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Phthalates in the environment: Their toxicology and associated risk to humans

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Abstract
This review describes the presence of phthalate diesters (PAEs) in various products and elements of the environment, their toxicology, and possible risk is presented as reported in the scientific literature. PAEs have been detected in a variety of environmental elements, including air, soils, sediments, and landfill leachate, as well as in ground, surface, and drinking water, which makes them a common environmental contaminant. The most common and detectable phthalate in all elements of the environment is di(2-ethylhexyl) phthalate (DEHP). When added up, the amounts of human exposure to all sources of phthalates can be significant and pose an equally significant health risk to humans and other living organisms. Several PAEs, including DEHP, di-n-butyl phthalate (DBP), di-isobutylphthalate (DIBP), and butyl benzyl phthalate (BBP) are classified as toxic to reproduction and have endocrine-disrupting properties. Despite the introduction of strict regulations and restrictions on PAEs worldwide, long-term monitoring of human exposure is needed to reduce the potential risk to humans and other living organisms.

1. INTRODUCTION

Phthalic acid esters (PAEs), popularly known as phthalates, have been used since the 1930s [Net et al. 2015a]. PAEs have been widely used as additives to polymers, mainly to make the materials soft and flexible [Gao, Wen 2016]. Historically, the longest-used, and therefore the phthalates most widely present in the environment, are di(2-ethylhexyl) phthalate (DEHP), dibutyl phthalate (DBP), diethyl phthalate (DEP), benzyl butyl phthalate (BBP), diisononyl phthalate (DINP), diisodecyl phthalate (DIDP), and dioctyl phthalate (DNOP) [Staples et al. 1997].

Mersiowsky et al. [2001] estimated that about 93% of polyvinyl chloride (PVC) plasticizers were phthalates and that approximately 95% of the phthalate produced was used in PVC blends. Also, the EU Risk report [2008] stated that in the EU, 95% of DEHP manufactured was used as a plasticizer for PVC. The proportion of PAEs in PVC may be as high as 40%–60% [Chao, Cheng 2007, Gao et al. 2016, Erythropel et al. 2014]. The second most frequently used phthalate in many countries was DBP phthalate [Fang et al. 2010]. PAEs were also used in the preparation of polyvinyl acetate, cellulosic materials, and polyurethane resins [Sailas et al. 2015].

PAEs can migrate to the polymer product surface and are continuously released to the surrounding environment [Net et al. 2015b, Sailas et al. 2015, Erythropel et al. 2014, Benjamin et al. 2017], during the production, storage, use, removal, and disposal phases [Clausen et al. 2012, Gao, Wen 2016]. PAEs are by far the most common chemical products that people encounter on a daily basis [Net et al. 2015b]. Phthalates have been detected in a variety of environmental elements, including air [Wensing et al. 2005, Li 2017], soils, sediments, and landfill leachate as well as in ground, surface, and drinking water [Schwarzbauer et al. 2002, Zheng et al. 2007], which makes them toxic [Grynkiewicz-Bylina 2011] and a common environmental contaminant [Przybylińska, Wyszkowski 2016, Chai et al. 2014], posing a threat to humans, other living organisms, and the environment. The biggest concerns related to human and animal contact with PAEs are their adverse reproductive effects, including problems with fertility, juvenile development, and carcinogenicity [Net et al. 2015b, Howdeshell et al. 2008a].

The scope of this review is to present recent advancements in the scientific knowledge for the presence of PAEs in various products and elements of the environment, their toxicology, possible risk, and mitigation strategies.

2. RESULTS AND DISCUSSION

2.1. Phthalate production in Poland and worldwide

Net et al. [2015b] reported that global PAE production has exceeded 150 million tons and in past decades production has risen sharply from about 1.8 million tons in 1975 to

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more than 8 million tons in 2011. Consumption of PAEs in China in 2010 was about 1.4 million tons, and it has been increasing at a rate of 7.7% per year [Zhang et al. 2015]. In 2014, DEHP accounted for 80% of total PAE production in China [Gao, Wen 2016]. In 2016, global PAE production was estimated at about 5–8 million tons per year [Przybylinska, Wyszkowski 2016, Gao et al. 2016].
It is estimated that at least 1 million tons of DEHP may have entered the Polish market since its production began in 1963 [Wowkonowicz et al. 2021].

2.2. Presence of phthalates in the environment, manufactured products, and the food chain

PAEs are widespread in the environment as a result of their extensive use in the manufacture of various products [Huang et al. 2021]. The most commonly detectable PAEs in all elements of the environment is DEHP [Gao, Wen 2016].

2.2.1. Waters and bottom sediments

Concentrations of DEHP in surface freshwater range from undetectable levels to 97.8 µg/l - detected in Germany (Table 1). In Poland, according to a study by Tokarz et al. [2017], DEHP phthalate concentrations determined in 2017 and 2018 in the upper, middle, and lower sections of the Vistula River ranged from <LOQ to 6.6 µg/l.
DEHP has also been measured in groundwater at concentrations ranging from undetectable to 5.6 µg/l. The maximum concentration of 5.6 mg/l was observed in Spain [Lopez-Roldan et al. 2004]. It should be noted that the occurrence of DEHP in groundwater is related to concentrations in surface water [Zhang et al. 2009]. Testing also detected DEHP phthalate in drinking water (China 3.47 µg/l, Greece 0.93 µg/l, USA 0.55 µg/l, and Germany and Poland 0.05–0.06 µg/l) [Liu et al. 2013, Psillakis, Kalogerakis 2003, Kavlock et al. 2006, Huerta-Fontela, Ventura 2008]. Some of the phthalates sedimentise and accumulate in bottom sediments during transport with flowing water

Table 1. Occurrence of PAEs in surface waters (µg/l)

Sampling site	DMP	DEP	BBP	DEHP	DBP	Reference
Kaveri River (India)	0.02	0.24	0.04	0.51	0.25	Selvaraj et al. 2015
Rivers: Jarama and Manzanares (Spain)	.	.	.	.	0.25–1.76	Domínguez-Morueco et al. 2014
Somme River (France)	0.02–0.25	0.26–6.98	.	5.16–20.80	0.22–3.86	Net et al. 2014
4 Rivers (Korea)	0.04–15.10	.	0.07	.	.	Cho et al. 2014
Songhua River (China)	0.98–4.12	1.33–6.67	- –4.39	2.26–11.6	1.69–11.80	Gao et al. 2014
Mopanshan Reservoir (China)	- –0.04	- –0.06	.	0.13–6.57	0.05–4.50	Liu et al. 2013
Jukskei River (South Africa)	0.04–0.56	0.08–0.39	.	0.49–5.58	0.79–3.65	Sibali et al. 2013
Seine River Estuary (France)	0.03–0.18	0.07–0.18	.	0.16–0.31	0.07–0.32	Dargnat et al. 2009
Seine River (France)	0.01–0.10	0.05–0.21	0.007–0.04	0.32–0.78	0.21–0.53	Teil et al. 2007
Port False Creek (Kanada)	0.002–0.005	0.05–0.35	0.002–0.006	0.17–0.44	0.05–0.244	Mackintosh et al. 2006
Port East London (RPA)	0.03–31.70	0.03–33.10	.	0.06–197	2.8–122	Fatoki, Noma 2002
Tama River (Japan)	- –0.09	- –0.31	- –0.06	- –3.09	- –0.54	Suzuki et al. 2001
Furu River (Japan)	.	.	.	8–25	.	Yuwatini et al. 2006
18 Rivers (Taiwan)	.	.	.	18.5 (maksymalne)	.	Yuan et al. 2002
Rivers, lakes, and canals (Germany)	.	.	.	0.33–97.8	0.12–8.80	Fromme et al. 2002

. – no data
- – not detected
Collected by Gao, Wen [2016] and supplemented by the author.

Table 2. Occurrence of PAEs in bottom sediments (µg/kg dry matter)

Sampling site	DMP	DEP	BBP	DEHP	DBP	Reference
Kaveri River (India)	1.6	16.5	2.6	278	35.5	Selvaraj et al. 2015
Guanting Reservoir (China)	- –94.50	0.20–89.5	- –380	- –278	- –571	Zheng et al. 2014
Shichahai River (China)	21.50–133	2.40–20.0	- – 287	83.5–5755	10.20–1114	Zheng et al. 2014
Songhua River (China)	25.20–87.80	26.70–38.20	- – 96.30	227–567	58.10–881	Gao et al. 2014
Jukskei River (South Africa)	0. 22–12.80	2.48–44.80	.	6.54–3660	6.27–57.1	Sibali et al. 2013
Kaohsiung Port (Taiwan)	.	.	.	400–34,800	13–1310	Chen et al. 2013
Gomti River (India)	- – 316	- – 137	.	- – 947	- – 312	Srivastava et al. 2010
Rivers (Taiwan)	.	100–1100	- – 1800	500–23,900	300–30,300	Yuan et al. 2002
Rivers (Germany)	.	.	.	210–8440	60–2080	Fromme et al. 2002

. — no data, - – not detected

(Table 2). DEHP concentrations ranging from 8 to 479 g/kg dry matter were observed in the bottom sediments of water bodies as they absorb large amounts of DEHP from river water [Zolfaghari 2014]. It is also stated that precipitation adds to the sources of DEHP in the environment [Kavlock et al. 2006].

2.2.2. Wastewater, sewage sludge, and landfill leachate

Concentrations of DEHP detected in wastewater ranged from 0.716 to 400 µg/l [Lin et al. 2009, Mersiowsky 2001], and the highest observed concentration was in municipal wastewater in Taiwan [Cheng et al. 2010]. According to Zolfaghari [2014], the high concentrations of DEHP in some wastewaters may be related to the fact that, in many countries, municipal and industrial wastewater, along with landfill leachate, are mixed in a single sewage system. DEHP is adsorbed on suspended organic particles and then accumulates in sewage sludge or bottom sludge [Gavala et al. 2003]. Concentrations of DEHP in sewage sludge range from 1.8 to 1.340 mg/kg dry weight [Chang et al. 2007, Cheng et al. 2000, Meng et al. 2014]. Sewage sludge and wastewater are the main sources of DEHP in the environment [Zolfaghari et al. 2014]. The use of sewage sludge as a fertilizer is considered a principal source of DEHP accumulation in agricultural soils [Gao, Wen 2016].
Landfilling was and still is one of the most common techniques of waste disposal [Kalka 2012, Gworek et al. 2015, Koda et al. 2017, Vaverková et al. 2019]. Therefore, plastics (mainly PVC) end up in municipal solid waste landfills. The release of phthalates from landfills is mainly through leaching, in which they end up in the leachate where they can be detected in significant concentrations [Wowkonowicz, Kijeńska 2017].
Over the past several years. many studies have been conducted in Europe and around the world on the concentrations of phthalates in landfill leachate [Gao et al. 2016, Liu et al. 2010, Jonsson et al. 2003, Asakura et al. 2004]. In Poland. extensive studies have been conducted by Kotowska et al. [2020] and Wowkonowicz et al. [2021]. The highest concentrations of DEHP determined in leachate were 249 µg/l and 394.4 µg/l, respectively.
In the case of landfills without sealing and leachate collection facilities or when the protective barriers are damaged or not operating properly, phthalates will leach into the environment along with the leachate, contaminating surface and groundwater.
Phthalates detected in landfill leachate and polluting nearby groundwater pose a high environmental risk [Kotowska et al. 2020, Wowkonowicz et al. 2021].

2.2.3. Soils and food chain

Use of large amounts of PAE-containing plastic foils and fertilizers in intensive vegetable cultivation. also results in the accumulation of DEHP in agricultural soils and increases the risk of DEHP presence in the food chain [Kong et al. 2012, Gao, Wen 2016]. Measured DEHP concentrations in soils (Table 3) range from 1 to 264 mg/kg of dry matter, with the highest concentrations detected in the soils of industrialized sites [Zeng et al. 2009].
It has been reported [Jiang et al. 2022] that DEHP has negative effects on soil microbes, which are very sensitive to soil contamination. Soil microbes are associated with soil health, fertility, growth, and crop quality; therefore, this impact is of great concern.
A study by Ning et al. [2017] reports that vegetables grown in greenhouses have higher levels of DBP and DEHP than those grown in open fields. DEHP can penetrate the soil through various pathways and can affect plant

Table 3. Occurrence of PAE in soils and soils (µg/kg dry matter)

Sampling site	DMP	DEP	DBP	DEHP	DOP	Reference
Agricultural soils (Spain)	.	.	.	1000–63,000	.	Plaza-Bolanos et al. 2012
Suburban soil (Tianjin, China)	2–101	2–114	7–285	26–4170	- –9780	Kong et al. 2012a,b
Surface soil (Fujian, China)	630–680	320–630	2530–3960	7320–11700	- –3460	Lin et al. 2010
Agricultural soils (Netherlands)	.	.	6 (average)	31.8 (average)	.	Peijnenburg, Struijs 2006
Clay, Brickearth (UK)	0.1	0.20–0.90	7.90–8	22.20–75.80	11.50–13.70	Gibson et al. 2005
Urban soil (Beijing, China)	0.07–31.58	0.07–99.93	0.15–2583.50	0.15–1350.20	1.50–29.88	Xia et al. 2011

. — no data, - —not detected

development and growth [Sharma, Kaur 2020]. Research by Fierens et al. [2012] shows that plants take up nutrients from the soil through roots. along with contaminants such as PAEs. In agricultural crops phthalates are detected in every part of the plant. The high frequency of PAE detection in commercially sold vegetables indicates that human exposure to PAE through ingestion of vegetable should be taken into account in cumulative risk assessments.
Phthalate contamination, specifically DIBP, DBP, BzBP, and DEHP, has also been detected in dairy products [Fierens et al. 2013]. The most likely source of this contamination is mechanical milking and ingestion of phthalate-containing feed by dairy cattle. A study on DMP, DEP, DIBP, DBP, BBP, DEHP, and DNOP in 400 food products, conducted in Belgium, finds that DEHP (concentrations ranging from 13 µg/kg in fruits and vegetables to 52 µg/kg in dairy products), followed by DBP (from 4 µg/kg in oils to 56 µg/kg in beverages), and BBP (from 3 µg/kg in meat to 45 µg/kg in beverages), were the most commonly detected phthalates in foods with DEHP phthalate reaching the highest concentrations [Fierens et al. 2012, Przybylinska, Wyszkowski 2016].

2.2.4. Air

Although PAEs have low volatility and their concentrations in the air is expected to be low. they have been detected in both rainwater and air (Table 4) [Gao, Wen 2017, Gao et al. 2018]. Concentrations of DEHP in indoor air might be elevated due to slow volatilization from plastic products [Bornehag et al. 2005]. In a study by Pei et al. [2013], Chinese researchers studying new residential buildings detected PAE in living rooms, bedrooms, and offices.
An increase in the release of DEHP into the indoor air occurs as the ambient temperature increases. Inside cars, DEHP concentrations of 1 µg/m^3 were detected at room temperature, while at 65°C they were found to be 34 µg/m^3 [Uhde et al. 2001].

Values of PAE concentrations in freshwater, bottom sediments, soil and ground, and air (collected from various sources by Gao, Wen [2016] and supplemented by the author) are presented in Tables 1–4.

2.2.5. Consumer goods, personal care products, and medical equipment

Humans dermal PAE absorption may happened through skin contact with various product containing phthalates, such as: personal care products, clothing, sanitary napkins, yoga pads, modelling clay, and toys [Das et al. 2021].
The occurrence of phthalates in cosmetics, available on the Canadian market, was tested in 252 products by Koniecki et al. [2002]. PAEs were detected in every product tested (Table 5), and the frequency of PAE detection was as follows: DEP (in 103 of 252 products), DBP (15 of 252), DiBP (9 of 252), DEHP (8 of 252), and DMP (1 of 252).
Another important factor involved in human exposure to PAE is direct contact with medical equipment, where plasticised PVC tubing is used, particularly during blood transfusions and hemodialysis [Calafat et al. 2004].

2.2.6. Toxicity of phthalates

PAEs have been reported to cause teratogenicity, mutagenicity, and carcinogenicity, even at very low concentrations [Caldwell 2012, Park, Kwak 2012].
Figure 1 shows the routes of human exposure to DEHP.
The links between PAE exposure and certain diseases have been proven in many studies [Huang et al. 2021]. Most of the potential anomalies associated with DEHP exposure in animals are associated with the pancreas [Selenskas et al. 1995], reproductive organs [Matsumoto et al. 2008, Saillenfait et al. 2009], and with causing respiratory [Xiao et al. 2023] and liver cancers [Rusyn, Corton 2011]. Moreover, exposure to DEHP leads to testicular atrophy,

Table 4. Average PAE values measured in ambient air (ng/m^3)

Sampling site	DMP	DEP	BBP	DEHP	DOP	Reference
North Atlantic	.	.	.	2.9	.	Giam et al. 1978
Sweden	.	.	.	2	2	Thuren, Larsson 1990
North Sea (Germany)	5.1	17.1	0.3	63.1	-	Xie et al. 2005
Urban areas (Paris, France)	5.9	9.1	4.7	13.2	0.4	Teil et al. 2006
Arctic	0.11	0.41	0.04	0.22	-	Xie et al. 2007
Urban areas (Nanjing, China)	9	3	2.6	15.7	0.9	Wang et al. 2008
Suburban areas (Nanjing, China)	2.4	1	0.8	6.2	.	Wang et al. 2008
Indoor (Berlin, Germany)	919	722.7	26.6	155.5	.	Weschler et al. 2008
Residential house (Sweden)	18	1598	28	208	.	Bergh et al. 2011
Nursing home (Sweden)	6.2	1256	19	267	.	Bergh et al. 2011
Workplace (Sweden)	4.6	667	16	118	.	Bergh et al. 2011
Xi'an City (China)	501	.	.	470	.	Wang et al. 2014

. — no data, - — not detected

Table 5. Maximum concentrations of PAE detected in cosmetics*

Product tested	Maximum PAE concentrations (µg/g)			
	DEP	DiBP	DBP	DEHP
Fragrance preparations/perfumes	25,542	.	.	521
Cosmetics and hair sprays	1,223	1.3	36	1.6
Deodorants and antiperspirants	3,634	4.5	.	.
Nail polish	.	0.4	24,304	1,045
Body lotions and creams	5,549	4.1	.	.
Skin cleansing products	277	1	6.6	30
Oils and creams for children	2,566	.	.	.
Shampoos for children	320	.	1.8	.

. — no data
*Data collected by Koniecki et al. [2002]

steroidogenesis, and embryonic mortality [Howdeshell et al. 2008], and increased oxidative stress [Ishihara et al. 2000].

Humans can inhale, ingest, and absorb PAEs through skin contact [Klöting 2015, Dobrzynska 2016, Magdouli et al. 2013; Gao, Wen 2016]. PAEs can potentially cause testicular dysgenesis syndrome (TDS), abnormal reproductive development [Howdeshell et al. 2008b], and sex reversal [Sailas et al. 2015]. PAEs affect sperm function by decreasing motility and sperm count, which can cause defects and can also increase the incidence of DNA damage [Lyche 2011, Cai et al. 2015].

Endocrine disruption caused by PAEs can contribute to many problems such as osteoporosis, hepatomegaly, weight loss, feminization of boys, and skin and breast cancer [Sailas et al. 2015, Gani et al. 2017]. Because PAEs exhibit the ability to bioaccumulate through long-term exposure people are at particularly increased risk from the continued ingesting of contaminated food or water [Gao et al. 2016, Ning et al. 2017].

In a study by Pei et al. [2013], where newly built living quarters were studied, it was proven that young children are particularly at higher risk of phthalate inhalation because of their low body weight, prolonged residence in places with high PAE concentrations, compared to adults and because they often put various objects in their mouths. Young children also ingest phthalates with breast milk [Mankidy et al. 2012]. Phthalates have been detected in urine samples of newborns, which indicates a risk to babies in the womb [Enke et al. 2013].

A correlation between PAE exposure through inhalation and asthma has been also identified in some studies [Ventrice et al. 2013, Mankidy et al. 2012].

According to European Chemicals Agency (ECHA) [www.echa.europa.eu/hot-topics/phthalates] several PAE, including DEHP, DBP, DIBP, and BBP, are 'classified as toxic to

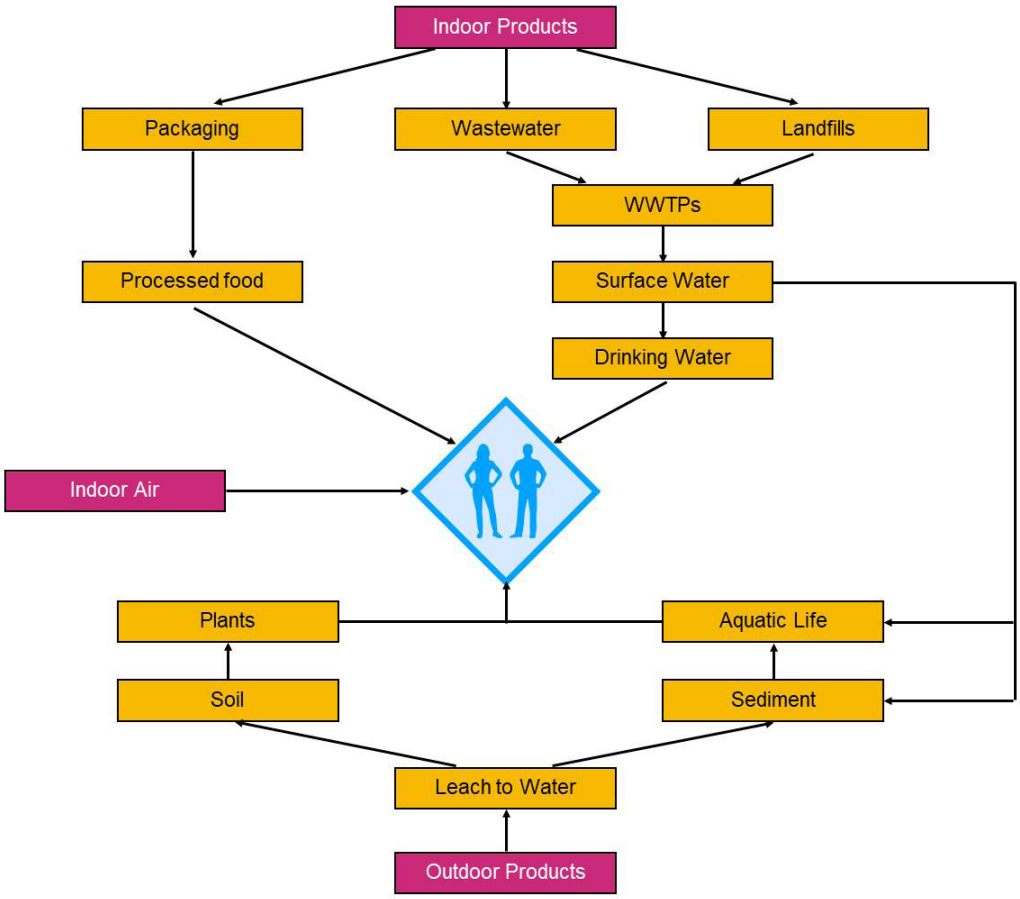


Figure 1. Pathways of human exposure to DEHP (author's design based on the report by Zolfaghari et al. 2014). WWTP, wastewater treatment plant

reproduction (Repr. 1B). This means that they are presumed to have a negative effect on human's ability to have children and on the unborn baby'. Those PAEs also have endocrine disrupting properties [European Commission 2006], and therefore can interact with or interfere with the endocrine system.

DBP and BBP are classified as very toxic to aquatic life (aquatic acute 1) and BBP also as very toxic to aquatic life with long lasting effects (aquatic chronic 1) [www.echa.europa.eu/hot-topics/phthalates].

2.2.7. Regulations, restriction of use and mitigation strategies

Due to the negative effects of PAEs on the health of humans and other living organisms, global organizations and institutions have introduced a number of regulations and restrictions on the use of phthalates. Environmentally friendly plasticizers have also been developed as another option for getting rid of phthalate-related problems.

The United States Environmental Protection Agency (US EPA) has included some PAEs (DMP, DEHP, and DBP) in its Toxics Release Inventory list, which includes all known substances that cause adverse effects on the environment or human health. PAEs were included in this list because of 'their toxicity and evidence of associated widespread environmental and human health exposures' [USEPA 2015].

Polish and European regulations have classified DEHP as a priority substance[1] in Europe, for which quality standard in surface waters should not exceed 1.3 µg/l [Directive 2013/39/EU 2013]. Also, DEHP concentrations in drinking water are regulated by various global environmental agencies. According to WHO guidelines maximum safe concentration of DEHP in drinking water is 8 µg/l [WHO 1996, Zia 2015]. Other countries, like US, Australia, Japan, and New Zealand, recommend the maximum allowable DEHP content in drinking water as 6, 9, 100, and 10 µg/l, respectively [Maycock et al. 2008, ATSDR 2022].

The Occupational Safety and Health Administration (OSHA) has set the limit for permitted concentration for DEHP in indoor air in the workplace at 5 mg/m3 of air

1 Priority substances are substances that pose a particular threat to the aquatic environment and to other environmental components (as a result of transport through water) due to toxicity, low susceptibility to degradation, bioaccumulation, risk to human health.

over 8 working hours. The short-term exposure limit (15 minutes) is 10 mg/m^3 [Magdouli et al. 2013].
According to Müller et al. [2003] DEHP is not degraded in sewage treatment plant but mainly accumulated at the sludge. Accumulation of DEHP in sewage sludge can significantly affect and limit its use for fertilizer in agriculture [Marttinen et al. 2003]. As a result, the European Commission has set the maximum allowable DEHP content in sewage sludge used in agriculture at 100 µg/g dry weight [Scopetani et al. 2022]. This guideline has not been implemented in Polish law on sludge use. In the case of uncontrolled sludge application, the risk of DEHP contamination of soil and groundwater can be high.
The occurrence of PAEs in cosmetic products is also regulated by Regulation 1223 [2009], in which selected phthalates (including DEHP, DBP) are prohibited for use in cosmetic products.
The legislation governing the use of selected PAEs in electrical and electronic equipment after July 2019 is the RoHS III Directive, which amends the substances covered by the restriction related to the value of the maximum concentration allowed by weight in homogeneous materials, including DEHP (0.1%), BBP (0.1%), DBP (0.1%), and DIBP (0.1%).
The withdrawal of phthalate products from global markets is a result of REACH Regulation 1907 [2006], a European Union regulation specifically introducing a chemical authorization process for European manufacturers, importers, and downstream users dealing with very high-risk substances. The process is being carried out to control the risks associated with the use of individual substances that pose a risk to human health and gradually replace them with safer substitutes. As of July 2020, restrictions have been placed on the phthalates DEHP, DBP, DIBP, and BBP under the REACH regulation for a wide range of products, such as baby swimming aids, recreational equipment, footwear, mattresses, coated fabrics and paper, office supplies and flooring. The EU-wide classification as toxic for reproduction included more phthalates (among others, DEHP, DBP, DIBP, BBP, bis(2-methoxyethyl) phthalate, dipentyl phthalate, and dihexyl phthalate). Accordingly, as of November 2020, restrictions on their content in products have been extended to consumer clothing and related accessories and other textiles that come into contact with the skin [www.echa.europa.eu/hot-topics/phthalates].
Finally, in November 2021, the European Commission added endocrine disrupting properties to DEHP, DBP, BBP, and DIBP (which were previously classified only as toxic to reproduction). This update will make it necessary for companies to apply for REACH authorization for: DEHP uses, in food contact materials, medical devices and direct packaging of medicinal products, and BBP and DBP uses in direct packaging of medicinal products [European Commission 2006, Vogel et al. 2023]. Those restrictions come into force from 2023 [European Commission 2021].
The main purpose of the above-mentioned actions is to reduce the widespread presence of PAEs in the environment and in products used, and to minimise PAEs contact with humans and living organisms.
With increasing global regulations that have led to the phase-out of phthalate plasticizers. including DEHP, non-phthalate plasticizers are expected to become increasingly important in the coming years. Non-phthalic plasticizers are believed to be able to solve some of the health problems previously associated with phthalates, while meeting production efficiency requirements [Plasticizers 2018].

3. Conclusion

This review of the scientific literature summarises the reported presence of PAEs in various products and elements of the environment as well as the possible risk PAEs pose on humans and other living organisms.
Phthalates and especially DEHP are considered widespread environmental contaminants. present in air, soils, sediments, landfill leachate, and in groundwater, surface water and drinking water, posing a threat to humans and the environment.
Humans are exposed to PAEs through inhalation, ingestion, and dermal absorption. Exposure to PAEs is believed to have potential adverse reproductive effects on juvenile development, problems with fertility, and carcinogenicity.
The use of phthalate-containing products is regulated through various EU and global legislation, which has led to the phthalate plasticizers, including DEHP, being phased out, but it does not change the fact that large amounts of PAEs are still present in the environment and human surroundings.
In the case of uncontrolled sludge application, the risk of DEHP contamination of soil and groundwater can be high. Therefore, monitoring and setting the maximum allowable DEHP content in sewage sludge used in agriculture is recommended (in Poland and in other countries).
Considering human exposure to various sources of phthalates, such as: contact with medical equipment (packaging), cosmetics, food (packaging and greenhouse grown vegetables), surface water pollution (discharges from wastewater treatment plants), groundwater contamination (leachate from landfills), agricultural use of sewage sludge, it can be significant and pose a significant threat to the health of humans and other living organisms.
In conclusion, despite the introduction of strict regulations and restrictions on PAEs use worldwide, long-term monitoring of human exposure is needed to reduce the potential risk to humans and living organisms.

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