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Heavy Metals – Definition, Natural and Anthropogenic Sources of Releasing into Ecosystems, Toxicity, and Removal Methods – An Overview Study

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ABSTRACT

The constant discharge of large quantities of toxic substances due to human activities has led to a global environmental issue. Numerous industrial sectors' effluents, which include coal-based power plants, mineral extraction activities, electroplating processes, as well as battery manufacturing, release metallic ions towards different ecosystems, such as Cadmium (Cd), Mercury (Hg), and Chromium (Cr). Heavy metals pose a significant danger to living organisms, humans, and environments because of their properties, mainly severe toxicity, and strong accumulation ability. Metallic ions are not subject to breakdown towards final components when contrasted with organic contaminants, which are significantly impacted by biochemical and chemical decomposition. Consequently, eliminating these elements has been regarded as a significant task within the water treatment sector. The purpose of this article is to analyze the literature related to heavy metals in terms of different issues. The heavy metals expression is explained. The natural sources and human activities responsible for releasing metallic ions into the environment are comprehensively discussed. In addition, heavy metals toxicity and potential risks to humans and different ecosystems are included. Various approaches for removing heavy metals from industrial wastewater, along with their associated advantages and drawbacks, are further evaluated.

Keywords: heavy metals, toxicity, water contamination, maximum contamination level, treatment, wastewater, health risks, environment.

INTRODUCTION

Water is an essential source to human beings since it is necessary for several areas of life's existence, including drinking, healthcare, agriculture, economics, as well as industry. However, millions of individuals across the globe struggle with a lack of safe drinkable water [Bhatnagar & Sillanpää, 2010; Taka et al., 2017]. Human population increase, global warming, and water resources contamination in different ways: drainage, industrial discharges, chemical products, residential wastes, fertilizers, and herbicides, among many other factors responsible for such a drinking water deficiency [Mhlanga et al., 2007; Amin et al., 2014]. It was estimated that the number of individuals still lacking access to clean potable water is about one billion globally. Meanwhile, an additional 2.5 billion individuals still need water for adequate hygiene [Shahadat & Isamil, 2018]. Therefore, water treatment and proper sanitation are among the most critical global problems [Taka et al., 2017]. The primary strategy for achieving effective water use and addressing the scarcity of available water resources appears to be the treatment of wastewater effluents [Ahmed et al., 2011]. In particular, freshwater makes up for less than 1% of the entire accessible water on the planet's surface [Han et al., 2009].

The primary causes of water contamination are insufficiently processed sanitation water, hazardous industrial pollutants, industrial wastewater, as well as runoff from farming areas [Bhatnagar & Sillanpää, 2010]. Among them, industrial wastewater is considered a main contributor to water contamination [Nabi et al., 2011]. Industrial effluents typically have a higher concentration of pollutants than other wastewater kinds, such as heavy metals and phenolic compounds. The contaminants listed are classified as extremely poisonous and barely degradable substances [Mutamim et al., 2012; Zhang et al., 2014]. Even at low levels, releasing such effluents towards lakes and rivers presents a serious danger to the water environment and its living things, causing major disruptions and significant harm [Shahadat & Isamil, 2018].

The amounts of metallic ions in industrial effluents have increased with the development of the manufacturing sectors and human-related activities, including the plating process, electrolysis, battery industry, pesticides and fertilizers, mining operations, metal purification methods, as well as the paper industry [Manzoor et al., 2013; Mubarak et al., 2014; Clemens & Ma, 2016]. In addition to contaminating surface water resources (e.g., rivers and lakes), metallic ions could reach underground water in very small quantities through their leaking with rain and snow, causing pollution as well [Kılıc et al., 2013; Ojedokun & Bello, 2016]. Several metals, such as lead (Pb), mercury (Hg), and nickel (Ni), are extremely harmful to both humans and ecosystems [Meena et al., 2008; Ojedokun & Bello, 2016; Alalwan et al., 2020]. Heavy metals are a significant component of soil and water contaminants and cause toxicity [Okeimen & Onyenkpa, 2000]. Such metals exist in different ecosystems, including soil and water, and could contaminate food and drinkable water [Ojedokun & Bello, 2016]. Therefore, big concerns have been raised globally about water contamination brought on by the discharge of heavy metals into the environment [Abbas et al., 2016].

TERMINOLOGY OF HEAVY METALS

Heavy metals commonly refer to a group of comparatively dense and harmful elements, even in very low concentrations [Duruibe et al., 2007; Appenroth, 2010]. Such a group comprises metals and metalloids, which possess densities higher than 5 g cm^{-3} and atomic masses varying from roughly 60 to 200 [Srivastava & Majumder, 2008; Barakat, 2011; Burakov et al., 2018]. Arsenic (As), chromium (Cr), cadmium (Cd) and copper (Cu) are a few instances of heavy metals

N	Classification A	Classification B	Category examples
1	Non-essential metals	Extremely toxic heavy metals	As, Cd, Hg, Pb, Se, Sn, Tl
2		Precious heavy metals	Au, Ag, Pd, Pt, Ru
3		Radionuclides metals	Am, Pr, Ra, Th, U
4	Essential metals	Micronutrient metals	Co, Cr, Cu, Fe, Mn, Mo, Ni, Zn
5		Macronutrient metals	Ca, K, Mg

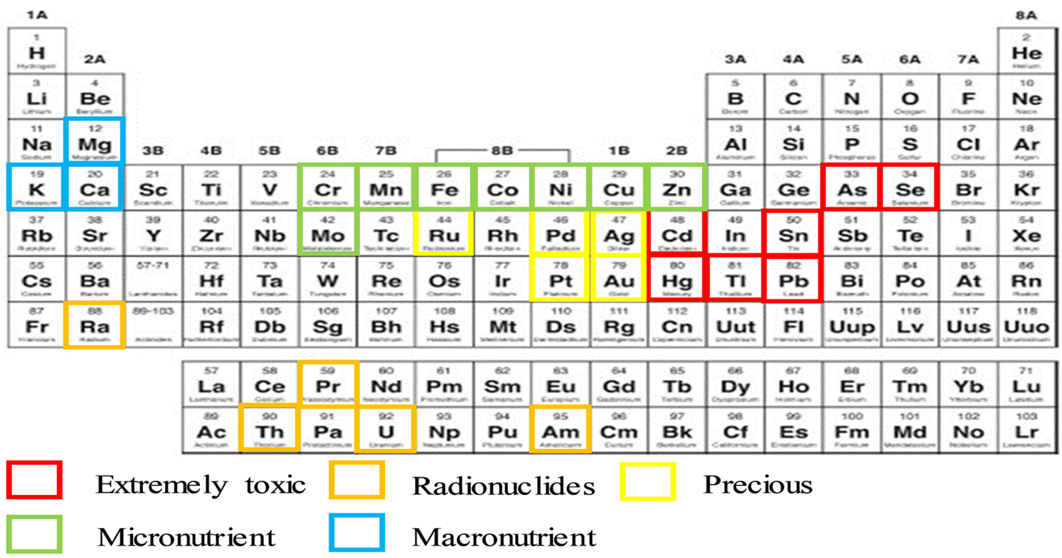

Figure 1. Classification of heavy metals into different groups, their representative examples, and their distribution in the periodic table

present in different ecosystems and wastewater, with levels varying typically from $ng \cdot L^{-1}$ to $mg \cdot L^{-1}$ [Kim et al., 2013; Singh et al., 2015; Fu et al., 2017]. Such metals are non-biodegradable elements compared to other pollutants and are typically classified into two categories. Poisonous metals like As and Pb make up the first category, which are entirely unfavourable substances, have no biochemical advantages to human beings, and are hazardous regardless of their levels. The second category consists of important metals such as manganese (Mn) and zinc (Zn), which are beneficial to humans biologically and favourable in small amounts. However, these metals are considered dangerous when existing in large quantities [Chen, 2012]. Similarly, heavy metals are divided into non-essential and essential elements of living things in terms of their functions during biological activities. Essential elements are necessary for living things and usually in very small amounts, while there is no proven biochemical function for non-essential elements to living beings. Zn, Mn, and Fe are essential elements, whereas Pb and Cd are considered physiologically unnecessary and are hazardous metals [Türkmen et al., 2009; Jović et al., 2012; Ali et al., 2019]. In contrast, others divided heavy metals into four more specific classes: toxic, nutrient, radionuclides, and precious group [Alalwan et al., 2020; Singh & Ambawat, 2020]. Figure 1 displays the categorization of heavy metals into various groups, along with some of their illustrative instances and locations within the periodic table.

HEAVY METALS CONTAMINATION LEVELS

Heavy metals being released into ecosystems have been significantly impacted by recent fast industrialization [Fu & Wang, 2011]. Such manufacturing activities include but are not limited to metal processing, the battery industry, paper production, the fabric and dyeing sector, electrolysis processes, and mining operations [Qasem et al., 2021]. Due to the activities of the sectors mentioned above, enormous quantities of effluent containing metallic ions are released continuously toward the ecosystems [O'Connell et al., 2008; Zhao et al., 2016; Jawed et al., 2020]. Because metallic ions are harmful, their existence in environments is a significant issue [Khan et al., 2004; Igwe & Abia, 2006]. Such metals are extremely dangerous elements even when present in low quantities due to their significant cancer-causing potential along with their accumulation capability [Nguyen et al., 2013; Zou et al., 2016; Agarwal & Singh, 2017]. The reason behind accumulation within various organisms is mainly because of their not degradable feature [El-Sherif et al., 2013; Abbas et al., 2016; He et al., 2020]. Additionally, heavy metals are highly soluble within aqueous environments, making it simple for various species to absorb. Therefore, when such metals get into the food chains, these elements can accumulate in large amounts, causing severe consequences for living things [Akpor et al., 2014; Harvey et al., 2015; Bhateria & Singh, 2019]. Heavy metals also pose a risk to ecosystems regarding waste issues due primarily to their features: high stability with a lack of degradability, even using biological decomposition [Ahluwalia & Goyal, 2007; Yang et al., 2019]. As a result, this would not be strange that water contamination with metallic ions is getting serious attention globally owing to its significant hazards for various species along with negative ecosystem effects [Kim et al., 2013; Fu et al., 2017; Ali et al., 2019]. Heavy metal pollution can cause significant harm to various living things, even in very low amounts. Therefore, heavy metal contaminants must be removed from polluted effluents [Amin et al., 2014]. In order to accomplish such an objective, different governmental agencies and research centres have placed guidelines and set targeted levels for heavy metals within drinkable water. The mentioned levels, regularly revised, represent the highest permissible amounts of pollutants, also called maximum contamination levels (MCL). Table 1 presents the targeted levels (MCL) of various heavy metals set by different agencies and compares and/or updates their corresponding values over time.

HEAVY METALS RESOURCES

Heavy metals are primarily released into ecosystems via two different paths: natural resources and various activities performed by humans (also referred to as anthropogenic activities). Volcanic explosions, soil deterioration (e.g., surface erosion), and disintegrating rocks are natural sources for releasing heavy metals [Burakov et al., 2018; Singh et al., 2021]. Sediments of rivers and pollution of the air have also been identified to be major contributors to the release of toxic heavy metals within

Table 1. MCL values that established by various governmental agencies and environmental research centers

N	Pollutant metal	M. W.	Class	US EPA[b]		California Standard[b]		Canadian Guide[c]		WHO Guide[d]	
		g mol^{-1}		MCL[a]	Date	MCL[a]	Date	MCL[a]	Date	MCL[a]	Date
1	Aluminum (Al)	26.98	Metal	0.05-0.2	January 1991	1	February 1989	2.9	2021	-	-
						0.2	September 1994	0.1	2021		
2	Antimony (Sb)	121.76	Metalloid	0.006	July 1992	0.006	-	0.006	1997	0.02	2003
3	Arsenic (As)	74.92	Metalloid	0.05	June 1977	0.05	1977	0.01	2006	0.01	2011
				0.01	January 2006	0.01	November 2008				
4	Barium (Ba)	137.33	Metal	1.0	June 1977	1.0	1977	2.0	2020	0.7	2003
				2.0	January 1991						
5	Beryllium (Be)	9.01	Metal	0.004	July 1992	0.004	September 1994	-	-	-	-
6	Boron (B)	10.81	Metalloid	-	-	-	-	5.0	1990	2.4	2009
7	Cadmium (Cd)	112.41	Metal	0.01	June 1977	0.01	1977	0.007	2020	0.003	2011
				0.005	January 1991	0.005	September 1994				
8	Chromium (Cr)	51.99	Metal	0.05	June 1977	0.05	1977	0.05	2018	0.05	1993
				0.1	January 1991						
9	Copper (Cu)	63.55	Metal	1.3	June 1991	1.0	1977	2.0	2019	2.0	2003
				0.25[e]	-	1.3	December 1995				
10	Iron (Fe)	55.85	Metal	-	-	-	-	-	-	-	1[f]
11	Lead (Pb)	207.2	Metal	0.05	June 1977	0.05	1977	0.005	2019	0.01	2011
				0.015	June 1991	0.015	December 1995				
				0.006[e]	-	-	-				
12	Manganese (Mn)	54.94	Metal	-	-	-	-	0.12	2019		2[f]
13	Mercury (Hg)	200.59	Metal	0.002	June 1977	0.002	1977	0.001	1986	0.006	2004
				0.00003	-	-	-				
14	Nickel (Ni)	58.69	Metal	0.2[e]	-	0.1	September 1994	-	-	0.07	2004
15	Radium (Ra)	226.03	Metal	0.0075	June 1977	0.0075	1977	-	-	-	-
						0.0075	June 2006				
16	Selenium (Se)	78.96	Non-metal	0.01	June 1977	0.01	1977	0.05	2014	0.04	2010
				0.05	January 1991	0.05	September 1994				
17	Silver (Ag)	107.87	Metal	-	-	-	-	-	-	-	3[f]
18	Thallium (Tl)	204.38	Metal	0.002	July 1992	0.002	September 1994	-	-	-	-
19	Uranium (U)	238.03	Metal	0.03	December 2000	0.03	January 1989	0.02	2019	0.03	2003
				-	-	0.03	June 2006				
20	Zinc (Zn)	65.38	Metal	0.8[e]	-	-	-	-	-	-	-

Note: (a) MCL values are in units of mg·L^{-1}; (b) MCL values of EPA and California guidelines were obtained from (Maximum contaminant levels, 2018); (c) MCL values of the Canadian guide were obtained from (Guidelines for Canadian drinking water quality, 2022); (d) MCL values of the World Health Organization were obtained from (Guidelines for drinking water quality, 2011); (e) The mentioned MCL values were taken from various references (Barakat, 2011; Nguyen et al., 2013; Burakov et al., 2018); (f) No recommended health-related standard (Guidelines for drinking water quality, 2011); (1) Fe staining occurs at amounts greater than 0.3 mg·L^{-1} in clothing and water fittings; (2) Mn levels exceeding 0.1 mg·L^{-1} impart an undesirable flavour to drinking water and stain both laundry and sanitation appliances; (3) Ag amounts up to 0.1 mg·L^{-1} are possibly permitted without threatening public safety.

coastal aquatic ecosystems [Krishnani et al., 2004]. Human-caused activities involve many manufacturing processes like mining-related industries, chip manufacturing, metal coating, battery manufacturing, pigments, drainage, garbage dumps, and agriculture-related activities [Reed et al., 1994; McLaughlin et al., 1996; Krishnani et al., 2004]. As a result, heavy metals have become among the most present poisonous substances within aquatic and terrestrial environments [Salem et al., 2000; Mohammed et al., 2011; Burakov et al., 2018].

In terms of As, many human and natural activities cause contamination of Arsenic water bodies [Sarkar & Paul, 2016]. As is discharged to available groundwater due to natural formations within rocks sediments, underground water, and worn volcano rocks [Abbas et al., 2016]. As is also released into aquatic environments by human-caused processes such as mining operations, mineral processing, smelting, thermal generation units, chemical pesticides, and preservation of wooden materials [Harvey et al., 2002; Srivastava et al., 2021]. As is found primarily in two forms: As (III) and As (V) [Igwe & Abia, 2006]. In ecosystems, however, it can be found in four different forms: arsine (AsH_3), metalloid form (As^0), organic, and inorganic form (As^{3+} and As^{5+}) [Shah et al., 2010; Sattar et al., 2016]. According to the National Arsenic Occurrence Survey (NAOS), As-related substances are found in about 10% of surface water resources such as rivers and lakes and approximately 21% of underground water available resources [Abbas et al., 2016].

Regarding Cd, despite it being uncommon metal, it is found naturally within sediments, water, and minerals such as carbonate compounds [Balali-Mood et al., 2021]. The heavy metal Cd and its ions are highly soluble in water. Thus, such metal and its ions can move quickly via soil and water resources and have a bioaccumulation tendency [Qi et al., 2018]. Rising Cd levels could be caused naturally as a result of volcanic activities as well as different human activities like fertilizer industries, power generation, wastewater drainage, waste products, mining, and battery industries, electroplating, and dyes industry [Suksabye et al., 2016; Dou et al., 2017; Khan et al., 2017]. However, the steel and plastics sectors are the two major uses of Cd metal. Industries involving metal plating, as well as coating processes, are two additional contributors to Cd pollution. Additionally, Cd is utilized in solar cells as the Cd-Te type and batteries as the Ni-Cd type [Li et al., 2004].

In terms of Cobalt (Co) metal, it represents one of the most uncommon metals on the planet's surface. Co is a tough, shiny silvery substance with an appealing look and rust resilience that shares many chemical characteristics with other elements like Ni and Fe [Barceloux[a], 1999; Haldar, 2017]. Co substances are found in two oxidation forms: (Co^{2+}) and (Co^{3+}); the first oxidation state is more readily accessible economically and ecologically [Barceloux[a], 1999; Paustenbach et al., 2013]. The hard metal sector uses nearly 15% of the Co produced globally to manufacture hard metals [Klasson et al., 2016]. Hard metals are widely produced using three main components: Co, tungsten, and tungsten carbide. The main component of the metal combination is tungsten carbide, which makes up about 90% of it. Co makes up the remaining 10% and is a binding material [Lison et al., 1996]. Co is also present in and released from several electrical and electronic equipment while recycling, frequently in amounts well above the local regulatory level [Nnorom & Osibanjo, 2009; Lim & Schoenung, 2010]. In addition, Co is frequently used as a drying agent in some paints and inks, as well as in Co blue-coloured pigments for decorating ceramic pots [Jensen & Tuchsen, 1990; Christensen & Poulsen, 1994].

In terms of Cr metal, it represents the sixth most common transition metal and one of the most naturally existing elements on the planet's surface. It can exist in natural formations associated with other different elements like ferric chromite ($FeCr_2O_4$) [Mohan & Pittman Jr, 2006]. Cr is a hazardous heavy metal occurring naturally in various valence states varying from -2 to 6+ [Tchounwou et al., 2012; Shekhawat et al., 2015]. However, Cr (VI) and Cr (III) are the two most stable forms that pose significant risks to ecosystems [Yu et al., 2000; Saifuddin M, & Kumaran, 2005; Shekhawat et al., 2015]. Cr is typically released into water resources via many industries such as dyes production for painting and wood protection materials, the textile industry, electrolysis, tannery, metal coating, and chromate synthesis process [Faisal & Hasnain, 2004; Ihsanullah et al., 2016; Kazakis et al., 2018].

Regarding Cu metal, it is an abundant mineral that may exist within a wide range of rock types at trace levels [Flemming & Trevors, 1989]. It also presents inside the human body in several cells and organs at trace levels, where the liver has its most considerable amount [Turnlund, 1998]. Natural water typically contains Cu concentrations ranging between 4 and 10 $\mu g \cdot L^{-1}$; its majority is linked with organic molecules, while its average level is about 50 ppm in soils [Gaetke & Chow, 2003]. Numerous manufacturing and agricultural processes require Cu substances, which could then discharge to ecosystems and finish in different water systems [Poole, 2017]. Such activities increase concentration above normal levels, resulting in ecosystems' Cu-contamination. Mining activities, tanning, metal plating and electronics manufacturing are the major sources of Cu release to the environment [Ahluwalia & Goyal, 2007; Igwe & Abia, 2006; Tóth et al., 2016].

In terms of heavy metal Hg, it exists naturally, mostly in two forms: element and sulfide; its concentration is about 0.5 ppm on the earth [Bernhoft, 2012]. Additionally, Hg can be found in the environment due to the natural degassing of the earth's rocks, volcanic emissions, and oceans evaporating [Langford & Ferner, 1999]. Mercury can be found in various forms; however, such forms are categorized into two main groups: organic and inorganic mercury. While the inorganic group involves Hg's metallic state, its vapour state, and mercuric and mercurous salts, the organic class contains different formations that consist of Hg linked to an organic structure and/or group (e.g., a methyl group) [Langford, & Ferner, 1999; Bernhoft, 2012; Li et al., 2017]. Hg can accumulate within sediments, aquatic resources, and the topsoil surfaces when released from natural formations, fossil fuels, and ores, as well as emitted from industrial sources [Bonzongo et al., 1996; Liu et al., 2016]. Anthropogenic causes of Hg levels in the environment include coal-based generation plants, mining activities, the metallurgical industry, chemical production, and metal coating [Boylan et al., 2003; Igwe & Abia, 2006; Streets et al., 2017]. Hg substances possess numerous uses in mineral extraction processes, including gold mining. In addition, fluorescent light lamps are made with Hg in lighting manufacturing plants. Moreover, plants can be protected against diseases using fungicides such as methyl-Hg and ethyl-Hg [Balali-Mood et al., 2021].

Regarding Ni metal, it counts as the twenty-fourth-most common mineral on the earth; it is considered one of the trace metals that poses a major danger to public health and ecology [Duda-Chodak & Blaszczyk, 2008; Sule et al., 2020]. Its concentration is estimated at 50 ppm within the earth's crust layers [Barceloux[b], 1999]. It is silver-white in appearance, with various valence states ranging between -1 and +4 [Barceloux[b], 1999; Denkhaus & Salnikow, 2002]. However, it was demonstrated that Ni^{+2} is the most widely spread state in biosystems among its different valent states [Denkhaus & Salnikow, 2002; Valko et al., 2005]. The Ni majority exists as hydroxides in a solid phase for pH values higher than 6.7, while all Ni complexes have moderate solubility when pH values are lower than 6.5 [Valko et al., 2005]. The Ni concentrations within soils are typically below 100 $mg \cdot kg^{-1}$, while its concentrations are usually less than 0.005 $mg \cdot kg^{-1}$ in surface water [McIlveen & Negusanti, 1994]. In freshwater, Ni levels, which may be varied between 1 and 10 $\mu g \cdot L^{-1}$, could be much higher and range between a few hundred and 1000 $\mu g \cdot L^{-1}$ in some seriously polluted waters [Pane et al., 2003]. The principal manufacturing processes that contribute to Ni contamination in the environment are those used to make batteries, certain alloy manufacturing, the printing industry, metal coating, smelting applications, waste incinerators, fossil fuel combustion, including power generation and car emissions [Barcan & Kovnatsky, 1998; Yang et al., 2009; Hassan et al., 2019]. Such industries employ different Ni-related substances, including nickel acetate ($Ni(CH_3CO_2)_2 \cdot 4H_2O$), nickel oxide ($NiO$), nickel hydroxide ($Ni(OH)_2$), and nickel carbonate ($Ni_4CO_3(OH)_6(H_2O)_4$) [Cempel & Nikel, 2006]. The mentioned substances eventually accumulate in different ecosystems (water resources and soils), and therefore they could be readily absorbed by the plants. As a result, these compounds may become part of the food chain and harm living things [Cempel & Nikel, 2006; Sreekanth et al., 2013].

In terms of Pb metal, it is a non-degradable chemical element considered the most dangerous substance within the heavy metals group in ecosystems [Ara & Usmani, 2015; Abbas et al., 2016; Charkiewicz & Backstrand, 2020]. It is a bluish-grayish-coloured element that occurs naturally in trace quantities on the planet's ground [Tchounwou et al., 2012]. Pb usage could be traced to the early centuries because of its significant physicochemical characteristics [Mahaffey, 1990]. Such remarkable features, including softness, flexibility, plasticity, weak conductivity, and corrosion resilience, pose a challenge to abandoning this substance [Ara & Usmani, 2015; Saeed et al., 2017]. Because of its non-degradable nature and continuing usage, Pb accumulates in the ecosystems; its concentrations increase and thus, the incidence of linked health problems increases dramatically [Ara & Usmani, 2015; Saeed et al., 2017; Irawati et al., 2022]. Pb exists in various forms on the earth, including metallic, Pb salts, and Pb-organic compounds [Assi et al., 2016]. Pb is employed for a wide variety of applications nowadays and has a long history of industrial usage. It could be estimated that Pb applications are found in about 900 various industries, some of which include metal processing, mining, and battery industries [Karrari et al., 2012]. In the environment, the major sources of Pb release include electroplating, smelting and its related combustion, painting and dyes manufacturing, the plastics industry, fabrics, yachts manufacturing, printing industry, Pb-contained tubes, and preservative materials [Ara & Usmani, 2015; Ince et al., 2017]. In the US alone, it was reported that 1.52 million tons of Pb were utilized for different commercial uses in 2004. The manufacture of Pb-based batteries represented 83% of the total consumption. The remainder was used in various goods, including Pb sheets, Pb oxides applied in painting, glass industry, dyes, and chemicals manufacturing, and Pb for munitions production, with values of 1.7%, 2.6%, and 3.5%, respectively [Tchounwou et al., 2012]. The ceramics industry, cables and steel recovery, cathode radiation tubes (high-vacuum tubes), finishing equipment, low-melting alloy manufacturing (solders), and flashing parts are also considered primary sources for Pb releasing into ecosystems [Adiana et al., 2017; Rosca et al., 2019]. In addition, Pb is currently employed in bearing manufacture, aviation fuel, cable covering, nuclear reactor shielding, and radioactive substances vessel manufacturing [Charkiewicz & Backstrand, 2020]. More importantly, the main sources of environmentally harmful Pb included the substance $Pb(C_2H_5)_4$ widely used as an additive material for vehicle fuel and Pb-based home painting till recently [Spivey, 2007; Ara & Usmani, 2015; Charkiewicz & Backstrand, 2020]. Pb-water contamination and its release through water or drinking water pipeline corrosion have lately caused significant concerns across the globe [Deshommes et al., 2016; Masters et al., 2016; Abokifa & Biswas, 2017]. Therefore, drinking water which contains significant Pb quantities is considered the main contributor to the presence of Pb inside human bodies [Abbas et al., 2016].

Table 2. Characteristics of heavy metals, their oxidation states, and human activities responsible for their environmental discharge

N	Metal type	Oxidation states	Stable form	Metal release resources to the environment
1	Arsenic (As)	As^0 to As^{+5}	As (III), As (V)	Mining operations, mineral processing, smelting, thermal generation units, and chemical pesticides.
2	Cadmium (Cd)	Cd^{-1} to Cd^{+2}	Cd (II)	Fertilizer industries, power generation, wastewater drainage, waste products, mining, battery industries, electroplating, dyes industry, metal plating, and the steel and plastics sectors.
3	Chromium (Cr)	Cr^{-2} to Cr^{+6}	Cr (III), Cr (VI)	Electrolysis, tannery, metal coating, dyes production for painting, wood protection materials, the textile industry, and chromate synthesis process.
4	Cobalt (Co)	Co^{-1} to Co^{+4}	Co (II), Co (III)	Hard metal sector, electrical and electronic equipment, drying agent in some paints and inks, and Co blue-coloured pigments.
5	Copper (Cu)	Cu^{-2} to Cu^{+4}	Cu (I), Cu (II)	Mining activities, tanning, metal plating and electronics manufacturing.
6	Lead (Pb)	Pb^{-4} to Pb^{+4}	Pb (II), Pb (IV)	Metal processing, mining, battery industry, electroplating, smelting, painting and dyes manufacturing, the plastics industry, fabrics, yachts manufacturing, printing industry, Pb-contained tubes, preservative materials, the ceramics industry, cables and steel recovery, cathode radiation tubes, bearing manufacture, aviation fuel, nuclear reactor shielding, and radioactive substances vessel manufacturing.
7	Mercury (Hg)	Hg^{-2} to Hg^{+2}	Hg (I), Hg (II)	Coal-based generation plants, mining activities, the metallurgical industry, chemical production, metal coating, mineral extraction processes, fluorescent light lamps, and fungicides.
8	Nickel (Ni)	Ni^{-2} to Ni^{+4}	Ni (II)	Batteries, certain alloy manufacturing, the printing industry, metal coating, smelting applications, waste incinerators, and fossil fuel combustion, including power generation and car emissions.
9	Zinc (Zn)	Zn^{-2} to Zn^{+2}	Zn (II)	Brass coating, brass and Zn metals-related working activities, manufacturing of wood-related pulp, steel work activities related to pipe coating, paper manufacturing, painting industry, dyes manufacturing, and pharmaceutical and cosmetic products.

Regarding Zn metal, it represents one of the commonly found transition elements on the planet's surface and a necessary minor element to nearly every living thing [Vallee & Falchuk, 1993; Roohani et al., 2013; Lee, 2018]. It is a bluish-white, fragile, shiny metal with a solid state at ambient temperature. It is typically known as a mildly reactive metal regarding its reaction with metals and O_2 and easily becomes mouldable and flexible once heated to higher than 110 °C [Wuana & Okieimen, 2011]. Zn is a naturally existing metal in the form of a sphalerite (ZnS) material with five isotopes, ^{64}Zn being the most commonly abundant isotope among them [Broadley et al., 2007; Audi et al., 2017]. Zn and magnesium (Mg) share many features, including valence state (+2) and size, making them chemically comparable elements [Kaur & Garg, 2021]. It is an essential molecular element found in a large number of protein molecules (zinc-finger), which perform a variety of roles [Berg & Shi, 1996]. It is a critical element of numerous protein molecules and functions in over 300 enzymes as a catalyst and/or co-enzyme [Rahman & Karim, 2018]. Zn^{2+} ions possess strong bond affinities with other elements, including N, O, and S of amino acids within different enzymes and/or proteins such as histidine, cysteine, and peptide [Leuci et al., 2020]. Zn is essential for the regulation of numerous metabolisms and physiological activities within biological tissues. On the other hand, excessive Zn levels have adverse effects on health [Abbas et al., 2016]. The commercial uses for Zn include brass coating, brass and Zn metals-related working activities, manufacturing of wood-related pulp, steel work activities related to pipe coating, paper manufacturing, painting industry, dyes manufacturing, and pharmaceutical and cosmetic products [Volesky & Schiewer, 2002; Deliyanni et al., 2007; Tóth et al., 2016]. Zinc enters ecosystems due to silt remobilization, farming-related practices, subsurface water infiltration, and a mix of the above causes [Deliyanni et al., 2007]. Heavy metals' properties, valence states and primary sources of release into the environment are summarized in Table 2.

METALLIC IONS TOXICITY

Massive amounts of dangerous metallic ions are discharged toward ecosystems by industrial wastewater in various sectors, including electrolysis and electroplating processes, metals-related industries, and dyes manufacturing. The release of these dangerous elements poses a big threat to human health, living things, and ecosystems [Ahluwalia & Goyal, 2007]. Heavy metals tend to cause genotoxic implications, immediate as well as long-lasting toxic consequences, development and generation toxicity impacts, and cancer-causing capability on living beings [Villaescusa & Bollinger, 2008; Zhitkovich, 2011; Fu et al., 2017]. Once metallic ions are present in sufficient quantities, they become hazardous for living beings in their environment. Nonetheless, several heavy metals, such as Cd and Ag, are highly poisonous, even in small quantities [Igwe & Abia, 2006]. Of various heavy metals, Pb and Hg are regarded to be the most hazardous elements due to their major ecological consequences [Volesky, 1994]. Meanwhile, Cd and Pb are considered extremely harmful to the Neural system, while Cr, Cu, and As are regarded as harmful metallic elements as well [Puranik & Paknikar, 1997]. Metallic ions could cause harm to physiological bodily functions forever, cause physical discomfort, and even result in possibly life-threatening illness [Malik, 2004; Barakat, 2011]. The adverse health effects of various heavy metals on human beings are explained comprehensively as follows.

In terms of As, the intestinal tract is the main route of As uptake. Additional pathways include As contact with the skin along with As inhaling. After being distributed to numerous bodily systems and tissues, such as the musculature, brain, kidneys, and lungs, As is converted into two different acids: Methylarsinic acid as well as Cacodylic acid (dimethyl arsinic), with the second type constituting the majority of As's elimination in the urine [Del Razo et al., 1997; Ratnaike, 2003]. As also attacks the skin, resulting in its damage and leading to develop skin cancer during its severe stages [Igwe & Abia, 2006]. Both acute and persistent As Poisoning has been associated with the malfunction of many essential enzymes. As works to prevent the function of enzymes by inhibiting their sulfhydryl groups, causing malfunction in enzymes' roles [Balali-Mood et al., 2021]. In addition, As metal causes capillary endothelial deterioration, causing an increase in arterial permeation, resulting in dilatation and circulation failure [Jolliffe et al., 1991]. Most people who have been subjected to As exposure in potable water experienced cancer-related issues. The illnesses that were observed in individuals who consume water-containing As include diabetes, arterial illnesses, skin-related and renal cancers, along with different interior malignancies [Ng, 2005; Sharma & Sohn, 2009].

Regarding Cd, it is a toxic element regarded as one of the leading hazardous contaminants in water [Abbas et al., 2016]. Cd metal accumulates mainly in the human kidneys, with a comparatively lengthy half-life of 10 to 35 years [Arias et al., 2002; Al-Khaldi et al., 2015]. Kidneys are the primary organ affected by cadmium poisoning as a water contaminant. Cd accumulation also impacts the bones and promotes cancer at its high levels. However, the most serious kind of Cd exposure seems to be intense bone pain which is known as *"itai-itai"* illness. In addition, Cd has been linked to liver disease and high blood pressure [Kasuya et al., 1992; Yasuda et al., 1995; Ahluwalia, & Goyal, 2007]. Moreover, Cd in polluted water may interfere with vital bodily functions and cause short-term and/or long-lasting issues [Jiang et al., 2015; Richter et al., 2017].

In terms of Co metal, it primarily targets the pulmonary system and skin among different organs [Leyssens et al., 2017]. There are three aspects related to inhaling the dust of Co element: work activities-related asthma, hypersensitivity lung disease, and inflammatory lungs associated with and without massive cells [Bezerra et al., 2009; Moreira et al., 2010]. During the initial exposure period, hypersensitivity lung disease typically develops as the initial inflammatory stage of fibrosis; however, after prolonged contact, it could progress to permanent fibrosis [Gotway et al., 2002; Dunlop et al., 2005; Enriquez et al., 2007]. Inflammatory lungs associated with massive cells involve various symptoms such as a decrease in weight, exhaustion, breathlessness with exercise, and coughing [Choi et al., 2005; Enriquez et al., 2007]. Of various skin disorders, contact allergic dermatitis is the most frequent form of workplace skin illness. As Co metal is one of the common substance allergens, Co, Cr, and Ni, in workplaces, interaction with such metal is the primary cause of the mentioned illness [Barceloux[a], 1999]. The danger of lung cancer associated with Co dust exposure has been taken into account. Nevertheless, it is clear that Co is not the primary cause of such cancer type; rather, the mixture of Co and tungsten carbide is regarded as a carcinogenic substance [Wild et al., 2009].

Regarding Cr metal, Cr (III) is a vital component of the human body, and it is far less harmful than the form of Cr (VI) [Atieh et al., 2010]. Cr (III) is a stationary ion form, but Cr (VI) is easily transported via water and soils and acts as a powerful oxidant that could also be absorbed by the body's skin [Park & Jung, 2001]. On the other hand, Cr (VI) is highly poisonous and can result in significant diarrhea, vomiting, lung congestion, as well as damage to the liver and renal system [Mohan et al., 2006; Fang et al., 2007; Hu et al., 2009]. In the environment, Cr-contained substances are considered nephrotoxic with a high carcinogenicity rate [Chen & Hao, 1998]. By bioaccumulating within the human parts, Cr is capable of causing several illnesses. Such conditions include cutaneous, neurological, and gastrointestinal tract diseases, as well as the emergence of various malignancies; cancers in the lungs, pharynx, bladder, and thyroid [Fang et al., 2014]. In addition, chromate (CrO_4^{-2}) exposure is highly concerning for many reasons, including its poisonous material with various effects such as mutagenicity, carcinogenicity, and teratogenicity [Igwe & Abia, 2006; Qureshi & Shakoori, 1998; Cheng et al., 1998].

In terms of Cu metal, it is regarded as an extremely hazardous element to drinkable water, and the only element more harmful when compared with Cu is Hg [Perić et al., 2004; Liu et al., 2008; Awual et al., 2013]. Even though Cu is essential to mammals' metabolic processes, excess Cu intake causes severe side effects such as elevated blood pressure, rapid breathing, renal and liver damage, seizures, cramping, sickness, and potential mortality [Bertinato & L'Abbé, 2004; Chan et al., 2010; Fu & Wang, 2011]. Cu (II) ions are typically accumulated in various body parts like the brain, skin, and pancreas, causing major toxicological issues, reaching to damaging them, especially the liver and kidneys, and respiratory system [Davis et al., 2000; Gaetke & Chow, 2003]. In addition, Wilson's illness and Menkes syndrome appear to be significantly impacted by unusual Cu amounts linked to proteins [Scheinberg & Sternlieb, 1996; Harris & Gitlin, 1996; Strausak et al., 2001].

Regarding Hg, it has no degradability with high mobility. Meanwhile, methylmercury (CH_3Hg) usually characterizes by its high tendency to accumulate [Abbas et al., 2016; Alalwan et al., 2020]. While mercury may go through various forms and stages during its life cycle, its most basic form, pure Hg, is toxic for both human beings as well as the ecosystem [Abbas et al., 2016].

At ambient temperature, the element of Hg has a liquid phase and can easily evaporate to form gas. The vaporized Hg is more dangerous than its liquid phase. In addition, organic Hg substances like CH_3Hg have a higher toxicity than inorganic substances [Balali-Mood et al., 2021]. Organic Hg is typically generated from various resources, primarily freshwater and seawater fishes. The USA banned fishing across over 3,000 water bodies because of Hg toxicity [Berlin & Zalups, 2007]. In addition, several seawater fish types are similarly contaminated with high Hg levels [Burger et al., 2011]. Although Methyl Hg passes the blood-brain interface less effectively compared to Hg element, it can be readily absorbed by the stomach and then accumulates into numerous organs; nevertheless, it is gradually converted to Hg element via demethylation once it reaches the brain [Berlin & Zalups, 2007]. On the other hand, Hg salts often have an insoluble nature, are moderately persistent, as well as weakly absorbed [Bernhoft, 2012]. Exposure to Hg compounds mainly affects the neurological system in the short term [Bonzongo et al., 1996; Alalwan et al., 2020]. If the body is exposed to Hg, it could cause severe harm to the central nervous system as well as nephrotoxic impacts [Boatti et al., 2017; Bridges & Zalups, 2017]. In terms of the long term, Hg's possible serious negative consequences involve damage to various organs, including the kidney and brain, as well as different body systems, such as hematologic, immune system, and pulmonary tract [Bonzongo et al., 1996; Alalwan et al., 2020]. Moreover, organic Hg exposure has been associated with a higher risk of neurodevelopmental problems, including disorders like a tic and autistic spectrum and slow speech and language development [Hviid et al., 2003; Young et al., 2008].

In terms of Ni toxicity, Ni-metal exposure has been linked to several adverse consequences. Some Ni substances like NiO are considered carcinogenic for humans, while its pure metallic particles are categorized as a possible carcinogens [Latvala et al., 2016; Das et al., 2019]. The more prevalent hazard path in humans is workplace exposure involving Ni dust and fumes due to its welding composites. For human beings, Sunderman's study was the first to evaluate the severe harm of nickel carbonyl exposure caused either due to its uptake via the digestive system or inhalation. Inhaling such a compound has either immediate or delayed severe harmful consequences. The immediate chronic effects could be nausea, itching skin, vomiting, and dizziness, which might persist between a few hours and several days. Due to its exposure, the subsequent delayed effects could include chest tightness or pain, persistent cough, shortness of breath, sinus arrhythmia, and body weakness [Das et al., 2019]. In addition to lung cancer, most of the mentioned symptoms have been confirmed by other studies [Yang et al., 2009; Mobasherpour et al., 2012]. Ni metallic particles could potentially harm human lungs [Scansetti et al., 1998; Barceloux[b], 1999]. In addition, inhaling Ni tetracarbonyl $Ni(CO)_4$, which is a hazardous volatile chemical produced during Ni metallic purification process, known as the Mond process, is usually linked to serious lung damage. The reason behind this impact is its high degree of lipid solubility, resulting in easy accessibility of Ni^{+2} ions to cells [Barceloux[b], 1999; Denkhaus & Salnikow, 2002]. Moreover, persistent inhalation of Ni compounds dust and fumes results in various respiratory illnesses such as asthma and acute bronchitis [Das et al., 2019]. Related to this, Ni has hazardous consequences that involve dry coughing, bone nostrils, the presence of cyan, chest constriction and pain, fast breathing, loss of breath, and vertigo [Yang et al., 2009; Mobasherpour et al., 2012]. Furthermore, Ni metal exposure has been connected to a wide range of adverse health implications, such as skin sensitivity, lung diseases including their fibrosis, neurological harms, kidneys related illnesses, skin allergy reactions, as well as respiratory system cancer [Andersen et al., 1996; Grimsrud et al., 2002; Green et al., 2013].

Regarding Pb metal, there are several scenarios for humans to be exposed to harmful Pb substance, which usually involves contaminating the related environment [Charkiewicz & Backstrand, 2020]. It was estimated that Pb is responsible for about 1.5% of the total fatalities worldwide each year, with a total number of 900,000 deaths, which is approximately equal to the (954,000) total victims caused by HIV/AIDS [Rees & Fuller, 2020]. Pb reaches the human body by ingesting and inhaling via different sources like foodstuff, soils, Pb's particles dust, as well as contacting Pb-contained items [Charkiewicz & Backstrand, 2020]. Once Pb reaches the body via the gastrointestinal or respiratory system, it is distributed by the blood to other organs [Abbas et al., 2016]. In addition, Pb has other ways to reach the human body, including skin penetration and mucosa, but they are considered less common routes than the former ways [Saeed et al., 2017]. However, Pb entering path mainly depends on its related environment type. For instance, Pb substances are mainly received via respiration in Pb-related workplaces, although the human body could also receive these substances through the gastrointestinal tract [Spivey, 2007; Drop et al., 2018]. Pb toxic accumulates over time and impacts different organs, including kidneys, liver, brain [Charkiewicz & Backstrand, 2020; Irawati et al., 2022], the related systems, and their bodily functions, such as the digestive tract, immunological, endocrine, renal, hematopoietic, nervous, and circulatory systems [Krzywy et al., 2010; Irawati et al., 2022]. Among the mentioned systems, the brain and its related neurological system are the most often highly impacted by Pb's exposure in adults and children [Cleveland et al., 2008; Ara & Usmani, 2015; Saeed et al., 2017]. Nevertheless, the effect of the toxin on children is higher than it is

Table 3. Health dangers correlated with heavy metal exposure

N	Metal type	Health risks of heavy metals exposure
1	Antimony (Sb)	Reduction of blood sugar levels and highly elevated cholesterol amounts.
2	Arsenic (As)	It targets the skin's surface, causing harm and triggering the development of skin cancer in its advanced phases; different circulatory system and arterial problems along with diabetes; skin-related, lung and renal cancers, along with different interior malignancies; increased infant death potential as well as reduced weight in the newborn infants; nervous system problems; developmental-related problems as well as neurobehavioral illnesses; blood diseases; and genotoxicity.
3	Barium (Ba)	Elevated blood pressure.
4	Beryllium (Be)	Abdominal illnesses
5	Cadmium (Cd)	Different renal issues that reach kidney damage; intense bone pain; liver disease and elevated blood pressure; and posing a significant risk of developing cancer.
6	Chromium (Cr)	Vomiting and severe diarrhea, pulmonary obstruction, and liver and kidney system issues; a nephrotoxic substance with a high carcinogenicity incidence; and it is connected with cutaneous, neurological, and gastrointestinal tract diseases and various malignancies and cancers in the lungs, pharynx, bladder, and thyroid.
7	Cobalt (Co)	The pulmonary system and skin are the primary targets; hypersensitivity lung disease, which could progress to permanent fibrosis; and dermatitis due to an inflammatory reaction.
8	Copper (Cu)	Elevated blood pressure, insomnia, rapid breathing, seizures, and cramping in the short term; it tends to accumulate in various parts like the brain, skin, and pancreas, causing major toxicological issues, reaching to damaging them, especially the liver and kidneys, in the long term; and linked with Wilson's illness and Menkes syndrome.
9	Lead (Pb)	Central neurological system (brain) damage to infants and fetal; behaviour issues and learning difficulties for children, such as deficits in concentration and learning skills; it is linked to anemia and a rise in blood pressure; and associated with a high incidence of blood problems, neurological system damage, kidney diseases and/or damage and mental impairment.
10	Mercury (Hg)	It mainly affects the neurological system in the short term; severe harm to the central nervous system as well as nephrotoxic impacts; serious consequences involve damage to various organs, including the kidney and brain, and different body systems, such as the hematologic, immune system, and pulmonary tract, in the long term; and associated with neurodevelopmental problems, including disorders like a tic and autistic spectrum and slow speech and language development.
11	Nickel (Ni)	Various respiratory illnesses such as asthma and acute bronchitis; it is linked to different consequences that involve dry coughing, bone nostrils, the presence of cyan, chest constriction and pain, fast breathing, loss of breath, and vertigo; and it is connected to many adverse health implications, such as skin sensitivity, lung diseases including their fibrosis, neurological harm, kidneys related illnesses, skin allergy reactions, and respiratory system cancer.
12	Radium (Ra)	Elevated cancer danger
13	Selenium (Se)	It is linked to several health problems, such as arterial issues, hair and nail loss, and fingers and toes numbness.
14	Zinc (Zn)	Associated with various health risks, including exhaustion, greater thirst, gloominess, and nervousness.

Note: References: (1) Ojedokun & Bello, 2016; (2) Barakat, 2011; Abbas et al., 2016; Ojedokun & Bello, 2016; (3) National primary drinking water regulations, 2009; (4) National primary drinking water regulations, 2009; (5) Yasuda et al., 1995; Ahluwalia, & Goyal, 2007; Barakat, 2011; (6) Mohan et al., 2006; Hu et al., 2009; Fang et al., 2014; (7) Barceloux[a], 1999; Dunlop et al., 2005; Leyssens et al., 2017; (8) Strausak et al., 2001; Davis et al., 2000; Chan et al., 2010; (9) Flora et al., 2012; Qu et al., 2013; Ara & Usmani, 2015; (10) Bonzongo et al., 1996; Young et al., 2008; Bridges & Zalups, 2017; (11) Grimsrud et al., 2002; Yang et al., 2009; Das et al., 2019; (12) National primary drinking water regulations, 2009; (13) National primary drinking water regulations, 2009; Ojedokun & Bello, 2016; (14) Barakat, 2011.

Table 4. Schematic representation of heavy metals toxicity levels

N	Metal type	Toxicity level	Pictogram
1 2 3	Barium (Ba)[a, b] Boron (B) Iron (Fe)[a]	Irritant	
4 5 6	Copper (Cu) Silver (Ag) Zinc (Zn)[a]	Environmental hazard	
7	Manganese (Mn)[a]	Irritant & Environmental hazard	
8	Nickel (Ni)	Irritant & Health hazard	
9	Lead (Pb)	Health hazard & Environmental hazard	
10	Arsenic (As)	Acute toxic & Environmental hazard	
11 12 13 14	Beryllium (Be) Selenium (Se) Thallium (Tl) Uranium (U)	Acute toxic & health hazard	
15 16	Antimony (Sb) Chromium (Cr)	Irritant, health Hazard & environmental Hazard	
17 18	Mercury (Hg) Cadmium (Cd)[a]	Acute toxic, health hazard & Environmental hazard	

Note: (1) The representation of elements pictograms was taken from the National Center for Biotechnology Information (NCBI)/National Library of Medicine (NLM) - USA; (a) flammable element; (b) corrosive element.

on adults because their interior and exterior tissues are softer compared to those of adults [Ara & Usmani, 2015]. In adults, the peripheral neurological system seems more typically involved and impacted by Pb exposure, whereas the central neurological system is significantly affected in exposed children [Flora et al., 2012]. In detail, adults may score worse on various cognitive test methods that assess neurological system activities in the long term, while both young kids as well as infants could have behaviour issues and learning difficulties [Ara & Usmani, 2015]. In addition, Pb contamination is associated with a higher risk of various illnesses that could potentially impact neurological system functions, such as high blood pressure, kidney dysfunction, and thyroid function [Mason et al., 2014]. Moreover, prolonged Pb exposure was linked to anemia and a rise in blood pressure, primarily in the elderly and middle-aged individuals. It was discovered that exposure to elevated Pb concentrations, which resulted in individual mortality, was connected with severe damage to different organs, such as the brain and kidneys. Excess Pb exposure during pregnancy could result in miscarriages. Male fertility was shown to be decreased by acute Pb poisoning. Pb intoxication was also associated with a high incidence of blood problems, neurological system damage, and mental impairment [Sokol & Berman, 1991; Marques et al., 2000; Qu et al., 2013].

In terms of Zn metal, it is essential for the regulation of numerous metabolic processes and bodily activities in tissues throughout the body. On the other hand, excess zinc can lead to adverse health effects like gastrointestinal sickness, vomiting, skin itching and rashes, and cramps pain [Fu & Wang, 2011]. Metal dust fever, caused by inhaling Zn oxide along with other metals, has been found to affect metallurgy industry employees. The related symptoms include nausea or vomiting, coughing, troubles related to headaches and fever, muscle soreness, and gastrointestinal tract pain. Still, they typically discontinue after a short time, about 2–3 days [Wallig & Keenan, 2013]. Health risks linked with heavy metal exposure are illustrated in Table 3, while the toxicity levels of different metallic ions are shown in Table 4.

REMOVAL APPROACHES

Addressing metallic ions-polluted discharges efficiently and affordably remains problematic for scholars or water treatment experts [Ahluwalia & Goyal, 2007; Tripathi & Ranjan, 2015]. Treatment of metallic ions-contaminated wastewater has been carried out in various ways to protect and/or avoid harming human health and sustain different ecosystems [Wang et al., 2019]. Such techniques, for instance, involve coagulation-flocculation [Kurniawan et al., 2006; Barakat, 2011; Abbas et al., 2016], chemical precipitation [Ojedokun & Bello, 2016; Taka et al., 2017; Burakov et al., 2018], electrodialysis [Pedersen, 2003; Barakat, 2011; Alalwan et al., 2020], filtration using a membrane [Ahluwalia & Goyal, 2007; Fu & Wang, 2011; Abbas et al., 2016], ion exchange method [Barakat, 2011; Huang et al., 2016; Taka et al., 2017]. The methods mentioned above do, however, come with a number of disadvantages, which includes the high costs associated with facility construction and implementation, operation management, and chemical usage. Additional disadvantages involve substantial power requirements, critical working circumstances, along with a lower degree of efficacy elimination, particularly for metallic ion concentrations of less than one hundred $mg \cdot L^{-1}$. Furthermore, those practices have been associated with the generation of toxic biosolid waste and disposing of this kind of waste results in more expensive and harmful ways to ecosystems [Sud et al., 2008; Vuković et al., 2010; Marín-Rangel et al., 2012].

Regarding a particular method, high costs from considerable chemical usage are among the major disadvantages of the flocculation and coagulation technique for heavy metal elimination. At the same time, substantial power use, high construction and implementation costs, and operational costs are the main disadvantages of applying the electrodialysis approach. In comparison, the elimination of the vast amounts of sediment released by the precipitation technique, in contrast, is regarded to be a significant problem. The regeneration process of polymeric-made material resin highly increases environmental pollution even though the ion exchange technique is very efficient [Abbas et al., 2016; Taka et al., 2017; Acharya et al., 2018]. The techniques used to remove heavy metals are listed in Table 5, along with their features as reported throughout the related scientific literature.

CONCLUSIONS

A significant environmental problem has resulted from the ongoing release of substantial

Table 5. A summary of the heavy metal removal approaches as described in the related literature

N	Removal approach	Approach advantages	Approach disadvantages
1	Adsorption using conventional adsorbents	Minimal initial costs. Simple operation and working under a broad range of pH. Great metallic bonds capabilities. A successful technique effectively removes the majority of metallic elements. Excellent effectiveness with a maximum of 99% efficacy.	Method outcomes are governed by the adsorbent material. Increased costs because absorbents are so expensive. No potential chance of adsorbent recovery. Limited ion selectivity according to the absorbent substance kind.
2	Biosorption utilizing different bio-adsorbents	Inexpensive bio-adsorbents. Superior efficacy with regenerative potential. Production of little residue quantities. Metallic ions recovered without extra nutritional requirements.	Bio-adsorbents might become saturated earlier. Little possibility of progress for biological techniques uses. No possibility of biologically altering the oxidation state of eliminated metallic ions.
3	Chemical precipitation	An easy process with simple operational parameters. Cost-effective method. Efficient removal of a broad range of metallic ions.	Production of large residue amounts. Sludge removal results in increased running costs. The method has inadequate settling. Ineffective method for removing metallic ions at minimum levels. Reduced pH levels and high ion concentration impact the procedure’s efficacy.
4	Electrodialysis	Highly selective process in metals separation. The process doesn’t consume chemicals. Pure metals are very likely to be attained.	Significant initial and operating expenses. Substantial power amounts are required. The problem of membrane clogging. Regular maintenance is required. Operational parameters, including current, intensity of current, and pH, influence process efficacy.
5	Flocculation and coagulation	Sludge generated with an excellent settlement rate. The sludge produced had good dewatering properties. The process can remove metallic ions and water turbidity.	Residue production. High-priced approach. Large chemical amounts are consumed. Sludge removal requires additional running costs.
6	Flotation treatment	Increased generation of intensified sludge. Good selectivity of targeted metal removal. High effectiveness of elimination. The method has short retention times with large overflow quantities.	Substantial setting-up expenses. Big running and maintaining expenses.
7	Ion-exchange	High effectiveness of elimination. Possibility of achieving ppb levels to metallic ions. Highly selective metallic ions elimination. A quite efficient recovery rate. The capability for treating large volumes. The process is described by fast removal kinetics.	Substantial initial cost, including resin cost. Fewer number of metallic ions are eliminated. The resin recovery process causes additional contamination. The capacity to remove metal varies based on various resin types.
8	Membrane filtration and ultrafiltration method	It is a highly selective process. Minimal pressure is needed. Little room is required for this approach. Lower dependency on chemicals. Excellent efficacy that could pass 95%. Minimal quantities of solid residue produced.	It is a complicated process. Considerable setup, running, and maintenance expenses. Clogging of membrane. Little treated rate. Excessive amounts of energy use. Process efficiency is lowered as additional metallic ions are present.
9	Photocatalysis	Metallic ions, along with organic matter, are eliminated simultaneously. Fewer number dangerous side products.	Lengthy reaction periods are needed. The process has a finite number of uses.
10	Reverse osmosis	It is primarily utilized in seawater desalination. It could be applied to remove different organic, mineral, and bacterial pollutants.	Producing solid residue. Elevated pressure is needed for this approach. The process requires big operating expenses. Consumption of large power amounts. Ineffective method to eliminate the micro-organic contaminants.

Note: References: (1) Perić et al., 2004; Barakat, 2011; Fu & Wang, 2011; (2) Mishra et al., 2010; Manzoor et al., 2013; Jiménez-Cedillo et al., 2013; (3) Khosravi & Alamdari, 2009; Abbas et al., 2016; Alalwan et al., 2020; (4) Barakat, 2011; Ojedokun & Bello, 2016; Taka et al., 2017; (5) Fu & Wang, 2011; Abbas et al., 2016; Taka et al., 2017; (6) Kurniawan et al., 2006; Fu & Wang, 2011; Taka et al., 2017; (7) Kang et al., 2004; Ojedokun & Bello, 2016; Alalwan et al., 2020; (8) Al-Rashdi et al., 2013; Abbas et al., 2016; Taka et al., 2017; (9) Kajitvichyanukul et al., 2005; Barakat, 2011; Taka et al., 2017; (10) Kurniawan et al., 2006; Taka et al., 2017.

amounts of harmful chemicals as a result of human activities. Cadmium (Cd), Mercury (Hg), and Chromium (Cr) are among the metallic ions that are released into the environment by a variety of industrial sectors, which include battery production, mining activities, electroplating, and coal-fired power plants. Because of their characteristics, particularly their extreme toxicity and potent ability to accumulate, heavy metals significantly threaten humans, other living things, and ecosystems. When compared to organic matter, which is greatly affected by biological and chemical degradation, metallic ions tend not to be capable of a breakdown toward end components. Therefore, removing these elements has been seen as a major task in water purification applications. This article aimed to examine the literature on heavy metals in various aspects. The meaning of this expression, heavy metals, was described. A comprehensive discussion was given on the natural and human-made causes of releasing metallic ions into the environment. Additionally, the toxicological consequences of heavy metals and possible dangers to individuals and various environments were reviewed. The benefits and disadvantages of various methods for eliminating heavy metals from wastewater effluents were further assessed.

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