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Leachates draining from controlled municipal solid waste landfill: Detailed geochemical characterization and toxicity tests

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ABSTRACT

Management of municipal solid wastes in many countries consists of waste disposal into landfill without treatment or selective collection of solid waste fractions including plastics, paper, glass, metals, electronic waste, and organic fraction leading to the unsolved problem of contamination of numerous ecosystems such as air, soil, surface, and ground water. Knowledge of leachate composition is critical in risk assessment of long-term impact of landfills on human health and the environment as well as for prevention of negative outcomes. The research presented in this paper investigates the seasonal variation of draining leachate composition and resulting toxicity as well as the contamination status of soil/sediment from lagoon basins receiving leachates from landfill in Mpasa, a suburb of Kinshasa in the Democratic Republic of the Congo. Samples were collected during the dry and rainy seasons and analyzed for pH, electrical conductivity, dissolved oxygen, soluble ions, toxic metals, and were then subjected to toxicity tests. Results highlight the significant seasonal difference in leachate physicochemical composition. Affected soil/sediment showed higher values for toxic metals than leachates, indicating the possibility of using lagoon system for the purification of landfill leachates, especially for organic matter and heavy metal sedimentation. However, the ecotoxicity tests demonstrated that leachates are still a significant source of toxicity for terrestrial and benthic organisms. Therefore, landfill leachates should not be discarded into the environment (soil or surface water) without prior treatment. Interest in the use of macrophytes in lagoon system is growing and toxic metal retention in lagoon basin receiving systems needs to be fully investigated in the future. This study presents useful tools for evaluating landfill leachate quality and risk in lagoon systems which can be applied to similar environmental compartments.

1. Introduction

Management of municipal solid waste (MSW) is a problem in many parts of the world and can pose risks to human health and the environment in both industrialized and developing countries. In many countries landfills are considered to be disposal sites for solid and liquid wastes from municipal refuse collection, commercial activities, hospitals, hazardous mining, energy generation residues, and industry (Augustin and Viero, 2012; Cutruneo et al., 2014; Wijesekara et al., 2014). Consequently, landfill leachates may contain several types of contaminants including toxic metals, persistent organic pollutants, pathogenic organisms, and pharmaceutical drugs which can cause major environmental concerns and risks to human health (Kjeldsen et al., 2002; Huang et al., 2009).

Uncontrolled urban landfills, hospital effluents, and urban run-off in most developing countries represent a significant source of toxic elements in the aquatic environment because the effluents are discharged into drainage systems, rivers, and lakes without prior treatment and then accumulate in sediments, which can have serious environmental effects and threaten human health (Pritchard et al., 2008; Mubedi et al., 2013; Atibu et al., 2013;

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Mwanamoki et al., 2015). The main risk is posed by accumulation of toxic substances in soils, input into surface water by runoff, accumulating in sediment receiving systems and living organisms as well as infiltrating into groundwater followed by remobilization of the contaminants and their return to the food chain (Wildi et al., 2004; Poté et al., 2008; Ngelinkoto et al., 2014). One way of preventing the potential risks of landfill to the surrounding environment is to practice selective collection of the different fractions of urban solid wastes such as plastics, paper, glass, metals, electronic wastes, and organic fraction favoring reuse of recycled materials from the different fractions and only disposing of unrecycled materials in landfill. Therefore, as receiving systems are affected by contaminated leachates, analyses of contaminants such as toxic hazardous elements as well as sediment toxicity are important for understanding and prevention of further risks (Kjeldsen et al., 2002; Mantis et al., 2005; Melnyk et al., 2014).

Kinshasa is the capital and largest city of the Democratic Republic of the Congo (DRC) and has an estimated population of more than 10 million. In the two decades up to the time of writing the largest cities in the DRC have been characterized by rapid increases in urbanization and industrialization which constitute the greatest problem of environmental compartment pollution by toxic metals and pathogenic organisms (Mwanamoki et al., 2014a,b, 2015). Municipal and industrial waste management systems are very limited and it is very difficult to estimate what exactly the waste production rate is. MSW production rate is variously estimated at 0.5–1 kg/person/day depending on the standard of living (Parau, 2015). Public spaces and urban rivers are customarily considered as possible landfill sites (Mwanamoki et al., 2015; Tshibanda et al., 2014). Moreover, there is a controlled municipal landfill in Mpasa which has been in operation since the year 2010.

Little information is available on the assessment of contaminants or about ecotoxicological aspects of landfill leachates in receiving systems in developing countries (under tropical conditions). Consequently, there is little data regarding the characterization of both leachates and soil/sediment from lagoon basins receiving draining leachates under tropical condition in developing countries. The aim of the research presented in this paper was to assess the quality of leachates draining from the Mpasa landfill and stored in the receiving system (lagoon basins receiving draining leachates). The assessment is based on (i) the physicochemical characterization of leachates including pH, electrical conductivity, dissolved oxygen, soluble ions, and toxic metal content (Cr, Co, Ni, Cu, Zn, As, Cd, Pb) according to seasonal variation, (ii) evaluation of the pollution status of soil/sediment from lagoon basins by determination of enrichment factor (EF) and the geoaccumulation index (*Igeo*), and (iii) leachate and soil/sediment ecotoxicological analysis in order to evaluate potential environmental risks.

2. Materials and methods

2.1. Study site description

The Mpasa landfill (named CET) is an exceptional active and controlled landfill site in Kinshasa City (capital of the Democratic Republic of Congo) which mainly serves 9 of the 24 communes (municipalities) of Kinshasa. The landfill activity started in May 2010. The CET is located about 35 km from Kinshasa city center (Latitude 4°22′04″ South-west and Longitude 15°32′08″) and extends over an area of 135 ha of which 50 ha have been used to date. The site has a capacity of 7,000,000 m^3 for disposal of domestic and commercial waste at an average of 420,000 tons per year (Parau, 2015). The landfill is composed of inverted trapezoidal compartments (30 m high base, 14 m small base which forms the bottom, 4 m deep) and each is composed of a sloping bottom with PVC pipes perforated to drain fluid from the percolation of rainwater through the mass of garbage and inclined walls covered with geomembrane (plastic film) (Fig. 1). The polyethylene pipes in the draining system leachate collection have a diameter of 110 mm with a flow rate of 7.2 m^3/day in the rainy season. The landfill leachates are collected via a draining system and stored in three lagoon basins (receiving system) interconnected by pipes. The leachate residence time is 50 days for the first lagoon basin and 40 days for the second and third. No appropriate treatment is performed for leachate from landfill. Lastly, there is an experimentation using macrophytes planted in the second and third lagoon basins for possible metal bioaccumulation (Fig. 2A). However to date no result is available from this experimentation.

2.2. Landfill leachates and soil/sediment collection

Leachate and soil/sediment samples were collected between May and August 2014 (dry season) and from January to April 2015 (rainy season) with leachates being collected during each season from: (i) B0 (n = 3): directly from the outlet pipe discharge into the first basin; (ii) B1 (n = 9): basin-1, surface area of 1080.86 m^2 (water depth 1 m maximum during the dry season sample collection); (iii) B2 (n = 9): basin-2, surface area 504.40 m^2, water depth 0.5 m; and (iv) B3 (n = 9): basin-3, surface area 541.61 m^2, water depth 0.5 m. The frequency of leachate sampling from each basin was three times per month/season, that is, at the beginning (first week), in the middle (at the end of second week), and during the last week of each month. The sediment samples labeled AS1 (n = 9), AS2 (n = 4), and AS3 (n = 4) were respectively collected manually (Fig. 2B) from basins B1, B2, and B3. The number of samples collected from lagoon basins was determined according to the dimension and form of lagoon basin (Fig. 1). Water and sediment were sampled from the same points. Water samples (250 mL sealed in sterile plastic bottles) were triplicated from each sampling point, and retrieved at 10–50 cm water depth and a maximum of 1 m from the shore. Approximately 100–250 gr of sediment were also taken from each point in triplicate. The soil sampling point ES1 located outside the landfill was used as control as it has no contact with waste and landfill leachates. Samples were collected in triplicate and the sampling distance between each replicate in the lagoon basins was approximately 15 cm.

Once collected, samples were stored at 4 °C and transported to the analytical platform of the University of Geneva for analysis within 72 h.

2.3. Leachate physicochemical analysis

Physicochemical parameters of leachates including temperature (T), pH, dissolved oxygen (O_2) and electrical conductivity (EC) were measured *in situ* using a Multi 350i (WTW, Germany). The dissolved organic carbon (DOC) and total organic carbon (TOC) measurements were performed using Shimadzu High Temperature Total Organic Carbon Analyser (5000 GmbH, Switzerland) on acidified samples (200 μL of 2 M HCl in 30 mL samples). The concentration of dissolved ions, cations (Na^+, K^+, Mg^{2+}, Ca^{2+}) and anions (Cl^-, SO_4^{2-}, NO_3^-, NO_2^-) was measured using Ion Chromatography (Dionex ICS-3000, Canada) according to the method described by Graham et al. (2014). The reference material (certified water CRM, Ontario-99) from the National Water Research Institute, Canada was used to verify the accuracy of the instrument. All CRM results were within the acceptance range on the CRM certificate.