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Insights for transformation of contaminants in leachate at a tropical landfill dominated by natural attenuation

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ABSTRACT

The purpose of this study was to track the long-term trends of contaminants distribution in the old landfill of Singapore through monitored natural attenuation and to explore the main parameters that rule such transition. Contaminants distribution, including dissolved organic matter (DOM), inorganic species, heavy metals, and organic compounds, was investigated via monitoring wells in the years 1997, 2004 and 2011. The data revealed that the distribution of contaminants possessed selective attention of spots associated with leachate movement. The hydrogeology of the landfill governed the fate and transportation of contaminants. More specifically, strong statistical correlations were identified between DOM and certain constituents in the leachate, suggesting enhanced mobilization potential. However, the leachate composition exhibited limited correspondence to the nearby solid waste, indicating the minor effect induced by the partitioning coefficient. The presence of sulphate unveiled air intrusion, suggesting increased stability of the landfill, where enhanced biodegradation occurred at earlier period responsible for higher BOD removal. Afterwards other parameters continued to facilitate the compounds removal resulting in overall low concentrations of the contaminants.

1. Introduction

Landfilling is still one of the popular approaches for solid waste disposal among many developing regions and countries. Concurrently, old landfills worldwide present several environmental concerns with their status of post-closure, as they frequently incorporate little engineering design to better isolate the waste from the surrounding environment. Even in many landfills designed with protection layers, uncontrolled leachate and gas may be released due to defects of the aged liner system (Tong et al., 2015). Landfill leachate may contain a variety of pollutants, such as humic acids and heavy metals, etc., which may adversely affect groundwater and surface water quality (Kjeldsen et al., 2002; Regadío et al., 2013). The landfill biogas, mainly comprised of CH_4, CO_2 and some non-methane organic carbon, could result in unpleasant odor, explosion, global warming and deleterious health effects (Barlaz et al., 2002). Herein counteraction measures, such as *in-situ* aeration, reactive barriers, pump and treat, advanced oxidation processes, innovative landfill bioreactor by leachate circulation and the placement of hygienic facilities, and facilitating biodegradation and isolation, are taken to minimize the negative impacts (Bilgili et al., 2007; Jun et al., 2009; Kurniawan et al., 2006; Pleasant et al., 2014; Tigini et al., 2014). However, landfill aftercare, under certain criteria, requires completion times of up to decades or even centuries (Stegmann et al., 2003; Wang et al., 2012).

The long-lasting stabilization period for the landfill is mainly associated with the heterogeneity of waste composition, the slow anaerobic processes as well as potential constrains from the site-specific conditions e.g. the moisture content, the climate and original soil properties in the site etc. (Barlaz et al., 2002). To obtain information in old landfills, monitored natural attenuation (MNA) may be performed at an affordable cost (Baun et al., 2003; Dong et al., 2015; Youcai et al., 2000). MNA relies on the natural processes to attenuate the contaminants. Landfill monitoring is performed for several groups of pollutants, i.e. dissolved organic matter, inorganic macrocomponents, heavy metals, and xenobiotic organic compounds (Baun et al., 2003; Sizirici and Tansel, 2015). Albeit the rapid growth of available information on attenuation processes (Christensen et al., 1994), the database based on Long-term monitoring and the constant recording remains limited, as natural attenuation processes are complicated by the large degree of heterogeneity and long lifetime of a landfill as a source for

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pollution. Researchers have proposed several indicators suggesting the completion of post-closure monitoring period and safe release of the landfill site, for instance the typical parameters such as leachate BOD/COD ratio and total organic carbon on solid sample. However, there are no established standards to define whether the landfill is safe (Barlaz et al., 2002; Pohland and Harper, 1985; Prantl et al., 2006; Reinhart and Grosh, 1998; Wimmer et al., 2013).

In this study, the natural attenuation of Long Halus Dumping Ground (LHDG-Phase III) in Singapore was monitored for the years 1997, 2004 and 2011. Evaluation on the transitional distribution of contaminants was made in the specific timeframe. A comparative examination was conducted to understand the natural attenuation with respect to investigated parameters. This understanding is valuable because it may be used to (1) identify the stability of the landfill, (2) locate the parameters affecting the landfill behavior, (3) investigate the ruling mechanisms behind parameters, and lastly (4) evaluate the landfill post-closure strategy in the context of long-term effects, both qualitatively and quantitatively.

2. Methodology

2.1. Background

The LHDG used to be the largest landfill in Singapore and was operated between the early 1970s and later 1990s. Previously known as the Tampines dumping grounds, it occupies some 230 ha of land in northeastern Singapore, flanking both sides of the Tampines Expressway. It has been divided into several distinct phases to receive wastes at different period of time. The key features of the LHDG such as the landfill type, landfill age, the phase area and waste quantity can be found in Table S1. This study was focused on Lorong Halus Phase III (Fig. 1), which lies on the northeastern portion of LHDG landmarked by the Serangoon River and the Tampines expressway running along its northeastern boundary (Meinhardt, 2004).

The LHDG-Phase III was an uncontrolled dumping site operated from 1983 to 1989 with limited engineering designs and hygienic measures (Fig. 1). It was originally a mangrove swamp covering about 44 ha. The area climate is classified as tropical rainforest climate, with no true distinct seasons. Completion of the first government incinerator in 1979 resulted in gradual diversion of landfill wastes from municipal solid waste (MSW) to incineration ashes (IA). In addition the rapid economic growth since 1980s saw significant generation of construction and demolition (C&D) waste, meaning that the LHDG-Phase III actually received a mixture of untreated MSW together with IA and C&D waste during its operation period (Meinhardt, 2004; Montgomery Watson, 1997). Since closure, no significant reclamation activities have been conducted except 2–5 m soil cap. The leachate strength was found weak in LHDG-Phase III (Tables S1 and S2). COD values were low across the site well matching with the typical closed unsanitary landfill over two decades (Kang et al., 2002; Lo, 1996), while BOD/COD ratio was measured at less than 0.1 (Table S2), suggesting the stable methanogenic phase. As a factor most consistently is shown to affect the rate of refuse decomposition, high precipitation further enhanced the organic removal (Kjeldsen et al., 2002). Landfill gas extraction wells were constructed in 2002 for flaring of landfill gases. Previously running on a continuous basis, the extraction system is now operated intermittently as landfill gas production diminishes in tandem with the increasing age of the site.

2.2. Geotechnical characterization

Geotechnical works were conducted in 1996–1997, 2004 and 2011 (Fig. 1). In brief, five boreholes (MW23 through MW27) were drilled at LHDG-Phase III in October - November 1996 (Fugro Singapore Pte Ltd, Singapore). All borings were converted to combined leachate monitoring wells until 1997. Six geotechnical borings (MH16–MH21) were made in June to September 2004 at the same region (Setsco Services Pte Ltd, Singapore), whereas MH16 was later completed as the leachate monitoring well. In 2011, seven boreholes were further drilled to 30 m in depth at Phase III again. These were subsequently converted into monitoring wells R1 through R7 (Setsco Services Pte Ltd, Singapore) (Fig. 1).

Prior to commencement of drilling, a cable detector was used to verify that the location was clear of electrical cables and/or metallic pipes. A hand auger or trial pit was then used to drill the top 1 m to ensure the clearance of any underground services. Spiral auger drilling method was used to drill the 100 mm boreholes. All the drillings, solid waste sampling and loggings were done in accordance with BS5930 (Code of Practice for Site Investigations 1981 and 1999).

The land survey was conducted using a global positioning system/real time kinematic positioning (GPS/RTK) methodology. The indicative locations, elevation and termination depth of borings (monitoring wells) are presented in Table 1. Static water level measurements were performed with a water level meter and referenced to ground elevation.

2.3. Solid waste sampling and analysis

Solid waste samples were collected using either a standard penetration test (SPT) split spoon or 75 mm diameter Shelby Tube sampler. The samples were placed into laboratory-supplied wide-mouth glass sample containers and stored in an ice chest while on site and during transportation to the laboratory. Environmental testing was performed on solid waste samples according to

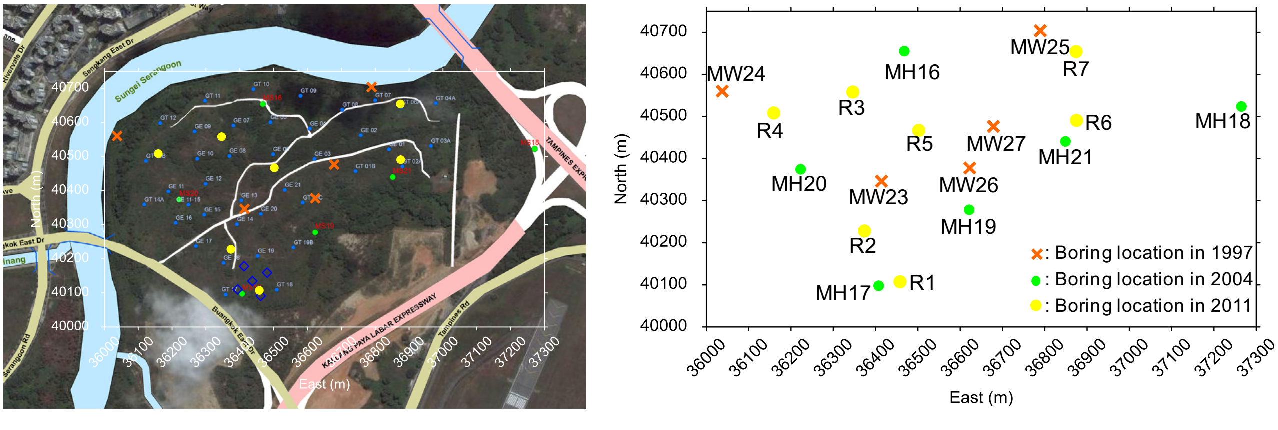

Fig. 1. Map and locations of boreholes and/or monitoring wells at LHDG-Phase III.

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