WATER RESEARCH XXX (2014) 1–13

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/watres

Emerging contaminants in urban groundwater sources in Africa

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ARTICLE INFO

Article history:
Received 30 May 2014
Received in revised form
11 July 2014
Accepted 1 August 2014
Available online xxx

Keywords:
Emerging contaminants
Groundwater
Africa
DEET
Vulnerability
Urban tracer

ABSTRACT

The occurrence of emerging organic contaminants within the aquatic environment in Africa is currently unknown. This study provides early insights by characterising a broad range of emerging organic contaminants (*n* > 1000) in groundwater sources in Kabwe, Zambia. Groundwater samples were obtained during both the dry and wet seasons from a selection of deep boreholes and shallow wells completed within the bedrock and overlying superficial aquifers, respectively. Groundwater sources were distributed across the city to encompass peri-urban, lower cost housing, higher cost housing, and industrial land uses. The insect repellent DEET was ubiquitous within groundwater at concentrations up to 1.8 μg/L. Other compounds (*n* = 26) were detected in less than 15% of the sources and included the bactericide triclosan (up to 0.03 μg/L), chlorination by-products – trihalomethanes (up to 50 μg/L), and the surfactant 2,4,7,9-tetramethyl-5-decyne-4,7-diol (up to 0.6 μg/L). Emerging contaminants were most prevalent in shallow wells sited in low cost housing areas. This is attributed to localised vulnerability associated with inadequate well protection, sanitation, and household waste disposal. The five-fold increase in median DEET concentration following the onset of the seasonal rains highlights that more mobile compounds can rapidly migrate from the surface to the aquifer suggesting the aquifer is more vulnerable than previously considered. Furthermore it suggests DEET is potentially useful as a wastewater tracer in Africa. There was a general absence of personal care products, life-style compounds, and pharmaceuticals which are commonly detected in the aquatic environment in the developed world. This perhaps reflects some degree of attenuation within the subsurface, but could also be a result of the current limited use of products containing emerging contaminants by locals due to unaffordability and unavailability. As development and population increases in Africa, it is likely a wider-range of emerging contaminants will be released into the environment.

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http://dx.doi.org/10.1016/j.watres.2014.08.002
0043-1354/© 2014 Published by Elsevier Ltd.

1. Introduction

Organic compounds previously not known to be significant in freshwater, in terms of distribution and/or concentration, are now being more widely detected as analytical techniques improve (Farré et al., 2012). These compounds, which have the potential to cause known or suspected adverse ecological or human health effects, are often collectively referred to as emerging contaminants (ECs). ECs include newly synthesised substances as well as ones that have long been present in the environment but whose presence and significance are only now being elucidated (Daughton, 2004). They include a wide array of different compounds and their transformation products: pharmaceuticals, personal care products, pesticides, veterinary products, industrial compounds/by-products, food additives, and engineered nano-materials (Murray et al., 2010; Pal et al., 2010; Schriks et al., 2010; Hughes et al., 2012; Lapworth et al., 2012; Postigo and Barceló, 2014).

ECs are also increasingly being used as environmental tracers for characterising sources and processes which may be controlling the occurrence, transport and fate of contaminants in the subsurface (e.g. Glassmeyer et al., 2005; Stuart et al., 2014). When used in combination with groundwater residence time tracers, such as chlorofluorocarbons (CFCs) or sulphur hexafluoride (SF_6), these could be powerful techniques for understanding contaminant processes and groundwater vulnerability.

In Africa, there is an increasing use of synthetic organic compounds in the domestic context, within agriculture and industry, as well as the growing concern of exported toxic wastes to Africa from richer countries (Breivik et al., 2011). Together, these pose a potential threat to surface and groundwater quality across this region. In urban settings, these risks are likely to be most significant, due to the higher density of contaminant sources, issues of contaminant legacy and a greater concentration of anthropogenic activity. Specifically, wastewaters are likely to be a major threat to freshwater resources, as they may contain pharmaceuticals, household detergents, fragrances, flavourings, and plant and animals steroids (Ellis, 2006; Watkinson et al., 2009; Verlicchi et al., 2010). Moreover, 70% of the total urban population in many large African cities is estimated to be unconnected to a reticulated sewerage system and 80% of wastewater is discharged untreated to surface waters or the soil (Nyenje et al., 2010). Therefore, potential threats from wastewaters are enhanced in comparison to areas with more advanced water and sanitation infrastructure.

There are growing demands for freshwater sources in Africa, with groundwater continuing to form a critical component across the continent (Adelana et al., 2008; MacDonald et al., 2012). Shallow groundwater sources are particularly important as local sources of drinking water, but are also potentially very vulnerable to anthropogenic contamination (Howard et al., 2003; Cronin et al., 2006; Nkhuwa et al., 2006; Kulabako et al., 2007; Hunter et al., 2010). There is a need to understand all potential risks to groundwater resources, including understanding the occurrence and sources of ECs.

A handful of studies have characterised pesticide contamination in Africa (e.g. Karlsson et al., 2000; Schulz, 2003). There has also been a focus on the distribution of phthalates within freshwater in South Africa (Mahomed et al., 2008; Aneck-Hahn et al., 2009; Fatoki et al., 2010) and a study demonstrating elevated polybrominated diphenyl ethers and other flame retardants in rainfall samples in East Africa (Arinaitwe et al., 2014). Lin et al. (2013) recently characterised a broad range of volatile organic compounds from pit latrines in Africa. There are no studies that have investigated many other ECs in groundwater, or indeed anywhere in the aquatic environment.

This is the first study to characterise the occurrence of a broad range of ECs ($n > 1000$) in African groundwater. The objectives are to: i) quantify the occurrence of ECs in groundwater sources in urban and peri-urban settings, ii) compare contamination in shallow sources against deep bedrock sources, iii) assess temporal variations in ECs between dry and wet seasons, iv) evaluate relationships between occurrence, land use and localised contaminant risk factors, v) understand the vulnerability of groundwater using ECs in conjunction with residence time indicators and in-situ electrical conductivity data.

2. Materials and methods

2.1. Study site

Kabwe is located on a plateau in Central Province, Zambia, about 150 km north of the capital Lusaka. The city was once the centre for Zambian lead and zinc production, which flourished during the twentieth century before the mine closure in 1994. However, sadly, the historic unregulated mining and smelting has left a legacy of heavy metal contamination (Tembo et al., 2006). The large exposed tailings piles remaining in proximity to the old mine workings are a continued source of contamination through weathering and erosion. Consequently, the city is labelled as one of the 10 most polluted places on Earth (Blacksmith Institute, 2013).

Kabwe is the provincial headquarters of Zambia's Central Province with a population of over 200,000. The central business district is encircled by higher cost housing areas, with a transition towards lower cost housing towards the periphery. The outermost limits of the city are ringed by informal settlements, such as Makululu which is home to almost 25% of the population (LgWSC, 2014). Since the mine closure, the main industries have included medical consumables, brewing, textiles, and leather tanning. Small-scale farming persists within peri-urban areas. Waste collection and disposal to the city landfill is uncommon beyond larger businesses in the town centre. Household waste is typically buried within the grounds of each property, burned, or dumped illegally in open areas.

The city is mostly underlain by the Precambrian metasedimentary Lower and Upper Roan Groups, which unconformably overlie granitic gneiss of the Basement Complex (Fig. S1). The Lower Roan Group consists of basal units of arkose and quartzite, totalling up to 700 m thick, succeeded by predominantly phyllite. The Upper Roan Group is locally known as the Kabwe Dolomite Formation and comprises a massive, light grey dolomite up to 870 m thick, with high degrees of lithological variation (Kamona and Friedrich, 2007).

Please cite this article in press as: Sorensen, J.P.R., et al., Emerging contaminants in urban groundwater sources in Africa, Water Research (2014), http://dx.doi.org/10.1016/j.watres.2014.08.002