins, uranium dioxide () with high efficiency from water. Studies have shown that zero-valent iron or iron nanoparticles (nZVI or Fe^0) are very effective for the transformation of heavy metal ions such as As(III), As(V), Pb(II), Cu(II), Ni(II), and Cr(VI). Reduction of Cr(VI) to Cr(III) was also done by using nZVI and bimetallic nZVI nanoparticles in a study.

Novel self-assembled 3D flower-like iron oxide nanostructures were also used to successfully adsorb both As(V) and Cr(VI). The 3D nanostructures of CeO_2 are used as good adsorbents for both As and Cr. The efficiency of NaP1 zeolites was evaluated for removal of heavy metals

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(Cr(III), Ni(II), Zn(II), Cu(II), and Cd(II)) from wastewater. Dendritic polymers were also used for treatment of toxic metal ions. The applicability of self-assembled monolayers on mesoporous supports for removing toxic metal ions novel was also evaluated by many researchers. Biopolymers have been used for heavy metal remediation from aqueous wastes. Chitosan nanoparticles for the sorption of Pb(II) were also used in one study.

Conclusions and Perspectives

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. The review of the literature has shown that water/wastewater treatment using nanomaterials is a promising field for current and future research.

Surface modifications of different nanomaterials like nanoscale TiO_2, 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 photocatalytic 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 nanocomposites for water/wastewater treatment.

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