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Estrogenic activity, chemical levels and health risk assessment of municipal distribution point water from Pretoria and Cape Town, South Africa

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HIGHLIGHTS

- Estrogenic activity was detected in Pretoria and Cape Town drinking water.
- Estrogens, bisphenol-A and phthalates were detected in distribution point water.
- Distribution point water is associated with acceptable health and carcinogenic risks.

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ABSTRACT

Endocrine disrupting chemicals (EDCs) are ubiquitous in the environment and have been detected in drinking water from various countries. Although various water treatment processes can remove EDCs, chemicals can also migrate from pipes that transport water and contaminate drinking water. This study investigated the estrogenic activity in drinking water from various distribution points in Pretoria (City of Tshwane) (n = 40) and Cape Town (n = 40), South Africa, using the recombinant yeast estrogen screen (YES) and the T47D-KBluc reporter gene assay. The samples were collected seasonally over four sampling periods. The samples were also analysed for bisphenol A (BPA), nonylphenol (NP), di(2-ethylhexyl) adipate (DEHA), dibutyl phthalate (DBP), di(2-ethylhexyl) phthalate (DEHP), diisononylphthalate (DINP), 17β-estradiol (E_2), estrone (E_1) and ethynylestradiol (EE_2) using ultra-performance liquid chromatography-tandem mass spectrophotometry (UPLC-MS/MS). This was followed by a scenario based health risk assessment to assess the carcinogenic and toxic human health risks associated with the consumption of distribution point water. None of the water extracts from the distribution points were above the detection limit in the YES bioassay, but the EEq values ranged from 0.002 to 0.114 ng/L using the T47D-KBluc bioassay. BPA, DEHA, DBP, DEHP, DINP E_1, E_2, and EE_2 were detected in distribution point water samples. NP was below the detection limit for all the samples. The estrogenic activity and levels of target chemicals were comparable to the levels found in other countries. Overall the health risk assessment revealed acceptable health and carcinogenic risks associated with the consumption of distribution point water.

1. Introduction

The demand for the supply of clean water is increasing due to the continuing human population growth (Loos et al., 2007). However, population growth and urbanization is associated with a reduction in water quality with industrial and agricultural activities

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Abbreviations

ADD	Average daily dose
β	Oral potency factor
BPA	Bisphenol A
BW	Body weight
C_{medium}	Concentration of substance in water
CPRG	Chlorophenol red-β-D-galactopyranoside
DBP	Dibutyl phthalate
dBPA	Deuterated BPA
DCM	Dichloromethane
DEHA	Di(2-ethylhexyl) adipate
DEHP	Di(2-ethylhexyl) phthalate
DiNP	Diisononyl phthalate
dl	Detection limit
E_1	Estrone
E_2	17β-Estradiol
ED	Exposure duration
EDCs	Endocrine disrupting chemicals
EE_2	Ethynylestradiol
EEq	Estradiol equivalents
FBS	Fetal bovine serum
HQ	Hazard quotient
IR	Daily intake rate
LADD	Lifetime average daily dose
Lft	Lifetime
loq	Level of quantification
MtBE	Methyl tertiarybutyl ether
NP	Nonylphenol
PBS	Phosphate buffered saline
PVC	Polyvinyl chloride
RfD	Reference dose
SPE	Solid phase extraction
UPLC-MS/MS	Ultra-performance liquid chromatography-tandem mass spectrophotometry
USEPA	United States Environmental Protection Agency
WHO	World Health Organization
YES	Yeast estrogen screen

contributing to the contamination of water sources (Guillette and Crain, 2000; Sumpter, 2005; Falconer et al., 2006). Some of these contaminants are endocrine disruptors that have the potential to cause adverse health effects in humans.

Endocrine disrupting chemicals (EDCs) can enter the aquatic environment via direct discharge into water, effluents from sewage treatment plants, leaching (e.g. leakage from septic tanks and landfill sites), storm water runoff and accidental spills (Slabbert et al., 2008; Burkhardt-Holm, 2010). Many environmental EDCs are estrogenic and estrogenic activity was found at varying concentrations in raw and treated water in various countries, including South Africa (Slabbert et al., 2008; Burkhardt-Holm, 2010; Genthe et al., 2010; Manickum and John, 2014). Natural and synthetic estrogens, bisphenol-A (BPA), nonylphenol (NP) and short chain phthalates are some of the substances that contribute to the estrogenic load in water bodies and may cause adverse effects in aquatic organisms (Kunz et al., 2015).

Natural hormones, including estrogens, can be released into the environment via sewage effluent and from such sources such as agricultural and pharmaceutical activities (Falconer et al., 2006; Slabbert et al., 2008; Burkhardt-Holm, 2010). Estrogenic potencies of natural and synthetic estrogens are three to seven orders of magnitude greater than the potencies of other EDCs, making them the major contributor to estrogenic activity in environmental water (Desbrow et al., 1998; Tanaka et al., 2001; Nakada et al., 2004; Racz and Goel, 2010). Although natural estrogens are essential for normal development and reproduction, natural and synthetic estrogens are also known human carcinogens (Metzler et al., 1998).

BPA may be present in some plastics, polyvinyl chloride (PVC) products and thermal receipts (Biederman et al., 2010; Rochester, 2013). These products are often disposed of in landfill sites. Compounds, like BPA, can enter waterways through leachate from landfill sites (Kawagoshi et al., 2003). BPA exposure is associated with adverse reproductive and developmental effects, metabolic disease, disruption of thyroid function and immune disorders (Rochester, 2013). NP is used in the manufacturing of industrial and household surfactants and plastics. It is introduced to the environment mainly through industrial effluents and wastewater discharges (Loyo-Rosales et al., 2004; Burkhardt-Holm, 2010). In addition to the steroid hormones, NP may contribute substantially to the estrogenic activity in aquatic environments (Ternes et al., 1999b; Johnson et al., 2005; Galli and Braun, 2008). The endocrine disruptive effects of NP include feminization of aquatic organisms and decreased male fertility (Soares et al., 2008).

Phthalates are used as plasticisers in PVC plastics and are found in numerous consumer products. Phthalates are not covalently bonded to the plastics in which they are used, and are therefore continuously being released from the products (Heudorf et al., 2007). Contamination of waterways may therefore be through leachate from landfill sites (Burkhardt-Holm, 2010). Phthalates are associated with increased adiposity and insulin resistance (Grun and Blumberg, 2009), decreased levels of sex hormones (Pan et al., 2006) and other adverse effects on the human reproductive system (Hauser and Calafat, 2005; Sax, 2010) as well as attention deficit hyperactivity disorder and reduced IQ scores in children (Cho et al., 2010). Di(2-ethylhexyl) adipate (DEHA) is used as an alternative to phthalates in flexible PVC products (Ghisari and Bonefeld-Jorgensen, 2009) and has been classified by the United States Environmental Protection Agency (USEPA) as a possible human carcinogen (USEPA, 1992).

EDCs can potentially be found in drinking water if drinking water treatment processes are not effectively removing these environmental water contaminants from the source water. Water treatment process technology differs at different water treatment plants and various steps in the water treatment process can remove estrogenic activity to some degree (Slabbert et al., 2008; Burkhardt-Holm, 2010). Treatment options to remove EDCs include separation processes, adsorption and biological and chemical conversion (Chang et al., 2009). Each treatment method has its own limitations and benefits to remove EDCs. Although water treatment processes can be effective in removing EDCs from drinking water, chemicals might also migrate from the water lines/pipes that transport water to distribution points and to the home, thereby adding to the contamination of the drinking water. NP, phthalate esters and BPA can migrate from reservoirs and pipes containing polyethylene plastic, epoxy resins or paints (Romero et al., 2002; Casajuana and Lacorte, 2003).

Limited information is available on estrogenic activity and levels of EDCs in drinking water from South Africa. This study investigated the estrogenic activity in drinking water from various distribution points in Pretoria (City of Tshwane) and Cape Town, South Africa. The drinking water samples were also analysed for selected target