NBU Journal of Plant Sciences Vol. 12, March 2020 p. 70-88

ISSN No. 0974-6927

Review on

Bisphenol A toxicity in aquatic flora: Impacts and possible remediation

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Abstract

Bisphenol A (BPA), is one of the high volume produced chemical which is extensively used as raw material for polycarbonate and epoxy resin manufacturing. Being one of major used and disposed material from a wide source, traces of BPA have been diagnosed from everywhere. BPA has been identified as an endocrine disruptor compound (EDC) for most of animals, due to structural similarity with hormones, and hinders many physiological functions. This review work focuses on the status of BPA in water bodies of different parts of the world. The review also focuses on the impact of BPA on aquatic plants and its possible remediation. Sub-standardly imposed policies by several countries and failure of water resource governance are rapidly leading towards incautious release of plastics and other BPA associated waste products in environments. BPA pollution affects humans, animals and even plants. Among the aquatic flora, most affected plant groups are the algal groups and macrophytes. At lower BPA concentration, many beneficial bacterial strains also show sensitivity whereas some other strains are known to metabolize or remove BPA from the water bodies. In this connection, several aquatic macrophytes have also been reported to contribute in the removal of BPA from the aquatic ecosystem.

Keywords: Bisphenol A, Endocrine disruptor compound (EDC), Macrophyte, Polycarbonate plastics, Phytoremediation.

Introduction

Enormous rise in human population in current and previous centuries immensely impacted the climate and most of the environmental factors (Amoatey and Baawain, 2019). Among these factors, water pollution (both freshwater and marine waterbodies) directly leads to severe human health problems and deterioration in healthy aquatic ecosystems around the globe. Both the fresh water and marine ecosystems play an important role in climate preservation, purification of water, nutrient recycling, and also provides habitat for aquatic flora and fauna (Oertel and Salánki, 2003). Irresponsible human actions in industrial, agricultural and urban wastes management have led toward serious damages to the water bodies and aquatic ecosystems in last few decades (Meijide *et al*., 2018). Huge number of contaminants are introduced every year as agricultural and industrial wastes in water bodies (lake, rivers, oceans, groundwater etc.). These contaminants are released in the form of heavy metals (As, Cd, Cr, Cu, Hg, Ni and Pb), nutrients (N, K, P etc.), polycarbonates and organic pollutants (e.g., petrochemicals). Meanwhile, substandard imposition of environmental

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DOI: https://doi.org/10.55734/NBUJPS.2020.v12i01.006

regulations resultsin the disruption of water quality in the environment (Hu and Cheng, 2013). These contaminants exceedingly influence the aquatic ecosystem and also show toxic effects on the aquatic flora and fauna (Sangai *et al*., 2016).

Polycarbonate contaminants are identified as one of the major water pollutant in the past few decades, which causesseveredamage to the aquatic ecosystem. Most used polycarbonates and epoxy resins are manufactured from an organic compound -Bisphenol A (BPA). Release of plastics into the environment during the manufacture of chemicals, processing, product packaging, transportation and improper disposal without proper regulation, results in to the release of BPA in the environment (Staples *et al*., 1998). A wide range of products are manufactured from BPA e.g., food containers, electronic parts, protective envelops for electrical, adhesives, dyes, paints, housing materials, thermal paper, paper coating, compact disks, automobile parts etc., which also contributes to the release of BPA in the environment (Staples *et al*., 1998).

Due to such wide-ranging source and sub-standard enforcement of discharge regulations, BPA has been ubiquitously detected in environment including waterbodies, soil and landfill leachate (Staples *et al*., 1998). They are also found as floating and non-floating polycarbonate plastics dumped worldwide in fresh waterbodies as well as oceans (Duxbury, 1992). Rivers, lakes and seafloor majorly dumped with plastics debris which are non-floating in nature slowly and gradually releases BPA (Galgani *et al*., 1996; Gregory *et al*., 1997). Water surface covered with dumped plastics all over the world constitutes about 45% of the buoyant plastics (Duxbury, 1992).

Bisphenol-A is chemically 2,2-bis-(4-hydroxyphenyl) propane. It has been estimated that approximately 8.4 million tons of BPA have been used in 2018 globally for the production of epoxy resin and polycarbonate plastic (Staples *et al*., 1998; PRWeb report, 2013). This huge amount of plastic production and the rapid degradation of plastics releases BPA (3-7 day's half-life) into the waste water, which exhibits moderate toxicity and lower accumulation in aquatic organisms (Staples *et al*., 1998).

BPA has been identified as an endocrine disruptor compound (EDC) for most of animals, due to structural similarity with hormones, and a result it hampers many physiological functions (Fang *et al*., 2020). Accumulation of BPA in phytoplankton causes acute toxicity and trophic transfer to zooplanktons (Radix *et al*, 2002). Toxic effect of BPA includes reduction in cell number, size and chlorophyll, observed in both freshwater and marine microalgae e.g., *Chlorella sorokiniana*, *Monoraphidium braunii*, *Chlorella pyrenoidosa*, *Nannochloropsis* sp. etc. (Gattullo *et al*, 2012; Eio *et al*., 2015; Guo *et al*., 2017; Ishihara and Nakajima, 2003). Effect of BPA exposure can also be observed in few other aquatic plants e.g., *Ipomoea aquatica*, water hyacinth, *Azolla filiculoides*, etc. (Noureddin *et al*., 2004; Kang and Kondo, 2006; Zazouli *et al*., 2014).

Traditional methods used in wastewater treatments employs physical and chemical methods, which are costly and hostile for environment health (Zhou *et al*., 2004). Phytoremediation is one of emerging biological methods for BPA removal from waste waterbodies. In the treatment of wastewater, appointment of algal-bacterial system to tree species have shown very promising results e.g., *Chlorella sorokiniana* (Microalga), *Azolla filiculoides* (Aquatic macrophyte), *Portulaca oleracea* (Herb), *Bruguiera gymnorhiza* (Mangrove), *Eucalyptus perriniana* (Tree) help in BPA elimination from waste water (Hamada *et al*., 2002; Imai *et al*., 2007; Saiyood *et al*., 2013; Zazouli *et al*., 2014; Eio *et al*., 2015).

Plenty of studies have been already reported for aquatic invertebrates, fishes, amphibians, birds and mammals subjected to BPA exposure, but there is lack of information for aquatic flora. The objective of this review work is primarily understanding BPA toxicity and its impact on the aquatic plant groups, and to also provide information about possible remediation by these aquatic plant groups.

Bisphenol A and its analogues

BPA has been recognized as one of world's highest produced chemicals and quite well known as endocrine disrupting chemical (EDC). It is mainly used in manufacturing of polycarbonates, epoxy resins, medical equipment, electronic components, pipes, thermal paper, most of water and food containers along with many other household and electronic products (Staples *et al*., 1998). At ambient condition BPA shows solid crystals or flake like physical properties along with low volatility, higher melting point (150-155º C) and moderate solubility in aqueous solution (Staples *et al*., 1998).

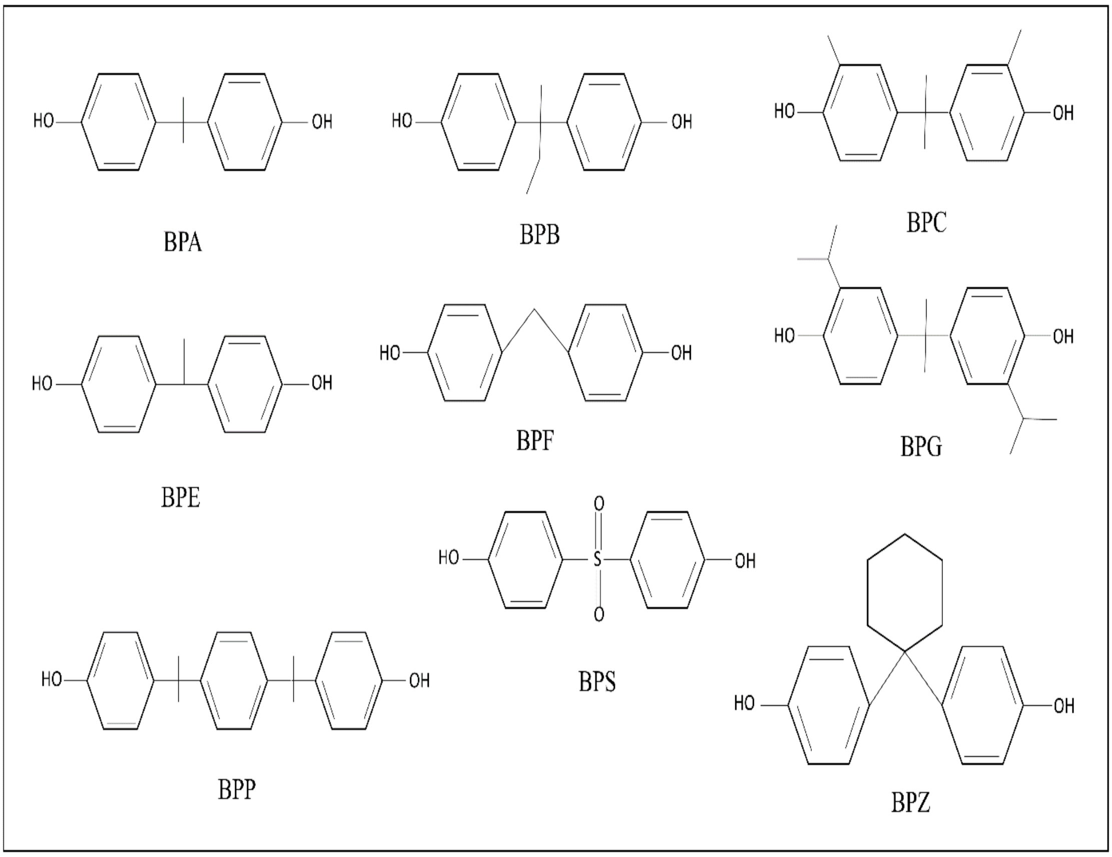

Figure 1 Chemical structures of Bisphenol A and its few common analogues.

A large number of chemicals are known to have structural similarity with BPA. In this connection, the chemical structures of few commonly studied BPA analogues have been presented in Figure 1. Among the analogues, Bisphenol F and Bisphenol S have also been widely used in polycarbonate manufacture. Several studies suggested most of these analogues also imparts EDC like functions (estrogenic, anti-estrogenic, androgenic, and anti-androgenic) with similar physiological effects like BPA (Rochester and Bolden, 2015). Few studies have claimed that some of the analogues has potential to replace BPA in the industrial sector.

Environmental distribution of BPA

Being one of the major disposed waste materials from a wide range of source, traces of BPA is present all over the environment. Environmental distribution of BPA is as follows -

BPA in air

Air is a geochemical reservoir for most of organic and inorganic particles (Sangai *et al*., 2016). BPA has lower volatility, although it can easily mix up with the atmosphere through industrial wastes (in particle form), which has been estimated to be approximately 100 tons per year (Sangai *et al*., 2016). BPA is also released via combustions of polycarbonate and epoxy resin products, domestic plastic wastes, paint spraying, electronic wastes etc. (Owens *et al*., 2007).

BPA in soil

Although BPA shows moderate affinity, slower biodegradation and lower half-life (1-10 days), the availability in soil and sediments, makes it notable pollutant (Sangai *et al*., 2016; Loffredo and Senesi, 2006). Land applied biosoilds or sewage sludge, mismanaged disposal of plastic wastes from industry, urban cites are among the primary source for BPA in soil (Lemos *et al*., 2010). With each passing year, record increase in the concentrations of BPA in the soil is occurring which poses serious concerns for many organisms. In a study, BPA has also been found to be interfere with the symbiotic association between *Sinorhizobium meliloti* and leguminous plant roots, indicating its prowess as a soil contaminant (Sangai *et al*., 2016).

BPA in water

Disposal of waste water, solid wastes from industry and households contains many water pollutants along with BPA and its analogues (Lee *et al*., 2015; Yu *et al*., 2015). Detection of BPA in different waterbodies has been reported which includes lakes, rivers, ground water, seawater and even present in drinking water (Sakai *et al*., 2007; Wan *et al*., 2018; Yang *et al*., 2014). Several studies have already determined BPA concentrations in various water bodies, including fresh and marine water, a list of which is presented in **Table 1**.

The concentrations of BPA vary according location, type of waterbodies or amount disposed waste materials. Observed BPA concentrations in Indian River waters ranges 0.006 μg/L to 14.8 μg/L (Lalwani *et al*., 2020; Yamazaki *et al*., 2015). Yamuna river reported most polluted and contains highest BPA concentrations (0.079 – 14.8 μg/L) among studied rivers in India (Lalwani *et al*., 2020). BPA levels in Indian municipal sewage industrial wastewater and drinking waters are 0.019 to 1.95 μg/L, 0.036 to

Table 1 Worldwide Bisphenol A concentrations in water surfaces (µg/L) and sediments (µg/g d.w.)

Study Locations	Source of Samples	BPA concentrations		Reference
		Values	Units	
Asia				
India	**River water**			
	Yamuna River (Near Delhi)	0.079 -14.8	µg/L	Lalwani *et al*., 2020
	Mula Mutha River (Maharastra)	0.1-0.15	µg/L	Lalwani *et al*., 2020
	Indus River (Jammu & Kashmir)	ND		Lalwani *et al*., 2020
	Hooghly River (Kolkata)	0.016-0.089	µg/L	Lalwani *et al*., 2020
	Cooum River (Chennai)	0.2-14.2	µg/L	Lalwani *et al*., 2020
	Kaveri River (Chennai)	0.006-0.13	µg/L	Yamazaki *et al*., 2015
	Adyar River (Chennai	0.05-0.51	µg/L	Yamazaki *et al*., 2015
	Lake water			
	Puzhal Lake	ND		Yamazaki *et al*., 2015
	Industrial and Municipal wastewater			
	Nationwide waste water	0.036-8.99	µg/L	Lalwani *et al*., 2020
	Sewage water (Patna)	0.019-0.022	µg/L	Karthikraj and Kannan, 2017
	Raw sewage water (Chennai)	0.054-0.077	µg/L	Karthikraj and Kannan, 2017
	Buckingham canal (Chennai)	0.835-1.95	µg/L	Yamazaki *et al*., 2015
	Drinking water			
	Nationwide sources	0.005-0.26	µg/L	Arnold *et al.,* 2013
China	**River water**			
	Pearl River (Guangdong)	ND-0.097	µg/L	Yamazaki *et al*., 2015
	West River (Guangdong)	ND-0.043	µg/L	Yamazaki *et al*., 2015
	Liaohe River (Liaoning)	0.006-0.14	µg/L	Jin and Zhu, 2016
	Liuxi River (Guangzhou)	0.075-7.48	µg/L	Huang *et al.,*2018
	Lake water			
	Taihu Lake	0.028-0.56	µg/L	Jin and Zhu, 2016
	Lake Basin (Eastern China)	0.001-5.35	µg/L	Zhang *et al.,* 2014
	Drinking waters			
	Nationwide sources	0.073-0.678	µg/L	Si *et al.,*2019
	Coastal area of Shenzhen	0.0011-0.776	µg/L	Liu *et al.,* 2010
Japan	**River waters**			
	Edogawa River	0.006-0.021	µg/L	Yamazaki *et al.,* 2015

	Tamagawa River	0.011-0.110	µg/L	Yamazaki *et al.,* 2015
	Arakawa River	0.003-0.057	µg/L	Yamazaki *et al.,* 2015
	Tokyo Bay	ND-0.431	µg/L	Yamazaki *et al.,* 2015
North	Fresh water surface	ND- 0.30	µg/L	Staples *et al.,*2018
America	Marine water surface	0.0011-0.024	µg/L	Staples *et al.,*2018
	Freshwater sediments	0.007-0.039	µg/g d.w.	Staples *et al.,*2018
	Marine sediments	0.001-0.1	µg/g d.w.	Staples *et al.,*2018
	River waters			
USA	Chateauguay River	ND-0.005	µg/L	Goeury *et al.,* 2019
Canada	Richelieu River	ND-0.004	µg/L	Goeury *et al.,* 2019
	Des Prairies River	0.005-0.017	µg/L	Goeury *et al.,* 2019
	Mille Iles River	ND- 0.007	µg/L	Goeury *et al.,* 2019
Europe	Fresh waters	ND-0.30	µg/L	Staples *et al.,*2018
	Marine waters	0.007-0.15	µg/L	Staples *et al.,*2018
	Freshwater sediments	0.007-0.177	µg/g d.w.	Staples *et al.,*2018
	Marine sediments	0.0003-0.063	µg/g d.w.	Staples *et al.,*2018
	River waters			
Portugal	Ave River	0.029-0.098	µg/L	Rocha *et al.,* 2013
	Cavado River	0.030-0.041	µg/L	Rocha *et al.,* 2013
	Douro River	ND-0.050	µg/L	Rocha *et al.,* 2013
Greece	Loudias River	ND- 0.138	µg/L	Arditsoglou and Voutsa, 2008
Spain	Garonne River	ND-0.060	µg/L	Gallart-Ayala *et al.,* 2010
	Waste water	0.115-0.183	µg/L	Gallart-Ayala *et al.,* 2010
Africa	**River waters**			
South	Bloukrans River	0.0173-0.477	µg/L	Farounbi and Ngqwala, 2020
Africa	Swartkops River	0.0067-0.341	µg/L	Farounbi and Ngqwala, 2020
	Tyhume River	0.017-0.117	µg/L	Farounbi and Ngqwala, 2020
	Waste waters	0.017-1.468	µg/L	Farounbi and Ngqwala, 2020
Polar				
region	Remote sites	11-17.3	pg/L	Fu and Kawamura, 2010

* ND- No detection, * d.w. - dry weight

8.99 µg/L and 0.005 to 0.026 µg/L respectively (Lalwani *et al*., 2020; Yamazaki *et al*., 2015; Arnold *et al*., 2013; Karthikraj and Kannan, 2017). Detection of BPA in major Chinese river and lakes also reported, ranges no detection to 7.48 µg/L (Yamazaki *et al*., 2015; Huang *et al*., 2018; Jin and Zhu, 2016; Zhang *et al*., 2014a). BPA in nationwide drinking water sources and coastal waters in China are 0.073 to 0.678 µg/L and 0.0011 to 0.776 µg/L (Liu *et al*., 2010; Si *et al*., 2019). Yamazaki *et al*. (2015) reported BPA levels in surface waters of Japanese rivers detection to 0.431 µg/L in Tokyo Bay.

Rivers in USA and Canada contains very low concentrations of BPA (no detection to 0.017 µg/L) (Goeury *et al*., 2019). Major fresh water surface and sediments contains up to 0.30 µg/L and 0.007 to 0.039 µg/g dry weight (d.w.) BPA respectively (Staples *et al*., 2018). Similarly in European fresh water surface and sediments hold BPA up to 0.30 µg/L and 0.007 to 0.177 µg/g d.w. respectively (Staples *et al*., 2018). Recent reports have shown that the American and European marine surface water contains 0.011 to 0.024 µg/L and 0.007 to 0.015 µg/L BPA respectively (Staples *et al*., 2018). Detection of BPA was also reported in few European rivers e.g., Ave river (Portugal), Douro river (Greece), Loudias river (Spain) etc. (Arditsoglou and Voutsa, 2008; Gallart-Ayala *et al*., 2010; Rocha *et al*., 2013). Few rivers of South Africa also contain significantly higher levels of BPA e.g., Bloukrans River (0.0173 to 0.477 µg/L), Swartkops river (0.006 to 0.341 µg/L), Tyhume river (0.017 to 0.117 µg/L) etc. (Farounbi and Ngqwala, 2020). Trace of BPA was also reported in few remote sites (11 to 17.3 pg/L) of both poles (Ji *et al*., 2014).

Concentrations of BPA has been measured in multiple studies from water bodies and sediments, and great variations have been reported. From Table 1, we can conclude that the highest concentrations of BPA (i) in river water can go up to 14.8 µg/L, (ii) in marine water 0.431 µg/L, (iii) in sediments 177 ng/L, and (iv) highest environmental concentration of BPA (17.2 mg/L) found in landfill leachate.

BPA Toxicity on aquatic flora

Frequent studies suggested existence of BPA in almost every ecosystem and impacts all life forms. Recent studies have reported several effects of BPA including cytotoxicity, reproductive toxicity, genotoxicity, dioxin like effects, endocrine disrupting effect etc. on both plants and animals. The aquatic flora greatly diverse, from single cell phytoplankton to complex multicellular macrophytes, are variably affected by BPA. Effect of BPA on aquatic plant groups are discussed below:

Algae

In the aquatic food chain, algae play a key role as primary producers and found relatively sensitive to many chemicals (Abdel-Hamid, 1996). BPA toxicity to the algae was reported in several studies e.g., *Chlorella sorokiniana*, *Monoraphidium braunii, Chlorella pyrenoidosa*, *Nannochloropsis* sp., *Stephanodiscus hantzschii*, *Scenedesmus obliquus* etc. (Ishihara and Nakajima, 2003; Li *et al*., 2009; Gattullo *et al*., 2012; Zhang *et al*., 2014b; Eio *et al*., 2015; Guo *et al*., 2017). The laboratory-based reports describing the toxic effects on these algae are presented in **Table 2**. BPA incurs significant decrease in growth, inhibition in synthesis of chlorophyll and carotenoids, reduction in the efficacy of photosystems, cytotoxicity by generation of ROS, reduction in activity of antioxidative enzymes etc.

Macrophytes and Mangroves

Among free floating macrophytes *Lemna* sp. is found to be much sensitive to BPA. At 20 mg/L concentration of BPA, significant decrease in growth was observed due to reduction in leaf density and biomass (Mihaich *et al*., 2009). In a study, another free floating macrophyte *Azolla filiculoides* has been found to have reduced growth on exposure to BPA, possible explanations could be reduction of photosynthetic pigments and inhibitory effects on nitrogen fixation (Zazouli *et al*., 2014). Raj *et al*. (2015) reported at 20 mg/L of BPA concentration, *Pistia stratiotes* show chlorosis, shriveling and shrinkage. On exposure to BPA for longer duration, significant change was observed in physiological responses in submerged macrophyte *Ceratophyllum demersum* (Zhang *et al*., 2017). Two other Macrophytes e.g., *Hydrilla verticillata* and *Potamogeton illinoensis* exhibits significant reduction in biomass, slower growth rate and increase in root density under BPA exposure (Zhang *et al*., 2017; Trueman and Erber, 2013). Zhang *et al*. (2007) found multiple effects of BPA toxicity e.g. decrease in plant growth, reduced rate of antioxidative enzymes (POX and GSH) and also shown disturbance in the cell membrane. Under exposure to BPA (40 mg/L), *Bruguiera gymnorhiza* (Mangrove) responded mainly

Table 2 Bisphenol A toxicity on aquatic flora

Aquatic Flora	Toxic Effects	BPA conentrations	References
Algae			
Chlamydomonas maxicana	Significant reduction in growth, dry weight and photosynthesis rate	10 µg/L	Ji *et al.,* 2014
Chlorella vulgaris	Inhibited growth and reduced chlorophyll content.	10 µg/L	Ji *et al.,* 2014
Pseudokirchneriella subcapitata	Reduced cell count and inhibited growth.	10 mg/L	Nakajima *et al.,* 2007
Ditylum brightwellii (Diatom)	Highly sensitive, reduction in chlorophyll and cell count.	0.1 mg/L	Ebenezer and Ki, 2016
Prorocentrum minimum	Highly sensitive, reduction in chlorophyll and cell count.	0.1 mg/L	Ebenezer and Ki, 2016
Tetraselmis suecica (Marine)	Sharp decrease in cell number and chlorophyll content.	2.5 mg/L	Ebenezer and Ki, 2016
Floating macrophytes			
Azolla filiculoides	Growth inhibition, reduction of N_2 fixation, photosynthesis.	25 mg/L	Zazouli *et al.,* 2014
Lemna gibba	Significant sensitivity, reduction in biomass and frond density.	20 mg/L	Mihaich *et al.,* 2009
Pistia stratiotes	Shrivelling, chlorosis and shrinkage of leaves	20 mg/L	Raj *et al.,* 2015
Submerged macrophytes			
Ceratophyllum demersum	Reduction in physiological responses and increase in POX activity	10 mg/L	Zhang *et al.,* 2017
Elodea nuttallii	Growth inhibition, reduced POD and GSH activity, cellular phospholipids disturbance	20 mg/L	Zhang *et al.,* 2007
Hydrilla verticillata	Reduction in growth due to accumulation in roots and leaves	20 mg/L	Zhang *et al.,* 2017
Potamogeton illinoensis	Decrease in dry biomass and higher root density on exposure	15 µg/L	Trueman and Erber, 2013
Mangroves			
Bruguiera gymnorhiza	Leaf damaging effects like necrosis and wilting	40mg/L	Saiyood *et al.,* 2013

through exhibiting leaf damaging symptoms like chlorosis, necrosis and wilting, along with reduced growth rate (Saiyood *et al*., 2013).

Possible Remediation

Environmental reduction or elimination of a compound up to non-toxic level from the air, water and soil has been one of the primary concerns shown by numerous researchers in last few decades. In water quality management, phytoremediation has been welcomed as one of best technique available due to its cost effectivity and ecological sustainability. In last few years, phytoremediation technique is universally accepted by several scientists, government authorities and also by common public, because of its great potential. Using green plants to degrade, remove, transform and stabilize organic or inorganic pollutants from air, water and soil has been of great interest for researchers due to being environment friendly approach, sustainable, low cost and energy requiring process for treatment (Loffredo *et al*., 2010; Okuhata *et al*., 2010). There are plenty of studies reported to employment of microorganism to higher plants for BPA removal from waste water. Also, assessment of few reports, claiming bioaccumulation, bio-transfer, absorption and metabolizing BPA by plants has been reported (Saiyood *et al*., 2010).

Bacteria

In the aquatic environment, BPA contamination is increasing at an alarming rate and immediate remediation is recommended for the sake of ecosystem revival. Several studies have reported that, in BPA removal one of the efficient method is to use bacterial strains. There are few bacterial strains that show potential efficiency in biodegradation of BPA by both gram-positive and gram-negative strains (**Table 3**). Among aquatic microbial strains *Pseudomonas* sp. (TA3, KA$ and KA5) has shown degradation capability of 66%, 90% and 91% respectively in 10 days duration from the initials BPA concentrations of 1000 µg/L (Kang and Kondo, 2002).

There are also few reports that show the potential of BPA degrading bacterial strains from sludge e.g., *Achromobacter xylosoxidans* and *Cupriavidus brasilensis* have shown efficacy up to 90% in 5 days of exposure (Fischer *et al*., 2010; Li *et al*., 2012). Soil and sediment residing microbial strains also exhibits potential ability to remove or metabolize 1000 µg/L BPA within 2- 3 days e.g., *Bacillus* sp. (up to 59%), *Klebsiella* sp. (up to 57%), *Enterobacter* sp. (up to 68%), *Bordetella* sp. (up to 41%), *Sphingomonas* sp. (up to 38%) etc. (Matsumura *et al*., 2009).

Algae

Algal groups also play a very important role in the remediation of many toxic chemicals due their versatility in habitat. Few fresh water and marine algal species has been studied for their role in BPA degradation efficacy (**Table 4**). Hirooka *et al*. (2003) reported a blue-green alga *Anabaena variabilis* and a green alga *Chlorella fusca* have shown capability to remove 23% and 85%, respectively from initial concentration of 10 mg/L BPA in a time duration of 5 days. Recently, multiple reports suggested different groups of algae from both fresh water and marine has BPA removal capability e.g., *Selanastrum*

Table 3 BPA biodegrading bacteria and their efficiency

Bacterial strains	BPA degraded or removed (%)	BPA concentrations (mg/L)	Duration (Days)	References
Water				
Pseudomonas sp. strain KA4	90%	1	10	Kang and Kondo, 2002
Pseudomonas putida strain KA5	91%	1	10	Kang and Kondo, 2002
Pseudomonas sp. strain TA3	66%	1	10	Kang and Kondo, 2002
Streptomyces sp.	90%	1	10	Kang *et al.,* 2004
Sphingomonas sp. strain BP-7	100%	1	40	Sakai *et al.,* 2007
Leachate and sludge				
Achromobacter xylosoxidans strain B-16	90%	3	5	Zhang *et al.,* 2007
Cupriavidus basilensis strain JF1	90%	1	5	Fischer *et al.,* 2010
Sediments and soil				
Bacillus sp. strain GZB	51%	5	8	Li *et al.,* 2012
Pseudomonas sp. strain SU1	51 %	1	2.5	Matsumura *et al.,* 2009
Bacillus sp. strains NO13	56%	1	2.5	Matsumura *et al.,* 2009
Bacillus sp. strains NO15	59%	1	2.5	Matsumura *et al.,* 2009
Bacillus sp. strains YA27	32%	1	2.5	Matsumura *et al.,* 2009
Klebsiella sp. strains NE2	51%	1	2.5	Matsumura *et al.,* 2009
Klebsiella sp. strains SU3	26%	1	2.5	Matsumura *et al.,* 2009
Klebsiella sp. strains SU5	57%	1	2.5	Matsumura *et al.,* 2009
Enterobacter sp. strains HI9	60%	1	2.5	Matsumura *et al.,* 2009
Enterobacter sp. strains HA18	68%	1	2.5	Matsumura *et al.,* 2009
Bordetella sp. strain OS17	41 %	1	2.5	Matsumura *et al.,* 2009
Sphingomonas sp. strains SO11	38%	1	2.5	Matsumura *et al.,* 2009
Sphingomonas sp. strains SO1a	34%	1	2.5	Matsumura *et al.,* 2009
Sphingomonas sp. strains SO4a	35%	1	2.5	Matsumura *et al.,* 2009

capricornutum (90%), *Chlorella sorokiniana* (50%), *Spirogyra sp.* (upto 96%),*Monoraphidium braunii* (48%), *Scenedesmus acutus* (64%),*Stephanodiscus hantzschii* (48%), *Skeletonoma costatum* (90%)etc.(Dorn *et al*., 1987; Nakajima *et al*., 2007; Li *et al*., 2009; Gattullo *et al*., 2012; Eio *et al*., 2015; Gracia-Rodriguez *et al*., 2015).

Macrophytes

The aquatic ecosystems are dominated by macrophytes and presents great potential to remove most of water pollutants. The macrophytes are major biological tools for phytoremediation, and also provides substrates and surface to the microbes and algae, which also play a role in

Table 4 Phytoremediation by algae and their efficiency

Algae	BPA degradation 0r removed (%)	Duration (Days)	BPA Concentrations (mg/L)	Reference
Fresh water				
Spirogyra sp.	96%	8	2	Garcia-Rodriguez *et al.,*2015
Selanastrum capricornutum	90%	4	2.7	Dorn *et al.,* 1987
Chlorella sorokiniana	50%	7	10	Eio *et al., 2015*
Monoraphidium braunii	48%	4	4	Gattullo *et al.,* 2012
Scenedesmus acutus	64%	8	2	Nakajima *et al.,* 2007
Chlorella fusca	85%	5	10	Hirooka *et al.,* 2003
Anabaena variabilis	23%	5	10	Hirooka *et al.,* 2003
Marine				
Ste*phanodiscus hantzschii*	48%	16	1	Li *et al.,* 2009
Skeletonoma costatum	90 %	4	1	Dorn *et al.,* 1987

accumulation, removal and metabolism of pollutants. Macrophytes can be classified into emergent, floating and submerged, on the basis of their residence on aquatic ecosystem.

Among the floating macrophytes *Lemna* sp. has been reported to have the efficiency to remove 1 mg/L BPA and requires more than 100 days (Reis and Sakakibara, 2012). However, free floating macrophytes like *Eichhornia crassipes* and *Pistia stratiotes* has been reported to have much faster rates of metabolizing BPA into β-glycoside through roots and then transported in to shoot with 100% efficacy in 3 days (Kang and Kondo, 2006; Raj *et al*., 2015).

Another emergent aquatic macrophyte *Ipomoea aquatica* has shown promising results and metabolize 100% of BPA (5mg/L) in a period of 21 days (Noureddin *et al*., 2004). Among the submerged macrophytes *Ceratophyllum demersum* (95%), *Elodea nuttallii* (50%), *Hydrilla verticillata* (62%), *Potamogeton crispus* (70%), *Myriophyllum spicatum* (83%), *Egeria densa* (27%) etc. have also shown good potential to remove BPA from the aqueous medium in a short time span of time (Zhang *et al*., 2007; Reis and Sakakibara, 2012; Zhang *et al*., 2017).

Conclusion

Urbanization and industrialization lead to increase in pollution by disposing off several pollutants in the environment, which causes severe damages to the ecosystem. Available studies have revealed that BPA induces cellular toxicity

Table.5 Phytoremediation by Macrophytes and their efficiency

Aquatic Flora	BPA degraded or removed (%)	BPA concentration (mg/L)	Duration (Days)	Reference
Floating				
Riccia fluitans	96%	1	110	Reis and Sakakibara, 2012
Azolla filiculoides	90%	10	20	Zazouli *et al.,* 2014
Lemna sp.	96%	2	8	Garcia-Rodriguez *et al.,* 2015
Lemna aoukikusa	73%	1	110	Reis and Sakakibara, 2012
Spirodella polyrhiza	60%	5	20	Li *et al.,* 2014
Pistia stratiotes	88%	10	3	Raj *et al.,* 2015
Eichhornia crassipes	100%	10	1	Kang and Kondo, 2006
Ipomoea aquatica	100%	5	21	Noureddin *et al.,* 2004
Submerged				
Ceratophyllum demersum	95%	5	10	Zhang *et al.,* 2017
Elodea nuttallii	50%	10	15	Zhang *et al.,* 2007
Hydrilla verticillata	62%	5	12	Zhang *et al.,* 2017
Potamogeton crispus	70%	5	10	Zhang *et al.,* 2017
Myriophyllum spicatum	83%	5	10	Zhang *et al.,* 2017
Egeria densa	27%	1	110	Reis and Sakakibara, 2012
Mangrove				
Bruguiera gymnorhiza	100%	20	51	Saiyood *at al.,* 2013

disturbance in cellular constructs, growth inhibition, photosynthetic hindrance and many more consequences in most of the aquatic flora. Although, toxicity of BPA on aquatic flora requires more studies for understanding the mechanism and pathways involving the accumulation and degradation of BPA. This review work focuses on the presence of BPA in environment and its effect mainly on the aquatic ecosystem. Increasing level of BPA release in environment demands strict regulation, policies and development of technologies to lower or eliminate this toxic pollutant. In this connection, many bacterial strains and macrophytic species can be used having capability to remove BPA from aquatic systems in a sustainable manner.

Acknowledgements

The author acknowledge the grants received from University Grants Commission, India on account of fellowships Ashis Sarkar [UGC Ref. No. 685/(CSIR-UGC NET DEC 2018)] that enabled the present work to be conducted smoothly. The corresponding author acknowledges the University of North Bengal for providing the necessary infrastructures and partial assistance required for conducting this work.

References

Abdel-Hamid, M.I. (1996). Development and application of a simple procedure for toxicity testing using immobilized algae. *Water Sci. Technol.* 33:129-138

Amoatey, P. and Baawain, M.S. (2019). Effects of pollution on freshwater aquatic organisms. *Water Environ. Res.* 91:1272-1287

Arditsoglou, A. and Voutsa, D. (2008). Determination of phenolic and steroid endocrine disrupting compounds in environmental matrices. *Environ. Sci. Pollut. Res. Int.,* 15:228-236

Arnold, S.M., Clark, K.E., Staples, C.A., Klecka, G.M., Dimond, S.S., Caspers, N. and Hentges, S.G. (2013). Relevance of drinking water as a source of human exposure to Bisphenol A. *J. Exposure Sci. Environ. Epidemiol.* 23:137-144

Brown, M. (2009). BPA has alternatives, but there are trade offs. http://www.glgroup.com.

Dorn, P.B., Chou, C.S. and Gentempo, J.J. (1987). Degradation of bisphenol a in natural waters. *Chemosphere,* 16:1501-1507

Duxbury, M. (1992). Plastic pellets in the aquatic environment: Sources and recommendations. *USEPA*, 842-B:92-100.

Ebenezer, V. and Ki, J.S. (2016). Toxic effects of Aroclor 1016 and bisphenol A on marine green algae *Tetraselmis suecica*, diatom *Ditylum brightwellii* and dinoflagellate *Prorocentrum minimum*. *Korean J. Microbiol.,* 52:306-312

Eio, E.J., Kawai, M., Niwa, C., Ito, M., Yamamoto, S. and Toda, T. (2015). Biodegradation of Bisphenol A by an algal-bacterial system. *Environ. Sci. Pollut. Res. Int.,* 22:15145-53

Fang, Z., Gao, Y., Wu, X., Xu, X., Sarmah, A.K., Bolan, N., Gao, B., Shaheen, S.M., Rinklebe, J., Ok, Y. S., Xu, S. and Wang, H. (2020). A critical review on remediation of Bisphenol S (BPS) contaminated water: Efficacy and mechanisms. *Crit. Rev. Environ. Sci. Technol.,* 50:476-522

Farounbi, A.I. and Ngqwala, N.P. (2020). Occurrence of selected endocrine disrupting compounds in the eastern cape province of South Africa. *Environ. Sci. Pollut. Res. Int.* 27:268-279

Fischer, J., Kappelmeyer, U., Kastner, M., Schauer, F. and Heipieper, H.J. (2010). The degradation of bisphenol A by the newly isolated bacterium Cupriavidus basilensis

JF1 can be enhanced by biostimulation with phenol. *Int. Biodeter. Biodegr.,* 64:324-330

Flint, S., Markle, T., Thompson, S. and Wallace, E. (2012). Bisphenol A exposure, effects, and policy: A wildlife perspective. *J. Environ. Manage.,* 104:19-34

Fu, P. and Kawamura, K. (2010). Ubiquity of Bisphenol A in the atmosphere. *Environ. Pollut.* 158:3138-3143

Galgani, F., Souplet, A. and Cadiou, Y. (1996). Accumulation of debris on the deep sea floor off the french mediterranean coast.*Mar. Ecol. Prog. Ser.,* 142:225-234.

Gallart-Ayala, H., Moyano, E. and Galceran, M.T. (2010). On-line solid phase extraction fast liquid chromatography-tandem mass spectrometry for the analysis of Bisphenol A and its chlorinated derivatives in water samples. *J. Chromatogr. A,* 1217:3511-3518

Garcia-Rodríguez, A., Matamoros, V., Fontàs, C. and Salvadó, V. (2015). The influence of *Lemna* sp. and *Spirogyra* sp. on the removal of pharmaceuticals and endocrine disruptors in treated wastewaters. *Int. J. Environ. Sci. Technol.* 12:2327-2338

Gattullo, C.E., Bahrs, H., Steinberg, C.E. and Loffredo, E. (2012). Removal of Bisphenol A by the freshwater green alga *Monoraphidium braunii* and the role of natural organic matter. *Sci. Total Environ.,* 416:501-506

Goeury, K., Vo Duy, S., Munoz, G., Prévost, M. and Sauvé, S. (2019). Analysis of environmental protection agency priority endocrine disruptor hormones and bisphenol a in tap, surface and wastewater by online concentration liquid chromatography tandem mass spectrometry. *J. Chromatogr. A,* 1591:87-98

Gregory, M.R. and Ryan, P.G. (1997). Pelagic plastics and other seaborne persistent synthetic debris: A review of southern hemisphere perspectives, Marine debris, Springer, pp. 49-66

Guo, R., Du, Y., Zheng, F., Wang, J., Wang, Z., Ji, R. and Chen, J. (2017) Bioaccumulation and elimination of Bisphenol A (BPA) in the alga *Chlorella pyrenoidosa* and the potential for trophic transfer to the *Rotifer brachionus calyciflorus*. *Environ. Pollut.,* 227:460-467

Hamada, H., Tomi, R., Asada, Y. and Furuya, T. (2002). Phytoremediation of Bisphenol A by cultured suspension cells of *Eucalyptusperriniana*-regioselective hydroxylation and glycosylation. *Tetrahedron Lett.,* 43:4087-4089

Hirooka, T., Akiyama, Y., Tsuji, N., Nakamura, T., Nagase, H., Hirata, K. and Miyamoto, K. (2003). Removal of hazardous phenols by microalgae under photoautotrophic conditions. *J. Biosci. Bioeng.,* 95:200-203

Hu, Y. and Cheng, H. (2013). Water pollution during china's industrial transition. *Environ. Dev.,* 8:57-73

Huang, C., Wu, L.H., Liu, G.Q., Shi, L. and Guo, Y. (2018). Occurrence and ecological risk assessment of eight endocrine-disrupting chemicals in urban river water and sediments of south China. *Arch.*

Environ. Contam. Toxicol. 75:224-235

Huang, Y.Q., Wong, C.K., Zheng, J.S., Bouwman, H., Barra, R., Wahlström, B., Neretin, L. and Wong, M.H. (2011). Bisphenol a (BPA) in China: A review of sources, environmental levels, and potential human health impacts. *Environ. Int.,* 42, 91-99

Imai, S., Shiraishi, A., Gamo, K., Watanabe, I., Okuhata, H., Miyasaka, H., Ikeda, K., Bamba, T. and Hirata, K. (2007). Removal of phenolic endocrine disruptors by *Portulaca oleracea*. *J. Biosci. Bioeng.,* 103:420-426

Ishihara, K. and Nakajima, N. (2003). Improvement of marine environmental pollution using eco-system: Decomposition and recovery of endocrine disrupting chemicals by marine phyto- and zooplanktons. *J. Mol. Cat. B-enzym.,* 23:419-424

Ji, M.K., Kabra, A.N., Choi, J., Hwang, J.H., Kim, J.R., Abou-Shanab, R.A.I., Oh, Y.K. and Jeon, B.H. (2014). Biodegradation of Bisphenol A by the freshwater microalgae *Chlamydomonas mexicana* and *Chlorella vulgaris*. *Ecol. Eng.,* 73:260-269

Jin, H. and Zhu, L. (2016). Occurrence and partitioning of bisphenol analogues in water and sediment from Liaohe river Basin and Taihu lake, China. *Water Res.,* 103:343-351

Kang, J.H. and Kondo, F. (2002). Bisphenol A degradation by bacteria isolated from river water. *Arch. Environ. Contam. Toxicol.,* 43:265-269

Kang, J.H. and Kondo, F. (2006). Distribution and biodegradation of bisphenol A in water hyacinth. *Bull. Environ. Contam. Toxicol.,* 77:500-507

Kang, J.H., Ri, N. and Kondo, F. (2004). *Streptomyces* sp. strain isolated from river water has high bisphenol A degradability. *Let. Appl. Microbiol.,* 39:178-180

Karthikraj, R., and Kannan, K., 2017, Mass loading and removal of benzotriazoles, benzothiazoles, benzophenones, and bisphenols in indian sewage treatment plants. *Chemosphere* 181, 216-223. doi: 10.1016/j.chemosphere.2017.04.075

Lalwani, D., Ruan, Y., Taniyasu, S., Yamazaki, E., Kumar, N.J.I., Lam, P.K.S., Wang, X. and Yamashita, N. (2020). Nationwide distribution and potential risk of bisphenol analogues in indian waters. *Ecotoxicol. Environ. Saf.* 200:1107-1118

Lee, S., Liao, C., Song, G. J., Ra, K., Kannan, K. and Moon, H.B. (2015). Emission of Bisphenol analogues including Bisphenol A and Bisphenol F from wastewater treatment plants in korea. *Chemosphere,* 119:1000-1006

Lemos, M.F.L., van Gestel, C.A.M. and Soares, A.M.V.M. (2010). Developmental toxicity of endocrine disrupters Bisphenol A and vinclozolin in a terrestrial isopod. *Arch. Environ. Contam. Toxicol.,* 59:274-281

Li, G., Zu, L., Wong, P.K., Hui, X., Lu, Y., Xiong, J. and An, T. (2012). Biodegradation and detoxification of bisphenol A with one newly-isolated strain *Bacillus* sp. Gzb: Kinetics, mechanism and estrogenic transition. *Biores. Technol.,* 114:224-230

Li, R., Chen, G.Z., Tam, N.F., Luan, T.G., Shin, P.K., Cheung, S.G. and Liu, Y. (2009). Toxicity of Bisphenol A and its bioaccumulation and removal by a marine microalga *Stephanodiscus hantzschii*. *Ecotoxicol. Environ. Saf.* 72:321-328

Li, Y., Toyama, T., Furuya, T., Iwanaga, K., Tanaka, Y. and Mori, K. (2014). Sustainable biodegradation of bisphenol A by *Spirodela polyrhiza* in association with *Novosphingobium sp*. FID3. *J. Water Environ. Technol.,* 12:43-54

Liu, B., Lehmler, H.J., Sun, Y., Xu, G., Sun, Q., Snetselaar, L.G., Wallace, R.B. and Bao, W. (2019). Association of bisphenol A and its substitutes, bisphenol F and bisphenol S, with obesity in United States children and adolescents. *Diabetes Metab. J.,* 43:59-75

Liu, Y., Guan, Y., Tam, N.F.Y., Mizuno, T., Tsuno, H. and Zhu, W. (2010). Influence of rainfall and basic water quality parameters on the distribution of endocrine-disrupting chemicals in coastal area. *Water Air Soil Pollut.,* 209:333-343

Loffredo, E. and Senesi, N. (2006). Fate of anthropogenic organic pollutants in soils with emphasis on adsorption/desorption processes of endocrine disruptor compounds. *Pure Appl. Chem.,* 78:947-961

Loffredo, E., Gattullo, C.E., Traversa, A. and Senesi, N. (2010). Potential of various herbaceous species to remove the endocrine disruptor bisphenol A from aqueous media. *Chemosphere,* 80:1274-1280

Matsumura, Y., Hosokawa, C., Sasaki-Mori, M., Akahira, A., Fukunaga, K., Ikeuchi, T., Oshiman, K. and Tsuchido, T. (2009). Isolation and characterization of novel bisphenol-A degrading bacteria from soils. *Biocontrol Sci.,* 14:161-169

Meijide, F.J., Da Cuña, R.H., Prieto, J.P., Dorelle, L.S., Babay, P.A. and Lo Nostro, F. L. (2018). Effects of waterborne exposure to the antidepressant fluoxetine on swimming, shoaling and anxiety behaviours of the mosquitofish *Gambusia holbrooki*. *Ecotoxicol. Environ. Saf.,* 163:646-655

Mihaich, E.M., Friederich, U., Caspers, N., Hall, A.T., Klecka, G.M., Dimond, S.S., Staples, C.A., Ortego, L.S. and Hentges, S.G. (2009). Acute and chronic toxicity testing of bisphenol A with aquatic invertebrates and plants. *Ecotoxicol. Environ. Saf.* 72:1392-1399

Nakajima, N., Teramoto, T., Kasai, F., Sano, T., Tamaoki, M., Aono, M., Kubo, A., Kamada, H., Azumi, Y. and Saji, H. (2007). Glycosylation of Bisphenol A by freshwater microalgae. *Chemosphere,* 69:934-941

Noureddin, I.M., Furumoto, T., Ishida, Y., and Fukui, H., (2004). Absorption and metabolism of bisphenol A, a possible endocrine disruptor, in the aquatic edible plant, water convolvulus (*Ipomoea aquatica*). *Biosci. Biotechnol. Biochem.,* 68:1398-1402

Oertel, N. and Salánki, J. (2003). Biomonitoring and Bioindicators in Aquatic Ecosystems. In: Ambasht R.S., Ambasht N.K. (eds.), Modern Trends in Applied Aquatic Ecology. Springer, Boston, pp. 219-246

Okuhata, H., Ikeda, K., Miyasaka, H., Takahashi, S., Matsui, T., Nakayama, H., Kato, K. and Hirata, K. (2010). Floricultural salvia plants have a high ability to eliminate bisphenol A. *J. Biosci. Bioeng.* 110:99-101

Owens, C.V., Lambright, C., Bobseine, K., Ryan, B., Gray, L.E., Gullett, B.K. and Wilson, V.S. (2007). Identification of estrogenic compounds emitted from the combustion of computer printed circuit boards in electronic waste. *Environ. Sci. Technol.,* 41, 8506-8511. doi: 10.1021/es071425p

PRWeb report, Global bisphenol a market to reach 8.4 million metric tons by 2018. http://www.prweb.com/releases/bisphenol_A_market/phenol_market/prweb10992205.

Radix, P., Severin, G., Schramm, K.W. and Kettrup, A. (2002). Reproduction disturbances of *Brachionus calyciflorus* (rotifer) for the screening of environmental endocrine disrupters. *Chemosphere,* 47:1097-101

Raj, M., Mustafa, M., Sethia, B., Kagganti, M., Namitha, S. and Harshitha, S. (2015). Phytoremediation of the endocrine disruptor bisphenol A using *Pistia stratiotes*. *Res. J. Pharm. Biol. Chem. Sci*. 6:1-7

Reis, A. and Sakakibara, Y. (2012). Enzymatic degradation of endocrine-disrupting chemicals in aquatic plants and relations to biological fenton reaction. *Water Sci. Technol.,* 66:775-782

Rocha, S., Domingues, V.F., Pinho, C., Fernandes, V.C., Delerue-Matos, C., Gameiro, P. and Mansilha, C. (2013). Occurrence of Bisphenol A, estrone, 17β-estradiol and 17α-ethinylestradiol in Portuguese rivers. *Bullet. Environ. Contam. Toxicol.,* 90:73-78

Rochester, J.R. and Bolden, A.L. (2015). Bisphenol S and F: A systematic review and comparison of the hormonal activity of Bisphenol A substitutes. *Environ. Health Perspect,* 123:643-650

Saiyood, S., Inthorn, D., Vangnai, A.S. and Thiravetyan, P. (2013). Phytoremediation of Bisphenol A and total dissolved solids by the mangrove plant, *Bruguiera gymnorhiza*. *Int. J. Phytoremediation,* 15:427-438

Saiyood, S., Vangnai, A.S., Thiravetyan, P. and Inthorn, D. (2010). Bisphenol a removal by the *Dracaena* plant and the role of plant-associating bacteria. *J. Hazard. Mater.* 178:777-785

Sakai, K., Yamanaka, H., Moriyoshi, K., Ohmoto, T. and Ohe, T. (2007). Biodegradation of Bisphenol A and related compounds by *Sphingomonas* sp. Strain BP-7 isolated from seawater. *Biosci. Biotechnol. Biochem.,* 71:51-57

Sangai, N., Pandya, H.A. and Singh, R. (2016). Critical review on bisphenol a: Invisible pollution. Int. J. Pharm. Res. Health Sci., 4:1043-1049

Si, W., Cai, Y., Liu, J., Shen, J., Chen, Q., Chen, C. and Ning, L. (2019). Investigating the role of colloids on the distribution of bisphenol analogues in surface water from an ecological demonstration area, China. *Sci. Total Environ.,* 673:699-707

Staples, C., van der Hoeven, N., Clark, K., Mihaich, E., Woelz, J. and Hentges, S. (2018). Distributions of concentrations of bisphenol a in north american and european surface waters and sediments determined from 19 years of monitoring data. *Chemosphere,* 201:448-458

Staples, C.A., Dome, P.B., Klecka, G.M., Oblock, S.T. and Harris, L.R. (1998). A review of the environmental fate, effects, and exposures of Bisphenol A. *Chemosphere,* 36:2149-2173

Trueman, R. and Erber, L. (2013). Invasive species may offer advanced phytoremediation of endocrine disrupting chemicals in aquatic ecosystems. *Emir. J. Food Agric.,* 25:648-656

Wan, Y., Xia, W., Yang, S., Pan, X., He, Z. and Kannan, K. (2018). Spatial distribution of Bisphenol S in surface water and human serum from yangtze river watershed, China: Implications for exposure through drinking water. *Chemosphere,* 199:595-602

Yamazaki, E., Yamashita, N., Taniyasu, S., Lam, J., Lam, P.K., Moon, H.B., Jeong, Y., Kannan, P., Achyuthan, H., Munuswamy, N. and Kannan, K. (2015). Bisphenol A and other bisphenol analogues including BPS and BPF in surface water samples from Japan, China, Korea and India. *Ecotoxicol. Environ. Saf.* 122:565-572

Yang, Y., Lu, L., Zhang, J., Yang, Y., Wu, Y. and Shao, B. (2014). Simultaneous determination of seven bisphenols in environmental water and solid samples by liquid chromatography-electrospray tandem mass spectrometry. *J. Chromatogr. A,* 1328:26-34

Yu, X., Xue, J., Yao, H., Wu, Q., Venkatesan, A.K., Halden, R.U. and Kannan, K. (2015). Occurrence and estrogenic potency of eight Bisphenol analogs in sewage sludge from the U.S. EPA targeted national sewage sludge survey. *J. Hazard. Mater.,* 299:733-739

Zazouli, M.A., Mahdavi, Y., Bazrafshan, E. and Balarak, D. (2014). Phytodegradation potential of bisphenola from aqueous solution by *Azolla filiculoides*. *J. Environ. Health Sci. Eng.,* 12:66-66

Zhang, B., Wu, Z., Cheng, S., He, F., Wang, Y. and Gao, Y. (2007). Primary study on phytodegradation of bisphenol A by *Elodea nuttallii*. *Wuhan Univ. J. Nat. Sci.* 12:1118-1124

Zhang, C., Zeng, G., Yuan, L., Yu, J., Li, J., Huang, G., Xi, B. and Liu, H. (2007). Aerobic degradation of bisphenol A by *Achromobacter xylosoxidans* strain b-16 isolated from compost leachate of municipal solid waste. *Chemosphere,* 68:181-190

Zhang, G., Wang, Y., Jiang, J. and Yang, S. (2017). Bisphenol A removal by submerged macrophytes and the contribution of epiphytic microorganisms to the removal process. *Bullet. Environ. Contam. Toxicol.* 98:770-775

Zhang, W., Xiong, B., Sun, W.F., An, S., Lin, K.F., Guo, M.J. and Cui, X.H. (2014). Acute and chronic toxic effects of Bisphenol A on *Chlorella pyrenoidosa* and *Scenedesmus obliquus*. *Environ. Toxicol.,* 29:714-722

Zhang, Y.Z., Meng, W. and Zhang, Y. (2014). Occurrence and partitioning of phenolic endocrine-disrupting chemicals (EDCS) between surface water and suspended particulate matter in the north Tai lake basin, eastern China. *Bull. Environ. Contam. Toxicol.,* 92:148-153

Zhou, D., Wu, F., Deng, N. and Xiang, W. (2004) Photooxidation of Bisphenol A (BPA) in water in the presence of ferric and carboxylate salts. *Water Res.,*38:4107-4116.