Review Article

Water Pollution and Its Treatment by Various Methods: A Review

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Abstract

In the last few decades, environmental issues about the organic, inorganic and biological contaminations of water have become a major concern for authorities. The human activities produce wastewater containing undesirable toxic contaminants. Present wastewater treatment methods involve a combination of physical, chemical and biological processes to remove suspended particles and soluble contaminants from effluents. This article provides information about methods for wastewater treatment, and describes the advantages and disadvantages of available technologies. It is shown that there are several procedures following one another for the treatment of wastewater all over the world. Successful results and techniques developed over the decades have improved the quality of infected water. In the present study, the paper discusses about the general causes of water pollution and the amount of heavy metals presents in water. In the shadow of the new technical weapons numerous new methods have come into existence. From general traditional method of boiling water to the most advanced use of nanoparticles the story has evolved drastically. Several researches are going on in different parts of the world in which scientists are dealing with the best and most effective ways to disinfect water. Rapid industrialization is the main cause of water pollution as the factories tend to discard the untreated heavy metal waste in the water bodies which accumulate over the years and ultimately pollute the entire water system. Use of nanoparticles has proven to be the boon in the agenda to provide clean fit drinking water to the world.

Keywords: Water pollution, technology, toxic metals, pollutants

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Introduction

Water is well known for its enormous uses to the human kind and along with humans it is also serving the technological sectors for the development of the world. The major contributors to water contamination are industries which leave the untreated waste like heavy, toxic metals into the water bodies and hence the government issued some norms which are to be followed by every factory before they release their waste into the running water. Increasing water exploitation has its major impacts on social, biological, financial, political and environmental grounds. Developing nations have a general tendency of mistreating water in the agricultural, construction purposes along with the industrial uses. Also, the available ground water level is severely depleting due to overuse in irrigation. The worse situation of the year is in summers where due to extreme heat there is a large dependence on clear water but it isn't available at the time of need [1]. As the water pollution tends to take its shape in the fixed solid sense, there was an urgent need for the government to take certain measures to stop this exploitation.

Owing to these laws in various sectors, different water purification techniques came into existence along with the previous traditional methods. The conventional methods include filtration, chemical treatment, UV mechanism, absorption, precipitation, distillation, ion exchange methods etc. [2].

All the methods mentioned above are very advantageous to clean the water but at small scale and basic level. The processes could not lead to the ultimate purity of water as they have some individual drawbacks. Hence, then came the emerging field of 'nano-materials'. The paper focuses on the sources, amount and methodologies for the removal of heavy metals from the water.

Technologies available for contaminant removal

Basically, wastewater treatment processes consist of the combination of physical, chemical and/or biological processes and operations to remove contaminants including colloids, organic, inorganic matter, nutrients, soluble matters (metals, organics, etc.) from effluents. A multitude of methods classified in conventional methods, established recovery processes and emerging removal methods can be used (**Figure 1**).

Selection of the methods depends on the wastewater categories and characteristics. The treatment has its own constraints not only in terms of cost efficiency, but also in terms of feasibility, efficiency, practicability, reliability, environmental impact, sludge production, operation difficulty, pre-treatment requirements and the formation of potentially toxic by-products. In general, removal of pollutants from effluents is done by physicochemical and/or biological means, with research concentrating on cheaper effective combinations of systems or new alternatives.

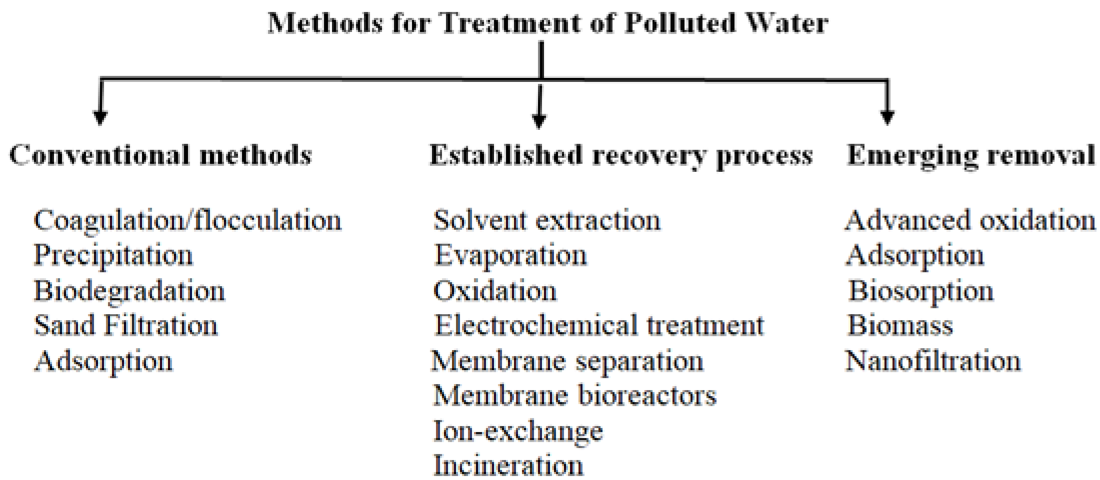

Figure 1 Classification of technologies available for pollutant removal and examples of techniques

Table 1 Common Source and Diseases of Heavy Metals in Indian Rivers [3].

S.NO	Metal	Major Source	Related Disease
1.	Arsenic	Arsenic containing fungicides, pesticides and herbicides, metal smelters.	Cancer, Discoloration of Skin
2.	Cadmium	Industries, electroplating, welding. Byproducts from Pb, Zn and Cu, fertilizers, pesticides, cadmium–nickel batteries, nuclear fission.	Bone softening, kidney failure
3.	Chromium	Metallurgical industries, cement and asbestos units.	Lung cancer
4.	Copper	Iron and steel industry, fertilizes, burning of wood, discharge of mine tailings, disposal of industrial wastes.	Gastrointestinal disease, vomiting
5.	Iron	Cast Iron, Wrought Iron, steel, alloys, machine manufacturing.	Hemochromatosis, diabetes
6.	Lead	Automobile emissions, lead smelters, burning of coal, lead arsenate pesticides, smoking, mining.	high blood pressure, anaemia
7.	Mercury	Mining and refining of mercury, organic mercurial, labs using mercury.	neurological and behavioural disorders
8.	Nickel	Metallurgical industries using nickel, burning coal, electroplating units using nickel salts.	chronic bronchitis
9.	Zinc	Galvanizing processes, brass manufacture, metal plating, and plumbing.	Stomach cramps, nausea and vomiting.

River Data Compilation-2 Directorate Central Water Commission. Status of Trace & Toxic Metals in Indian Rivers 2019.

Methods for Heavy Metal Removal

Conventional methods

This category includes mainly the physical methods for the separation like mechanical screening, hydrodynamics, concentration, floatation, density factor between soil and water, hydrophobic properties of metals, hydrophilic properties of metals [4].

Coagulation and flocculation

In this process of water purification, water analysis is done prior to steps. Zeta potential is firstly measured between the pollutants and the coagulant agent [4, 5].

The process of coagulation reduces the electrostatic repulsion and flocculation increase the particle size. Once the particles size is increased they are removed by filtration.

Biological methods

Since ancient times, biological and natural techniques have always been useful to mankind. For the water purification case, the microorganisms work in the water bodies and form sludge. The activated sludge is used as it decomposes the metals present in the water by aeration and agitation and then the unwanted part is settled and separated out. The bacteria working repeats the cycle again and again depending upon the demand. Biosorption is another method for the removal of heavy metals from water. Red mud provides a selective adsorption for particular metals [6].

Chemical precipitation

As a result of its easy operation, the process of chemical operation is widely used in the process of removing the inorganic impurities from the water containing them. The experimental procedure is quite simple. The sample water is taken and a precipitating agent is added as a result of which the heavy metals present in the water starts to precipitate as their corresponding sulphides, chlorides etc. depending upon their affinity with them. Once the precipitate is formed it starts to settle at the bottom of the sample holder, as more and more of tiny particles starts to come together. Later, the solid impurity is removed by the simple methods of filtration or via filter membrane.

Established Recovery Process

Membrane filtration

Membrane filtration is a widely used method in different sectors for different purposes. It serves to be an easy, effective and quick method. It has a high capacity to remove the heavy metal even in the form of organic, inorganic effluent. The principal of the membrane technology is the relative size between the membrane itself and the substance to be eliminated. The size may vary from the nano size to the reverse osmosis.

The type of membrane used to remove the heavy particles of the size 5-25 nm is the Ultrafiltration [7]. Depending upon the need they can work within the limits of 90% efficiency. The other types of membrane used are the polymer based Polymer-Supported Ultrafiltration (PSU) [8]. They require low energy and works as binding the heavy metal to the solvent and making a macromolecular structure. Kinetically it is a very fast and effective reaction. Other similar technique is complexation-filtration.

Electrochemical method

The process of converting electrical energy into chemical energy is known as electrolysis. The setup is not a complicated suitcase. It consists of two metal electrodes, ionic electrolytic, connecting wires, a salt bridge and a source of electricity. It is again an easy yet effective method for the removal of heavy method by the process of coagulation. As the current passes into the solution the chemical reaction starts to take place and the sample water ions gets attracted to the anodic compartment of the electrochemical cell. As the ions starts to move to the left, the electrons moving also combines to them and electrodestabilization of colloids occurs. As a result, the heavy metal is separated from the water and is accumulated at anode. The removal technique is again simple. The insoluble precipitate is removed by filtration [9].

Ion exchange method

Another cost effective, reliant and easy method for the inorganic impurity removal from water is the Ion exchanger. It is used when the foreigner heavy metal is present in low concentration. It consists of a column which is filled with the cationic resin. Resin is an aluminosilicate which has the capacity to exchange the ions passing through it. As the process starts, the impure water is sent through the resin and the cationic heavy metals like nickel, zinc, copper as exchanged by the cationic ions of the resin which can be hydrogen or sodium ions.

As they get trap into the exchanger, the water which comes out from the nozzle is free from these heavy metals and then can be forwarded for the further treatments [10, 11].

Emerging Removal

Adsorption by zeolites

Zeolites are the repeating structural units of aluminosilicates bearing oxygen in between the sharing tetrahedral units. In zeolite adsorption surface area is not an important factor. The ion exchange capacity plays a dominant role. A type of zeolite Clinoptillite has a high affinity for some heavy metals which are Pb, Cd, Zn, and Cu all in (II) oxidation state [12-14].

Nanomaterials and Nanoadsorbants

The most advanced and highly précised inventions in science include the making of the nano sized particles which serve their purpose in fields such as Quantum, Biomedical, Electrical, engineering fields etc. Nano means the range of 1-100 nm with specific properties. They have nano sized pores which have high adsorption capacity due to high effectiveness, selectivity and large surface area [15, 16].

Mechanism for Heavy Metal Removal by Nanoadsorbants

An adsorbent surface is created for adsorbing the heavy metals such as Cu (II), Zn (II), Pu (II) and Cd (II) from aqueous solutions. The iron magnetic nanoparticles Fe_3O_4 are modified with 3-aminopropyltriethoxysilane. The entire process is a pH depended process in which according to the pH, the ions present in the adsorbent bed are converted into the desired forms and oxidation state. The surface of the adsorbent is in carboxyl form. The process of adsorption occurs on the functional groups which in turn are pH dependent. As the pH increases the carboxyl ions are converted into carboxylate ions as the acidity decreases and alkalinity increases. The process of Chelation the ions and carboxylate ions provide interaction between metal ions and adsorbent.

Another nanofibrous membrane based absorber is used to separate heavy particles. Poly (ether sulfones)/poly(ethyleneimine) (PES/PEI) micro nano structure. Adsorbing sites in PEI are the amino and imino groups. They adsorb both cations and anions. At lower pH value i.e. high proton concentration, NH_3^+ and NH_2^+ are formed and this process is not so feasible at lower concentration of protons. The metal complex is formed when nitrogen of adsorbent combines with metal ion. For the removal of Cu (II), the chemical reactions observed are given by Eq. 1-4 [15].

Protonation/deprotonation reaction of the amine groups of the NH_2-NMPs in the solution:

$$-NH_2 + H^+ \rightarrow NH_3^+ \qquad (1)$$

Formation of surface complexes of Cu^{2+} with the amine groups through coordination interactions:

$$-NH_2 + Cu^{2+} \rightarrow NH_2Cu^{2+} \qquad (2)$$

$$-NH_2 + OH^+ \rightarrow NH_2OH- \qquad (3)$$

$$-NH_2OH^- + Cu^{2+}(\text{or } CuOH^+ \rightarrow -NH_2OH- ....Cu^{2+} (\text{or } -NH_2OH-.....CuOH^+) \qquad (4)$$

Several experiments are performed by scientists to use the particular type of nanomaterial (CNT, CQD) for the determination of the impurities present in water and most of them are successfully completed as well. Recent work aims at using these materials in detecting and removing these particular types of impurities from infected water. Some of the detected elements are mentioned in the upcoming section and also the particular type of nanomaterial used [17].

Carbon Nanotube application for Water Treatment

The Carbon nanotube based technology is flourishing at a higher rate in the forms of sorbents, membranes, catalyst for the water treatment. They are also used in the form of filter membranes but as not much cost effective. Different adsorbing materials are known since decades but the most effective element for the process of adsorption is proved to be the carbon based materials. CNT s came into existence couple of years back and are serving their purpose right. **Table 2** gives the information about some of the organic/inorganic substances present in the water which were categorized as pollutants by using some specifically designed CNT [18].

Table 2 Detection of chemical substances as pollutants by CNT [19]

Adsorbent	Element detected
CNT purified with acid mixture	Uranium
CNT activated by KOH etching	Tylosin
Al_2O_3 supported CNT	Fluorite
Ceria supported CNT	Arsenic
CNT purified by HNO_3	Lead
Graphized CNT	1,2-Dichlorobenzene

The morphology of the carbon nanotube reveals that the structure is not linear but a curvature is present and the chiral graphene layers. The helical structure has a strong affinity to bind to the organic and inorganic substances acting as pollutants due to pi-pi interaction and electrostatic interactions.

Carbon Quantum dots for Water Treatment

Carbon quantum dots are next in the category and are equally important and significant due to their very small size (upto10 nm) and additionally super fascinating technological abilities. Apart from small size they also are chemically inert; they possess low toxicity, biologically compatible etc. CQD are much used because they are economically comparatively cheaper, less hazardous and eco-friendly. Several studies have shown that CQD have high capacity to treat the waste water. They have a strong sense to detect hazardous metals and precisely Uranium [20]. Along with this element, CQD have proved to be useful in detoxing the unfit water from the Cadmium (II) [21]. Their eye catching results are in the treatment of the colored waste water since they are photo sensitive and fluorescence active substances. An experiment was performed of direct UV-photolysis for the determination and treatment of the colored water and its disinfection using a CdSe/Zn core shells QD. **Table 3** shows the general physical specifications for a particular type of QD used [22].

Table 3 Physical parameters of CdSe/Zn Quantum Dot [22]

Property	Value
λE (emission peak)	520 nm
d (crystal diameter)	3.3 nm
ε (molar extinction coefficient)	$5.0 \times 104\ ((mol/L)\cdot cm))^{-1}$
Mr (molecular weight)	94 µg/nmol
Φ (quantum yield)	> 50%
Coloration of QD suspension in toluene	Green

Similarly, Wang et al also introduced a MIP-based phosphorescence by attaching a layer of MIP on the surface of ZnS based QD. The setup was used for the determination of pentachlorophenol in water [23]. Another scientist used the same ZnS based QD for the chemiluminescence for the detection of 4-nitrophenol in tap water [24].

Conclusion

Water management is such a delicate and an alarming issue for which entire world is working and sending up new inventions on a regular basis. All the methods mentioned above have been approved and used to their best depending upon the aspect and the requirement of the situation. In the recent times, the most effective and widely used technique is the production and use of the ion exchange, nanomaterials and nanoadsorbants for water purification. They are precise, cost effective, they are chemically inert, and they provide a larger surface area to the reactant.

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