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Field investigation of the quality of fresh and aged leachates from selected landfills receiving e-waste in an arid climate

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ABSTRACT

The management of electronic waste (e-waste) is a serious problem worldwide and much of it is landfilled. A survey of four selected landfills in an arid region of South Australia was conducted to determine the proportion of e-waste in municipal waste and the properties of each landfill site. Leachate and groundwater samples were collected upgradient and downgradient of the landfills for analysis of polybrominated diphenyl ethers (PBDEs) and 14 metals and metalloids, including Al, As, Ba, Be, Cd, Co, Cr, Cu, Fe, Ni, Pb, Sb, V and Zn. Our data demonstrate that the selected landfills in South Australia continue to receive municipal waste containing in excess of 6%, or 25,000 tonnes per year, of e-waste. The leachates and groundwater collected from the landfills contained significantly elevated concentrations of Pb with the highest concentration in groundwater of 38 μg/l, almost four times higher than the Australian drinking water guideline of 10 μg/l. The presence of PBDEs was detected in both leachate and groundwater samples. Total PBDEs values of 2.13–59.75 ng/l in leachate samples were 10 times higher than in groundwater samples, which recorded a range of 0.41–6.53 ng/l at all sites. Moreover, the concentrations of metals and metalloids in sampled groundwater contained elevated levels of Al, As, Fe, Ni and Pb that exceeded Australian drinking water guideline values. For these reasons potential leaching of these contaminants is of concern and while difficult to attribute elevated contaminant levels to e-waste, we do not recommend continued disposal of e-waste in old landfills that were not originally designed to contain leachates. The survey also revealed temporal variation in the electrical conductivity and concentrations of As, Cd and Pb present in leachates of landfills in arid Mediterranean climates. These results are consistent with the marked variations in rainfall patterns observed for such climates. The solute concentration (EC and other ions including As, Cd and Pb) declines in the leachates during wet winter months (June to September), in contrast to tropical countries where such changes are observed during wet summer months.

1. Introduction

Electronic waste (e-waste) has become the fastest-growing stream of all waste types and its management and safe disposal are serious issues worldwide (Kiddee et al., 2013a). The proliferation of 'smart' devices, new designs and innovative technology in the electronics sector are all causing the early obsolescence of many electronic products. The lifespan of several electronic goods has been substantially reduced due to advanced electronics, attractive designs and compatibility issues. For example, the average lifespan of a new model of computer has decreased from 4 to 6 years in 1997 to an estimated 2 years in 2005, and is further rapidly decreasing (Widmer et al., 2005). The disposal of innumerable analogue appliances is also posing a major challenge worldwide.

Australia is one of the top ten countries in terms of the utilisation of information and communication technology (Ongondo et al., 2011). It ranks tenth and fifth in the world for spending per capita and spending as a percentage of GDP, respectively (Department of Communications Information Technology and the Arts, 2002). This leads to vast amounts of e-waste which are growing at over three times the rate of general municipal solid waste production (Australian Bureau of Statistics, 2006). Most e-waste is disposed in landfills. In 2008, 16.8 million obsolete televisions and computers were discarded and sent to landfill (Department of the Environment Water Heritage and the Arts, 2009). Of the total

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e-waste generated, 84% (by weight) of e-waste was landfilled whereas only 10% was recycled. The remaining 6% of the e-waste was exported to developing countries. E-waste is predicted to reach 44 million items or 181,000 tonnes per year by 2027/28 (Environment Protection and Heritage Council, 2009).

Disposal of increasing quantities of e-waste to landfills is a major problem because such wastes have been shown to contain significant quantities of toxic materials (Townsend et al., 2005). There have been a number of studies to investigate the leachability of the components that comprise e-waste in both actual and simulated landfills and laboratory tests. These show that the concentrations of lead (Pb) in landfills were lower than Toxicity Characterisation Leaching Procedure (TCLP) set by USEPA. Using column studies simulating landfills containing e-waste, Spalvins et al. (2008) studied the release and movement of Pb from e-waste. They found soluble Pb ranging in concentration from 7 to 66 μg/l in the leachates compared with the column without e-waste, in which leachate Pb ranged from <2 to 54 μg/l. A similar study conducted by Kiddee et al. (2013b) found that the average concentrations of Al, Ba, Be, Cd, Co, Cr, Cu, Ni, Pb, Sb and V in leachates from the column that contained broken e-waste items were significantly higher than in the column without e-waste, but the average of total polybrominated diphenyl ether (PBDE) levels in columns that contained intact e-waste were not significantly higher than that in the leachates from the control column. Many researches showed that disposal of e-waste in landfills had greater concentration of toxicity than landfill without e-waste (Kiddee et al., 2013b; Spalvins et al., 2008). Several researchers have demonstrated that toxic metals and polyhalogenated organics, including PBDEs, can be released from e-waste which if released into the environment could pose serious risks to the environment and to human health (Czuczwa and Hites, 1984; Robinson, 2009).

The presence of toxic substances in landfill leachates is exacerbated especially with old landfills that were not originally designed to receive e-waste and do not have appropriate liners or barriers to prevent leakage of leachates. This is a global problem in both industrialised and developing countries given the presence of many landfills that were created at a time when environmental legislations were in their infancy. In Australia, however, there is now legislation for modern engineered landfills that include appropriate liners. If improperly managed, these landfill leachates can cause considerable pollution problems to the surrounding soil, surface or groundwater and therefore they are considered major pollution hazards unless precautionary measures are implemented (Baccini et al., 1987). The leachate problem is further aggravated given that many old landfills are still operating without an effective collection and treatment system (Tatsi and Zouboulis, 2002). Therefore, continued disposal of wastes into old landfills poses significant risk to both environmental and human health. This is also a challenging problem in developing countries that lack policy guidance and sufficient financial backing to develop modern engineered landfills.

E-waste has been reported to contribute approximately 70% of the heavy metals detected in leachates (Grossman, 2006), and it also constitutes up to 30% of PBDEs (Danon-Schaffer et al., 2006). In older landfills in South Australia, the leaching process includes percolation of rainwater through the topsoil and from this into domestic waste mixed with e-waste containing toxic substances such as heavy metals and PBDEs. Many old landfills were designed prior to recognising that contaminants can leach from the collected waste and potentially migrate into the subsurface. This is a global problem particularly with landfills subjected to a Mediterranean climatic regime where rainfall is slow and persistent. Given such a rainfall pattern, percolation of water down the landfill profile can be much more effective resulting in significant movement of leachates into the subsurface environment (Abu-Rukah and Al-Kofahi, 2001). In their study, Naidu et al. (1993) used a number of field lysimeters in South Australia to demonstrate a high degree of percolation of surface water during the wet winter months when rainfall was slow and persistent under the prevailing Mediterranean climate. The investigators found significant levels of dissolved organic carbon and, associated with these, soluble metals as metal–organic complexes mobile in the subsurface water. Although a number of studies have been conducted in developed countries with different rainfall patterns and climatic regimes (for example Tsarpali et al., 2012 and references there in), there is a general lack of information on landfills in countries experiencing an arid Mediterranean climatic regime. In our study, we investigated the composition of fresh and aged landfill leachates subjected to the arid climate of South Australia to determine if waste disposal to landfills may lead to contamination of the groundwater.

2. Materials and methods

2.1. Landfill site selection

A survey to determine the characteristics of landfills was conducted by sending a questionnaire to 13 landfill site operators around South Australia. The questionnaire focused on the major sources of waste, landfill operations, operating conditions, disposal processes, whether the landfill receives e-waste, and whether leachate treatment and liner protection are in place. On the basis of the responses, four landfills in the Adelaide metropolitan area were selected. Of these, three are major landfills (sites A, B and D) (Government of South Australia, 1999) with the fourth being a small landfill (site C) used to dispose municipal solid waste (MSW) from residential parts of Adelaide. All sites are active landfills that have operated since the early 2000s, except for site C, which has operated since the 1990s.

The major sources of waste, landfill operations, leachate treatments and liner protection for the four landfills was obtained from the survey responses received from the 13 landfill site operators (Table 1). Three of the sites (A, B, and D) received most of their waste from residential areas, whereas site C received waste mainly from commercial and industrial sources. However, all four landfill sites receive e-waste. All sites have a leachate treatment system based on oxidation ponds, and all have liners to prevent leachate leakage from the pond.

2.2. Municipal solid waste components in landfills

The ASTM International (formerly known as the American Society for Testing and Materials) method was used for solid waste component analysis (ASTM International, 2008). Replicate samples of MSW were collected at each of the three landfill sites A, B and D. The waste was collected at transfer stations at each landfill site where MSW is delivered from kerbside collection trucks and baled or directly reloaded to a larger truck for transport to the landfill site. A series of random samples were collected between May and August 2010. MSW components were classified into 13 categories: paper, glass, plastics, metals, food wastes, wood, garden wastes, textiles, leather, tyres and rubber, e-waste, and construction and demolition waste. Sampling was not possible at site C, which is an old quarry with a deep pit and a high slope with no transfer station.

2.3. Leachate and groundwater sampling

Field sampling was conducted at the four selected landfills. Leachates and groundwater samples upgradient and downgradient