
ELSEVIER
Volume 248, issues 1–3
15 NOVEMBER 2009
ISSN: 0011-9164
DESALINATION
The International Journal on the Science and Technology of Desalting and Water Purification
On-line access via: www.elsevier.com/locate/desal

Available online at www.sciencedirect.com
ScienceDirect
ELSEVIER
Desalination 248 (2009) 578–585
DESALINATION
www.elsevier.com/locate/desal

Occurrences of endocrine disrupting compounds and pharmaceuticals in the aquatic environment and their removal from drinking water: Challenges in the context of the developing world

M.F. Rahman[a]*, E.K. Yanful[a], S.Y. Jasim[b]

[a]*Department of Civil and Environmental Engineering, University of Western Ontario, Ontario N6A 5B9, Canada*
Tel. 1-519-888-4567 Ext. 38805; email: mrahma49@uwo.ca
[b]*Walkerton Clean Water Centre, Walkerton, Ontario N0G 2V0, Canada*

Received 31 January 2008; revised accepted 15 May 2008

Abstract

The presence of endocrine disrupting compounds (EDCs) and pharmaceuticals and personal care products (PPCPs) in the aquatic environment and their impact on the ecosystem and humans are emerging issues in environmental health. Many scientists fear that these chemicals may be detrimental even in minute concentrations (ng/L to μg/L). Due to inappropriate uses, uncontrolled disposal of chemicals and lack of regulations, the risk of exposure to chemicals is probably greater in the developing world. Conventional drinking water treatment technologies have shown insufficient removal of EDCs and PPCPs. Advanced treatment technologies, such as ozonation, may seem a luxury for developing countries where there are more immediate problems such as water supply and sanitation. However, it would not be pragmatic to ignore the long-term dangers. An awareness of EDCs and PPCPs removal techniques in developing countries could help prioritise research to respond to perceived risks and develop appropriate technologies and policies.

Keywords: EDCs; PPCPs; Environmental health; Advanced water treatment technologies

1. Introduction

Water quality is one of the fundamental determinants of public health and it greatly enhances or complements economic progress and sustainable development of a country. Developing countries are combating a wide range of water quality problems from microbial contamination to toxic chemicals, and are doing so in an environment where economic progress is severely limited [1]. Also, the frequent limited applications of the scientific knowledge base together with lack of skilled labour make water quality programs in these countries grossly inefficient [1]. The detection of endocrine disrupting compounds (EDCs)

Presented at the Water and Sanitation in International Development and Disaster Relief (WSIDDR) International Workshop Edinburgh, Scotland, UK, 28–30 May 2008.

0011-9164/09/$– See front matter
doi:10.1016/j.desal.2008.05.105

Table 1

Definition	
	An endocrine disrupter is an exogenous agent that interferes with the synthesis, secretion, transport, binding, action or elimination of natural hormones in the body that are responsible for the maintenance of homeostasis, reproduction, development and/or behaviour [3]
Suspected EDCs	
	Certain natural and synthetic hormones, alkylphenols, pesticides, herbicides, organochlorines, polyaromatic hydrocarbons (PAHs), dioxins
	Pharmaceuticals and personal care products (PPCPs) such as cosmetics, sunscreens, detergents, shampoos can also act as EDCs
Sources	
	Sewage treatment plants, agricultural and cattle feedlot runoffs, household disposal, industrial uses and spills, atmospheric deposition
How do they work?	
	EDCs can mimic hormones (agonistic) or block hormones (antagonistic) or do both [2]
Is there any definitive list of EDCs?	
	No. Most chemicals have not been tested for endocrine disrupting activity and for some there are limited or controversial data [4,5]
Important physicochemical properties	
	Water solubility, adsorption coefficient (log K_{OC}), bioaccumulation potential (log K_{OW}), Henry's law constant [2,6]
	Despite their short half lives some PPCPs are persistent due to their continuous disposal and release in water [7]

and pharmaceuticals and personal care products (PPCPs) in the aquatic environment has added a new dimension to water quality programs in developing regions of the world.

The occurrence of EDCs and PPCPs in the aquatic environment has been receiving increasing attention in recent times, notably in the industrialized countries. These chemicals, at their reported trace level concentrations (ng/L to μg/L), are thought to be harmful to public health. Although exposure to pesticides and other endocrine disrupting chemicals are probably higher in developing countries, this issue has received very little attention in those countries. The fact that many of those countries are dealing with more immediate problems, would probably explain why emerging problems of toxic micropollutants have received little attention. In this paper, we list some challenges that aquatic occurrence of EDCs and PPCPs present to developing countries and how research could address the issue in those countries. We also hope that this article would raise awareness among researchers from those regions and encourage them to undertake research to evaluate the extent of the problem and minimize overall long-term risks.

2. EDCs and their impacts

EDCs are a diverse group of natural or synthetic chemicals that interfere with the functioning of hormone systems resulting in unnatural responses in the receiving organism [3]. Table 1 presents a summary of EDCs, their potential sources and important properties.

Research and published data are increasingly showing evidence of deleterious impacts of EDCs and PPCPs on the ecosystem. Feminizations of fishes and gulls and sexual abnormalities in alligators due to exposure to organochlorines have been reported [8,9]. Worldwide increases of hormone related cancers have often been attributed to EDCs and PPCPs. In recent years usage of herbicides and pesticides in developing countries to boost the agricultural productivity has been escalating alarmingly. For example, Pakistan has seen an increase of 1169% of pesticide use in the last 20 years [10]. Such increases have led to acute exposure of different groups to those chemicals, agricultural workers in particular and may result in hormone-dependent cancers as well. Ejaj et al. [10] reported the detection of elevated levels of endocrine disrupting pesticides in serum among the farmers of

Punjab, Pakistan and, also, increased incidences of cancer in the same area. Pocar et al. [11] noted that EDCs may cause infertility, pregnancy loss, birth defects, ovarian failure, growth retardation. Declined sex ratios in Canada and the United States have also been reported [9,12]. However, impact data on humans are not conclusive.

Sex hormones and some xenoestrogens can affect various non-reproductive tissues, especially, the immune system [13,14]. It is evident now that these estrogens are almost ubiquitous in the environment and, as such, exposure to them is almost unavoidable. Estrogens have the potential to bio-accumulate in body fat and may subsequently achieve a considerable dose [14]. They may be released from body fat during starvation and can also enter infants during pregnancy or through breast milk. Sustained low-level intake of EDCs may lead to a bi-directional interaction between the immune system and the endocrine system. EDCs may alter the reproductive system, which in turn may affect the immune system and vice versa [14].

3. Persistent organic pollutants (POPs), antibiotics, anti-neoplastics and steroid hormones

Of the various classes of chemicals, POPs, antibiotics, anti-neoplastics and steroids probably need special attention. Most POPs are organochlorine compounds (e.g. DDT, DDE, toxaphene, dieldrin, mirex) mainly used for industrial and agricultural applications. Following the revelation of the persistent nature of these chemicals, their bioaccumulation potentials and adverse impact on humans, their use have been restricted or banned in industrialized countries. However, some developing countries still use these chemicals, as they are cheap. POPs can undergo long transport via water and air to new areas far from their sources such as the Arctic where they have never been used or produced [6,15]. Voldner and Li [16] reported that the cumulative global usage (in metric tons) is 450,000 for toxaphene, 1,500,000 for DDT, 550,000 for HCH and 720,000 for lindane. Often these pesticides, which are banned in industrialized countries, are exported to developing countries. Moreover, many countries do not keep records of pesticide use and, in some countries, this information is classified [19]. Thus, the actual usage of organochlorines is probably higher than what is being reported.

Antibiotics in water could increase the resistance in the natural bacterial population. There is a recent concern with the increased sales and use of antiviral "Tamiflu", which has been found to be effective against the avian influenza. It was found that sewage treatment plants (STPs) cannot remove Tamiflu and even ultraviolet (UV) radiation cannot substantially degrade them [17]. Thus, Tamiflu might be released in the aquatic environment and lead to the increased resistance of the H5N1 virus. Okeke et al. [18] reported the acquired bacterial resistance to antibiotics in developing countries. Poor quality antibiotics including degraded and expired antibiotics, misuse and overuse of antibiotics by physicians in clinical practice, misuse by the public, over the counter availability of antibiotics together with crowding and improper sewage disposal contribute to the development of antibacterial resistant strains in developing countries [18].

Comparison between daily or life intake of pharmaceuticals via drinking water with therapeutic doses indicate that the exposure levels are low and well below the dosage that can cause pharmacological effects [19]. However, cytotoxic drugs like antineoplastics (e.g. cyclophosphamide), which are carcinogenic, are hazardous at any concentration [19]. Thus, the use of therapeutic doses to estimate the risk may not be applicable to genotoxins like cyclophosphamide [19]. Sex steroid hormones as stated above can alter the reproductive health and development of the receiving organisms. Consequences of prenatal exposure to diethylstilbestrol have been attributed to reproductive disorders, cognitive impairment and miscarriage have been reported [13,15]. Ethinylestradiol originating from contraceptives was assumed to be accountable for the feminization of rainbow trouts caged and placed in STP effluents [20].

4. EDCs in drinking water and their removal

Insufficient removal by STPs and subsequent disposal of effluents contribute to the occurrence of chemicals in surface waters. The same water body (for example, river or lake) might be serving as a drinking water source. Also, contamination of drinking water might arise from the leaching of chemicals to groundwater or water supply lines [21]. However, to date, occurrence data of EDCs and PPCPs in drinking water are sparse.

EDCs such as bisphenol-A (BPA), alkylphenols, phthalates and polyaromatic hydrocarbons (PAHs) may leach into drinking water when plastics pipes are used in supply lines. Also BPA might leach from infant bottles and coatings in food cans [21,22]. Drinking water supply mains that are coated with coal tars to prevent corrosion can leach PAHs in drinking water and are the main source of PAHs in drinking water. A physical damage of the tar coating in the distribution line or recent repair works may increase the concentration of PAH [23]. Disinfection with chlorine might also leach PAH from coal tar pitch [24]. PAH concentrations of 190–302 ng/L in chlorine treated water have been reported [21].

Removal of an EDC or a PPCP is dependent upon its intrinsic chemical properties such as molecular weight, relative hydrophobicity, aromatic carbon content and functional group composition [7,25]. Conventional treatments such as coagulation, sedimentation and filtration have been found to remove less than 25% of most EDCs and PPCPs [5,25]. Advanced water treatment technologies such as ozonation, granular activated carbon (GAC) adsorption, and UV irradiation have been reported to be efficient in removing trace organic contaminants. For UV treatment, a typical disinfection dose of (>5–40 mJ/cm^2) was found to be several orders of magnitude lower than for the removal of most micropollutants [26,27]. USEPA recommends GAC as the best available treatment for removal of many EDCs including methoxychlor, endosulfan, DDT and polychlorinated biphenyls [3]. However, there are several drug compounds with high water solubility and/or poor degradability that can be resistant to GAC [28]. The X-ray contrast medium iopromide, analgesics ibuprofen, naproxen and dichlofenac, sulfamehtoxazole and meprobamate are some compounds that were found to be recalcitrant for activated carbon removal [26]. Ozonation and ozone/hydrogen peroxide based advanced oxidation processes (AOPs) have been found to be very effective in removing drugs like carbamazepine, dichlofenac, ethinyl-estradiol and benzafibrate at ozone doses of 0.5–3 mg/L [29]. Compounds like iopromide, the pesticide atrazine and clofibric acid have been found extremely recalcitrant to ozone alone even at higher ozone doses. In ozone treatment, ozone (O_3) attacks the organic contaminants either by direct reaction (as molecular O_3), or through the formation of free radicals, such as the hydroxyl radical (•OH). O_3 is a selective oxidant; some organic contaminants are oxidized readily and others are not oxidized at all [30]. On the other hand, the •OH radical is not selective and is a stronger oxidant. In the advanced ozonation process, hydrogen peroxide (H_2O_2) initiates and propagates the decomposition of ozone, which in turn generates •OH radicals, and may improve the removal of the recalcitrant compounds [30,31]. Research studying the removal of selected target compounds from drinking water using O_3/H_2O_2 is underway at the University of Western Ontario, Canada. If satisfactory removals are obtained, this treatment process can be applied to drinking water treatment for EDCs and PPCPs removal. The proposed treatment process is also expected to bring secondary benefits such as better inactivation of micro-organisms (giardia, viruses), removal of taste and odor, and removal of iron and manganese. However, given that advanced ozonation processes are highly expensive, water programs in most developing countries would probably not be interested in using these processes at the present time. Some other issues that would have to be considered are discussed later.

5. EDCs and PPCPs in the environment: implications for developing countries

World Health Organization (WHO) estimates show that developing countries consume about 20% of the pesticide produced worldwide [10]. Yet due to lack of knowledge, absence of regulatory framework and appropriate pesticide market control policy, people in those countries are probably exposed to higher levels of toxic pesticides. Estimates show that there are about 20,000 deaths each year around the world due to acute pesticide intoxications 99% of which probably occur in developing countries [32,33]. Moreover, organochlorine pesticides are still being used in a number of developing regions to fight

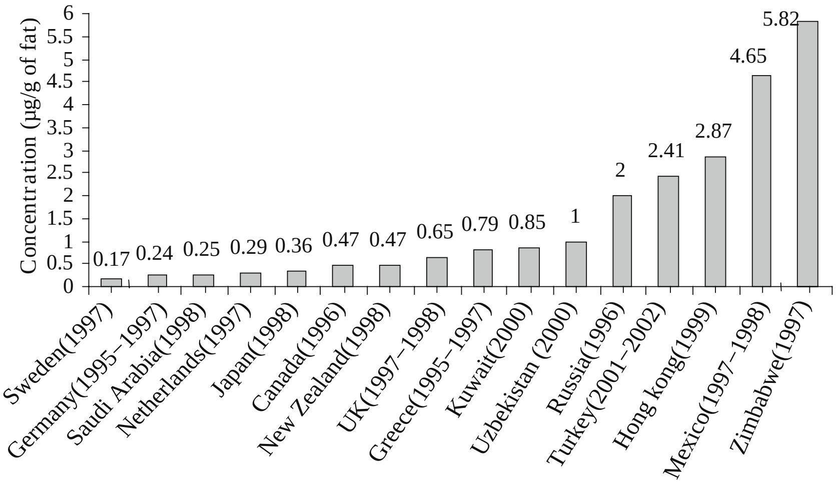

Fig. 1. Concentration of DDTs in human milk in different countries in between 1995 and 2002 adapted from Kunisue et al. [35] and Wong et al. [36]).

diseases such as malaria. High levels of organochlorine pesticides have been identified in the environment and also in human breast milk in many developing countries [34,35]. Fig. 1 shows concentration of DDTs observed in breast milk in some developing and industrialized countries in between 1995 and 2002 (adapted from [35,36]). Clearly concentration of DDTs in human milk in countries like Zimbabwe, Mexico, Turkey, Uzbekistan are much higher compared to the industrialized countries. Thus, infants in those countries are exposed to higher levels of DDTs through lactation. Due to poor waste disposal practices and insufficient sanitary landfills, the possibility of groundwater pollution with EDCs is also potentially high in the developing countries [34]. Moreover, often chemicals or drugs that are expired or banned from the market or fail to register in the industrialized countries find their way to the markets of developing countries [18,33]. For example, between 1987 and 1989 manufacturers in the United States produced and exported nearly 5,000,000 pounds of insecticides chlordane and heptachlor which were already banned in the United States [33]. Significant portions of the population in developing countries already being under the stress of malnutrition and infectious diseases have aggravated the scenario even more. Environmental toxins would interact with malnutrition and infectious disease to magnify their individual impact and also affect the immune system [33]. Thus, people in developing countries are often more vulnerable to chemical pollution leading to adverse health effects [37].

Industrialized nations, along the pathway of their development, have observed a shift from the epidemiological transition to the suite of chronic illness such as asthma, learning disabilities, congenital malformations and cancers as the leading causes of death [38]. It is probably synthetic chemicals in air, water, soil and food chain that are contributing to the changing patterns of paediatric diseases, especially the increasing incidences of the chronic diseases in children [38]. It can be presumed that these chronic diseases in children also prevail in developing and under-developed countries but are probably not reported widely. Availability of cheap child labour, lack of occupational and environmental protection in conjunction with constant export of hazardous chemicals and toxic wastes from industrialized nations to the developing regions have placed children in those countries at a two fold risk of infectious diseases and chemical hazards [38]. Reports have indicated frequent occurrence of abortions, childhood cancers, and congenital malformations among children, whose parents had occupational exposure to pesticides. Health implications of toxic chemicals for children are considerably higher compared to the adults as their developing systems are more delicate and they might not be able to repair the damage that is triggered by early exposure to toxicants [38].

Global rise in antibiotic resistance have increased the overall medical costs of communities due to frequent hospitalization, longer hospital stays and elevated treatment costs. This is of even greater repercussion in developing countries where the economy is already overburdened. Political unrest, mass migration and unhygienic environment with lack of health care facilities, all these nurture the antibiotic resistance in those countries [39].

Although perils of chemicals causing endocrine disruption are significantly higher in developing countries, little has been done towards addressing this issue. Partly because many developing nations are still fighting with more immediate problems such as infectious diseases, water supply, sanitation, waste disposal, war and famine. Thus, in many developing countries, long-term risks of EDCs may not be seen as a pressing issue at the current time [40]. There is also a significant gap in scientific knowledge and awareness regarding the potential adverse impacts of EDCs and their handling technologies. Another challenge the water industry in developing countries will face is the lack of information on advanced water treatment technologies. Installation of advanced water treatment technologies would require significant capital investment and skilled labour. The cost of operation might seem expensive even in some communities in the developed world. Also, analytical costs would be significant. Furthermore people might not be willing to pay for removal of compounds, adverse impacts of which are yet to be proven. Thus, advanced water treatment technologies for the removal of EDCs and PPCPs might seem a luxury for most developing countries at the present time. Despite the fact that indirect human exposure via drinking water is relatively low, there is a need for assessment of long-term low-level synergistic effects of EDCs and PPCPs, their metabolites and degradation products via drinking water. It would simply not be pragmatic to ignore long-term hazards these chemicals pose to a large population in developing regions. Therefore, research on EDCs should not be limited to the industrialized countries only. It should be promoted in developing countries as well. This would help characterize the extent of the problem in those regions and will help researchers and scientists in those regions to learn more about advanced water treatment technologies and to develop appropriate technologies to remove EDCs and PPCPs in water. For example, Vieno et al. [41] noted that removal of EDCs and PPCPs can occur through natural phototransformation or biotransformation, which is increased considerably during summer. For many hot climate countries where adequate sun is available for a longer period of the year, this could be a viable option for removal of EDCs and PPCPs in lagoons.

6. Concluding remarks

The occurrence of synthetic chemicals in the aquatic environment is of much concern in terms of the global health. Although adverse effects on aquatic and other wildlife are established, long-term threats of these chemicals on human health are yet to be confirmed and are being debated [42]. Extensive environmental health research, carried out mostly in developed countries, has obviously benefited developing countries in fostering environmental awareness and in enacting more stringent environmental legislations than what the developed countries had in the past in similar situations. However, often the absence of proper social, economic and infrastructural considerations have led to the failure of strict enforcement in developing countries [43]. Even some of the underdeveloped communities in many developed countries are not well served by the health research and interventions [44]. Each society perceives and manages the risks according to its own values and priorities [37]. It can be speculated that technologies to handle emerging contaminants such as EDCs and PPCPs would fail if passed to developing countries without building the capacity to identify and perceive their ill effects. Thus, timely and appropriate technical assistance from industrialized countries is essential. The global nature of many environmental problems is becoming more and more evident. Concerted international effort and research towards characterizing the risk and, also, co-ordination among governmental and other agencies for appropriate chemical usage policies is therefore urgent. Effective communication and translation of hazards of EDCs and PPCPs in terms of individual regions or cultures, education and formulation of policies that are compatible with local conditions would probably lessen the vulnerability in developing countries and the globe at large.

Acknowledgement

Thanks to Dr. M.A. Bergougnou for reviewing the revised manuscript.

References

[1] E.D. Ongley, Matching water quality programs to management needs in developing countries: the challenge of program modernization, in: Proceedings of the Monitoring Tailor Made – II. Why to Integrate Water Quality Information, Nunspeet, Netharlands, 1996, pp. 13-20.

[2] J.W. Birklett and J.N. Lester, Scope of the problem, in: J.W. Birklett, J.N. Lester, eds., Endocrine Disruptors in Wastewater and Sludge Treatment Processes, Lewis Publishers, New York, 2003, pp. 1-34.

[3] USEPA, Removal of Endocrine Disruptor Chemicals using Drinking Water Treatment Processes, EPA/625/R-00/015, 2001.

[4] S.A. Snyder, S. Adham, A.M. Redding, F.S. Cannon, J. Decarolis, J. Oppenheimer, E.C. Wert and Y. Yoon, Role of membranes and activated carbon removal of endocrine disruptors and pharmaceuticals, Desalination, 202 (2006) 156-181.

[5] S.D. Kim, J. Cho, I.S. Kim, B.J. Vanderford and S.A. Snyder, Occurrence and removal of pharmaceuticals and endocrine disruptors in South Korean surface, drinking and waste waters, Water Res., 41 (2007) 1013-1021.

[6] J. Lintelmann, A. Katayama, N. Kurihara, L. Shore and A. Wenzel, Endocrine disruptors in the environment, Pure Appl. Chem., 75(5) (2003) 631-681.

[7] S.Y. Jasim, A. Irabelli, P. Yang, S. Ahmed and L. Schweitzer, Presence of pharmaceuticals and pesticides in Detroit river water and the effect of ozone on removal, Ozone: Sci. Eng. 28 (2006) 415-423.

[8] D.M. Fry, Reproductive effects in birds exposed to pesticides and industrial chemicals, Environ. Health Perspect., 103(7) (1995) 165-171.

[9] S.H. Safe, Endocrine disruption and human health-is there a problem? An update, Environ. Health Perspect., 108(6) (2000) 487-493.

[10] S. Ejaj, W. Akram, C.W. Lim, J.J. Lee and I. Hussain, Endocrine disrupting pesticides: a leading cause of cancer among rural people in Pakistan, Exp. Oncol., 26(2) (2004) 98-105.

[11] P. Pocar, T.A.L. Bervini, B. Fischer and F. Gandolfi, The impact of endocrine disruptors on oocyte competence, Reproduction, 125 (2003) 313-325.

[12] C.A. Mackenzie, A. Lockridge and M. Keith, Declining sex ratio in a first nation community, Environ. Health Perspect., 113(10) (2005) 1295-1298.

[13] H. Inadera, The immune system as a target for environmental chemicals: xenoestrogen and other compounds, Toxicol. Lett., 164 (2006) 191-206.

[14] S.A. Ahmed, The immune system as a potential target for environmental estrogens (endocrine disrupters): a new emerging field, Toxicology, 150 (2000) 191-206.

[15] L.S. Birnbaum, Endocrine effects of prenatal exposure to PCBs, dioxins and other xenobiotics: implications for policy and future research, Environ. Health Perspect., 102(8) (1994) 676-679.

[16] E.C. Voldner and Y.F. Li, Global usage of selected persistent organochlorines, Sci. Total Environ., 160/161 (1995) 201-210.

[17] J. Fick, R.H. Lindberg, M. Tysklind, P.D. Haemig, J. Waledenstrom, A. Wallensten and B. Olsen, Antiviral oseltamivir is not removed or degraded in normal sewage water treatment: implications for the development of resistance by influenza A virus, PloS ONE, 2(10) (2007) e986, 1-5.

[18] I.N. Okeke, A. Lamikanra and R. Edelman, Socioeconomic and behavioral factors leading to acquired bacterial resistance to antibiotics in developing countries, Emerg. Infect. Dis., 5(1) (1999) 18-26.

[19] S. Webb, T. Ternes, M. Gilbert and K. Olejniczak, Indirect human exposure to pharmaceuticals via drinking water, Toxicol. Lett., 142(3) (2003) 157-167.

[20] C.E. Purdom, P.A. Hardiman, V.J. Bye, N.C. Eno, C.R. Tyler and J.P. Sumpter, Estrogenic effects of effluents from sewage treatment works, Chem. Ecol., 8 (1994) 275-285.

[21] R. Gomes and J.N. Lester, Endocrine disrupters in drinking water and water reuse, in: J.W. Birklett, J.N. Lester, eds., Endocrine Disruptors in Wastewater and Sludge Treatment Processes, Lewis Publishers, New York, 2003, pp. 219-266.

[22] http://www.theglobeandmail.com/servlet/story/RTGAM.20080119.wbisphenol19/BNStory/National/home [accessed 1045 hrs, 2007 23 January].

[23] K.A. Fahnrich, M. Pravda and G.G. Guilbault, Immunological detection of polycyclic aromatic hydrocarbond (PAHs), Anal. Lett., 35(8) (2002) 1269-1300.

[24] M. Maier, D. Maier and B.J. Lloyd, Factors influencing the mobilization of polycyclic aromatic hydrocarbons (PAHs) from the coal-tar Lining of Water Mains, Water Res., 34 (2000) 773.

[25] P. Westerhoff, Removal of endocrine disruptors, pharmaceuticals and personal care products during water treatment, Southwest Hydrol., 2(6) (2003) 18-19.

[26] D. Khiari, Endocrine disruptors, pharmaceuticals and personal care products in drinking water: an overview of AwwaRF research to date, Drinking Water Research, January/February 2007 [accessed 1600 hrs, 2008 30 January]; http://www.cwwa.ca/pdf_files/AwwaRF_EDC%20article1.pdf.

[27] S.A. Snyder, P. Westerhoff, Y. Yoon and D.L. Sedlak, Pharmaceuticals, personal care products, and endocrine disruptors in water: implications for the water industry, Environ. Eng. Sci., 20(5) (2003) 449-469.

[28] O.A.H. Jones, J.N. Lester and N. Voulvoulis, Pharmaceuticals: a threat to drinking water? Trends Biotechnol., 23(4) (2005) 163-167.

[29] T.A. Ternes, M. Meisenheimer, D. Mcdowell, F. Sacher, H.-J. Brauch, G. Preuss, U. Wilme and N. Zulei-Seibert, Removal of pharmaceuticals during drinking water treatment, Environ. Sci. Technol., 36 (2002) 3855-3863.

[30] U. Von Gunten, Ozonation of drinking water: Part I. Oxidation kinetics and product formation, Water Res., 37 (2003) 1443-1467.

[31] M.M. Huber, S. Canonica, G.-Y. Park and U. Von Gunten, Oxidation of pharmaceuticals during ozonation and advanced oxidation processes, Environ. Sci. Technol., 37 (2003) 1016-1024.

[32] P. Vineis, A case in point: occupational cancer, Bull. World Health Org., 78(9) (2000) 1158-1159.

[33] I.S. Jamall and B. Davis, Chemicals and environmentally caused diseases in developing countries, Infect. Dis. Clin. N. Am., 5(2) (1991) 365-373.

[34] N.H. Minh, T.B. Minh, N. Kajiwara, A. Subramanian, H. Iwata, T.S. Tana, R. Baburajendran, S. Karuppiah, P.H. Viet, B.C. Tuyen and S. Tanabe, Contamination of persistent organic pollutants in dumping sites of Asian developing countries: implication of emerging pollutant sources, Arch. Environ. Contaminat. Toxicol., 50 (2006) 474-481.

[35] T. Kunisue, M. Someya, F. Kayama, Y. Jin and S. Tanabe, Persistent organic pollutants in human breast milk collected from Dalian and Shenyang, China, Org. Compd., 66 (2004) 2779-2784.

[36] M.H. Wong, A.O.W. Leung, J.K.Y. Chan and M.P.K. Choi, A review of the usage of POP pesticides in China, with emphasis on DDT loadings in human milk, Chemosphere, 60 (2005) 740-752.

[37] S.E. Craft, K.C. Donnelly, I. Neamtiu, K.M. McCarty, E. Bruce, I. Surkova, D. Kim, I. Uhnakova, E. Gyorffy, E. Tesarova and B. Anderson. Prioritizing environmental issues around the world: opinions from an international central and eastern European environmental health conference, Environ. Health Perspect., 114(12) (2006) 1813-1817.

[38] W.A. Suk, K.M. Ruchirawat, K. Balakrishnan, M. Berger, D. Carpenter, T. Damstra, J.P. De Garbino, D. Koh, P.J. Landrigan, I. Makalinao, P.D. Sly, Y. Xu and B.S. Zheng, Environmental threats to children's health in Southeast Asia and the Western Pacific, Environ. Health Perspect., 111(10) (2003) 1340-1347.

[39] A. Kapil, The challenge of antibiotic resistance: need to contemplate, Ind. J. Med. Res., 12 (2005) 83-91.

[40] C. Ijsselmuiden, Better to die at 50 from cancer than at 1 from malnutrition? Bull. World Health Org., 78(9) (2000) 1157-1158.

[41] N.M. Vieno, H. Harkki, T. Tuhkanen and L. Kronberg, Occurrence of pharmaceuticals in river water and their elimination in a pilot-scale drinking water treatment plant, Environ. Sci. Technol., 41 (2007) 5077-5084.

[42] O.A.H. Jones, N. Voulvoulis and J.N. Lester, Potential ecological and human health risks associated with the presence of pharmaceutically active compounds in the aquatic environment, Crit. Rev. Toxicol., 34(4) (2004) 335-350.

[43] K.R. Smith, Environmental health – for the rich or for all? Bull. World Health Org., 78(9) (2000) 1156-1157.

[44] A. Woodward, Hard choices, Bull. World Health Org., 78(9) (2000) 1156-1157.