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Fate and transport of pollutants through a municipal solid waste landfill leachate in Sri Lanka

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Abstract This study focuses on the characterization of leachate generated from Gohagoda dumpsite in Kandy, Sri Lanka, assessment of its spatial and temporal variations, and identification of subsurface canals and perched water bodies in the wetland system affected by the leachate flow. Leachate samples were collected monthly throughout dry and rainy seasons from different points of the leachate drainage channel over a period of 1 year and they were tested for quality parameters: pH, temperature, electrical conductivity, total dissolved soils, alkalinity, hardness, total solids, volatile solids, total suspended solids, volatile suspended solids, biochemical oxygen demand (BOD₅), chemical oxygen demand, nitrate-nitrogen, nitrite-nitrogen, phosphates, ammonium-nitrogen, chloride, dissolved organic carbon, total organic carbon and heavy metals. Sequential soil extraction procedures were performed for the

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K. Kawamoto Graduate School of Science and Engineering, Saitama University, Saitama, Japan characterization of leachate-affected local soil. A geophysical survey using direct current resistivity technique was conducted at locations downstream of the dumpsite. Leachate characteristics indicated that the leachate is in the methanogenic phase and the results strongly suggest that the leachate may be polluting the river where the leachate is discharged directly. Leachate exceeds the allowable limits of Sri Lankan wastewater discharge standards for many of the parameters. Significant difference (P < 0.05) was observed for most of organic and inorganic parameters among all sampling locations. Many parameters showed a negative correlation with pH. The affected soils showed high heavy metal concentrations. Resistivity study confirmed a confined leachate flow at the near surface with few subsurface canals. However, no separate subsurface plume movement was observed. The results of this research can effectively be used for the establishment of an efficient and effective treatment method for the Gohagoda landfill leachate.

Keywords Nutrients · Chemical oxygen demand · Subsurface canals · Geophysical survey · Heavy metals · Sri Lanka

Introduction

One of the biggest challenges of the twenty-first century is the environmentally friendly municipal solid waste (MSW) management in many countries. Open dumping of waste is the most common method used in most developing countries to dispose municipal solid residues (Mor et al. 2006; Menikpura and Basnayake 2009). It is estimated that more than 90 % of all landfills in South and Southeast Asia are non-engineered disposal facilities (Trankler et al. 2005). In Sri Lanka too, the predominant practice of waste disposal is open and controlled dumping (Basnayake et al. 2008). Unfortunately, none of the open dumpsites in Sri Lanka are engineered and therefore the pollutants are released directly into the environment and often to the nearest water body (Ariyawansha et al. 2009). Presently, MSW generation rate in Sri Lanka is estimated as 0.8 kg/capita/day and by year 2025, it is estimated that this will increase to 1.0 kg/capita/day (Bandara and Hettiaratchi 2010). Even though this predicted value is low compared to the prevailing MSW generating rates ($\sim 1-2$ kg/capita/day) in developed countries, the predicted increments of MSW generation reflect the potential risks associated with the local environmental issues (Al-Wabel et al. 2011; Troschinetz and Mihelcic 2009). Therefore, it is very important to consider this issue as one of the main environmental concerns in developing countries as it may lead to many adverse impacts in the present as well as in the future.

Landfill leachate is generated in open dump sites mainly due to the infiltration of rainwater through the columns of MSW. Hence, a direct relationship can be identified between precipitation or seasonal variation with leachate generation (Trankler et al. 2005). In addition, the moisture content of the waste significantly influences the quantity of leachate. Generally, the leachate has been identified by many countries as a toxic contaminant for surface and ground waters and soil (Mor et al. 2006; Abbas et al. 2009). In addition, under methanogenic conditions, this liquid possesses strong reducing ability. Many studies can be found on either direct experimental determination of contaminants or their estimation through mathematical modeling (Mor et al. 2006). Landfill leachate is considered to be highly toxic to higher plants, algae, invertebrates, fish and human beings (Langler 2004; Natale et al. 2008). It has been reported that high concentrations of Cd, Hg, Ni, Mn, Cu, Zn and Pb have been associated with leachates and these metals have been identified as enhancing their transport ability with dissolved organic carbon (DOC) derivatives by anaerobic degradation of organic compound present in the leachate such as humic, fulvic and hydrophilic acids (Robinson 2007; Asadi 2008; Christensen et al. 1996). In addition, DOC makes the leachate dark brown by complexation of ferric hydroxide colloids with humic and fulvic substances (Chu et al. 1994). Presence of the alloys, paints, lamp filaments, electrical wiring batteries, ceramics and automotive parts in a dumpsite can be the reasons for the presence of several heavy metals (Trabelsi et al. 2009; Fetter 1993). Further, inorganic ions (such as NO₃⁻, NO₂⁻, NH₄⁺, SO₄³⁻, PO₄³⁻ and Cl⁻), xenobiotic organic compounds (such as phenols, halogenated hydrocarbons, chlorinated aliphatics and aromatic hydrocarbons) are reported in landfill leachates which may cause serious biological effects (Mor et al. 2006; Asadi 2008). The landfill leachate can be classified as acetogenic and methanogenic leachate according to their characteristics (Robinson 2007). Recorded chemical oxygen demand (COD), biochemical oxygen demand (BOD) and other solids such as total suspended solids (TSS), volatile suspended solids (VSS), total solids (TS) for acetogenic leachate are very high compared to the methanogenic leachate (Robinson 2007). In addition, leachate characteristics can be different from temperate to tropical countries due to the climatic differences and solid waste composition and age of the landfill (Trankler et al. 2005).

Even though, many characterization studies and extensive reviews of the composition of landfill leachates are available, most of these are restricted to developed nations. Only a few studies have been reported on the landfill leachate, and its transport and fate in the tropics especially from the developing Asian regions (Kale et al. 2010; Vasanthi et al. 2008; Mor et al. 2006). This situation of lack of studies has been identified as a significant limitation for proper establishment of effective treatment measures of landfill leachate (Trankler et al. 2005). To date, few studies had been carried out to characterize leachates that are generated from Gohagoda dumpsite, one of the largest MSW open dumpsites in Sri Lanka. For instance, a ground water quality study based on shallow wells and drains around revealed high contamination of the river Mahaweli indicating BOD, COD, nitrate and phosphate as high as 20,000, 48,000, 64, 56 mg/L, respectively (Wimalasuriya et al. 2011). In addition, different treatment approaches had been considered in the laboratories and field scales to treat this leachate (Wijesekara et al. 2012; Ariyawansha et al. 2011). However, none of these studies have focused on leachate characterization including the patterns of temporal and spatial variation, seasonality, flow and transport of leachate through subsurface, etc. Therefore, the aim of this study was to characterize landfill leachate generated from an open dump site (i.e., Gohagoda) in Sri Lanka, assess the spatial and temporal variation of leachate characteristics, estimate heavy metals in the leachate-affected soils through toxic metal fractionation to understand the metal mobility, and identify subsurface canals and perched water bodies in the wetland system affected by the leachate flow.

Materials and methods

Study area

The Gohagoda open dumpsite is situated in Kandy (7° 18' 47.85" N and 80° 37' 19.02" E) which lies at an altitude of 461 m above mean sea level in central of Sri Lanka. The dumpsite covers an area of 2.5 ha and the land is underlain by hornblende biotite gneisses with coarse-to-medium grained xenomorphic intragranular texture (Envioronmental Impact Assessment Study Report 2011). The





Fig. 1 a Schematic diagram of the leachate drainage channel (*red arrows*), leachate sampling points (*yellow dots*) and leachate-affected soil sampling locations (*orange dots*) with the distances among

sampling points at Gohagoda dump site. \mathbf{b} Leachate-affected soil sample locations with depth of sample points

permeability of the low-lying lands in the former paddy fields indicates high values of 0.003-0.021 cm/s (Envioronmental Impact Assessment Study Report 2011). This site receives MSW from the world heritage city, Kandy since 1960s. Presently, residential population nearly 120,000 and floating population of over 50,000 visit Kandy daily, mainly as the pilgrims due to the presence of sacred temple of Lord Buddha's tooth relic located in the middle of the city. About 130 tons/day of MSW including waste from slaughter house, fish market, households and non-infectious hospital waste are being directly dumped without any sorting or pretreatment (Welikannage and Livanage 2009). Approximately 59 % of disposed wastes are of food waste, while garden trimmings, wood, polythene, cardboards and paper 18, 6, 5, 3 and 2 % of the total waste mass, respectively (Menikpura et al. 2008). Similar to all other MSW dumpsites in Sri Lanka, no environmental impact assessment (EIA) or initial environmental assessment (IEA) has been carried out prior to the selection of this site.

Landfill leachate collection and characterization

The leachate characterization was conducted from June 2011 to October 2012. In order to understand the spatial and temporal variations in the geochemistry of landfill leachates, the leachate sample locations were selected based on the topography, areas close to the dumpsite, flow regimes and natural streams draining the area. The samples were collected at four sampling points of the drainage channel. The locations GS1 and GS4 were located at starting and end points of the channel, whereas GS2 and GS3 points were at the middle (Fig. 1a). Leachate from sub-channels and wastewater seepage from nearby piggery collects at the GS2 point frequently. The characterization of the collected

leachate samples was performed at field conditions and after being immediately transferred into the laboratory environment under 4 °C conditions. The leachate characterization methods and recorded chemical constituents are shown in Table 1. To ensure standard quality control/quality assurance procedures, three replicates were collected and analyzed for each sample. Further, the data were statistically analyzed for correlation coefficient using *R* package, a free software environment for statistical computing, and ANOVA. Although a linear correlation between the quality constituents may not lead to the identification of potentially complex, nonlinear relationships, we used a linear correlation coefficient to identify possible dependence among constituents. As our standard practice, this was used as the first step in exploring sampling data.

Landfill leachate-affected soil collection

The leachate-affected soil sampling locations were selected considering the ground water movement of the region which mainly occurs south west to the north east since the fractures and joints distribution go along the paddy field towards the Mahaweli River (Wimalasuriya et al. 2011). The soil sampling locations and the distances among sampling points are shown in Fig. 1a schematic diagram. Soil samples were obtained from the bore holes made for ground water level observations at every 15-m interval. Soil samples were collected from auger (approximately 150 mm internal diameter) at 0.5 m above to the bed rock and closer to the bed rock as shown in Fig. 1b. About 20 g of soil was collected from each sampling depth and kept separately in sealed plastic bags. In addition, soil samples from surrounding upstream areas that were not affected from leachate were obtained as controls.

Table 1Comparison of theexperimental results for landfillleachates in Gohagoda opendump site (GS 1 locationleachate)

Constituents	Method	Gohagoda leachates ^a	Acetogenic leachates ^b	Methanogenic leachates ^b
рН	ROSS sure-flow combination epoxy body electrode	8.0-8.60	5.5–7	7.5–8.5
EC	Conductivity meter (Orion 5 star series)	3.2–31	7–30	<1
BOD ₅	Winkler method	18–3,590	4,000–30,000	<500-1,000
COD	Spectrophotometer (HACH DRB 200)	480–69,700	10,000-50,000	2,000-6,000
TOC	TOC analyzer (Analytikjena Multi N/C	36,955	3,000-20,000	<10-300
DOC	2100)	28,493		
TS	Membrane filter paper techniques	100–78,531		
TSS		322-14,418		
VS		180-25,198		
VSS		34–2,630		
Alkalinity	Titrimetric method	725–39,606	2,000-10,000	10,000-30,000
Ammonia– nitrogen	Iron selective electrode	6-4,095	750-2,000	1,500-3,000
Nitrate- nitrogen	Cadmium reduction method	30–780	<1	<1
Nitrite- nitrogen	Diazotization method	0.2–410	<0.1	<0.1
Phosphate	Ascorbic acid method	5-260	5-20	1,000-3,000
Zinc	Atomic adsorption spectrophotometer	0.2-1.15	5-20	< 0.01-0.05
Cadmium	(GBC933, Australia)	0.004-0.062	<0.1-<0.2	<0.02-0.01
Nickel		0.133-0.532	<0.1-<1	<0.05-0.1
Chromium		0.021-0.323	0.1-<0.5	0.02–5
Copper		0.048-0.443	<0.1-0.1	<0.3-2
Lead		0.015-0.416	<0.1-<0.5	<0.05-0.2
Iron		1.49–317	100-800	-0.5
Manganese		0.155-32	10–50	5-50
Arsenic		ND-0.002	<0.1-0.3	< 0.001 - 0.002

Soil analysis

by Robinson (2007)

Results in mg/L unless pH, conductivity mS/cm ND not detectable values ^a Annual average value ^b Methanogenic and acetogenic leachate characteristics reported

Initially, plant residue or debris were removed in the soil samples, air dried under shade at ambient temperature (25-30 °C) and crushed by mortar and pestle then sieved through 63–105 µm stainless steel screen. Determination of soil pH, electrical conductivity (EC) and organic matter content [total organic carbon (TOC) and dissolved organic carbon (DOC)] were measured using standard protocols (Anderson and Ingram 1993). Three replicates from each soil sampling depth were tested. Soil extraction procedure steps and other experiments were conducted according to the methodology given in Table 2 and mean value for the triplicate soil samples for each location was presented.

Resistivity survey

The ABEM Terameter 300-c SAS, Sweden (1-D resistivity survey) and AGI (Advanced Geosciences Inc, Texas, USA) Mini-sting system with accessories (2-D imaging) were used for this study. Very low resistivity values of leachate compared to the background is the significant physical property for the techniques. Three 1-D survey lines and seven 2-D profile lines were used for the acquisition of resistivity data covering the entire study area (Fig. 2a, b). Three locations were selected for 1-D vertical electrical sounding (VES) in standard Schlumberger array with 100 m maximum current speed. Additionally, 2-D resistivity data were acquired along five regular profiles with distance as line spacing, electrode spacing and total spread; 10, 1.5 and 40.5 m, respectively. Apart of the evenly spaced grid, two extended lines were completed with 2.5 m electrode separation and the total length of the profile is 67.5 m. Data processing in 1-D was carried out in Resist freeware package while maintaining RMS error below 5 %. The 2-D data were processed via Earth Imager licensed software by fixing resistivity ranges 10–400 Ωm.

Table 2	Schemes	of the	sequential	extraction	procedures	and	other	experiments
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Constituents	Reference	Method
Exchangeable fraction	Kumari (2010)	1 g soil extracted room temperature 1 h with 20 ml of 1 M MgCl ₂ , pH 7.0 at continuous agitation
Bioavailable fraction	Houba et al. (1996)	2 g soil extracted room temperature 2 h with 20 ml of 0.01 M CaCl ₂ , pH 7.0 at continuous agitation
Total metal concentration	Milestone ETHOS PLUS labstation with HRP-1000/ 10S high pressure segmented rotor	1 g soil with 16 ml HNO ₃ , 10 ml HCl, 3 ml HF and digested in closed vessel device
Cation exchange capacity (CEC)	Anderson and Ingram (1993)	2.5 g soil extracted to 1 M $\rm NH_4Ac$ and 1 M KCl
Zero net proton charge (pH _{zpc})	Langmuir (1997)	20 g/L <63 μm soil. pH changed to 4.0 and titration carried out up to pH 9.0 with 0.5 pH variation
Material characteristics	FTIR Nicolet 6700, USA and OMNIC version 7.3	Fused 100 mg KBr and 30 mg <63 μ m soil. Transmission spectra obtained 4,000 and 400 cm ⁻¹ , with 4 cm ⁻¹ resolution
Specific surface area	Santamarina et al. (2002)	2 g/L of <63 μm soil equilibrated and added series of methylene blue (MB) per 10 ml, overnight equilibration shaking 75 rpm and the MB concentration is determined by UV-Vis Spectrophotometry (UV-160A)

Results and discussion

Leachate assessment

Organic constitutes COD and BOD

Most of the leachate from the early stages of sampling showed high COD levels (above 20,000 mg/L). With time, COD stabilizes at values of 3,000 mg/L or less which corroborates with other studies (Irene 1996). In addition, the recorded COD concentrations were significantly low during the study period indicating values below 7,000 mg/L for all sampling locations. However, we noticed very high COD (50,000–67,900 mg/L) concentrations on few occasions at GS1 sampling point. Similar to COD, considerably high BOD₅ as 27,500 mg/L had been recorded in the GS1 point (Wijesekara et al. 2010). These parameters reflect well the changes of solid waste degradability in dumpsites and organic contaminant amounts (Irene 1996).

Figure 3a, b illustrates the BOD₅ and COD variation throughout the study period. Accordingly, maximum BOD₅ was recorded as 3,590 mg/L in the GS1 point which is the closest point to the dumpsite. However, at all other sampling times, the BOD₅ was recorded below 2,190 mg/L indicating typical methanogenic phase conditions (Robinson 2007). Further, low BOD values with continuous fluctuation have been observed during the study period. Highly concentrated landfill leachate can be generated in biodegradable waste rich landfill cells during the initial period of refuse degradation process (Tatsi and Zouboulis 2002; Trankler et al. 2005). As in typical South Asian MSW landfills, a composition study in Gohagoda dumpsite for solid waste reveals that there is a large quantity of biodegradable waste and it has a direct relationship with high organic content of leachate (Menikpura and Basnayake 2009). In addition, it is obvious that the uncontrolled dumping of the waste can produce leachate with various ages due to the irregular degradation pattern of the refuse material. Also, peak COD values were observed at the extreme rainfall events and this observation agrees well with a previous lysimeter-based study (Trankler et al. 2005). Further, a considerable degree of pollution can be predicted throughout study period to the river Mahaweli due to the exceedance of wastewater discharge tolerance values (standards) for inland water bodies in the country (BOD₅ and COD; 30 and 250 mg/L, respectively) [National Environmental (Protection and Quality) Regulations 2008].

DOC and TOC

According to Table 1, the average TOC and DOC were 36,955 and 28,493 mg/L, respectively, during the study period. The recorded TOC values in the acetogenic leachate seem to be significantly high as reported by Robinson (Robinson 2007). The DOC in the leachate originates from the organic waste decomposition in the landfill and it may cause numerous environmental effects by reducing removal effects of heavy metals and depleting dissolved oxygen in ground water sources (Christensen et al. 1998). Further, it is reported that DOC remains as non-biodegradable compounds and may even be resistant to biological treatments (Zouboulis et al. 2004). Conversely, TOC indicates the total amount of organic carbon in the leachate matrices. Leachate contains high TOC in active landfill sites than leachate from closed landfill sites due to the high decomposition rate (Irene 1996). Further, the ratio of COD to TOC indirectly

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Fig. 2 a Schematic diagram of the resistivity survey area (*yellow rectangle*) at Gohagoda dump site. **b** Schematic diagram of the resistivity survey plan, five *black lines* are the regular grid for 3-D resistivity cube with 10 m line spacing and 40.5 m profile length.



Two *red lines* are the traces for 67.5 m profiles that were designed to obtain details from depths to conclude bedrock characters. *Yellow circles* are locations for 1-D resistivity (VES) survey

Fig. 3 The radial plots (mean monthly values plotted radially) for **a** BOD **b** COD **c** $NO_3^{-}-N$ and **d** PO_4^{3-} show the seasonality of the data among four sites in the analyzed leachate samples. *Red*, *blue*, *brown* and *green* colors for GS1, GS2, GS3 and GS4 locations, respectively



reflects the characteristics of the organic matter in the leachate and it can be used to determine the approximately age of the landfill (Irene 1996). Accordingly, observed low COD/TOC ratio (1.59) indirectly indicates that the age of the particular landfill site is more than 20 years and the presence of the more oxidized state of organic carbon for less readily available energy source for microorganisms growth (Irene 1996).

TS, VS, TSS VSS and TDS

Understanding the variations of different solid contents is important from a landfill leachate management perspective since many recommended standards are focused substantially on solids. The TS and VS values obtained below 20,000 and 10,000 mg/L were similar as in previous literature (Chu et al. 1994). However, on a few occasions, we observed considerable deviations indicating 80,000 and 45,000 mg/L for TS and VS, respectively. This may be due to the accelerated dissolution of solids under mechanical mixing of waste in the dump site. The average TSS and VSS during the study period were 1,493 and 416 mg/L, respectively. In addition, concentrations of all parameters analyzed in solids shows a declining pattern from the dumpsite to the river side and this may be due to the coagulation and settling of solid particles.

The greater TSS concentrations reflect higher enzyme activity and TSS concentrations of leachate which highly depend on the abundance of microorganisms as well as the dilution conditions (Loehr 1984). VSS could be directly proportional to the microbial mass (Loehr 1984). In addition, VSS is frequently used as an estimate of the concentration of active microorganisms in a biological treatment unit and it is an imperfect measure of the active mass. Similarly, VSS is considered as a useful design and management parameter for wastewaters. According to the literature, the mean VSS values of leachate at various landfills between the range of 50-200 mg/L is close to the observed values (10-4,810 mg/L) (Fan et al. 2006). Literature reveals that VSS value of an old landfill (more than 10 years) is 7 mg/L (Kang et al. 2002). This value corroborates with Gohagoda leachate data which further supports that it is in the methanogenic stage.

Generally, the total dissolved soils (TDS) concentrations fluctuate <8,000 mg/L during dry season and has significant increases beyond 8,000 mg/L during the rainy season. In addition, from GS1 to GS4 the TDS concentration showed a decreasing pattern similar to solids. TDS is the product of biochemical transformations of both organic and inorganic molecules and thereby TDS becomes the substrate for the acetogenic and methanogenic microorganisms. Hence, TDS is a good indicator that can be used to understand several parameters since it has a strong correlation with a number of parameters, such as hardness, SO₄³⁻ and Cl⁻ (Mor et al. 2006). The leachate derived from the GS2 point recorded the highest TDS, TS and VS since GS2 point receive concentrated leachate through sub-channels from the dumpsite as well as stagnant leachate pockets, and seepage from nearby piggery. In addition, mechanical mixing of waste can be observed to record high solid concentrations since some excavating processes were going on at the later study period.

Inorganic constitutes

pH, EC, alkalinity and hardness of leachate

The phase changes from acetogenic to methanogenic can be effectively identified by the pH changes of landfill leachate (Trankler et al. 2005). The pH was observed between 8 and 8.6 in all sampling occasions with few exceptions during the studied period. Mainly, pH changed to acidic values in the later study period. This may be due to the uncontrolled open dumping of MSW with manual mixing of waste and enhancing microbial activities due to influence of rainfall (Trankler et al. 2005). Hence, the alkaline pH can be considered due to the mineralization of carbonates, bicarbonates and hydroxides in the well established methanogenic phase of landfill (Maqbool et al. 2011; Robinson 2007). The recorded EC of the leachate samples was high as in range of 3.2-31.4 mS/cm indicating high content of dissolved salts. However, the dilution and flushing of organic and inorganic materials appeared to be the reason for the decrease of EC values towards river side. Generally, the maximum temperature of leachate was recorded at GS1 point which may be due to the microbial activities.

Alkalinity is the acid neutralizing capacity and is a function of HCO_3^{-1} and CO_3^{2-1} content (William 1997). The alkalinity was within a range of 725-39,606 mg/L. Dissolution of metal carbonates under prevailing pH conditions might be the reason to increase the alkalinity with time (Bhambulkar 2011). The hardness is normally expressed as the total concentration of Mg²⁺ and Ca²⁺ in mg/L and it was recorded within the range of 15-800 mg/L during the study period. GS2 showed the highest value for the hardness at the beginning, but it shows a rapid decrease with time. In all other points, the pattern of variation is narrow except GS4. Thus, it is evident that GS1 and GS2 points are highly contaminated with Mg²⁺ and Ca²⁺ multivalent cations which may be added by soap, detergents, batteries and other types of industrial and household waste. The reason for the decrease in hardness with time may be related to dilution and attenuation by soil. In addition, chloride ranged during the study period from 68 to 723 mg/L (Table 1). Farm animal waste, household waste and septic effluents might be the sources for high chloride levels in leachate (Mor et al. 2006).

Nutrients (nitrate-N, nitrite-N, ammonia-N and phosphate)

Among the nutrients, nitrogenous compounds were observed in high concentrations. Figure 3c shows the nitrate-N variation of analyzed leachate samples. Nitrate-N ranged from 30 to 780 mg/L. Sewage, fertilizer, farm animal waste, food waste, etc., may be the sources of nitrate in leachate. Higher concentrations of nitrate-N that resulted during the final period may be attributed to rainwater that infiltrated into the landfill that promotes solubilisation of pollutants from actively decomposing waste mass into leachates. Further, nitrite-N ranged between 0.1 and 410 mg/L indicating a complex fluctuating pattern. High concentration of nitrite-N has been observed in the methanogenic leachate worldwide (Robinson 2007). The

Table 3 Comparison with recommended standards of tolerance limits for discharge of effluent for inland surface waters by the Central Environmental Authority (CEA), Sri Lanka (National Environmental (Protection and Quality) Regulations 2008)

Constituents	Average at GS1 location ^a	Average at GS4 location ^a	Background values	CEA
рН	8.12	8.16	6.89	6–8.5
BOD ₅	1,096	528	6	30
COD	13,248	1,425	15	250
TSS	1,730	126	35	50
Alkalinity	8,890	2,589	577	
Ammonia- nitrogen	1,113	330	1.4	50
Nitrate- nitrogen	128	32	0.6	
Phosphate	107	54	2.1	5
Zinc	1.15	0.30	0.002	5
Cadmium	0.04	0.01	ND	0.1
Nickel	0.33	0.11	ND	3
Chromium	0.13	0.09	ND	0.1
Copper	0.22	0.07	0.001	3
Lead	0.18	0.14	ND	0.1

Results in mg/L unless pH, conductivity mS/cm

ND detected values

^a Annual average value

ammonium-N may be present in leachate due to fermentable organic matter with high concentrations of proteins (Mor et al. 2006). Results for ammonia-N appeared within a wide range indicating 6-4,095 mg/L. Considerably high concentrations (around 3,000 mg/L) were observed at the end of the study period with heavy rainfall (100-150 mm as in October 2012). Since ammonia is a product of anaerobic protein degradation, stabilization of anaerobic digestion might have led to accumulation of ammonia during final time period. The phosphate levels varied considerably within wide ranges exceeding country's standards values for wastewater discharge to the inland waters as 2 mg/L (Table 3) [National Environmental (Protection and Quality) Regulations 2008]. As in the case of nitrate, phosphate also increased suddenly at the end of sampling, during which heavy rainfall was observed Fig. 3d. This may be due to the enhanced leaching of nutrients from the fresh wastes dumped at the site during the initial precipitation followed by the dilution effects of rainfall (El-Fadel et al. 1997).

Heavy metals

Heavy metals can accumulate through the food web and reach living beings causing several adverse effects especially among humans (Natale et al. 2008). Inspection of Fig. 4a-d reveals the variation of some selected heavy metal species during the study period. To summarize, the respective concentrations of Zn, Cu, Pb, Ni, Cr and Cd ranged 0.049-0.337, 0-0.443, 0-0.356, 0.004-0.390, 0.015-0.168 and 0-0.033 mg/L, respectively at the sampling point near the dumpsite. In addition, aluminum in leachate varied within the range of 0.122-0.98 mg/L. The sources of Aluminum may be attributed to waste coming from engines, cables, etc. In some cases, the Al level was recorded to be higher than the country's permissible level of 0.2 mg/L [National Environmental (Protection and Quality) Regulations 2008]. The presence of high levels of heavy metals suggests their origin could be from the various wastes dumped in the landfill (Trabelsi et al. 2009). High concentration of Fe in the leachate may be from the Fe scraps dumped on the landfill. The presence of Pb exceeding even country's wastewater discharge permissible level; 0.1 mg/L may be attributed largely to the disposal of batteries, lead-based paints, chemicals for photograph processing and lead pipes found at the site [National Environmental (Protection and Quality) Regulations 2008; Mor et al. 2006]. High concentrations of Zn may indicate the presence of fluorescent tubes, batteries and a variety of food wastes. Possible sources of cadmium may be discarding of dry cell batteries and paint (Aderemi et al. 2011). Effect of aeration by mechanical mixing of waste was identified as a factor which accelerates releasing heavy metals into leachate flow and contaminates open water bodies such as rivers as well as ground water resources through percolation (Mor et al. 2006).

Correlation analysis

A correlation analysis was performed as a preliminary descriptive technique to understand the statistical relationship between two or more variables or systematic changes in the value of one variable are accompanied by systematic changes in the other. Hence, this statistical explanation can be used to understand the relationship between two variables. The graphical representation of pair-wise Pearson correlation matrices between various parameters is shown in Fig. 5. In summary, most of the parameters were found to have a statistically significant correlation with each other. For instance, pH found to have a strong negative correlation with heavy metals such as Mn and Cr. This would be possibly due to dissolution of these metal species at low pH and hence the bioavailable metal fraction can be observed in high concentrations. On the other hand, the metal species can be precipitated as metal hydroxides resulting low metal concentrations at high pH conditions. Therefore, the high pH of the landfill leachate is favorable for immobilization

Fig. 4 Heavy metal concentration variation in the analyzed leachate samples **a** Pb **b** Ni **c** Cr and **d** Cd. *Red*, *blue*, *brown* and *green colors* for GS1, GS2, GS3 and GS4 locations, respectively



of heavy metals (i.e., Mn and Cr) through aquatic environment. The calculated matrix on COD follows previous research findings on the leachate characterization indicating a strong negative correlation with pH (Robinson 2007). The recorded pH of the leachate during the experimental period ranged 8-8.6 which is alkaline, indicating the site is in the methanogenic conditions. During the methanogenic phase, hydrogen and fermentation products that have been produced by acidogenesis and acetogenesis are converted to methane and water at higher biochemical transformation rate. Consequently, the COD concentration declined. In addition, pH showed a weak negative correlation with nitrate-nitrogen, chloride, and heavy metals like Zn, Pb, Ni and Cd. Further, similar statistics were found from a previous landfill leachate characterization on nitrate-nitrogen and Zn with pH (Mor et al. 2006). Moreover, TDS showed a significant positive correlation with COD, nitrate-nitrogen and heavy metals (e.g., Pb, Ni and Cr) indicating high mobility and bioavailability of these pollutants. This clearly shows the risk of soil and aquatic environments pollution through the landfill leachate. Based on the ANOVA tests, pH, TDS, conductivity, BOD, COD, NO3⁻, Cu, Ni and Cd showed significant differences among all locations at 5 % probability level (P < 0.05) (Table 4). Similarly, no significant differences were observed for the PO43-, chloride, Zn, Mn, Pb and Cr (P > 0.05) at same locations. However,



Fig. 5 Pairwise Pearson correlation coefficient plot for different quality parameters. The temperature of the landfill leachate was found to be statistically positively correlated with most parameters, such as pH, TDS, conductivity, COD, nitrate-nitrogen, phosphate, chloride and all heavy metals

still the significantly high values may be due to the rainfall intensity changes and washing and draining of contaminated soil into the existing leachate channel, etc.

Table 4 ANOVA table

	Variable	P value
	pН	0.003
	TDS	0
	Conductivity	0
	BOD	0.037
	COD	0.005
	$NO_3^{-}-N$	0.013
	PO_4^{3-}	0.431
	Cl	0.493
	Zn	0.177
	Mn	0.815
	Cu	0.025
	Pb	0.378
	Ni	0.002
nong	Cr	0.261
e in	Cd	0.003

Significant differences among four sites at 5 % level are in bold

Soil characterization

Total metal concentration

Our previous data showed that the leachate-contaminated soil is kaolinitic clay which lacks organic matter (Wijese-kara et al. 2011). The total heavy metal concentration showed an increasing pattern towards the river to the dumpsite direction indicating Zn>Cu>Pb>Cr>Ni>Cd (318, 124, 98, 69, 70, 3 mg/kg, respectively) for soils that are 0.5 m above from the bed rock (Fig. 6a). According to observed data, all binding sites in soil particles may have been occupied by metals in the upper layer (Griffin et al. 1976). However, a scattered pattern was observed closer to bed rock which may be due to the adsorption of toxic metals in the deeper soil layers (Fig. 6b). The observed background concentrations for Zn, Cu, Pb and Ni were 0.5, 0.1, 1.5 and 1.0 mg/kg, respectively, and Cd and Cr were not detected.

Bioavailable fraction

According to the results, upper layer soil samples had slightly high concentrations of heavy metal such as Pb, Zn, Cu, Ni, Cd; 38, 10, 9, 4, 3 mg/kg, respectively (Fig. 6c). Low metal concentrations at the bottom layer was recorded as Zn, Pb, Cd; 5, 3, 2 mg/kg, respectively, and Cu, Ni and Cr were not in measurable amount as shown in Fig. 6d. This result can arise due to many factors associated with soil; desorption and solubilization of mineral phases, etc. (Houba et al. 1996). Furthermore, these metal leaching patterns are similar to the total concentration variation at the bottom and upper layers soil sample leaching patterns. The heavy metal ions can be transferred from abiotic (soil) to biotic environments and further facilitated to enter to the food chains by bioaccumulation (Peijnenburg et al. 2007). However, critical contents of trace elements or prescribed element concentrations in the food have not been declared in Sri Lanka at this time. Furthermore, the recorded values exceeded regulatory values for agricultural applicability of plant used as feed (Chojnacka et al. 2005). Thus, the plants that grow in polluted areas are not suitable as food due to the potential risk of bioaccumulation.

Exchangeable metal fraction

According to the exchangeable metal fraction results, Zn (59 mg/kg) was recorded predominantly expressing a threat to the surrounding environment since the concentrations are high. Further, Pb, Ni, Cu were recorded as 10, 7, 5 mg/kg, respectively. In addition, Cr was not recorded as exchangeable although a significant amount was reported in total metal content. The heavy metals in the exchangeable fraction can be released rapidly to the environment (Stone and Droppo 1996). Similar results have been observed by Tessier et al. (1979) for Pb, Ni and Cu (Tessier et al. 1979). This may be the reason for the representation of negatively charged complexes of soil in fewer amounts (Hall et al. 1996). Low cation exchange capacity (49.09 meq/100 g) and specific surface area $(9.25 \text{ m}^2/\text{g})$ give enough evidences to confirm that the analyzed soil has low ability to adsorb metal ions.

Resistivity results

The resistivity imaging techniques are widely used in the environmental monitoring studies such as mapping of open dumpsites and sanitary landfills (Dawson et al. 2002; Doll et al. 2000). Results from the VES sounding indicated that the depth to the bedrock is about 3-5 m and bedrock is plunging towards the river with a gentle slope and these results agree with bore hole depths (Wijesekara et al. 2011). Further, few subsurface canals were found in the abandoned paddy field area and the leachate flow is mainly confined to the near surface (Fig. 7a, b). No perched water pockets were observed and that may be due to the continuous flow in the subsurface, the morphology and the dipping bedrock towards the river controls the flow pattern. The height of ground water varies in the dumpsite area since the ground stratification has been observed that tends to be denser away from the dumpsite in the direction of the river. Therefore, a shallow ground water table (27-107 cm for low-lying lands beyond the dumpsite) can be observed closer to the river and surface water drainage patterns can be observed as a characteristic feature. These findings can be effectively used to understand the leachate flow regime in order to manage these types of open landfills without any





Fig. 7 a Images of 2-D profiles (L1) Line-01 (L2) Line-02 and (L3) Line-03. b 3-D cube synthesized from 2-D imaging profile. Normal to Y axis and normal to Z axis indicates the flow patterns describing the leachate flow are at very shallow level, and limited to 3 m level

landfill liners. In addition, the ongoing resistivity study of the dump area could be expected to identify leachate-collected base characteristics including possible leachate pockets inside the dump to extract leachate and recirculation purposes to avoid direct ground water pollution.

Conclusions

(a)

L1 2.1 4.3 6.4

8.5

L2^{0.0} 2.1

4.3

6.4

8.5

L3^{0.0} 2.1

4.3 6.4 8.5

The physicochemical composition of leachate generated from Gohagoda dumpsite along with its temporal and spatial variations from June 2011 to late November 2012 was investigated in this study. In fact, this study provides a general assessment about the contaminants considering spatial and temporal variation of leachate. Accordingly, precipitation was observed changing the landfill leachate quality with a wide range of fluctuation patterns. In addition the geographical features, flow dynamics and distance from dumpsite (pollution source) to the sampling points, etc., in the study area have greatly influenced the contaminant movement and their characteristics in the landfill leachate during transport. The geophysical investigations confirmed

that the leachate flow is confined to the near surface and no perched water pockets in the subsurface. The demonstrated values for BOD₅, COD and ammonium-N were falling into a large range 20–3,590, 480–69,400 and 10–4,095 mg/L, respectively, showing spatial and temporal complexity. Some solids such as TSS showed an average of 1,730 mg/L and Pb concentrations (0.18 mg/L) were higher exceeding the country's permissible levels for wastewater discharge which are as TSS, and Pb; 50 and 0.1 mg/L, respectively. Even though, some parameters showed values below the recommended values, there is a greater threat by the cumulative load discharged to the river annually. In addition, some heavy metals are present in trace concentrations but the potential risks of these contaminants cannot be ignored due to their adverse effects on ground water and plants.

The leachate-affected soil at Gohagoda open landfill area of high heavy metal concentrations in soil poses a great environmental concern. This concern is further exhibited by some heavy metals which exceed high concentrations compared to the Sri Lankan standard limits of heavy metals for compost. High toxic metal concentrations in exchangeable (i.e., Zn, Pb and Ni; 59, 10 and 7 mg/kg, respectively) and bioavailable (i.e., Pb, Zn and Cu; 38, 10 and 9 mg/kg, respectively) fractions show the risk on local living beings as well as the open water bodies such as rivers and ground water sources.

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