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Review article

Endocrine disrupting compounds in drinking water supply system and human health risk implication

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ABSTRACT

To date, experimental and epidemiological evidence of endocrine disrupting compounds (EDCs) adversely affecting human and animal populations has been widely debated. Notably, human health risk assessment is required for risk mitigation. The lack of human health risk assessment and management may thus unreliably regulate the quality of water resources and efficiency of treatment processes. Therefore, drinking water supply systems (DWSSs) may be still unwarranted in assuring safe access to potable drinking water. Drinking water supply, such as tap water, is an additional and crucial route of human exposure to the health risks associated with EDCs. A holistic system, incorporating continuous research in DWSS monitoring and management using multi-barrier approach, is proposed as a preventive measure to reduce human exposure to the risks associated with EDCs through drinking water consumption. The occurrence of EDCs in DWSSs and corresponding human health risk implications are analyzed using the Needs, Approaches, Benefits, and Challenges (NABC) method. Therefore, this review may act as a supportive tool in protecting human health and environmental quality from EDCs, which is essential for decision-making regarding environmental monitoring and management purposes. Subsequently, the public could have sustainable access to safer and more reliable drinking water.

1. Introduction

Endocrine disrupting compounds (EDCs) have received critical growing interest for years because of the severe and wide-ranging diseases associated with them, particularly abnormal endocrine systems in exposed individuals and populations. Consequently, several measures had been taken in regulating the use of EDCs. For example, the United States (US) started with the Toxic Substances Control Act (TSCA), followed by integration of the respective EDC controls in the Food Quality Protection Act (FQPA) and the Safe Drinking Water Act (SDWA). The Australian Drinking Water Guidelines 2011 (ADWG) have been revised and updated recently, incorporating guidelines for EDCs in drinking water, because of the frequent detection of EDCs in drinking water and the high incidence of illnesses associated with them, particularly among poor families, especially in the bottom 40% (B40) income group. Continuous EDC contamination is not merely threatening the health of exposed individuals, populations, and ecosystems but also is increasing the cost of water treatment and remediation for sufficient drinking water supply. Because of limited access to clean and safe drinking water, international confidence in water security is at stake.

EDCs that exist as either natural or synthetic compounds are capable of altering hormonal and homeostatic systems, causing the organism to communicate with and respond to its environment through environmental or inappropriate developmental exposures (Diamanti-Kandarakis et al., 2009). Given the health risk problem from human exposure to EDCs, all European Union countries are subjected to risk assessment, comprising of hazard identification, dose-response assessment, exposure assessment, risk characterization, and risk management, for risk mitigation. Risk assessment was in accordance with the Regulations 793/93 and 1488/94 for existing substances, the Directive 67/548 and 93/67 for new substances, and the Directive 98/8 for active substances and substances of concern in a biocidal product.

Ultimately, several studies on EDCs have included environmental concentration assessment (Cai et al., 2015; de Jesus Gaffney et al., 2015; Gou et al., 2016; Li et al., 2015; Simazaki et al., 2015; Sun et al., 2015; Tran et al., 2013; Xu et al., 2011), treatment and remediation (Boleda et al., 2011; Fan et al., 2013; Kim et al., 2015; Yoon et al., 2006), risk assessment (de Jesus Gaffney et al., 2015; Genthe et al., 2013; Leung et al., 2013; Li et al., 2015), and risk perception and communication (Bound et al., 2006; Dohle et al., 2013; Tyshenko et al., 2008; Van Donk et al., 2016). However, research on EDC health risk implication to humans is lacking, thus health issues are of less concern or even ignored in the scientific and medical communities. Currently,

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the recognition and understanding of EDCs are rather new and have yet to be investigated thoroughly. Thus, the US Environmental Protection Agency (EPA) implemented the Endocrine Disruptor Screening Program (EDSP) for identification and characterization of endocrine disrupting activity (US EPA, 2016a).

In this decade, the quality of drinking water sources, namely surface water, groundwater, and reclaimed water, is a global concern. This is because raw water from these sources is treated by drinking water treatment plants (DWTPs) to be consumed by humans as drinking water, and drinking water itself is a potential source for human exposure to EDCs. Kolpin et al. (2002) reported at least one pharmaceutical was found in 80% of 139 US streams sampled in 1999–2000. Trace concentrations of wide-ranging EDCs (i.e., pharmaceuticals, hormones, pesticides, and plasticizers) were observed across the drinking water supply of 28 million Americans (Benotti et al., 2009). Currently, EDCs are being detected frequently in drinking water sources in countries worldwide, including Taiwan (Gou et al., 2016), China (Cai et al., 2015; Li et al., 2015; Liu et al., 2013; Sun et al., 2015), Japan (Simazaki et al., 2015), South Korea (Kim et al., 2007), Singapore (Tran et al., 2013; Xu et al., 2011), Spain (de Jesus Gaffney et al., 2015; Huerta-Fontela et al., 2011), and the US (Barber et al., 2015; Benotti et al., 2009; Blair et al., 2013; Padhye et al., 2014). Removal efficiency of EDCs by DWTPs is of tremendous concern because of the occurrences of EDCs in the drinking water supply, exposing humans to the EDCs via drinking water consumption, which increases their associated health risk (Benotti et al., 2009; Caban et al., 2016; Cai et al., 2015; de Jesus Gaffney et al., 2015; Esteban et al., 2014; Gou et al., 2016; Huerta-Fontela et al., 2011; Leung et al., 2013; Li et al., 2010; Padhye et al., 2014; Simazaki et al., 2015).

To date, numerous EDC exposure studies have focused separately on drinking water source, water treatment efficiency, and drinking water supply throughout the world for environmental monitoring purposes. To understand the exposure routes of EDCs better, studies on EDC exposure in drinking water supply systems (DWSSs), from drinking water source to DWTP and eventually drinking water supply, as a whole, are required. Subsequently, the aim of this review is to provide a critical overview on occurrence of EDCs in worldwide DWSSs, particularly in drinking water sources (surface water, groundwater, and reclaimed water) and drinking water supplies (tap water), concerning human health risk in exposure to EDCs. In this review, a DWSS comprises drinking water source (the raw water to be treated), DWTP, and drinking water supply (the distributed treated water).

With the detailed human health risk implication, this review can contribute to comprehensive exposure studies in determining the nature and extent of contact with EDCs. Consequently, this review can be used as a principal basis for decision-making in legislative and policy ratification, especially regarding the integration of risk mitigation into existing legislative and policy frameworks to prescribe more stringent drinking water regulatory compliance, thus reducing the extent of EDC exposure and risk to the environment and humans. In respect to safeguarding human health via safe drinking water, this review also suggests a preventive measure, which is a holistic system using a multi-barrier approach. The holistic system builds on continuous research in DWSS monitoring and management, thus providing a database for decision-making. Therefore, this review, which acts as a supportive tool in mitigating potential human health risk from EDCs, is expected to be useful for environmental monitoring and management purposes.

2. Endocrine disrupting compounds

EDCs, which are exogenous and emerging, comprise a wide-ranging scope of chemicals, both natural and synthetic. Natural EDCs include estrogens, androgens, and phytoestrogens. Meanwhile, synthetic EDCs, mainly industrial chemicals and their by-products, encompass polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), polybrominated biphenyls (PBBs), dioxins, furans, alkylphenols (APs), pharmaceuticals and personal care products (PPCPs), and pesticides (Aris et al., 2014; Diamanti-Kandarakis et al., 2009; Kabir et al., 2015; Maqbool et al., 2016). The respective usage of EDCs is summarized in Table 1. The broad scope of consumer products includes extensive utilization of industrial chemicals as additives for manufacturing with considerable production. The wide-ranging additive groups have been used in fragrances, flame retardants, paints, surfactants, plastics, adhesives, lubricants, sealants, detergents, disinfectants, surface cleaners, construction materials, electrical appliances, furniture, textiles, etc. Meanwhile, pharmaceuticals were utilized specifically as human and veterinary therapies. These numerous usages generate EDC loadings in environmental compartments from various point and nonpoint sources, during product manufacturing, usage and application, disposal, and discharge of chemicals or products. The varying behaviors, depending on their respective physicochemical properties, of the wide-ranging EDCs are presented in Table 2, whereas Fig. 1 illustrates the hierarchy of EDCs.

2.1. Polyhalogenated compounds

EDCs are commonly used and act as additives in plastic manufacturing, although awareness on associated risks arose when plastic pollution occurred on a large scale, comprising aquatic and terrestrial habitats (Rochman et al., 2014). EDCs such as polyhalogenated compounds, including PCBs, PBBs, polybrominated diphenyl ethers (PBDEs), perfluorooctane sulfonate (PFOS), and perfluorooctanoic acid (PFOA), which are listed as persistent organic pollutants (POPs), are common in plastic pollution because of the physical (e.g., entanglement and smothering) and chemical (e.g., bioaccumulation and sorption of contaminants) characteristics of the plastic debris (Rochman et al., 2014). EDCs listed as POPs are highly persistent, bioaccumulative, toxic, and transported long range, as they are resistant to chemical, physical, and biological transformation (Rudel and Perovich, 2009). PCBs, PBBs, and PBDEs are halogenated flame retardants used in electrical equipment, furniture, textiles, paints, and surface coatings, whereas PFOS and PFOA have been commonly used as surfactants. With high octanol-water partition coefficients (log K_{OW}) (Table 2), polyhalogenated compounds are highly stable, both thermally and chemically, and very hydrophobic. Due to their high persistence and stability, to date, dioxin-like PCBs are still detectable even though PCBs have been restricted since the mid-1980s after approximately 35 years of usage. Typically, POPs are fat-soluble and bioaccumulative in human body fat deposits. Furthermore, dibenzodioxins and dibenzofurans are EDCs that are commonly emitted as PCB combustion by-products in thermal and industrial processes, for instance, waste incineration, biomass combustion, bleaching of pulp and paper, and certain industrial manufacturing processes. Because of their similar structure, polyhalogenated compounds are linked to dioxin and furan. Based on the study by Wang et al. (2016a), it is estimated that the total global dioxin and furan release was about 100.4 kg toxic equivalent (TEQ)/year, with almost half of that contributed by Asia. Bioaccumulation and biomagnification of contaminants through food webs is a growing global concern, particularly regarding the high human and wildlife exposures and the associated health risk.

2.2. Phenolic compounds

Bisphenol A (BPA) is excessively utilized at a global capacity of 2.9 billion kg/year (vom Saal and Hughes, 2005). Globally, BPA is used in the production of polycarbonate (PC) resin for the manufacturing of bottles, toys, containers, and water pipes. In the context of EDC migration from packaging materials to food, BPA concentration varied the most, as hydrolysis of ester bonds within the BPA structure in plastics and resins, along with BPA diffusion, take place only during heating for sterilization and in the presence of either acidic or basic