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Review

Environmental behavior and eco-toxicity of xylene in aquatic environments: A review

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ABSTRACT

With the demand for chemicals and fuels increasing continuously, the occurrence of accidental leakage poses great risks to the aquatic environment. Xylene, a hazardous and noxious substance, has been major concerns with regard to heterogeneity and eco-toxicity towards aquatic organisms. This review focused on the ecotoxicological hazards of *m*-, *o*-, and *p*-xylene, as well as mixed xylene, on aquatic organisms. The mechanism of action of xylenes was also demonstrated in details. The purpose of this review was to further understand transfer and diffusion of toxicity on marine and freshwater organisms of xylene in the aquatic environment. Another aim was to screen sensitive biomarkers which were suitable for ecotoxicological assessment and monitoring in an aquatic system.

1. Introduction

Xylene, in liquid form at room temperature, is a volatile aromatic hydrocarbon produced through petrochemistry (Le Floch et al., 2012). It is often a mixture of isomers [meta-(*m*-), ortho-(*o*-), and para-(*p*-)] containing variable proportions of ethylbenzene. Xylene is used as a solvent, a cleaning agent, and in particular in the paint, printing, rubber, and leather industries (Le Floch et al., 2012). It is used extensively in industry, making it ubiquitous in the aquatic environment downstream from industrial discharges (Schultz et al., 1996). The global annual yield of *p*-xylene, the most widely used form thereof, was 36.96 million t in 2015 (Luo and Zhao, 2016).

Moreover, leakage accidents further increased the emission of xylene into environments. To meet the continuously rising transportation tonnages of xylene, the shipping and maritime industry has developed rapidly in the past 20 years, resulting in an increase in the frequency of leakage accidents. Accidental spills of xylene, which happened in the Mississippi River (USA) and Zhuhai Port (China), caused temporary closure of a section of those waterways and increases in the concentration of xylene therein: this poses a threat to water quality and organisms in the water (Huron Daily Tribune, 2003; China Chemical Safety Association, 2007). It is important to formulate preliminary planning of risk management emergency response projects and transportation regulations associated with the haulage of chemicals. To fulfil this purpose, there is a need to understand the environmental behavior and eco-toxicity of xylene in the aquatic environment.

In Europe, among the top 100 chemicals being transported in, and along, European waterways identified by the Health and Safety Representatives (HASREP) project (Response to Harmful Substances spilled at sea), xylene was one of the 15 bulk HNSs (hazardous and noxious substances) handled most often (HASREP, 2005). Currently, xylene has been named on a list of the top 20 chemicals likely to pose the highest risk of being involved in an HNS incident held by the International Maritime Organization (IMO) (ITOPF, 2011).

In this study, a literature review of the ecotoxicological effects on freshwater and marine organisms and their mitigation and transformation in aquatic systems was conducted for xylene in its three isomeric forms. Moreover, information relating to the action mechanism of HNSs on aquatic life is collated to acquire a better knowledge of their eco-toxicity and to screen sensitive biomarkers which are suitable for ecotoxicological assessment and monitoring in aquatic systems.

2. Pollution status of xylenes in the aquatic environment

Aiming at acquiring knowledge of the pollutant status of xylene in the aquatic environment, information about the concentrations of xylenes in natural waters was compiled (Table 1). Previous studies show that the maximum concentrations of surface waters were 6.80 μg/L and 7.7 μg/L for *o*-xylene and *p*-xylene, respectively (Table 1). Cavalcante et al. (2010) concluded that the main source of organic pollutants was the release of urban pluvial water flows (urban runoff) in Fortaleza (Brazil). The source in Huaihe River (China) came from discharges of chemical enterprises (Wang et al., 2002). Overall, the concentrations in surface waters are far less than 500 μg/L (WHO Water Quality Criteria

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Table 1
The concentration of xylenes in natural waters.

Place	Matrix	Ranges detected (μg/L)	References
Greece	River, lake, and seawater	Mixed xylene: < 0.05	Lekkas et al. (2004)
Southern North Sea	Surface water	*o*-Xylene: 0.0021–0.11 *m*/*p*-Xylene: < 0.011–0.17	Huybrechts et al. (2005)
Liverpool Bay, Irish Sea	Seawater	*m*-Xylene: 0.0043–0.3326	Bravo-Linares et al. (2007)
Fortaleza coast, Brazil	Seawater	*o*-Xylene: 0.18–6.80 (1.15 ± 1.8)[*] *m*/*p*-Xylene: ND to 1.91 (0.480 ± 0.52)[a]	Cavalcante et al. (2010)
–	Tap water, pond water, and reservoir water	*o*-Xylene: 0.03–0.07 *m*/*p*-Xylene: 0.05–0.12	Laaks et al. (2010)
Brazilian Sub-tropical Hydrographic Basin	Surface water	Mixed xylene: ND	Fernandes et al. (2014)
Jiaozhou Bay, China	Seawater	*m*-Xylene: 0.0109–0.0794 *o*-Xylene: 0.0124–0.0801 *p*-Xylene: 0.0152–0.0785	Cui and Cui (1996)
Huaihe River, China	River water	*o*-Xylene: 0.9–2.2 *p*-Xylene: 3.6–7.7	Wang et al. (2002)
Second Songhua River, China	River water	Mixed xylene: ND to 0.139	Li et al. (2008)
Shenyang, China	Surface water	*o*-Xylene: < 0.30–1.20 *m*/*p*-Xylene: < 0.30–3.14	Pan et al. (2010)

[a] Mean ± SD is inserted in brackets when possible; ND means not detected; - means not mentioned.

and Environmental quality standards for surface water for xylene) (SEPA, 2002; PAN, 2017) (Table 1). Nevertheless, accidental leakages of xylene, on sea or rivers, may result in significant risk of harm to the ecological environment due to the high toxicity to aquatic systems (see below). For instance, a chemical tanker – Grape One – laden with 3000 t of xylene, sank with her cargo in 1993 (Mamaca et al., 2009).

3. Environmental behavior of xylenes in the aquatic environment

The environmental behavior of chemicals depends upon their physico-chemical properties (ITOPF, 2011). The Standard European Behavior Classification (SEBC) codes give a set of criteria for theoretical behavior of chemical substances based upon their physico-chemical properties. Floating liquid (density ≤ seawater) with solubility of 0.1% below and vapor pressure of 0.3–3 kPa are classified as floater/evaporators (FE) by SEBC (Le Floch et al., 2012). The physico-chemical properties of mixed xylene and its three isomers (vapor pressure of 0.77–1.16 kPa at 20–25 °C, density of 0.861–0.880 g/cm^3, and a solubility between 10.6 and 17.8 mg per 100 mL of water) indicate that they will, in theory, behave as an FE (ATSDR, 2007; van Leeuwen, 2009). Reported bioconcentration factors (BCFs) indicate that xylenes present a low potential to bioaccumulate in aquatic organisms (Section 4.3), considering the threshold of BCF ≥ 1000 to classify a chemical as highly bioaccumulative (Beek et al., 2000); however, sound evidence in this review can be obtained to the effect that xylenes show high acute toxicity and potentially sub-acute toxicity to freshwater and marine systems (see below). Therefore, the toxicity of xylenes to aquatic ecosystems is more likely to be a direct effect of the chemical on a particular creature or group of creatures rather than their transfer via the food chain (Rocha et al., 2016).

Xylenes are mainly removed through volatilization in surface water and biodegradation in groundwater (ATSDR, 2007; Cheng et al., 2016). Yet, these two pathways suffer from the effects of much disturbance *in situ*. Therefore, the Centre of Documentation, Research and Experimentation on Accidental Water Pollution (*Cedre*) performed a series of trials. It is concluded that, xylene, which is classified as an FE in theory, can behave as an FED (floater/evaporator/dissolver) because a slick of xylene on the sea surface will initially emulsify, hindering evaporation and accelerating the migration to the water column through natural diffusion processes (Le Floch et al., 2012). Moreover, compared with the volatilization in the seawater sample at room temperature, biodegradation of xylene isomers is predominant (Han et al., 2006). After eight days, the percentages of volatilization and degradation are 17.35% and 76.36% for *m*/*p*-xylene, and 9.91% and 85.86% for *o*-xylene, respectively (Han et al., 2006). Temperature is one of the important factors influencing xylene bioconcentration and its development (Han et al., 2006).

These three xylene isomers are not susceptible to direct photolysis by sunlight as they do not absorb UV radiation at wavelengths of greater than 290 nm (Thomas and Burgess, 2007). On the basis of the available research results, bacteria, fungi, and microalgae are able to biodegrade xylene to a certain extent, and bacteria isolated from a polluted environment are the most extensively investigated among these. The removal efficiency of xylenes by isolated bacteria ranged

Table 2
Xylene biodegradation and corresponding experimental conditions with different microorganisms.

Organism species	Scientific name	Concentration (mg/L)	pH	Temperature (°C)	Removal efficiency (%)	Degradation time (h)	References
Bacteria	*Pseudomonas* sp. BTEX – 30	*m*-Xylene: 125	7.4	35	82	45	Khodaei et al. (2017)
	Immobilized *Ps.* sp.	*m*-Xylene: 18.9 *o*-Xylene: 20.7 *p*-Xylene: 33.3	7.0	25	*m*, *p*-xylene: 96.3-96.8 *o*-xylene: 98.2-99.0	120	Lu et al. (2015)
	Mixed *Bacillus subtilis* DM – 04 and *Ps. aeruginosa* M and NM	*m*-Xylene	7.0	45	84 to 98	120	Mukherjee and Bordoloi (2012)
	Pandoraea sp. strain WL1	*o*-Xylene: 16.6	–	30	91.8	6	Wang et al. (2015)
	Ps. sp. LJ5	*o*-Xylene: 2500	7.0–8.0	35	70	30	Chen et al. (2016)
	Janibacter sp. SB2[a]	Mixed xylene: 60	7.0	25	62.8	60	Jin et al. (2013)
		Mixed xylene: 120	7.0	25	45.5	60	Jin et al. (2013)
		Mixed xylene: 180	7.0	25	20.1	60	Jin et al. (2013)
Fungus	*Penicillium* sp. CHY – 2	Mixed xylene: 50	6	15	23.6	168	Chang et al. (2016)
Microalgae	*Parachlorella kessleri*	Mixed xylene: 0.1	7.4	22	56	48	Takáčová et al. (2015)

[a] Marine organism.