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Quantification of regional leachate variance from municipal solid waste landfills in China

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ABSTRACT

The quantity of leachate is crucial when assessing pollution emanating from municipal landfills. In most cases, existing leachate quantification measures only take into account one source – precipitation, which resulted in serious underestimation in China due to its waste properties: high moisture contents. To overcome this problem, a new estimation method was established considering two sources: (1) precipitation infiltrated throughout waste layers, which was simulated with the HELP model, (2) water squeezed out of the waste itself, which was theoretically calculated using actual data of Chinese waste. The two sources depended on climate conditions and waste characteristics, respectively, which both varied in different regions. In this study, 31 Chinese cities were investigated and classified into three geographic regions according to landfill leachate generation performance: northwestern China (China-NW) with semi-arid and temperate climate and waste moisture content of about 46.0%, northern China (China-N) with semi-humid and temperate climate and waste moisture content of about 58.2%, and southern China (China-S) with humid and sub-tropical/tropical climate and waste moisture content of about 58.2%. In China-NW, accumulated leachate amounts were very low and mainly the result of waste degradation, implying on-site spraying/irrigation or recirculation may be an economic approach to treatment. In China-N, water squeezed out of waste by compaction totaled 22–45% of overall leachate amounts in the first 40 years, so decreasing the initial moisture content of waste arriving at landfills could reduce leachate generation. In China-S, the leachate generated by infiltrated precipitation after HDPE geomembranes in top cover started failing, contributed more than 60% of the overall amounts over 100 years of landfilling. Therefore, the quality and placing of HDPE geomembranes in the top cover should be controlled strictly for the purpose of mitigation leachate generation.

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1. Introduction

Due to its economic advantages, landfilling is still the most dominant treatment method used worldwide for municipal solid waste (MSW), especially in developing countries such as China (National Bureau of Statistics of China, 2012). Leachate from MSW landfills is a threat to the quality of groundwater and surface waters (Kelly, 1976; Mor et al., 2006; Reinhard et al., 1984). Even though a series of leachate control systems may be installed in a landfill site, their performance is associated significantly with the amount of leachate generated, which is often underestimated in landfills in China (Lan et al., 2012) and results in an increased water head above the liner system, due to insufficient design capacities for collection and treatment. Subsequently, the high water level in a landfill body may lead potentially to leaching into the surrounding area and cause landfill instability. In addition, as the content of organic fractions in Chinese MSWs is usually high, the storage of water in a landfill may encourage the accumulation of acid and delay the arrival of the methanogenic phase, thereby making the landfill an “acid tomb” (He, 2009). In an “acid tomb”, decaying carbon in the waste is most likely to be transferred into leachate rather than released as landfill gas, which aggravates the pollution loads and limits the energy recovery potential. Therefore, it is important to establish a leachate quantification method suitable for MSW landfills in China, to be able to control landfill pollution.

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In addition to the control of leachate contamination, estimating landfill leachate quantities is also important in life cycle assessments (LCAs) of landfilling technology, as leachate is the origin of one of the most serious local environmental impacts. In LCA modelling for decision support, environmental impacts are normally modelled as the impact caused by one unit of waste (Banar et al., 2009; Cherubini et al., 2009; Hong et al., 2010), e.g. one tonne of waste or the waste generated in a defined geographical region in a given time (e.g. 1 year). This type of LCA modelling of landfill is often used for comparisons with other technologies (incineration, composting, etc.). However, existing methods in previous research (ElFadel et al., 1997) and in the Chinese national standards for landfill construction (Ministry of Housing and Urban-Rural Development of the People's Republic of China, 2013) were developed mainly to estimate leachate amounts generated from the entire landfill and with all the waste buried, in order to design leachate collection and treatment systems. In addition, most of the conventional LCA models (specific waste LCA models the exception (Gentil et al., 2010)) estimate the leachate quantities with default values without considering spatial and temporal variations. However, leachate generation amounts in different regions could vary a great deal, due to different climate conditions, waste properties.

Landfill leachate quantification is traditionally modelled based on water balance principles by summing the amounts of water entering the landfill and subtracting the amounts of water consumed by degradation and lost as water vapour (Blakey, 1992; ElFadel et al., 1997; Kjeldsen and Beaven, 2011). Accordingly, several mathematical models have been developed, in which Hydrologic Evaluation of Landfill Performance (HELP) model is most widely used for hydrological modelling of precipitation (Schroeder et al., 1994). The validation of existing HELP models were conducted for cover systems in tested field (Berger, 2015), which indicated that "the sum of measured lateral drainage and liner leakage is close to the sum of the corresponding simulated values" (overestimation by HELP model for 1.4% of the precipitation). However, the HELP model was questioned for leachate quantification in recent years because it neglected the water balance of waste, which was proved to be important processes during leachate generation. For instance, Komilis and Athiniotou (2014), Pantini et al. (2014) and Sao Mateus et al. (2012) established their own water budget models and demonstrated that water which leached out by waste compression and biodegradation contributed to the leachate amounts to a large extent. In China, researchers (Lan et al., 2012; Yang, 2012b) widely believed that the failure to include water leaching out from waste itself in the Chinese national standard (Ministry of Housing and Urban-Rural Development of the People's Republic of China, 2013) was the main reason for the underestimation of leachate generation amounts in landfills.

In this study, an estimation approach for leachate generation per tonne of waste landfilled in China is developed. The influences of waste properties, climate conditions and top cover types on leachate generation are investigated, and regional values are suggested accordingly. Finally, suggestions are provided, to mitigate the leachate amounts in different geographic regions of China.

2. Data sources and model assumptions

The water balance approach of a landfill used in this study is shown schematically in Fig. 1. Leachate generated from MSW landfills can be divided into two sources: (1) precipitation infiltrated throughout waste layers (PI), which occurs in all types of landfill and lasts for the whole lifetime of the landfill, and (2) water squeezed out of waste itself by gravity and compaction, as well as degradation (WS), which occurs in the landfills receiving dumped waste with a high moisture and organics content. It should be notice that although water storage occurred in a real landfill, it was not considered in our simulation, as it is just the temporary situation for leachate in a long time scale (e.g. 100 years in this study). The amount of leachate can be calculated using Eq. (1). More details for each of the two parts can be found in Sections 2.1 and 2.2.

$$L = \mathrm{PI} + \mathrm{WS} \tag{1}$$

where L is the sum total of leachate generation. L, PI and WS are leachate quantities in litres per tonne of landfilled waste wet weight, $\mathrm{L\,t^{-1}}$ ww.

In order to verify the reliability of the leachate quantification method developed by this study, actual amounts of leachate – as measured in several landfill sites – were obtained and compared with the estimated values.

2.1. Infiltration from precipitation

Leachate generated from infiltrated precipitation can be calculated by Eq. (2), which was established according mass balance theory.

$$\mathrm{PI} = \sum_{c}^{n} \frac{P \times (I_c/100) \times t_c}{\rho \times h} \tag{2}$$

where P is precipitation at a locality, at mm·year^{-1}; c means the top cover type in a landfill; I_c is the ratio of precipitation infiltrated throughout waste layers with the top cover type of c, in % terms; t_c is the time period a top cover type of c is utilised, in years; ρ represents waste density in landfill, at t m^{-3}; h is the waste height in the landfill, in metres.

A generic landfill was established to calculate the amount of leachate associated with precipitation over a 100 year period after landfilling. In the landfill, a uniform height of 20 m of waste was assumed to be buried. After landfilling, waste density changed along with time due to compaction and degradation. The density of fresh waste and old waste were set as 0.8 and 1.3 t m^{-3}, respectively (Qu et al., 2005). According to current Chinese national standards (Ministry of Housing and Urban-Rural Development of the People's Republic of China, 2013), four top cover types were investigated: daily cover (DC), intermediate cover (IC), unplanted final cover (UFC) and planted final cover (PFC). Based on a field survey by Ecobalance Inc. (1999), the timescales for the four types of top cover were set as follows: during the first 2 years after landfilling, the proportion of DC decreased from 100% to 0%, whilst IC increased from 0% to 100%; during 3–10 years after landfilling, the proportion of IC decreased from 100% to 0%, whilst UFC increased from 0% to 100%; over 10 years after landfilling, the top covers of the landfill were entirely set as PFC. The tensile strength of HDPE geomembranes decreases with its ageing, which may induce defects and influence the infiltration process. Accordingly, PFC were separated into two stages, i.e. with intact HDPE geomembranes (PFC-I) and with defective HDPE geomembranes (PFC-D). The service lifetime of HDPE geomembranes was likely more than 40 years according to Rowe (2011). To simulate the worst situation, PFC-I was assumed to be converted into PFC-D after 40 years of landfilling in this study.

The infiltration ratios of precipitation ending up as leachate (I_c) are critical parameters for calculating PI, which are closely associated with regional climate conditions and landfill structures. In current Chinese national standard (Ministry of Housing and Urban-Rural Development of the People's Republic of China, 2013), I_c are provided but are experience factors lacking practical verification. In this study, the specific I_c under typical climate conditions with five different landfill top covers were obtained using

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