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Contamination of Water by Heavy Metals and Treatment Methods – A Review

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Abstract

Water is an indispensable need for the survival of living ecosystems. Industrialization and urbanization gifted a sophisticated life as well as a polluted environment. Water is getting polluted by various means like human activities, industries, and sewage. One of the serious issues around the globe in the upcoming days is heavy metal pollution. A voluminous amount of heavy metals are let into the environment from various sources like agricultural, industry, sewage, and mining. It causes adverse effects on the environment and human beings when the heavy metals concentration is beyond the expected permissible limit. Innovative processes are developing day by day for the operational deletion of heavy metals. This review article provides a consolidated report of the treatment techniques used for heavy metals removal of with excellent efficiency like precipitation, ion-exchange process, adsorption, solvent extraction, electrocoagulation and membrane processes.

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Water.

Introduction

Pure water is essential for leading a harmonious life. Due to the vital role of water for humanity, it is very significant to maintain and improve the quality of water. Currently, because of rapid industrialization and technological advancements, the claim for usage of water is high in both the local and industrial regions.[1] The availability of fresh water is becoming inadequate due to many man-made accomplishments. Because of the growing living standards, the increasing world population surges water supply.[2] Nowadays the world is facing a great challenge of destruction of the environment particularly by water pollution.[2,3,4] The discharge of heavy metals and other toxic pollutants by human and industrial activities has become a major problem for both humans and aquatic life.[4] There are some common pollutants like palladium (Pd), Mercury (Hg), Chromium (Cr), Cadmium (Cd) and Nickel (Ni) that are often detected in industrial effluents.[5,6,7] Heavy metals are important in many aspects to mankind, especially in the manufacturing of accumulators,

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thermometers, and utensils. If these heavy metals present in higher concentrations beyond the limit, it is hazardous to the lives of both flora and fauna. Due to its bio-toxic effect, it is hazardous to the environment. Many techniques are existing to effectively remove heavy metals from industrial effluents. Some treatments are flocculation, coagulation, adsorption, membrane process, ion-exchange process, chemical precipitation, filtration, solvent extractions, photodegradation and electrodialysis.[4,5,8] All these techniques have both merits and demerits. In recent days, there are numerous cost efficient and eco-friendly studies available in literature for the elimination of toxic heavy metals from the wastewater and to improve the quality of treated effluent.[8,9]

Heavy Metals

They are trace elements such as Cadmium, Mercury, Arsenic, Nickel, Copper, Lead, Iron, Chromium, Zinc and Cobalt.[10, 11] Heavy metals are toxic, carcinogenic, non-biodegradable and mutagenic. Heavy metals are toxic and hazardous to the environment when the concentration is beyond the acceptable limit.[11, 12, 13] Lead, Cadmium, Mercury and Arsenic have no advantageous effects in humans.[14] Low concentrations of heavy metals are known to have neurotoxic and carcinogenic actions.[15]

Permissible Limits of Heavy Metals

World Health Organization (WHO) is answerable for people health and several public health problems, healthy diet, food security and nutrition. WHO and EPA are the top most agencies of health organization in the world. These agencies also provide a guideline for drinking water. WHO and EPA study the drinking water and provide the acceptable limit of various heavy metals and other parameters in drinking water. The table below shows the permissible limit of different toxic heavy metals.

Table 1: Permitted limit of heavy metals (WHO and EPA) in ppm [4, 13, 16]

S.No.	Heavy metals	WHO (ppm)	USEPA (ppm)
1.	Chromium	0.05	0.05
2	Iron	0.3	-
3.	Cobalt	0.10	-
4.	Nickel	0.1	-
5.	Copper	0.05	0.20
6.	Zinc	5.0	5.0
7.	Arsenic	0.05	0.01
8.	Cadmium	0.005	0.005
9.	Mercury	0.001	0.002
10.	Lead	0.05	0.015

Applications of heavy metals

Chromium is used in the process of electroplating, leather tanning, metal finishing, textile industry and photography industry.[4] Chromium is used in nuclear power plants, data storage and also in metallurgical processes.[15] Iron is used for coating metal corrosion and steel industry mining.[16]Cobalt is used as a semiconductor. Co(II) is used in nuclear power plants, enamel painting on glass, manufacturing of aerospace materials, batteries and in the synthesis of vitamin B_{12}.[4]

Nickel is used in non-ferrous alloys, superalloy, electroplating industries, rechargeable batteries, catalysts, microphone capsules.[4, 6] Copper is used in mining operations, pharmaceutical

equipment manufacturing, paper industry and kitchenware manufacturing.[17] Zinc is used in batteries, anti-corrosion coating, cans, paints, cosmetics, rubber industries, pigments and as Zn alloys.[18]

Arsenic is used in the industries of pesticides, mining, insecticides, ceramics, metallurgy, textile, veterinary medicine productions and also in the tanning process.[15] Cadmium is used in welding and electroplating processes. Cadmium plays a

role in petroleum retaining, plastic stabilizers, coal combustion and nuclear fission plants.[4] Mercury is used in batteries, dental amalgams, photography, fuel combustion, pharmaceutical industries and textiles. It is also used as catalyst rectifiers, Hg vapour lamps and fungicides.[19] Lead is used in the production of electronic products, paints and also used in the electroplating process.[20] Lead also plays a role in the production of bullets and shot materials for soldiers.[14]

Table 2: Applications of Heavy metals

S No	Heavy metals	Industrial application	Biological application
1.	Chromium	Electroplating, leather tanning, metal finishing, textile industry and photography industry,[17] nuclear power plants, data storage, metallurgy processes.[21]	Glucose metabolism,[17] lipid metabolism
2.	Iron	Coating metal corrosion, steel industry, mining,[22] missionary, hospital equipments23 kton[26] Blood production,	Helps in photosynthesis, nutrient for phytoplan-
3.	Cobalt	Semiconductor, nuclear power plants, enamel painting on glass, aerospace materials, batteries[25]	Formation of vitamin B_{12}[4] Promote angiogenesis, erythropoiesis and anaerobic metabolism[24]
4.	Nickel	Non-ferrous alloys, super alloy, electroplating industries[16] Rechargeable batteries, catalysts, microphone [21]	Capsules[4]
5.	Copper	Mining operations, pharmaceutical equipment, paper industry, kitchenware [7]	Cofactor for enzymatic reactions4, Radiotherapy of cancer, killing of cancer cells[25]
6.	Zinc	Batteries, anti-corrosion coating, cans, paints, cosmetics, rubber, industries, pigments, Zn alloys[15]	Absorption of calcium in the bones, creation of connective tissues, function of cell membrane
7.	Arsenic	Pesticides, mining, insecticides, ceramics, metallurgy, textile, tanning process[7]	Veterinary medicine productions[15]
8.	Cadmium	Welding, electroplating, petroleum retaining, plastic stabilizers, coal combustion, nuclear fission plants [20]	No known biological function
9.	Mercury	Batteries, dental amalgams, photography, fuel combustion, pharmaceutical, textile, catalyst rectifiers, Hg vapour lamps, fungicides [22]	No known biological role
10.	Lead	Electronic products, metal processing, paints, pigments, electroplating process,[4] production of bullets and shot materials for soldiers[14]	No known biological role

Toxicity and Impacts

Various health-related pollutants, especially heavy metals surges in the environment due to their non-degradable, persistent and bioaccumulative nature. Long-term consumption and frequent exposure to toxic heavy metals can result in severe health problems.[9] Heavy metals such as zinc subgroup ions, Hg^{2+} and Cd^{2+} will lead to serious extortions to human health because they are unsafe and have carcinogenic nature.[19,20]

Chromium

Chromium (VI) in water are dangerous to the environment because of its high toxicity. Hexavalent-Chromium holds a high risk due to its water-soluble nature to enter into the living cells and cause acute

health issues. It causes headache, diarrhoea, nausea, vomiting, carcinogenic and ulcer oedema,[24] skin rashes and irritation, weakness of immune systems and genetic constituents.[9] It also produces lung tumours, allergic dermatitis.[22] It can cause health disorders such as haemorrhage, pulmonary congestion and it affects human physiology.[13]

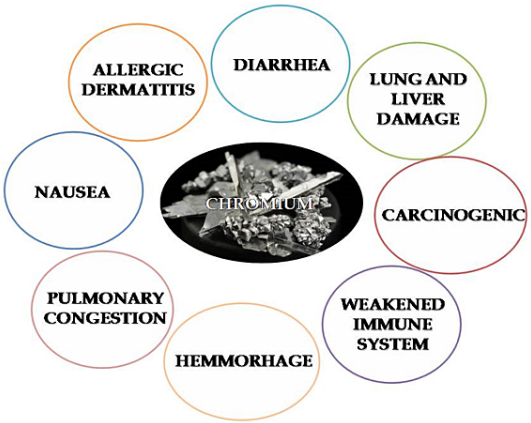

Fig 1: Schematic representation of Chromium toxicity

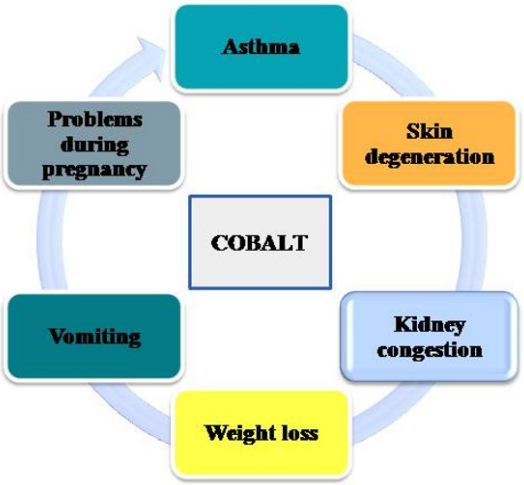

Fig 2: Schematic representation of Cobalt toxicity

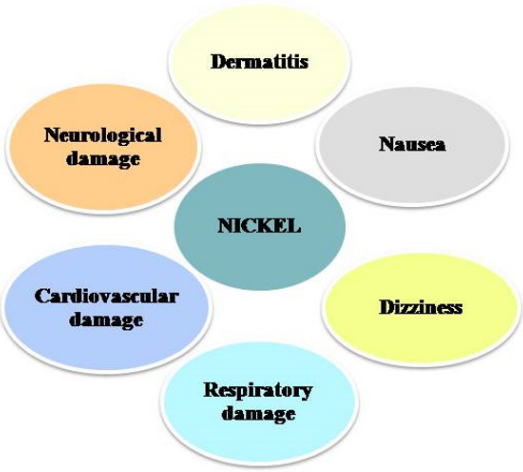

Fig 3: Schematic representation of Nickel toxicity

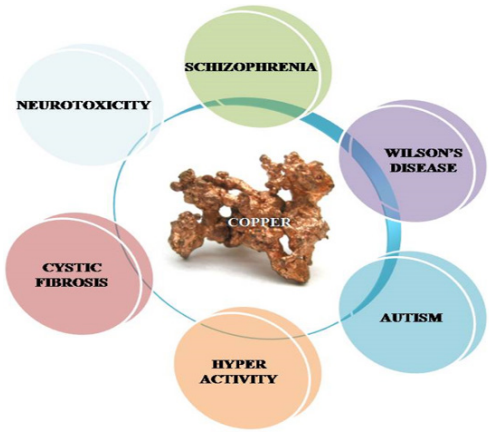

Fig 4: Schematic representation of Copper toxicity

Iron

Iron shows a major role in the biological system of complex formation in hemoglobin.[27] High levels of iron cause side effects such as vomiting sensation, diarrhea or stomach upset.[15]

Cobalt

Exposure to high amounts of cobalt may cause problems to fetal development during pregnancy and sometimes it is carcinogenic.[18] Cobalt may lead to physical and mental problems like vomiting, asthma, kidney congestion, skin degeneration and weight loss.[15]

Nickel

Toxic effects of Nickel cause damage to internal organs and mental and neural systems. Ni^{2+} is fatal to sensitive species of water living organisms.[21, 28] It causes dermatitis, headache, dizziness, nausea, vomiting.

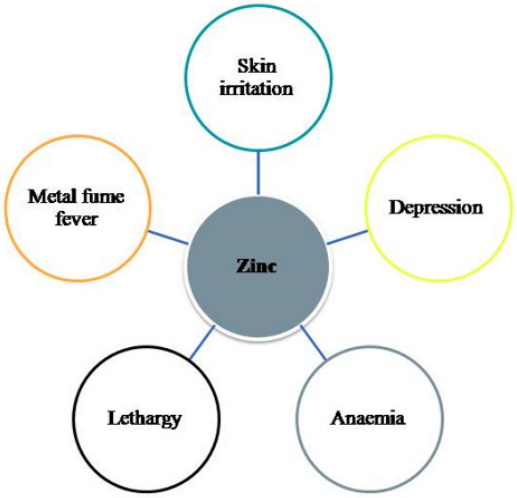

Fig 5: Schematic representation of zinc toxicity

Fig 6: Schematic representation of arsenic toxicity

Copper

If the copper intake is in excess, it accumulates in the liver causing gastrointestinal problems, kidney damage and anaemia.[11] The toxicity of copper leads to hair loss, headache,[12] liver failure, Wilson's disease and Insomnia.[9,11,14] It also causes renal disorder and irritate the mouth, and also causes stomach ache, vomiting, diarrhea and headache.[22]

Zinc

Zinc is non-biodegradable and highly toxic and has a reverse effect on humans. High exposure to zinc causes depression, lethargy and increased thirst.[7] And it also causes skin irritations, stomach cramps, anemia[4] and bloody urine.[11] It leads to gastrointestinal distress and metal fume fever.[9]

Arsenic

Exposure to arsenic affects the internal organs of the human body. Long term exposure causes skin, lung, kidney and bladder cancer.[14] And also it causes muscle weakness, neurological disorders.[13]

Cadmium

Itai-Itai disease is caused because of chronic cadmium toxicity. Cadmium induces gastrointestinal disorder, bronchitis, hypertension[23] and it is a human carcinogen, emphysema,[9] dyspnea and weight loss. Itai-Itai disease also causes cancer on lung, kidney liver and reproductive organs.[13, 21, 27]

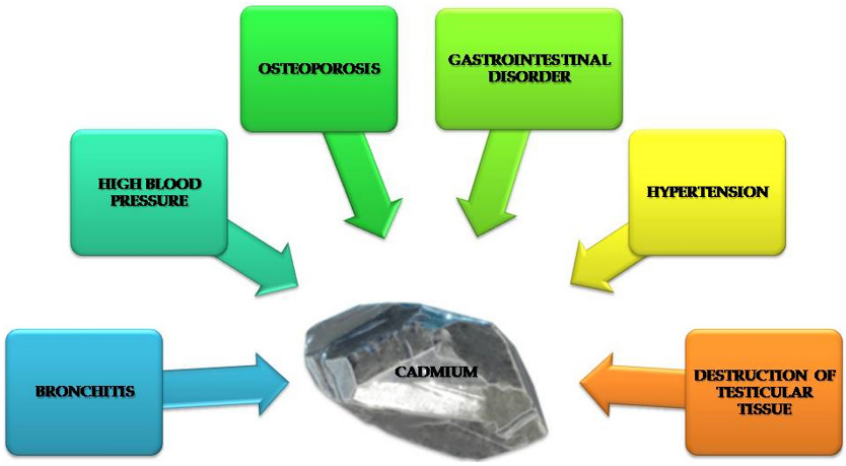

Fig 7: Schematic representation of cadmium toxicity

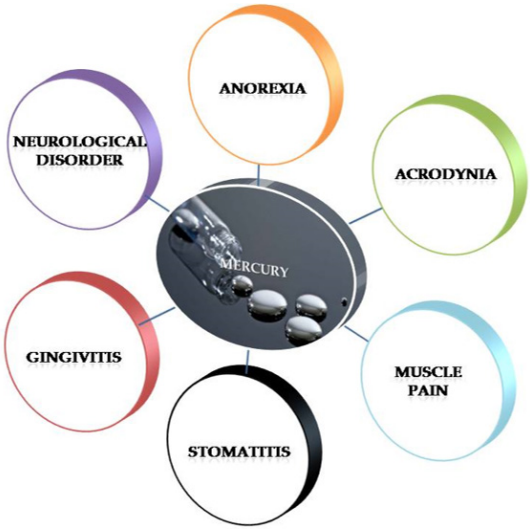

Fig 8: Schematic representation of mercury toxicity

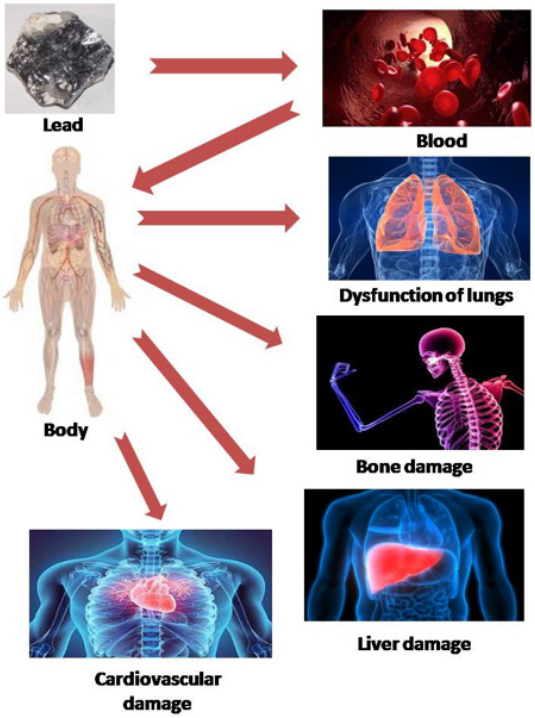

Fig 9: Schematic representation of Lead toxicity

Mercury

Mercury causes retardation, genetic defects, teratogenic effects, rheumatoid arthritis, protoplasm poisoning.[16, 17, 22] It is a neurotoxin and high concentration of mercury causes dyspnea,[15] abnormal irritation, acrodynia, gingivitis, stomatitis, neurological disorders and congenital malfunction.[29] Inorganic mercury causes spontaneous abortion and hematochezia.[21]

Lead

Lead poisoning has been accepted as one of the major public health risks. Pb^{2+} accumulates mainly in bones, kidneys, brain and muscle, acute and chronic damage to the central nervous system and peripheral nervous system. [28] It may cause anaemia, headache, irritability and muscle weakness, insomnia, hallucination, renal damage, dizziness, Malaise and anorexia.[30] Series effect of lead toxicity of its teratogenic effect, gastrointestinal damage. Children are sensitive to this metal and leads to high growth rate and metabolism and mental retardation.[13]

Sources of Heavy Metals in Water Samples

Heavy metal pollution continuously increases in the environment due to industrial development and urbanization. Due to the rapid development of industries, mining, electroplating, batteries, and paper industries, huge amounts of toxic metals are getting discharged into the environment. The metal plating industry is one of the major source that shed large amounts of wastewaters. Metal surface treatment processes and electroplating generate large quantities of wastewater containing heavy metals.

Chromium

The main source by which chromium entered into the environment is several industrial actions such as metal smelting, tanning, electroplating, metallurgy, steel industries.[23] It is also released from dyes, textile industry and leather industry.[20,21]

Iron

The major source of iron are natural deposits, wastes from metal processing industries, ores, and corrosion of vessels and rods.[24]

Cobalt

Cobalt is released from nuclear power plants and industries like petrochemical, metallurgical, electronics, dyes.[14]

Nickel
Nickel is spread via industrial process batteries manufacturing paint, mining, metal finishing & forging.[17] Petroleum refining, electroplating are also other sources of nickel contamination.[13]

Copper
Main sources of copper in industrial discharge are paints and pigments fertilizer industries, pulp, wood pulp production, metal cleaning, paperboard mills, mining, batteries, copper cooking pots.[20, 27] As a pollutant in food specifically shellfish, mushroom, chocolate, liver, nuts, electroplating industry.[22]

Zinc
Sources of zinc include steel processing, mining and coal combustion, brass metal works, paper and pulp industries.[30]

Arsenic
The major source of Arsenic in water is via dissolution of minerals, ores, sediments, bio- organisms, rocks, ground water, combustion of fossil fuels, mining and pesticides.[19]

Cadmium
Cadmium is released via nuclear fission plants, refining pesticides, mining, plants and plastics, Cd and Ni batteries, fertilizers and electroplating.[29] It is also emitted by metal smelters and tobacco smoke.[13]

Mercury
Liberation of mercury into environments through the mining paper & paint industries.[30] And also includes fertilizer industries, Batteries, Textile photographic fossil fuel combustion, waste incineration scientific instruments, pharmaceutical industries.[4, 22] Agriculture industries, pulp and paper preservatives, catalysts in organic synthesis are also other means of mercury liberation into the environment.[13]

Lead
Lead enters into the atmosphere from windblown dust, biogenic material.[28] Other sources of lead are industrial old lead pigment paints, fuel, mining sources, leaded gasoline, batteries, explosives, electroplating, glass manufacturing industries.[16, 19, 22]

Table: 3 Sources of Heavy metals [20, 22, 28]

S.No	Sources	Heavy Metals
1.	Mining	Cr, Ni, Cu, Zn, As, Cd, Hg, Pb
2.	Electroplating	Cr, Ni, Cd, Pb
3.	Textile Industry	Cr, Hg
4.	Industrial waste	Fe, Cu
5.	Petrochemical Industries	Ni, Co
6.	Batteries	Ni, Cu, Hg, Pb, Cd

Methodology used for the Elimination of Heavy Metals
Removal of toxic heavy metals from wastewater has become a major concern nowadays. Unproductive ways of dealing heavy metal ions may cause long-term risk to the ecosystem and

humans. Number of techniques for the efficient elimination of heavy metals from wastewater are available.

Chemical Precipitation
This is the physicochemical process and a very flexible approach to various pollutants removals. In chemical precipitation, a reagent is added which reacted with heavy metal ions and resulting in the formation of insoluble compounds or insoluble precipitates.[29] Additional methods like sedimentation and filtration are required to remove the precipitates.[29] To reduce the solubility of the dissolved pollutants, it can be carried out by lowering the temperature or by adding some chemicals like sodium bicarbonate and ferric chloride to the solution.[23] But chemical precipitation is not preferred due to increased cost. Chemical precipitation is applied for chromium and nickel plating industries.[24] The removal of the chemical precipitation process depends on pH, charge of the ions, temperature,[18] alkalinity, concentration of metal ions and phosphate level.[33]

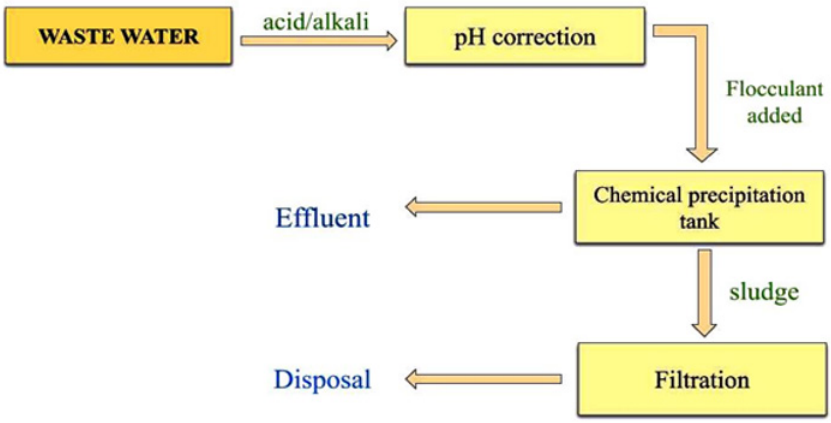

Fig 10: Schematic representation of chemical precipitation

Hydroxide Precipitation

Heavy metal ions have low solubility in alkaline medium, thus the precipitation technique is often organised in alkaline condition.[26] Lime, Limestone[29] and NaOH[33] are frequently used precipitants because they are cheap and available easily. Sodium carbonate, Calcium hydroxide , Ammonium hydroxide,[33] Magnesium hydroxide and Calcium chloride are other available precipitants used for the formation of hydroxide precipitates.

$M^{n+} + n(OH^-) \rightarrow M(OH)_n$ (precipitate)

where M^{n+} denotes the metal ions, OH^- ions denotes the precipitants and $M(OH)_n$ denotes the insoluble metal hydroxide precipitate.[33] Cr is removed using NaOH as precipitants.[26] Removal efficiency of Zinc is 99.3% by using lime as a precipitant.[23] The commonly used method is hydroxide treatment because cost of precipitant is cheap, relative simplicity and ease of automatic pH control.[34] Some metal hydroxides are amphoteric, that leads to secondary precipitation in solution.[33]

Sulphide Precipitation

This method is frequently used method and precipitants are mostly FeS, CaS (solid),[34] BaS, $Na_2S_2O_3$,[28] aqueous precipitants like NaHS, $(NH_4)_2S$ and Na_2S.[23] Sulphide precipitates are non-amphoteric, so it has high removal efficiency.[29]

$Na_2S + MSO_4 \rightarrow MS$ (precipitate) + Na_2SO_4

The sulphide precipitation overcomes the hydroxide precipitation because the solubility of sulphide precipitates are lower than the hydroxide precipitates.[33] Other advantages are rapid reaction rate, better setting properties,[33] reuse of sulphide precipitates by smelting and selective removal of metal ions.[23] The factors that influence the sulphide precipitation are pH, type of sulphur source, initial metal concentration, the precipitation agent, ratio of the two components.[32]

Formation of colloidal precipitates,[29] toxic fumes of Hydrogen sulphide [33] are the disadvantages of sulphide precipitation. It is not a conventional method for the mine water treatment, but it is widely used to eliminate heavy metals from the metal finishing industry. This process removes heavy metals like Lead, Chromium, Zinc, Nickel, cadmium and Mercury.[36]

Adsorption

A surface phenomenon where atoms or ions occupy to the active site of adsorbent, creating a layer of the adsorbate over the surface of the adsorbent is known as adsorption.[18] Adsorption is an effective purification and separation technique used in industries due to its flexibility in design and ease of operation.[37] Adsorption is a physicochemical technique extensively applied to eliminate heavy metals from the wastewater through the interaction between the adsorbents and pollutants.[39]Adsorption process increases with proliferation in the surface area of adsorbents.[40] The interaction between the adsorbent and adsorbate are classified into physical and chemical adsorption.[39] A very weak Vander Waals force of attraction holds the adsorbate particles and adsorbent and the process is called physisorption and it has low adsorption

capacity.[41,42] If the adsorbate and adsorbent are bound due to chemical bonds like covalent or ionic, then it is chemisorption.[43] Chemisorption has high efficiency but causes secondary pollution.[45, 46, 47]

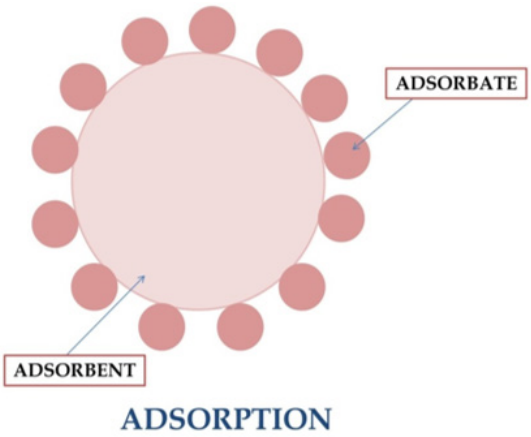

Fig 11: Schematic representation of adsorption

Generally, when pollutants get adsorbed on the solid adsorbents, there are three steps involved [49,52]:

i) The transference of the adsorbate from the bulk solution to the surface of the adsorbent
ii) Adsorption on the surface of the adsorbent
iii) Transport of pollutants within the adsorbent

All substances have an adsorption effect. But selection of adsorbents for the effective removal is an important component.[50]Adsorbents should have strong adsorption capacity, low equilibrium solubility, good selectivity and stability, ease of desorption.[52] The adsorption depends on time, quantity and nature of adsorbent, temperature, concentration of adsorbate, pH, etc.[54]

Depending on the amount of adsorbate desorbed from the adsorbent surface, the reversibility of the adsorption process can be measured.[55, 56]

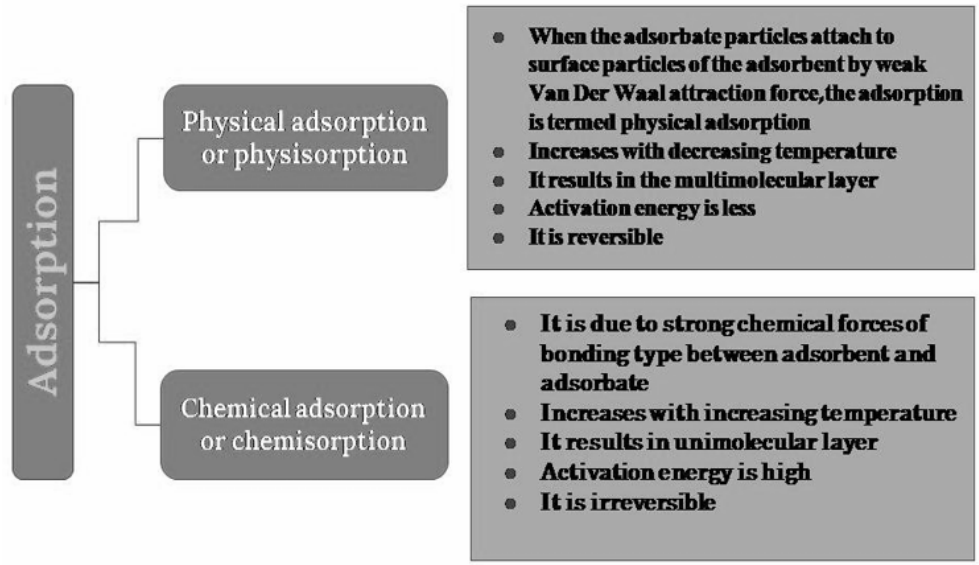

Fig 12: Different between physical adsorption and chemical adsorption

Adsorbents

To make an effective adsorption process, the selected adsorbent should be readily available, inexpensive, eco-friendly and abundant in nature58. The elimination of heavy metals utilizing cheaper adsorbents is developing in recent days. There are several cheap adsorbents resulting from manufacturing byproducts, farm waste, biomaterials, reformed biopolymers, etc. that are slightly modified to effectively remove heavy metals from polluted wastewater.[52] Modified natural materials are used for adsorption such as clay, peat moss, zeolite, etc. Clinoptilolite and Peat moss are the most frequently used zeolite due to its specificity to some heavy metals such as lead, copper, cadmium and zinc.[34] Calcinated phosphates are used to adsorb Pb^{2+}, Cu^{2+} and Zn^{2+}[7].

Adsorption using biological wastes and modified agricultural wastes is called Biosorption. Orange peel is effectively used for the removal Ni^{2+7}. Cr^{6+} are removed using almond shell, neem leaf powder,[9] crushed coconut shell, hazelnut shell, palm flower,[17] groundnut hull,[29] activated rice husk,[56] UlvaLactuca,[29] rose wood,[37] eggshells,[37] etc. Cu^{2+} are adsorbed using sesame husk,[81] tea waste,[59] marine green macroalgae,[49] UlvaLactuca,[49] etc. Musa paradisiaca peels are effevtively utilised to remove of Cd^{2+} and Pb^{2+}.[54] Some biosorbents utilized to remove heavy metals effectively are, CoriandrumSativum, grape stalk wastes,[34] coffee husk, sugar beet peel in gels, citrus peels, potato peels.[49,56,59,60] Agricultural waste is the most preferred adsorbent due to several reasons such as availability in abundance, economic and ecofriendly, efficient, unique chemical composition and low cost.[54] Heavy metals are also removed by using industrial solid wastes.[58,61] Cement bypass is used to treat tanneries effluent wastewater.[60] Treated waste newspaper has 72%

efficiency to remove Chromium(VI).[38] Zn^{2+} are removed using powdered waste sludge, dried marine green macroalgae.[61]

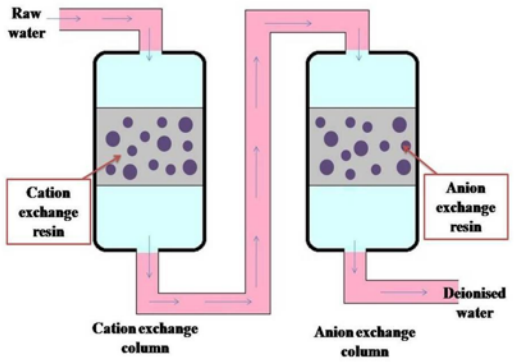

Fig 13: Schematic representation of ion exchange process

Ion Exchange Process

The phenomenon used in the ion exchange process is, it draws dissolved ions present in the liquid state to the solid state.[62] This method is utilized only for low concentration of metals present in the solution and it is extremely sensitive to the pH of the aqueous phase. The resin eliminates metal ions in the dissolved form and releases other ions of like charges without altering the internal structure of the resin.[62,63] In the cationic resins H^+ and Na^+ are exchanged with Ni, Cu and Zn ions in the same resin. Similarly hydroxyl and chloride ions present in the anionic resin can be replaced by the chromate, sulphate, NO_3^-, CN^- and DOC present in the solution.[64] Cation exchange resins called IRN77 and SKNI removes 95% of Chromium(III) from wastewater.[18] Among all the available kinds, synthetic polymers were preferred such as styrene- divinylbenzene, gel-like resins, macropore resin, etc.[26]

Membrane Process

The membrane filtration process has been increasingly used to treat wastewater due to its convenient operation.[69] A membrane adsorbent is ready by joining the functional groups to the surface and pore walls of the membrane. The aimed pollutants are preferentially adsorbed to the functional group site. When the polluted water moves via the membrane the functional active binding sites will be linked with the target pollutant to remove contaminants with a high adsorption rate and capacity.[71] Generally three types of membrane with minor differences are. There are many parameters that can disturb the membrane process like used materials, pore size and composition, which displays highly competent and feasible separation of heavy metals.[73] Membrane filtration is the most economic process because the water obtained from this process is of ultrapure water. Membrane process was also coupled with other techniques like ion-exchange process, adsorption, etc.,.[70] To achieve the required filtration, membranes like cellulose, zeolite, polyamide, polyester, natural mineral based ceramic membranes and carbon membranes are used.[69]

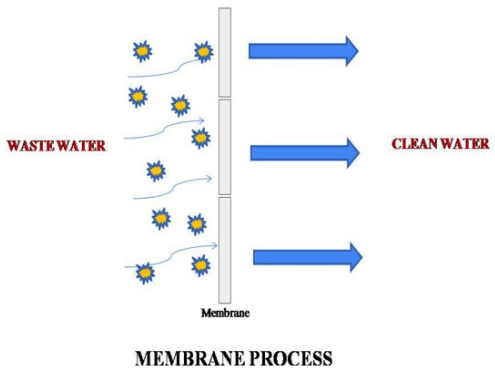

Fig 14: Schematic representation of membrane process

There are several membranes available to remove heavy metals.

- Cd is removed by montmorillonite kaolin, tobermorite, magnetitesiligagili and alumina membranes
- Cu is removed by chitosan nanoparticles embedded ketoglutaric acid membranes
- Lead is removed by polymeric cation exchanger having nano- Zr
- Arsenic removed by acid modified carbon membranes [61]

Ultrafiltration

Ultrafiltration uses permeable membranes to distinct heavy metals and suspended solids (1000-10000 Da) on the basis of its pore size stretching from 5 to 20 nm. Ultrafiltration 30 is mainly used for product recovery and pollution control in the food, chemical, electronics, pharmaceuticals, metal plating industries due to its lower driving force, lesser space necessity and high loading density.[29] More than 90% of removal efficiency can achieve by UF.[70]

Reverse Osmosis

A process that utilizes pressure to move the solution through a membrane that has solute on one side and permits the pure solvent on the other side is known as Reverse osmosis (RO). RO is dependent on the solute concentration, pH, pressure and water flux rate.[32] According to various studies from the literature, the removal percentage of reverse osmosis has achieved 99.9%.[72]

Nanofiltration

Nanofiltration performs separation between RO and UF. The molecular weight of the solute ranging from 200 to 1000 Da is rejected by a nanofiltration membrane with pore size ranging from 0.5 to 2 nm.[74] Analysing the comparative study of RO and NF, RO performs superior than NF in wastewater separation due to its anti- compressing ability of membrane.[75] Copper, Arsenic, Nickel and Chromium are removed from this process.[37]

Solvent Extraction

The relocation of material from one solvent to another solvent in which the distribution coefficient is different is referred by extraction. Majority of the material can be extracted by repeated extraction.[22] Solvent Extraction is the cost effective energy efficient process to extract heavy metals from various complex leach products and industrial effluents using organic solvents.[29] Organic solvents like acetone, ethanol, hexane, methanol, acetonitrile, etc., are the most commonly used solvents.[24] Solvent extraction is widely used in the field of biomedical industries, inorganic, organic chemistry labs and wastewater treatment.[10] The solvent extraction process is used to separate metals like Zinc,[78] Nickel, lead, chromium[30] and Cobalt.[34]

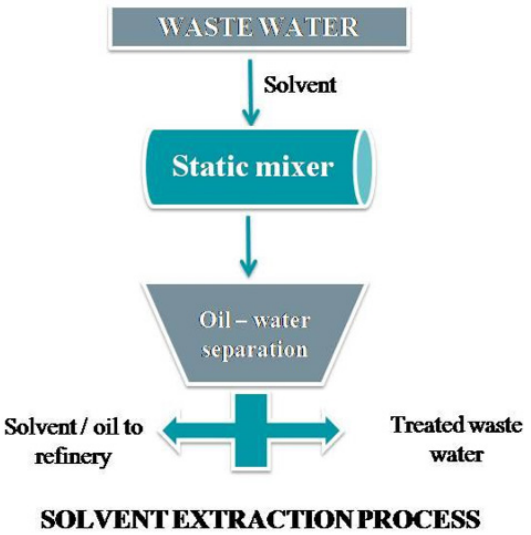

Fig 15: Schematic representation of solvent extraction Process

Electrocoagulation

Electrocoagulation (EC) is an electrochemical approach that uses electrical current to remove metals from the solution. The oxidation occurs at anode and reduction occurs at cathode when electricity is applied.[81] Electrocoagulation is one of the most promising techniques in the present era due to its high removal efficiency.[81] This method is utilized to remove heavy metals from industries like steam cleaners, municipal sewage, palm oil effluents, pressure washers,[82] electroplating, laundry, restaurant, poultry slaughterhouse,[82] textile, paper, acid mine drainage and organic matters.[82] Electrocoagulation process is used to remove suspended solids, dissolved metals, tanninsand dyes. EC process is able to eliminate heavy metals like Cr, Cd, Zn, Ni, Hg and Co.[83] pH, current density, conductivity,[83] gap between the electrodes [88] and treatment time are the major factors that affect the

performance of EC process.[89] Aluminium and Iron plates are widely used as sacrificial electrodes in EC processes.[61,66] But the usage of less reactive metal alloys like magnesium and aluminium alloy is a new trend.[84] Arsenic and Chromium are effectively removed using Iron electrode rather than Aluminium electrode.[85] By adjusting the pH and operating conditions, Cr (75%), Cu (97%), Zn (100%), and Ni (90%) removal efficiencies were obtained.[85]

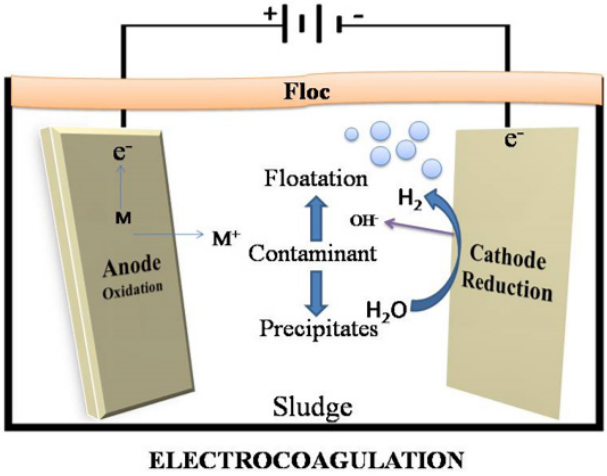

Fig 16: Schematic representation of electrocoagulation

Electrocoagulation Mechanism

Two electrodes were taken and current was applied between them and thereby the dissolution of the sacrificial anodes occurs and the supply ions to the wastewater was done by electrocoagulation. It allows settled, coagulated or soluble contaminants to develop aggregates.[86] This process depends on the nature of aqueous solution, specifically conductivity.[86\]

Table 4: Heavy metal removal methodologies –uses and limitations

S. No	Techniques	Advantages	Disadvantages
1.	Adsorption	Highly effective, low cost4, flexibility in design,[27] ease of operation10, eco- friendly	High production of waste products, Low selectivity[4]
2.	Ion exchange process	Low energy requirements ,[26] reversible, less sludge production ,[18] selectivity [10]	High cost process, resin does not exist for all heavy metals, not applicable for a large scale system, produce secondary pollutant [18]
3.	Membrane process	Small space requirement, low pressure ,[18] high separation selectivity[7]	Expensive7, complex process [23]
4.	Solvent extraction	Speed, simplicity,[21] less implementation time[10]	High cost and selective [10]
5.	Electro-coagulation	High efficiency, easy to handle,[17] eco-friendly[25]	Large source requirement of electricity,[17] high investment[25]

Steps involved in Electrocoagulation process are:

- oxidation of the “sacrificial electrodes”
- water molecules reduced at the negative electrode
- the formed ions migrate to the oppositely charged electrodes
- metallic hydroxides are formed by the interaction

of the positive ion and hydroxyl ion
- larger aggregates are formed by the absorption of pollutants into the hydroxide structures
- removal of aggregates by flotation [7]

Reuse of Treated Water

Water is an invaluable commodity that was once available almost for free cost. Water fulfills several needs in almost every industry. The utilised water from the industry comes out as wastewater with hazardous pollutants and leads the environment to danger. Wastewater is treated with various effective techniques.[94] The treated wastewater is almost free from pollutants and heavy metals are removed to the maximum extent. Reuse of the treated wastewater depends on factors such as waste volume, percentage of raw water, effluent standards, operation and maintenance costs. In the present era, reuse of treated wastewater is becoming a trend 96. The applications of purified wastewater includes washing, coating, cooling, spraying, boiler water make-up etc. Treated wastewater by Electrocoagulation is used for recoveries of Pb and Zn.[92] Treated textile wastewater is used for the irrigation of container grown ornamental shrubs.[97] Treated effluents from the dairy industry are used in cooling towers or boilers, washing the floors and external parts of trucks and rinsing outside areas in the dairy industry.[96]

Summary

This review article elaborates on the properties and role of heavy metals in various fields. On the basis of the study, Mercury and Chromium (VI) is the most toxic heavy metal that contaminates the environment from various sources. Iron does not cause much impact on the environment and human beings. Mining is the major source that releases many heavy metals into the environment. Various industries like textile, battery, electroplating are the other major sources that cause heavy metal pollution. The heavy metal contaminated wastewater is treated using various techniques like ion-exchange, adsorption, solvent extraction, electrocoagulation, membrane filtration and chemical precipitation. Among these techniques, Adsorption technique is used widely because of its simplicity. From the recent studies on adsorption, bio-sorbents are the extensively used adsorbent because of its easy availability. Among the three membrane filtration processes, reverse osmosis has a high removal efficiency of 99.9%. Electrocoagulation process has 90% removal efficiency to remove copper. 90% of Cr is removed using the ion- exchange process. Reuse of treated wastewater has various applications like growing shrubs, washing and cleaning.

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Conflict of Interest

The authors declare no conflict of interest.

Authors' Contribution

All the authors involved in reviewing and preparing the content for the review article.

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All data underlying the results are available as part of the article and no additional source data are required.

Ethics Approval Statement

Ethical review and approval were not required for the present review.

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