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Review Paper

A review on heavy metal contamination of surface water and their health effect with SWOT analysis of removal methods available

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Abstract

One of the major environmental and human health issues is heavy metal contamination of surface water. The persistent heavy metal contamination level in surface water causes deterioration of water quality. Many methods are reported for the removal of heavy metals from water but conventional treatment system are not much effective and use of inexpensive materials for removal can improve the current treatment process. Among the available methods for heavy metal removal adsorption is the most common and feasible in which many low cost adsorbents are used which are collected from agricultural waste, seafood waste, food waste, industrial by-product and soil. SWOT analysis (strength, weakness, opportunities, threat) is also performed on the available methods for heavy metals removal. This tool helps to determine the comparative potential quality of all removal methods available for water and wastewater treatment.

Keywords: Heavy metal, Contamination, Surface water, Health effect, SWOT analysis, Removal methods.

Introduction

One of the major environmental problems of India is Water pollution. The statistical and numerous date obtained from different sources indicates the depletion of surface water quality which makes it polluted. According to UN Climate report 2014 by the year 2025 India is expected to face water scarcity due to drying up of water bodies. The main sources of surface water pollution are: untreated sewage, industrial effluents, dumping of garbage into surface water, immersion of idols etc[1]. The water pollution has direct implication on aquatic and human life hence monitoring and assessment of surface water has become a very critical area of study. The heavy metal contamination of surface water is a severe environmental problem due to bioaccumulation and bio magnifications nature of some toxic metals through food chain and web. Some of the heavy metals are essential in low concentration while they are toxic at high concentration. The time dependent study of heavy metals contamination of surface water can help to identify and quantify trends in water quality pollution and help the management and regulatory agencies to evaluate alternatives and make necessary decisions[2,3]. Principal component analysis and cluster analysis coupled with metal concentration analysis and correlation analysis are considered as the effective tool for identification of pollution sources[4-6].

Sources of heavy metals in surface water

In surface water pollution, study the major heavy metals, which are found in water bodies are arsenic, cadmium, iron, cobalt, chromium, copper, manganese, mercury, molybdenum, nickel, lead, selenium, vanadium and zinc. These heavy metals are found in earth crust and can found its way to surface and subsurface water by many natural processes. The heavy metals, which are present in earth's crust in complex geologic form, can be leached out by many processes like heavy rain, flowing water or by any economic activity like mining. Acid Mine Drainage (AMD) can be one of the consequences of these processes. This AMD along with low pH condition can favor the leaching of heavy metals to surface water. Mining activities and mineral processing operations can generate significant heavy metals as waste. Though the mining sector possess the highest risk for heavy metal pollution the other industrial operations are also responsible for heavy metal pollution like electroplating industry, tannery industry, paints and dye manufacturing industry etc. which generates large volume of waste water with high heavy metal concentration. Minimizing metal discharge not only improves the environmental aspect but also improves the resource efficiency of the industry. Other Industries like lead acid industry also generates metal rich effluent and metal rich fly ash which can pollute air, water and land, Coal fired power plants also pollute the air and water segment. Hence there is maximum risk of environmental pollution from those industries of which heavy metals are key input material. Recent technologies can play important role in minimizing these pollutions like wet scrubbing. Heavy metals have mutagenic, carcinogenic and neurological impact on human due to their bio-accumulative and toxic nature. The toxic metals can interfere with many enzymatic biochemical processes. Heavy metal pollution possesses serious environmental, economic and social impacts. To combat heavy metal pollution problems, the best strategy is to focus on the sources of the pollution.

Treatment methods for heavy metal removal are generally not available for all circumstances but if those methods are applied then proper disposal of waste generated should be carried out through best management of waste practices. Other heavy metal pollutants are chemical, electronic, mining, manufacturing, paints and dyes, jewelry, soils, research exposure, unapproved chemicals, and the misapplication of approved chemicals. One of the major threats to aquatic environment is by inorganic chemicals. The agricultural runoff containing pesticides, fertilizers and trace metals, industrial discharges, sewage effluents deposited considerable quantity of inorganic anions and heavy metals to water bodies and sediment[7]. The most anthropogenic sources of metals are industrial, petroleum contamination and sewage disposal[8]. Due to bio accumulative nature of toxic metal ions they can affect the physiological state of aquatic organism. Out of many heavy metals some like Zn, Cu, Fe are essential for aquatic animals in trace quantity due to their biochemical role in life processes. The main source of Cu and Pb are industrial waste and algaecides and of Cd is phoaphatic fertilizers[9]. The different natural and anthropogenic components produced or derived are finally finds their way to the sediment system of any water body hence quality of sediment is a good indicator of water pollution because heavy metal and other organic pollutants tend to concentrate on sediments.

Health effects of heavy metal

Those metals heaving a specific gravity and their elements having atomic weight between 63.5 and 200.6 are heavy metals. Mostly heavy metals are dangerous for environment and human health. Heavy metals like chromium, mercury, selenium, arsenic, zinc, cadmium are generally found in industrial wastewater[10]. Many international bodies such as WHO reviewed these metals and their effect on human health. Lungs, kidney, endocrine glands, bones cardiovascular and central nervous system may damage by acute heavy metals. These same systems chronic heavy metals are implicated in several degenerative diseases. Acute heavy metal intoxications may damage central nervous function, the cardiovascular and gastrointestinal (GI) systems, lungs, kidneys, liver, endocrine glands, and bones. Chronic heavy metal exposure has been implicated in several degenerative diseases of these same systems and may increase the risk of some cancers. Source and toxic effects pf some heavy metals are shown in Table-1.

Heavy metal removal methods: i. Chemical Precipitation, ii. Coagulation and Flocculation, iii. Electrochemical Treatments, iv. Membrane Filtration, v. Ion Exchange, vi. Electrodialysis.

Recalcitrant wastes, which are Non-biodegradable and heavy metal, cannot be removed by conventional wastewater treatment methods. For the removal of these pollutants other methods like chemical precipitation, ion exchange, adsorption, electrodialysis, nanofiltration, coagulation, etc have been used[12]. Due to their unacceptable drawbacks like metallic sludge, which needs further disposal, unacceptably high total dissolved solids in effluent after treatment, high cost and require high level of expertise these are not applied by many users. In comparison to these the adsorption method has higher acceptance due to its inherent low cost, simplicity, versatility and robustness. Bio adsorbents are derived from agricultural by products and industrial solid wastes which can reduce the cost of waste disposal also for corresponding industries. The adsorption of toxic waste from industrial wastewater using agricultural waste and industrial by-products has beenmassively investigated[13,14]. The technical feasibility of some low cost adsorbents like chitosan, activated carbon, agricultural by products with high adsorption capacity and are locally available, are high as compared to commercially activated adsorbents[15].

Heavy Metal Removal Methods

Chemical precipitation: In this method, some chemical reagents are used for the removal of heavy metals from waste waters, which is then followed by filtering precipitate from treated water. For this purpose of precipitation some coagulants are used like alum ferrous sulphate, organic polymers etc.A joint hydroxide precipitation and air flotation method reported 80% removal of Zn, Cu, and Pb, and up to 96.2% removal of oil from industrial wastewaters[16].

Table-1: Sources and toxicological effects of some heavy metals[11].

Heavy metal	Sources	Effect
As	In agricultural soil, as pesticides, semiconductor manufacturing, Preservation of timber	Abdominal pain, skin manifestation, visceral cancers, vascular diseases
Cr	Metal alloys and pigment for paints, rubbers	Headache, diarrhea, nausea, vomiting, carcinogen
Cd	In batteries, as rechargeable, in alloys and electronic compounds	Kidney damage, renal disorder, human carcinogen
Hg	Leaking from mercury amalgam filling, in fish (especially tuna) cosmetics, pesticides, plastics fungicides, adhesives, floor waxes.	Arthritis and problems in circulatory and nervous system, kidney problems
Cu	Water heaters, Alcoholic beverages, Hormone pills, Copper jewelry, Copper cooking pots.	Dermatitis, nausea, chronic asthma coughing, human carcinogen

Electro dialysis: In electro dialysis method, the heavy metals are separated from wastewater by passing waste water through a semi permeable membrane under the influence of electric potential. These membranes are sensitive towards cations and anions and can allow only passing selectively charged ions.

Coagulation/flocculation

This method is suitable for the treatment of wastewaters. The coagulation process is done by adding some coagulants to the water, which felicitates the formation of flocks after that suspended matter is then attracted towards these flocks. The coagulation is followed by flocculation in which through gentle mixing of the water with coagulant the size of the flocks is increased, which can be easily settled down and can be removed by filtration. The basic mechanism involved in the removal of organic contaminants by coagulation is studied by many researchers. They studied the effects of initial pH and turbidity, alum and pre ozonation doses, and flocculation time.

Ultra filtration

In Ultra filtration process, separation of toxic heavy metals is carried out by using membrane with pore sizes in the range 0.1micron to 0.001 micron. In this process pressure is applied for purification. In this method water and low molecular weight substances are filtered and high molecular weight substances like colloidal materials, organic and inorganic substances are retained on the filter. Membrane characteristics, electric charge and surface chemistry of the particles may affect this process.

Reverse osmosis

In this method, the process of reverse osmosis (RO) is used for the purification of contaminated water. RO process is applied to treat the wastewater from electroplating and metal finishing industry, pulp and paper, mining and petrochemical, textile, food processing industries, radioactive wastewater, municipal wastewater, and contaminated groundwater[17-20].

Adsorption

Adsorption is process in which the adsorbate is adsorbed on the surface of the adsorbents, forming a molecular or atomic film. In industrial application, the most widely used process is adsorption using activated charcoal, synthetic resins etc. and can be used in many natural, physical and chemical processes. Due to its cost effectiveness and simplicity in operation, adsorption is considered as most suitable process for the treatment of water and wastewaters[21,22].

For the removal of heavy metals from industrial waste water adsorption is widely used technique[23]. Some common adsorbents used for adsorption of metal ions are activated carbon[24,25], clay minerals[26], biomaterials, industrial solid wastes and zeolites[27]. Natural material or certain waste from industrial or agricultural operation is one of the resources used as low cost adsorbents.

Table-2: SWOT analysis of the methods available.

Method	Strength	Weakness	Opportunity	Threat
Chemical Precipitation	Simple, Effective	High chemical reagent requirement	Specific components can be removed.	waste maybe toxic if contains heavy metals
Electro dialysis	Low energy consumption, simple pretreatment	Organic matter cannot be removed	Separates non ionized and ionized ions	Membrane and construction material should be compatible.
Coagulation/ Filtration	Simple in oeration, high efficiency in charged suspended and dissolved particles removal, Reliable	Skilled operation is required	Low cost, improves filtration by removing solids	Continuous consumption of chemical and energy
Ultrafilteration	Particle removal of size 0.001 to 1 um, Recovery is more	Pretreatment needed, chemical corrosion such as oxidation	Can treat waste and drinking water, can work on low pressure than RO.	Membrane failure
Reverse Osmosis	Easy maintenance and low space requirement	Slow process, frequent filter replacement, compatibility of membrane and toxic material is required.	Low energy requirement	Pre treatment and high pressure is needed, Not applicable for concentrated solution
Adsorption	Simple, effective	Low pH conditions are favorable	Economical, versatile	Generation of toxic sludge

The most commonly used adsorbent is activated carbon due to its highly porous and amorphous nature consisting of micro crystallites with graphite lattice and capability of removing wide variety of toxic metals. These adsorbents are inexpensive and have little economic value because these are easily and locally available in large quantities[28]. Some of the reported low-cost sorbents include bark/tannin-rich materials, lignin chitin/ chitosan, dead biomass, seaweed/algae/alginate, xanthate, zeolite, clay, ash, peatmoss, bone gelatin beads, leaf mould, moss, iron-oxide-coated sand, modified wool, modified cotton.

Conclusion

Over the past two decades, environmental regulations have become more stringent to improve the quality of surface water. In recent years, a wide range of treatment technologies such as chemical precipitation, adsorption, membrane filtration, electro dialysis, and coagulation and flocculation are used to treat wastewaters. Chemical precipitation is simple in operation with high required of chemical reagent while Electro-dialysis is runs on low energy and can separates ionized and non-ionized ions but organic matter cannot be removed. Coagulation is simple and is effective in removing suspended and dissolved solids while skilled operation high need of chemical and energy on the limiting factors. Ultrafiltration can removal particles as low as size of 0.001µm drinking and wastewater with limitation of membrane failure and high operating cost. Reverse osmosis needs low energy and low space but process is low pretreatment and high pressure is needed. Adsorption process is simple effective, economical and versatile but is generally suitable for industrial waste treatment due to low pH removal and generation of toxic sludge is a matter of concern. Some basic parameters such as pH, initial metal concentration and overall treatment performance compared to other technologies decides the suitability and feasibility of the treatment process which are applied for the removal of heavy metals from water and waste waters. Technical applicability, simplicity of the operation and cost effectiveness are the key factors which decides the selection of most suitable treatment processes. All the factors mentioned above should be taken into consideration while selecting the most effective and inexpensive treatment in order to protect the environment.

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