Hazards Associated with Industrial Effluents and Its Mitigation Strategies

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Abstract Industrial effluent is related to liquid waste generated by industries that may be emitted into the municipal drainage or sewer system. The effluents composition is extremely variable and heavily influenced by the various industries from which they originate. Contaminants can be grouped into different classes such as endocrine disrupting compounds (EDCs), pharmaceuticals, pesticides, heavy metals and metalloids, per- and polyfluoroalkyl substances (PFAS), and microplastics. Each contaminant upon exposure possesses a specific health impact on humans and animals as well as on marine life when mixed in the sewer.

This harmful effluent needs to be treated to reduce its adverse effect either on-site or off-site. There are a variety of conventional and advanced wastewater treatment facilities available for use. For on-site installation of treatment facilities, the cost of such plants can be reduced by the government by taxing less on equipment purchases. For off-site installation of the treatment plant, the local body can seek financial support from the industries producing these effluents.

Keywords Effluent · Wastewater · Endocrine · Heavy metals · Per- and polyfluoroalkyl · Pharmaceuticals · Pesticides · Microplastics

Abbreviations

AMR	Antimicrobial resistance
BBP	Benzyl butyl phthalate
BPA	Bisphenol A
DBP	Di-n-butyl phthalate
DEHP	Di(2-ethylhexyl) phthalate
DiBP	Di-iso butylphthalate

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DVFA	Danish Veterinary and Food Administration
EC	European commission
EDCs	Endocrine-disrupting compounds
EFSA	European Food Safety Authority
EPA	Environmental Protection Agency
kg bw	Kilograms of body weight
LOAEL	Lowest observed adverse effect level
MRL	Minimum risk level
PCBs	Polychlorinated biphenyls
PCDDs	Polychlorinated dibenzo-p-dioxins
PCDFs	Polychlorinated dibenzofurans
PFAS	Per- and polyfluoroalkyl substances
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctane sulfonate
POPs	Persistent organic pollutants
PTMI	Provisional tolerable monthly intake
RfD	Reference dose
TCDD	2,3,7,8- tetrachlorodibenzo-p-dioxin
TDI	Tolerable daily intake
TMI	Tolerable monthly intake
TWI	Tolerable weekly intake
WHO	World Health Organization
μg/kg	Microgram per kilogram

1 Introduction

Industries, a key factor of economic growth, also have caused serious pollution and environmental issues (Wen 2009; Wei and Huang 2001). Industrial waste refers to unwanted residual materials generated by industrial processes or operations. Waste materials can be in solid, liquid, or gaseous form (Wen 2009; Misra and Pandey 2005; Ojoawo et al. 2011) that include among others food wastes, packaging materials, ashes, smoke, rubbish, debris, special wastes, and hazardous wastes (Aivalioti et al. 2014; Abduli 1996; Tchobanoglous et al. 1993; Casares et al. 2005; Vigneswaran et al. 1999). Special wastes including clinical and pharmaceutical wastes are considered nonhazardous waste but possess unique regulatory requirements.

Wastes can be categorized as hazardous and nonhazardous according to their effect on human or other organisms. Hazardous materials as listed in the Resource Conservation and Recovery Act (RCRA) regulations can be toxic, flammable, ignitable, reactive, or corrosive. Oil, printing ink, paint, varnish, soluble cutting emulsion, and disinfectants are some examples of hazardous wastes. Wastes that do fall under the category of hazardous wastes as the Environmental Protection Agency

(EPA)'s definition are termed as nonhazardous waste. Laboratory waste consists of empty aerosol cans, nonsurgical and nonradioactive medical refuse, as well as food and packaging waste, which are a few examples of nonhazardous wastes.

In industrialized countries, public pressure regarding pollution led local bodies to act strictly, while in developing countries, awareness of pollution is lower in public, and the action of the local body is also not significant. Rapid industrialization and the use of toxic materials in processing have led to problems with environmental pollution (Wen 2009).

1.1 Solid Wastes

Annually, about 12 billion tons of industrial waste is being generated which will exceed upto 19 billion tons soon (Li 2009; Pappu et al. 2007; Yoshizawa et al. 2004). They can be of hazardous and nonhazardous nature (Li 2009). Unwanted materials produced during processing depend upon the types of industries. Mining industries produce waste stones, metallurgical industries produce slag, power industries produce ash, and chemical industries produce inferior products, unreacted materials, and disabled catalysts. Oil chemical industries produce oil mud and slag.

1.2 Liquid Wastes

Industrial liquid wastes include feedstock materials, by-products, product material in soluble or particulate form, washing and cleaning agents, solvents, etc. These wastes may be nontoxic inorganic substances or toxic organic substances. The effluents or wastewater including these materials pass through sewer network and affect the aquatic environment (Fig. 1).

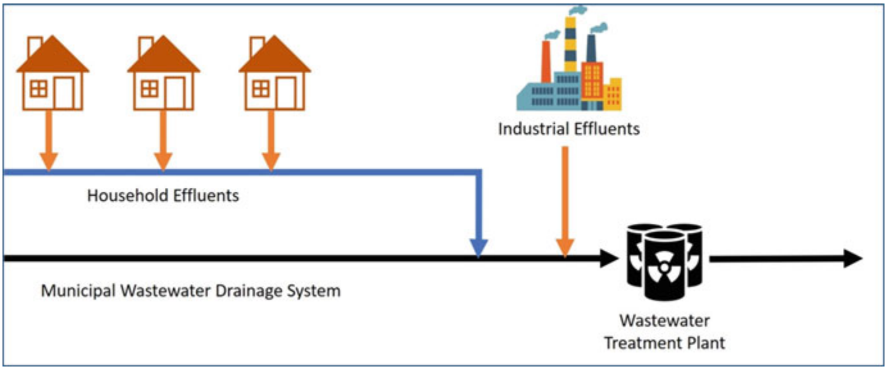

Fig. 1 Schematic diagram of domestic and industrial effluent

1.3 Gaseous Wastes

Industrial emissions are in the form of particulate vapor, powder, mineral fumes, and smoke. Depending on the local regulations, they can be emitted into the atmosphere with or without prior treatment. The components in the emissions depend upon the types of fuel used and the nature of industries (Ojoawo et al. 2011). The environmental impacts of waste, such as pollution and disease, have turned into a source of major concern. When inadequately managed, wastes may lead to the deterioration of sewage systems with increasing environmental pollution and diseases (Hasheela 2009).

Sewage effluent-containing pathogens led to diseases such as diarrhea, polio, meningitis, and hepatitis. WHO (2003) estimated in 1998 that approximately 1.8 million children passed away in developing nations due to microorganisms, the vast majority of which originated from contaminated food and water. It is estimated that 12 million people die annually around the globe due to improper waste management (Davidson et al. 1992). Humans come into contact with wastes or are exposed to wastes by different routes such as ingestion, inhalation, and absorption. Drinking water and food containing hazardous substances from refuse residues constitute an ingestion route, the inhaling route is breathing airborne wastes, and the absorption route is by direct contact with waste residues (Hinga and Batchellor 2005).

Hazardous industrial wastes may have short- or long-term effects on humans and ecological systems. The potential health effects on human depend upon the characteristics of the hazardous chemicals, the duration of exposure, the health status of the exposed individual, as well as weather conditions (Misra and Pandey 2005; Grisham 1986). Health effects on human due to exposure to hazardous wastes may be carcinogenesis (i.e., causing cancers), genetic defects, reproductive abnormalities, alterations of immunobiological homeostasis, central nervous system (CNS disorder), and congenital anomalies (El Sidig NOA 2004). To prevent the adverse effect of hazardous materials or wastes on human and the environment, proper storage and treatment and disposal by the latest technology are required.

At present, waste management is one of the world's greatest environmental challenges (Kan 2009). Industrial wastes can be toxic, ignitable, corrosive, and reactive substances that need to reduce the adverse effect before being discharged into the environment (Zurbrugg 2002). Waste management methods differ from developed countries to developing countries and also differ in urban to rural areas (Addo 2013). Waste is managed in accordance with public health, economics, engineering, conservation, esthetics, and other environmental considerations and public attitudes (Tchobanoglous et al. 1977; Demirbas 2011).

Solid waste management covers control of the generation, storage, collection, transfer and transport, processing, and disposal of solids. Liquid waste management deals with wastewater treatment and sewage treatment. A variety of waste streams is generated by industries, referred as industrial effluents, which are discharged to either the municipal or public effluent treatment system or directly to receiving waters. These effluents contain numerous substances that may pose health hazards to humans. Depending on the industries, to reduce contaminant concentrations effluents may be treated on-site, or are discharged to municipal effluent treatment system or directly to receiving waters. Countries possess policies regarding discharging effluents at tolerable levels and determining concentration limits for a variety of potentially hazardous contaminants. Additionally, sewage sludge, a potentially hazardous substance that settles out of domestic and industrial wastewater during remediation, also poses a threat to public health (Eaton 2022).

Different countries have set their own standards for concentration limits for several potentially harmful contaminants present in the discharge effluent. Also, the land is polluted by the addition of unstabilized sewage sludge from the treatment plant. The finding of new contaminants, their harmful effects, and their discharge limits will keep on being researched. Using global data, this report attempts to determine contaminants that are of more concern to human health and the types of industries that are discharging them. Depending on international data, contaminants that are of most concerns for human health are reported here (Stewart et al. 2016). The considered contaminants fall into seven general categories.: endocrine-disrupting compounds (EDCs), heavy metals and metalloids, per- and polyfluoroalkyl substances (PFAS), pharmaceuticals, pesticides, and microplastics. The potential health concern associated with each contaminant is discussed. However, the precise health hazard they pose is currently unclear and uncertain.

2 Endocrine-Disrupting Compounds

These are substances that interfere with biosynthesis, metabolism, or action of hormones to disrupt normal hormone signaling. (Diamanti-Kandarakis et al. 2009). The above chemicals of various categories have associated with variety of health issues and are considered a public health concern (Zoeller et al. 2014). These compounds are found in food, consumer goods, and pharmaceuticals (such as birth control medication), which upon discarded by human through excretion or activity pass to the municipal wastewater.

2.1 Nonylphenol and Nonylphenol Ethoxylates

Nonylphenol is a synthetic alkylphenol used in the production of antioxidants and lubricating oil additives and nonylphenol ethoxylate surfactants (Soares et al. 2008). Such surfactants are extensively used in cosmetics and coatings, detergents and cleaning products, degreasers, emulsifiers, and wetting and de-wetting agents (Environment Canada and Health Canada 2001; Soares et al. 2008). On account of their widespread use, considerable amounts of NPEs enter into both industrial and residential wastewater systems. Nonylphenol and its ethoxylates have high environmental persistence. The estimated half-life of NPEs in sediments is greater than 60 years (Shang et al. 1999), they bioaccumulate over aquatic creature (Gautam et al. 2015), and also been identified in human lactation (Sise and Uguz 2017).

2.1.1 Health Hazard

The studies of laboratory animals reflect that nonylphenol can have a negative impact on reproduction and the immune and nervous systems (Cressey 2018). Danish Veterinary and Food Administration (DVFA) (Nielsen et al. 2000) and European Commission (EC) (2002) have recommended nonylphenol and its ethoxylates exposure limits which is represented in Table 1.

2.1.2 Sources of Industrial Effluent

NPEs is mostly used for processes such as wool scouring, bleaching, laundering, and dyeing in Textile industries (Ho and Watanabe 2017). The concentrations range of 0.23–26 μg/L of nonylphenol was found to be in textile industry effluent which was discharged to the municipal wastewater management system of Canada (Environment Canada and Health Canada 2001). NPEs are used in paper and pulp industry for wetting of pulp fibers, and in the leather industry (Groshart et al. 2001).

2.1.3 Limit of Discharge and Policies

In the European Union (EU), the discharge limit under Directive 2008/105/EC in surface water is 2 μg/L for nonylphenols. Canadian Environmental Protection Act (1999) has classified both nonylphenol and its ethoxylates as harmful compounds under Schedule 1. In the United States, the Environmental Protection Agency (EPA) set the rule of Agency review for its use. In New Zealand, 50 mg/kg dry weight is the proposed concentration limit of nonylphenol and its ethoxylates (Water New Zealand 2017).

2.2 *Bisphenol A*

It is a synthetic chemical which is mainly used for the manufacture of epoxy resins, polycarbonate plastics (NIEHS 2021), as well as food storage vessels (Cressey 2018).

Table 1 Recommended nonylphenol and its ethoxylates exposure limits

Substance	LOAEL EC (mg/kg bw/day)	TDI DVFA (mg/kg bw/day)	LOAEL DVFA (mg/kg bw/day)
4-Nonylphenol (NP)	15	0.005	15
Nonylphenol ethoxylates (NPEs)	–	0.013	40

2.2.1 Health Hazard

New Zealand Environmental Protection Authority suspected Bisphenol A could harm fertility or a fetus (EPA 2021). United States Food and Drug Administration (EPA 2021) and European Food Safety Authority (EFSA 2015) diminished the tolerable daily intake (TDI) of BPA to 5 and 4 μg/kg body weight/day respectively. However, a recent study reflects effects on concentrations as minimum as 2.5 microgram per kilogram of body weight per day (Heindel et al. 2020).

2.2.2 Sources of Industrial Effluent

Municipal wastewater contains BPA that comes from food and beverage packaging. Industrial effluent from paper mills (Balabanic and Klemencic 2011; Fuerhacker 2003; Lee and Peart 2000; Lee et al. 2015), textile industries (Lee and Peart 2000; Pothitou and Voutsa 2008), tanning industries (Pothitou and Voutsa 2008), metal or wood industries, chemical industries, dry cleaning/cloth washing, plastics and polymer industries (Fuerhacker 2003; Lee and Peart 2000), and petrochemical industries (Mirzaee et al. 2019) contains subsequent amount of BPA.

2.2.3 Discharge Limits and Regulation

The set limit for BPA in industrial effluent is 1.75 μg/L in Canada (Government of Canada 2018), whereas in the United States, BPA action plan has been created by EPA (US EPA 2021a, b, c, d, e, f, g, h) without a discharge concentration limit.

2.3 Phthalates

Phthalates or phthalate plasticizers are used for solvent properties to make products more durable and flexible. They are used in various products such as vinyl flooring, plastic packaging, medical tubing, shampoos, hair sprays, soaps (CDC 2021), and cosmetics (U.S. Food and Drug 2021). Phthalates, which have a different types of derivatives, are diesters of 1,2-benzenedicarboxylic acid. Four derivatives included in discussion are BBP, DBP, DiBP, and DEHP.

2.3.1 Health Hazards

Phthalate syndrome is a common health effect that refers to the capacity to inhibit androgen biosynthesis, thereby disrupting sexual differentiation of male (CHAP 2014; National Research Council 2008). The health hazard posed by above listed

Table 2 Phthalate health implications and intake limits

Phthalate compound	RfD (mg/kg bw/day)	RPF (EFSA 2022a, b)
BBP	0.2 (US EPA 1989)	0.1
DBP	0.1 (US EPA 1987a, b)	5
DEHP	0.02 (US EPA 1987a, b)	1
DiBP	–	–

phthalates is reproductive or developmental toxicity (antiandrogenic) concerns (Ashworth and Chappell 2015). Other report suspected that they damaged fertility or the unborn child (Cressey 2018). The TDI for phthalates is set as 0.05 mg/kg bw/day by EFSA by setting the index compound as DEHP and expressing potency of another phthalate's relative to DEHP (EFSA 2022a, b) (Table 2).

2.3.2 Sources of Industrial Effluent

In Slovenia, DBP, BB, and DEHP were found in the waste from paper and pulp industries (Balabanic and Klemencic 2011). In Argentina and India, BBP, DBP, DEHP, and DiBP were found in the effluent from tanneries (Bharagava et al. 2018; Zubair Alam et al. 2010; Labunska et al. 2011). France found the DBP, BBP, and DEHP in the waste generated from the textile industries, pharmaceutical industries, aerospace company, waste management, vehicle washing, cosmetics products, metallurgy, and transportation maintenance industries (Bergé et al. 2014). Effluents from a turkey processing plant also reported DiBP concentration (Buyukada 2019).

2.3.3 Limit of Discharge and Policies

There are regulations regarding phthalate levels in kids toys, cosmetics kids care products etc., information about its level in sewage is not sufficient (Government of Canada 2017). In United States, EPA set discharge limits for DEHP, BBP, and DBP summarized in Table 3 (US EPA ELGs 2022a, b, c).

2.4 Dioxins

Dioxin, or 2,3,7,8- tetrachlorodibenzo-p-dioxin (TCDD), refers to chemicals polychlorinated dibenzofurans (PCDFs), polychlorinated dibenzo-p-dioxins (PCDDs), and polychlorinated biphenyls (PCBs). Stockholm Convention concluded these three classes of dioxin as persistent organic pollutants (POPs). It means signatories must act either to reduce or minimize or eliminate its release where possible. Chlorine-containing industrial processes produces dioxin as unwanted

Table 3 Description of phthalate compounds US EPA effluent limits

Phthalate compound	Source	Max concentration daily (μg/L)	Max monthly average (μg/L)
DEHP	Plastics, organic substances, and synthetic fibers	258–279	95–103
	Centralized waste management	215–267	101–158
DBP	Plastics, organic substances, and synthetic fibers	43–57	20–27
BBP	Centralized waste management	188	BBP

Table 4 Recommended dioxin and dioxin-like compound exposure limits

RfD (US EPA 2021) (ng/kg bw/day)	TWI (EFSA 2018) (ng/kg bw/week)	PTMI JECFA (WHO 2019) (ng/kg bw/month)	TMI New Zealand (MoH 2020) (ng/kg bw/month)
0.0007 (for TCDD)	0.002	0.07	0.03

by-products from pulp and paper industries, herbicide/pesticide production, and smelting.

2.4.1 Health Hazards

There is sufficient evidence that dioxin causes among others chloracne, non-Hodgkin and Hodgkin disease, hypertension, etc. (Ministry of Health 2020). Table 4 represents the recommended dioxins and dioxin-like compounds exposure limits set by different agencies, such as US EPA, Joint Food and Agriculture Organization of the United Nations (FAO)/WHO Expert Committee on Food Additives (JECFA), EFSA, and New Zealand Ministry of Health.

2.4.2 Sources of Industrial Effluent

Effluent and sludge from pulp and paper mills contain dioxins as they perform chlorine bleaching (Whittemore et al. 1990). Dioxin is also found in the effluents from other manufacturing industries such as caprolactam (an intermediate of nylon), vinyl chloride, acetylene, alumina fibers, chlorobenzene, 4-chloro sodium hydrogen phthalate, 2,3-dichloro-1,4-naphthoquinone, and organic colored pigments (Kawamoto and Weber 2021). Dioxins were found in the effluents of chemical industries that manufacture petroleum, plastics, synthetic polymers, nonvolatile elastics, industrial organic chemicals, cyclic organic crudes, dyes and pigments, pesticides, and agricultural chemicals (Sappington et al. 2015).

2.4.3 Limit of Discharge and Policies

In Japan, the PCDD/PCDFs discharge limit is set to 10 picogram toxic equivalentper litrefor industrial effluent (Kawamoto and Weber 2021). Canadian Environmental Protection Act, 1999 (Government of Canada 2021) prohibited pulp and paper industry from releasing 2,3,7,8-TCDD and 2,3,7,8-TCDF into the environment. For 2,3,7,8-TCDD and 2,3,7,8-TCDF by the pulp, paper and paperboard industries EPA has set discharge limit of maximum 10 pg/L per day (US EPA ELGs 2022a, b, c). Trade Waste Standard (Standards New Zealand 2004) set a maximum concentration of 0.002 g/m^3 (2 μg/L) for PCBs.

3 Heavy Metals and Metalloids

Heavy metals are high density (i.e., minimum five times denser in comparison with water) metallic elements (Tchounwou et al. 2012). Industrial effluents may contain chromium, nickel, lead, copper, metalloid arsenic, zinc, and cadmium (Wang 2018) and in sewage sludge as bio-solids.

3.1 Cadmium

It is a harmful and undesirable heavy metal present in phosphate rock, ingredient of superphosphate fertilizer. Cadmium enters the agricultural land through the use of fertilizer and industrial effluents containing cadmium to wastewater.

3.1.1 Health Hazards

Despite lowest levels, cadmium is toxic to body. It damages kidneys and gets accumulated with a half-life of approximately 15 years (Mannetje et al. 2018). Cadmium is used in various industries such as textile, electronics, electroplating, chemical, metal finishing, and metallurgical industries (Velusamy et al. 2021).

Table 5 represent the recommended exposure limits set by different agencies, such as Dutch National Institute of Public Health and the Environment (RIVM), JECFA, US EPA, European Food Safety Authority (EFSA), and Food Standards Australia New Zealand (FSANZ), US Agency for Toxic Substances and Disease Registry (ATSDR).

Table 5 Recommended cadmium exposure limits

TDI RIVM (Baars et al. 2001) (ng/kg bw/day)	RfD (EPA 2021) (ng/kg bw/day)	PTMI JECFA (WHO 2021a, b) (ng/kg bw/month)	TWI (EFSA 2021) (ng/kg bw/week)	PTMI (FSANZ 2011) (ng/kg bw/month)	MRL (ATSDR 2021) (ng/kg bw/day)
500 (oral)	500 (water) 1000 (food)	25,000	2500	25,000	100 (chronic oral)

Table 6 US EPA cadmium discharge limits summary

Point source	Daily maximum concentration (mg/L)	Average concentration [monthly] (μg/L)	Max average concentration [monthly] (μg/L)
Electroplating	1.2	–	–
Inorganic chemicals production	0.84	0.28	–
Metal coating	0.11–0.69	0.07–0.26	–
Centralized waste management	0.0172–0.782	–	0.0102–0.163
Ore mining and dressing	0.1	0.05	–
Electronic components	0.06–0.55	–	–

3.1.2 Limit of Discharge and Policies

The summary of discharge limits set by EPA (US EPA ELGs 2021) is represented in Table 6.

3.2 Chromium

Chromium (Cr) is found in oxidation states such as most stable chromium VI and chromium III (Wilbur et al. 2012). An essential nutrient chromium III is found naturally, whereas highly toxic chromium VI seldom occurs naturally which readily occur reduction reaction to chromium III (US EPA 1984). Anthropogenic activities produced chromium VI which when enters water form relatively stable (US EPA 1984; Wilbur et al. 2012).

Table 7 Recommended chromium III and VI exposures limits

	TDI RIVM (Baars et al. 2001) (mg/kg bw/day)	RfD (mg/kg bw/day)	TDI CONTAM (EFSA 2014a, b) (mg/kg bw/day)	TDI (WHO IPCS 2013) (mg/kg bw/day)	MRL (ATSDR 2021) (mg/kg bw/day)
Cr III	0.005 (water soluble) 5 (insoluble)	1.5 (EPA 2021) (insoluble)	0.3	–	–
Cr VI	0.005* (oral)	0.003 (EPA 2021) (oral)	–	0.0009 (oral)	0.0009 (chronic oral)

*Provisional Maximum Permissible Risk, noncarcinogenic effects

3.2.1 Health Hazards

The exposure of chromium VI may affect on the respiratory system and kidneys and also causes cancer (Mannetje et al. 2018). Different organizations have set recommended exposure limits which are mentioned in Table 7.

3.2.2 Sources of Industrial Effluent

Chromium is present in the effluent of industries such as textiles, metal finishing and electroplating, tanneries, dyes and pigment, wood preservation, and fertilizer industries. (Dermentzis et al. 2011, Verma et al. 2013). Very high level of chromium in the effluent is reported from the electroplating industry (reportedly up to 2500 mg/L of the highly toxic chromium VI) (Dermentzis et al. 2011), substantial chromium concentrations in textile dying wastewaters (Çetin et al. 2008), and leather tanneries (0.2 to more than 14 mg/L) in Argentina (Labunska et al. 2011).

3.2.3 Limit of Discharge and Policies

In the European Union, discharge limits of total chromium vary among member states, with a maximum discharge limit of 5 mg/L for total chromium and 1 mg/L for chromium VI in water (Vaiopoulou and Gikas 2020).

In the US, discharge limit is set for total chromium on daily maximum concentration for electroplating 7 mg/L, leather tanning and finishing (12–19) mg/L, and timber 4 mg/L (US EPA ELGs 2021). The discharge limits for total chromium are summarized in Table 8.

Table 8 US EPA total chromium discharge limits summary

Point source	Daily maximum concentration (μg/L)	Average concentration [monthly] (μg/L)	Max average concentration [monthly] (μg/L)
Electroplating	7000	–	–
Inorganic chemicals production	230–3000	120–1200	–
Metal coating	2770	1710	–
Centralized waste management	167–15,500	–	52.2–3070
Electronic components	560–650	–	260–300

3.3 Lead

Lead (Pb) in environment can be found in trace amounts. In early days, industries used it extensively in products such as ceramics, cosmetics, petrol, paints, batteries, and plumbing materials (EPA 2021). Its uses have been phased out because of its toxicity.(Pickston et al. 1985).

3.3.1 Health Hazards

Lead (Pb) exposure is associated with a several adverse health hazard, which include increased blood pressure, decrease in renal function and fertility, and neurocognitive effects. Neurodevelopmental effects in children even at low level (Mannetje et al. 2018). The exposure limit reported by RIVM is 3.6 μg/kg bw/day, oral (Baars et al. 2001).

3.3.2 Sources of Industrial Effluent

Lead in the effluent from the iron, steel, pulp and paper industries (US Environmental Protection Agency 2018), paint industries (Malakootian et al. 2009), a brewery, and a textile industry (Muhammd et al. 2018) are found.

3.3.3 Limit of Discharge and Policies

The discharge limits set by US EPA ELGs are summarized in Table 9.

Table 9 US EPA lead discharge limits summary

Point source	Daily maximum concentration (μg/L)	Average concentration [monthly] (μg/L)	Max average concentration [monthly] (μg/L)
Electroplating	600	–	–
Inorganic chemicals production	180–3400	48–1400	–
Metal coating	690	430	–
Centralized waste management	222–1320	–	160–283
Electronic components	720–1120	–	270–410

Table 10 Recommended mercury exposure limits

TDI RIVM (Baars et al. 2001) (ng/kg bw/day)	PTWI JECFA (2011) (ng/kg bw/week)	RfD (EPA 2021) (ng/kg bw/day)	MRL (ATSDR 2021) (ng/kg bw/day)
2000 (inorganic, oral) 100 (organic, oral)	4000 (inorganic) (WHO 2021a, b) 1600 (methylmercury) (WHO 2022)	100 (methylmercury, oral)	300 (methylmercury, chronic oral)

MRL minimum risk level

3.4 Mercury

Mercury (Hg) is a highly toxic, its uses are in products such as personal care products, thermometers, fluorescent light bulbs, electrical switches, pigments, batteries, and dental amalgams. Its usage is being phased out due to its adverse effects on human health (Crossett 2011; Suess et al. 2020).

3.4.1 Health Hazards

The health hazards caused by exposure of mercury depend upon its form (elemental, organic, or inorganic). Mercury can be accumulated in the human body and is also harmful to many biological systems, including the kidneys, the brain, and the epidermis. The elemental and organic forms of mercury can cross the blood–brain and placental barriers, accumulate in the brain, and develop a fetus (Ministry of Health 2021a, b). Mercury affects the kidneys, brain, skin and can accumulate in the brain, neurological effects, and developing fetus (ATSDR 1999; JECFA 2007). Table 10 represents different government agencies recommended exposure limits for mercury.

3.4.2 Sources of Industrial Effluent

Mercury in effluent is found from dental practice wastes (Bender 2008), papers, electrical utilities, and also from metal sectors (such as mining, primary, and fabricated metals).

3.4.3 Limit of Discharge and Policies

Many countries have recognized mercury as a hazardous substance which led Minamata Convention to diminish mercury emissions in the world (Suess et al. 2020). Under the ELGs, the US EPA has set mercury discharge limits for various point source categories (EPA 2021) summarized in Table 11. The daily maximum concentration of mercury in point source inorganic chemicals manufacturing is highest 110 μg/L to lowest in generating steam electric power (0.0018–0.788) μg/L, other contributors being centralized waste management, ore mining and dressing, etc.

3.5 Arsenic

Arsenic (As), a metalloid, was used in pesticides, pharmaceuticals, and agriculture-based industries (IARC Working Group on the Evaluation of Carcinogenic Risks to Humans 2012). Due to its toxic nature, many industries stopped its uses, though metal industry uses it as an alloying agent, leather industry uses during tanning of hides, and other uses is in manufacturing of paper, paint pigments, metal adhesives, glass, ammunition, and wood preservatives.

3.5.1 Health Hazards

Inorganic arsenic is highly toxic as compared to organic arsenic. Arsenic is known to be carcinogenic, lead to skin, bladder, and lung cancer. Moderate levels but long-term exposure damage heart, kidneys, liver, nerves and blood vessels (Ministry of

Table 11 US EPA mercury discharge limits summary

Point source	Daily maximum concentration (ng/L)	Average concentration [monthly] (μg/L)	Max average concentration [monthly] (μg/L)
Ore mining and dressing	2000	1000	–
Inorganic chemicals production	110,000	48,000	–
Waste combustors	2300	–	1300
Centralized waste management	641–17,200	–	246–6470

Table 12 Recommended arsenic exposure limits

TDI RIVM (Baars et al. 2001) (ng/kg bw/month)	RfD (EPA 2021) (ng/kg bw/day)	MRL (ATSDR 2021) (ng/kg bw/day)
30,000 (inorganic, oral)	300 (inorganic, oral)	300 (chronic, oral)

Health 2021a, b). Table 12 represents the different government agencies recommended exposure limits for arsenic.

3.5.2 Sources of Industrial Effluent

Arsenic is usually found as an impurity from metal ores and consequently enters the mining industry. Other potential sources of arsenic include the paper industry, the generation of steam-powered electricity, the refining of wood products, and waste treatment, among others.

3.5.3 Limit of Discharge and Policies

The US EPA has set limits for arsenic present in discharges as daily maximum concentration from different point source (US EPA ELGs 2021), as described in Table 13.

4 Per- and Polyfluoroalkyl Substances

Per- and poly-fluoroalkyl substances are a broad family of synthetic chemicals with resistance to water, oil, grease, and fire. These properties led to its widespread use in the production of numerous products, such as fabrics and carpets that are stain- and water-resistant, coatings, aviation hydraulic fluids, cleaning products, insect lures, firefighting foams, and in the electroplating and electronic industries all contain

Table 13 US EPA arsenic discharge limits summary

Sources	Maximum concentration [daily] (ng/L)	Average concentration [monthly] (ng/L)	Max average concentration [monthly] (ng/L)
Ore mining and dressing	1000	500	–
Inorganic chemicals production	3000	1000	–
Timber product processing	4000	–	–
Waste combustors	84	–	72
Centralized waste management	99.3–2950	–	19.9–1330
Landfills	1100	–	540
Electrical components	2090	830	–

polyurethane. Due to their resistance to degradation, these substances persist in the environment for extended periods of time and bioaccumulate in tissues. Among the 3000 PFAS, perfluoro octane sulfonate (PFOS) and perfluorooctanoic acid (PFOA) are the most well known (Wang et al. 2017). Several PFAS being phased out because of environmental concerns, Stockholm Convention also enlisted PFOS and PFOA.

These substances gets mixed with wastewater network from both industrial and residential sources which are most substantial (Rumsby 2018). The estimated half-lives of PFOS and PFOA in the human body are 3.4 and 2.7 years, respectively (Li et al. 2018), though PFOS and PFOA are not considered to pose acute health risks. Industrial sources for these compounds among others are the textile, metal plating industry, pulp and paper industry, semiconductor, and electronics business (Lin et al. 2009; Tonkin and Taylor Ltd 2018; Kim et al. 2021).

4.1 Health Hazards

The effects of PFOS and PFOA exposure are not considered to pose an acute health risk (Ministry for the Environment 2021). The chronic exposure limit is on serum cholesterol levels and immune effects, in spite of that the estimated half-lives of PFOS and PFOA in the human body are 3.4 and 2.7 years, respectively (Li et al. 2018), Table 14 represents the different government agencies recommended arsenic exposure limits.

4.2 Sources of Industrial Effluent

Textile industry is one of the major industries utilizing PFAS (Ministry of Environment and Food, The Danish Environmental Protection Agency 2015), in flame-retardant clothing and to impart water, oil, and dirt resistance into fabrics and carpets (Tonkin and Taylor Ltd 2018).

PFAS is commonly used in the metal plating industry (HRP Associates 2021), chromium electroplating facilities, pulp and paper industry, and semiconductor and electronics industries (Tonkin and Taylor Ltd 2018) resulted in contamination to wastewater (US EPA 2021a, b, c, d, e, f, g, h).

Table 14 Recommended PFOS and PFOA exposure limits

Substance	TWI (pg/kg bw/week) (EFSA 2022a, b)	TDI (pg/kg bw/day) (FSANZ 2022)	Draft RfD (pg/kg bw/day) (EPA 2021)
PFOS	4400*	20,000	7.9 (chronic oral)
PFOA		160,000	1.5 (chronic oral)

*A group TWI for PFAS based on PFOA, PFOS, perfluorononanoic acid (PFNA), and perfluorohexane sulfonic acid (PFHxS) assessments

Table 15 PFOS and PFOA discharge reported by the US Toxics Release Inventory 2020

Substances	Main industry linked to the facility	TRI industry sector	Surface water discharge (kg)[2]
PFOS	All other chemical preparation and product production	Chemicals	0.5
PFOA	All other chemical preparation and product production	Chemicals	4.1

4.3 Limit of Discharge and Policies

The US EPA developed effluent guidelines based on data acquired from a "preliminary multi-industry PFAS study" and mandated PFAS manufacturers to adhere to these standards (US EPA 2021a, b, c, d, e, f, g, h).The New Zealand EPA set PFOS and PFOA in waste discharge limits at 0.1 μg/L and 1 μg/L for total PFAS (Dawson 2018). The EPA also proposed limit for PFOS in biosolids to be at 0.3 mg per kg dry weight (Table 15).

5 Pharmaceuticals

It is not possible to individually assess the hazards posed by each industrial effluent due to the wide variety of pharmaceutical drugs available worldwide. Wastewater treatment plants in industries are noted to be poorly equipped (Orias and Perrodin 2013), and this becomes the major source of pharmaceuticals to the aquatic species (Larsson et al. 2007; Sengar and Vijayanandan 2022; ANSES 2013; Khetan and Collins 2007; WHO 2012). Also from human excretion, it entered municipal wastewater and groundwater.

5.1 Health Hazards

Several researches have determined the environmental and ecological effects of pharmaceuticals in aquatic environments (Khetan and Collins (2007), Orias and Perrodin (2013), and Orias and Perrodin (2014)), its impact on human is less known (Khetan and Collins 2007). It has been determined that very little amounts of pharmaceuticals in drinking water are extremely unlikely to pose health hazards to humans (WHO 2012), antibiotics contribution to the growth of antimicrobial resistance (AMR) may constitute a threat to human health (Kumar et al. 2019; Larsson et al. 2007; Sengar and Vijayanandan 2022).

5.2 Sources of Industrial Effluent

Pharmaceuticals entered municipal WWTPs through residential and trade waste route. Consumed or improperly discarded medications that are flushed down the commode or sink constitute residential contributions (WHO 2012), whereas industrial contributions consist of effluents containing pharmaceuticals from hospital waste, pharmaceutical company, and old care facilities (Orias and Perrodin 2014). Compared to residential wastewater, hospital effluents contain significantly higher concentrations of pharmaceuticals (Verlicchi et al. 2012; Majumder et al. 2021).

5.3 Limit of Discharge and Policies

There are guidelines relating to hospital wastewater management (WHO 2014; US EPA ELGs for Hospitals) without specific standards for pharmaceutical pollutants (Majumder et al. 2021). The US EPA has also set ELGs for the pharmaceutical manufacturers (US EPA ELGs 2022a, b, c) without mentioning discharge limits for specific pharmaceutical products. The Organization for Economic Cooperation and Development (OECD) 2019 published a report categorizing source-directed, use-oriented, and end-of-pipe policy instruments.

All these three categories are further subdivided into regulatory, economic, and voluntary. Regulations include environmental quality, good manufacturing practices, effluent discharge, best available techniques, and product bans. Economic include product or substance charges and subsidies. Lastly, voluntary includes advisory services, waste collection, public environmental health campaigns, disease prevention, and eco-labeling of green pharmaceuticals. It is directed to decrease or diminish the discharge of pharmaceuticals into water resources (OECD 2019) to protect drinking water sources.

6 Pesticides

As like pharmaceuticals, pesticides also exist in wide variety in numbers. It is not possible to assess individually the risk posed by each chemical in industrial effluents. They entered to wastewater through industrial effluent and from agricultural land and thus effect the aquatic environment.

Table 16 World Health Organization basis for pesticide classifications

	LD_{50} for the rat (gm/kg body weight)	
Class	Oral	Dermal
Ia extremely hazardous	<0.005	<0.05
Ib highly hazardous	0.005–0.05	0.05–0.2
II moderately hazardous	0.05–2	0.2–2
III slightly hazardous	Over 2	Over 2
U unlikely to present acute hazardous	5 or higher	

6.1 Health Hazards

Among the three primary categories of pesticides, only insecticides interfere with the nervous system, whereas fungicides and herbicides have a much wider range of potential health effects. The World Health Organization categorizes pesticides in accordance with their acute oral and dermal toxicity to rats (WHO 2020). These categories are extremely (Ia) and highly hazardous (Ib); moderately hazardous (II); slightly hazardous (III); and unlikely to present acute hazard (U) in normal use (WHO 2020), as summarized in Table 16.

6.2 Sources of Industrial Effluent

Significant quantities of pesticides have been detected in the wastewaters from multiple pesticide manufacturing facilities around the world (Affam et al. 2014, Pham et al. 2021). In addition, pesticides have been detected in effluent discharged from the agro-based industry, including fruits and vegetables (Campos-Mañas et al. 2019), and fruit-packaging industry (Karas et al. 2016).

6.3 Limit of Discharge and Policies

The US EPA has determined ELGs of a daily maximum of 0.01 kg of organic pesticide chemicals per 1000 kg of total organic active ingredients and a monthly average of 0.0018 kg of organic pesticide chemicals per 1000 kg of total organic active ingredients (US EPA ELGs 2022a, b, c). In Italy, the discharge limit of total pesticides is 50 μg/L (Mezzanotte et al. 2005), in New Zealand, the Model General Bylaw for Trade Waste (Standards New Zealand 2004) sets a maximum concentration of 0.2 g/m^3 (200 μg/L) for total pesticides discharge limit, and in Taiwan, discharge limits depend on types pesticides (Hamilton et al. 2003).

7 Microplastics

Microplastics refer to plastic smaller than 5 mm in length, it comprises various polymers and different chemical additives (Rochman et al. 2019). They emerge from the breakdown of larger plastic pollutant that comes from residential and industrial sources.

7.1 Health Hazards

Microplastics serve as vectors for toxic contaminants; they can be transported through circulatory system to distant sites in the body (Rahman et al. 2021). In addition, microplastics have also been detected in human placentas (Ragusa et al. 2021). Microplastics infiltrate the wastewater network in large quantities from several household sources, including significant amounts of microfibers released when washing synthetic clothing (Prata 2018).

7.2 Sources of Industrial Effluent

Large amounts of microplastics pass through wastewater network from several household sources, including washing of synthetic clothes in the form of microfibers (Prata 2018). Though treatment processes reduce microplastic concentration to low level, a high volume of effluents released daily add substantial amount to wastewater (Conley et al. 2019, Prata 2018, Sun et al. 2019, Conley et al. 2019). Wastewater-containing antibiotics get contact with microplastics and together they may develop extracellular antibiotic resistance genes and antibiotic-resistant bacteria (Syranidou and Kalogerakis 2021). Industrially, polymer processing plant (Bitter and Lackner 2020), textile manufacturing industry (Chan et al. 2021, Xu et al. 2018, Zhou et al. 2020), marine construction facilities (Franco et al. 2020), machine manufacturing, and chemical and electroplating plants in China (Wang et al. 2020) contribute microplastic to wastewaters.

7.3 Limit of Discharge and Policies

The European Commission is creating a microplastics initiative to decrease the accidental discharge of microplastics into the environment (European Commission 2021). Water Research Australia studied that effluents that contain microplastic are not currently regulated under discharge licenses (Water Research Australia 2021). In New Zealand, Aotearoa Impacts and Mitigation of Microplastics (AIM2) Ministry of

Business, Innovation and Employment Endeavour (MBIE) also investigates microplastics in wastewater (ESR 2021).

8 Conclusions

The objective of this study was to understand contaminants originating from industrial as well as municipal waste. This chapter tries to provide an international perspective on contaminants that are more concerned with human health determined in industrial effluents based on the literature. The selected contaminants were grouped into six classes, such as endocrine-disrupting compounds, heavy metals and metalloids, per- and polyfluoroalkyl substances, pharmaceuticals, pesticides, and microplastics. The industries generating these effluents were identified and potential health effects to human were also highlighted. Biodiversity and ecosystem services are also affected by these pollutants. Within the context of the mitigation hierarchy, environmental impacts should first be avoided, then minimized, and finally restored where possible. To reduce the adverse effect, treatment facilities, both onsite and off-site, need to installed. Factors causing the unrepaired environmental damage pay compensation, while the society does not bear the cost. The methods of environmental compensation and minimization of negative impacts on the environment are measures to protect environmental elements. This environmental compensation may relate to protecting plants, animals, or protection against pollution of air, water, and soil. The local body should also ensure that industries compensate the farmer for the loss of vegetation caused by the effluent.

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