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TEMPORAL VARIATIONS IN PERCHED WATER AND GROUNDWATER QUALITIES AT AN OPEN SOLID WASTE DUMPSITE IN SRI LANKA

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ABSTRACT: Open dumping of municipal solid waste is a common practice in many developing countries and contaminates surface and groundwater in the vicinity. In this study, long-term monitoring was conducted at an abandoned solid waste dumpsite to characterize temporal variations of perched water and groundwater qualities. The dumpsite was located at Udapalatha PS in Central Province of Sri Lanka and consisted of two sections (namely Old and New sections). The Old section was used for waste dumping for seven years from 2003 to 2010, and the New section was used for six months in 2011. Multiple wells were installed at each section and water qualities monitored for two years from May 2013 to March 2015. Water quality parameters such as pH, EC, BOD, COD, TN, TP, major cations, major anions, and heavy metals were measured monthly. Leachate pollution index (LPI) was used to quantify the leachate contamination potential of landfill site. Results showed that groundwater samples from both Old and New sections exhibited relatively low LPI during the monitoring period, whereas perched water samples from New section showed high LPI with fluctuations. At the monitoring site, perched water and groundwater seem to persist as two independent bodies for both Old and New sections. Especially, the dumped waste at lower layer at the Old section was fully washed out by rainfall and surface water after waste dumping and currently carries a low risk of groundwater contamination.

Key words: Municipal solid waste, Open dumping, Groundwater, Leachate pollution index (LPI), Monitoring

1. INTRODUCTION

Open dumping of waste is prevalent in most of developing countries due to its minimal operational and maintenance costs and inadequate technical background [1]. These open dumpsites are not designed with landfill bottom liners, soil covers, leachate collection and treatment systems. Thus this causes serious environmental pollution and threat to public health and safety especially in locations such as riverbanks, swamps, and marshy lands. Drinking water sources close to a dumpsite are directly affected by landfill leachate. The leachate migration has also been identified to affect the surrounding ecosystem and bio-diversity [2].

Many groundwater contamination incidents have been reported at open dumpsites and their surroundings, due to leachate generated as a result of waste degradation [3]. Leachate consists of high concentrations of organic compounds dominated by high biological oxygen demand (BOD), chemical oxygen demand (COD), total organic carbon (TOC), and inorganic contaminants with elevated concentrations of cations, anions, other toxic materials as xenobiotic compounds, and heavy metals. Especially, the absence of proper waste separation techniques leads to high concentrations of heavy metals in leachate [4]. High concentrations of Cd, Hg, Ni, Mn, Cu, and Pb that exceed the maximum tolerable limits have been reported from leachate collected at many open dumpsites [5].

Leachate generated in waste layers as a result of waste degradation moves downward while being mixed with rainwater and surface water. The mixture of polluted water is retained at the bottom of the dumped waste as perched water due to the restriction by low infiltration at the soil surface. The polluted perched water may enter gradually into groundwater aquifers through the soil. The subsequent migration of leachate through the sides and/or bottom of the dumpsite into subsurface formations.

Quality of leachate greatly varies with the type of dumped waste, age of the dumpsite, management practices at the dumpsites, climatic factors, site hydrology, degree of waste compaction, and interaction of leachate with surrounding environment. The leachate pollution index (LPI) has been used to characterize the landfill leachate with respect to the quality and severity of contamination [6], [7]. The LPI enables analysis of the effects of organic pollutants, inorganic pollutants, and heavy metals with different sub-indices, and is a good indicator of the leachate contamination potential of a waste landfill [8]. LPI can be used to determine whether a landfill requires immediate attention in terms of introducing remediation measures. In this study, the LPI has been applied to assess temporal variations of water qualities in perched and groundwater at an open dump site and to examine the effects of the age of dumped waste. Furthermore, correlations between major equivalent cations/anions and EC in perched water were also examined.

2. MATERIALS AND METHODS

2.1 Site selection and water quality monitoring

Figure 1 shows the location of the dumpsite and monitoring wells. The study area is an abandoned open waste dumpsite located in Udapalatha Pradeshiya Sabha (07° 80' 30.1" N and 80° 34' 43.2" E) in Central province, Sri Lanka. The average annual rainfall is above 2000 mm with an average annual temperature of 24.7°C [9]. The dumpsite consisted of two sections, namely the Old and New sections. The Old section was used for waste dumping for seven years from 2003 to 2010, and the New section was used for six months in 2011. Both sections have a steep slope toward the right bank of the Mahaweli River. The waste dumping rate was approximately 15–20 ton/day during the operational period.

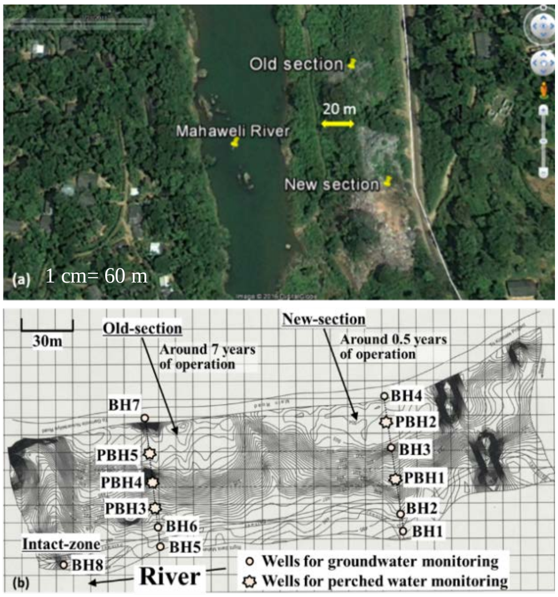


Fig.1 (a) Location of the dumpsite and (b) location of the monitoring wells at the dumpsite (Source: 2015 Google Inc. 17-03-2011)

Groundwater and perched water monitoring wells were installed along the two transits of the Old and New sections. The perched water monitoring wells (PBH) were drilled to the original soil surface through buried waste, whereas groundwater monitoring wells (BH) were drilled to the bedrock. Cross-sectional views of monitoring wells are shown in Fig. 2.

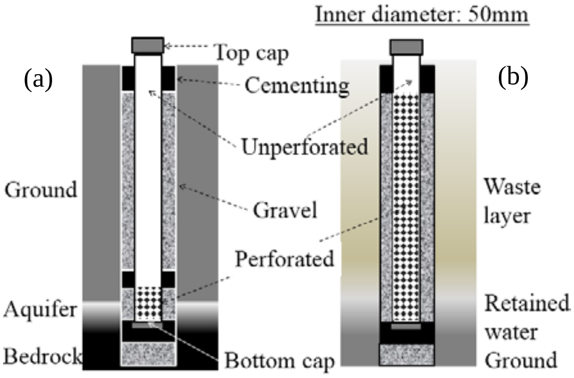


Fig.2 Cross-section of (a) groundwater (BH) and (b) perched water (PBH) monitoring well

The fluctuations in groundwater level at the monitoring wells and geomorphological featuers of the site such as strata of dumped waste and altitue of wells have been reported by Nagamori et al., (2015) [10]. During the monitored period, the water levels in perched water (PBH) observed as almost constant and those in groundwater (BH) varied slightly irrespective of the rainfall amount.

2.2 Monitoring water quality

The dumpsite was monitored for a period of two years from May 2013 to March 2015 with a one-month interval. Perched and groundwater samples were collected from PBH and BH wells. Stagnant water in wells was removed by manual pumping before sampling. Water samples were analyzed for BOD_5, COD, TOC, major cations/anions, and heavy metals. Onsite measurements were taken for pH, electric conductivity (EC), and water temperature with HACH portable meters (APHA 4500-H). Standard methods were used to analyze BOD_5 (hereafter BOD) and COD_{cr} (hereafter COD) without any pretreatment for water samples. TOC analyzer (TOC-LCSH/TNM-L Shimadzu, Japan) was used to measure TOC, IC, and TN after filtering samples through 0.45 µm filters. Heavy metals Fe, Ni, Cu, Zn, and Pb were measured by atomic absorption spectrophotometer, AAS, (AA-7000 Shimadzu Corporation, Japan), and As and Cr were analyzed by inductively coupled plasma mass spectrometry (ICPM-8500, Shimadzu, Japan). Water samples were acidified with 2% HNO_3 acid and filtered through 0.45 µm filters before analyzed for heavy metals. Cl^-, SO_4^{2-}, and NO_3^- were analyzed by ion chromatography (HPLC-IC, SHIM-PACK IC-A3 Shimadzu, Japan). Cations Na^+, K^+, Mg^{2+}, Ca^{2+} were analyzed with AAS. NH_4^+ was analyzed with UV-Vis spectrophotometer (UV-2700 Shimadzu, Japan) with Nitrogen-Ammonia, Salicylate Method at 655nm. All the analysis were done in New Environmental Engineering laboratory, Faculty of Engineering, University of Peradeniya, Sri Lanka.

2.3 Leachate pollution index (LPI)

LPI is a quantitative tool which provide an overview of the leachate contamination potential of landfill sites [11]. In this study, sub-indices and the overall LPI were used to evaluate perched water and groundwater contamination over the monitoring session. Sub-indices of LPI consisting of LPI organic (LPI_{or}), LPI inorganic (LPI_{in}), and LPI heavy metal (LPI_{hm}) were calculated according to Eq. (1).

$$LPI = \frac{\sum_{i=1}^{n} W_i P_i}{\sum_{i=1}^{n} W_i} \quad (1)$$

Then the overall LPI was calculated by Eq. (2).

$$LPI_{overall} = 0.232\ LPI_{or} + 0.257\ LPI_{in} + 0.511\ LPI_{hm} \quad (2)$$

where LPI is leachate pollution index, W_i is weight for the i^{th} pollutant variable, P_i is sub- index score of the i^{th} pollutant variable, and n is number of leachate pollutant variables used in calculating LPI [7], [11].

In the calculation of LPI, each pollutant sub-index score varies from 5-100 based on the relation between sub-index score and contaminant concentration for each water quality parameter. The minimum value of 5 of sub-index score is determined when there is no contamination, thus the LPI value does not result in zero even if some of the pollutants do not show any pollution.

The weight factors are calculated to indicate the importance of the individual pollutants. Different pollutant variables received different weight factors since the significance in contamination at landfill site is depends on the type of contaminant. The arithmetic sum of the significance ratings for all the selected pollutant variables was calculated for deriving the weights. Each pollutant was given a weight in proportion to the significance it obtained on a scale of 1, so as to make the total weight of all the pollutant variables 1 [7], [11].

3. RESULTS AND DISCUSSION

3.1 Temporal variations in water quality parameters

Table 1 exemplifies the LPI calculation. Sub-index values LPI_{or}, LPI_{in}, and LPI_{hm} were calculated using measured data and weighted function. The $LPI_{overall}$ was then calculated by the sum of each sub-index values. Temporal variations in general water quality parameters, heavy metals, total nitrogen, total phosphate, and LPI indices, during the monitoring period are shown in Fig. 3. The temporal variations in perched and groundwater qualities at New and Old sections are shown in this figure. Rainfall data and temperatures in perched and groundwater are also depicted in Fig. 3. It is very clear that LPI highly fluctutes in perched water compared to the groundwater. For both Old and New sections, BOD, COD, TN, and TP values in perched water were higher than those in groundwater. The perched water collected from the New section (PBH2) showed higher concentrations of most contaminants than those from the Old section (PBH4). The monitored BOD and COD values in groundwater were mostly below the effluent water quality standards of Sri Lanka [12] during the monitoring session, whereas those values in perched water exceeded the standards. Concentrations of heavy metals such as Cr and Pb of both perched and groundwater samples became similar and were comparatively lower than those reported values from other waste dumpsites under operation in Sri Lanka [8]. Except for LPI_{hm}, LPI_{in}, LPI_{or}, and $LPI_{overall}$ in perched water in the New section (PBH2) became 3--4 times higher than those for other monitoring wells.

For reference, the LPI_{or}, LPI_{in}, LPI_{hm}, and $LPI_{overall}$ corresponding to tolerance limits in water quality standards for effluent in Sri Lanka [12] were calculated and shown in Table 1. During the monitoring period, all LPI values of groundwater samples showed lower than those of the tolerance limits in water quality standards for effluent. Further the LPI_{hm} values calculated for both perched water and groundwater samples were lower than those of the tolerance limits in water quality standards for effluent.

The highest $LPI_{overall}$ observed in the study area was 16.8, New section: Perched water (PBH2) in December 2013. The LPI values has a great fluctuation with time in this location. Kumar and Alappat (2005) [7] calculated LPI for two active landfills and two closed landfills in Hong Kong and they have obtained highest LPI from one of the closed landfill (45.01) and the lowest from the other closed landfill (15.97). This is attributed to the difference in the quality of landfill leachate. However, it is difficult to identify the exact controlling factor because the quality of landfill leachate vary with several factors including climate and hydrological conditions, topographical feature, waste composition brought to the dumpsite, and age of the dumpsite.

Table 1 Sub-indices and LPI $_{overall}$ calculated for PBH2, BH: June 2013 and effluent water quality (Sri Lanka)

		New section : Perched water (PBH2)					New section : Groundwater (BH2)					Effluent water quality standards (Sri Lanka)				
Index	Parameter	Value *	Sub-index (P_i)	Weight factor (w_i)	W_iP_i	LPI	Value *	Sub-index (P_i)	Weight factor (w_i)	W_iP_i	LPI	Value *	Sub-index (P_i)	Weight factor (w_i)	W_iP_i	LPI
LPI $_{or}$	BOD	11.0	5.02	0.061	0.3	9.3	6.40	5.00	0.061	0.3	6.1	30	5.4	0.061	0.3	7.7
	COD	333	13.5	0.062	0.8		115	7.18	0.062	0.4		250	10.0	0.062	0.6	
LPI $_{in}$	pH	7.10	5.00	0.055	0.3		6.40	5.00	0.055	0.3		6-8.5	5.0	0.055	0.3	
	TDS	3.20	9.00	0.050	0.5		0.93	6.10	0.050	0.3		1.75	7.2	0.050	0.4	
	TN	856	27.2	0.053	1.4	17	146	7.09	0.053	0.4	5.9	150	7.1	0.053	0.4	6.3
	NH_4^+-N	472	41.5	0.051	2.1		98.6	9.90	0.051	0.5		50	7.1	0.051	0.4	
	Cl^-	331	6.18	0.048	0.3		272	5.97	0.048	0.3		1	5.0	0.048	0.2	
LPI$_{hm}$	Total Fe	7.60	5.20	0.045	0.2		10.0	5.25	0.045	0.2		3	5.1	0.045	0.2	
	Cu	0.01	5.01	0.050	0.3		0.001	5.00	0.050	0.3		3	20.0	0.050	1.0	
	Zn	0.20	5.04	0.056	0.3		0.06	5.01	0.056	0.3		2	5.4	0.056	0.3	
	Pb	0.03	5.15	0.063	0.3	5.1	0.07	5.28	0.063	0.3	5.1	0.1	5.4	0.063	0.3	7.8
	Ni	0.06	5.14	0.052	0.3		0.04	5.09	0.052	0.3		3	10.0	0.052	0.5	
	As	0.01	5.01	0.061	0.3		0.002	5.01	0.061	0.3		0.2	5.4	0.061	0.3	
	Cr	0.04	5.09	0.064	0.3		0.05	5.11	0.064	0.3		0.1	5.2	0.064	0.3	
LPI $_{overall}$						9.3					5.7					6.1

* All the values are in mg/L except pH

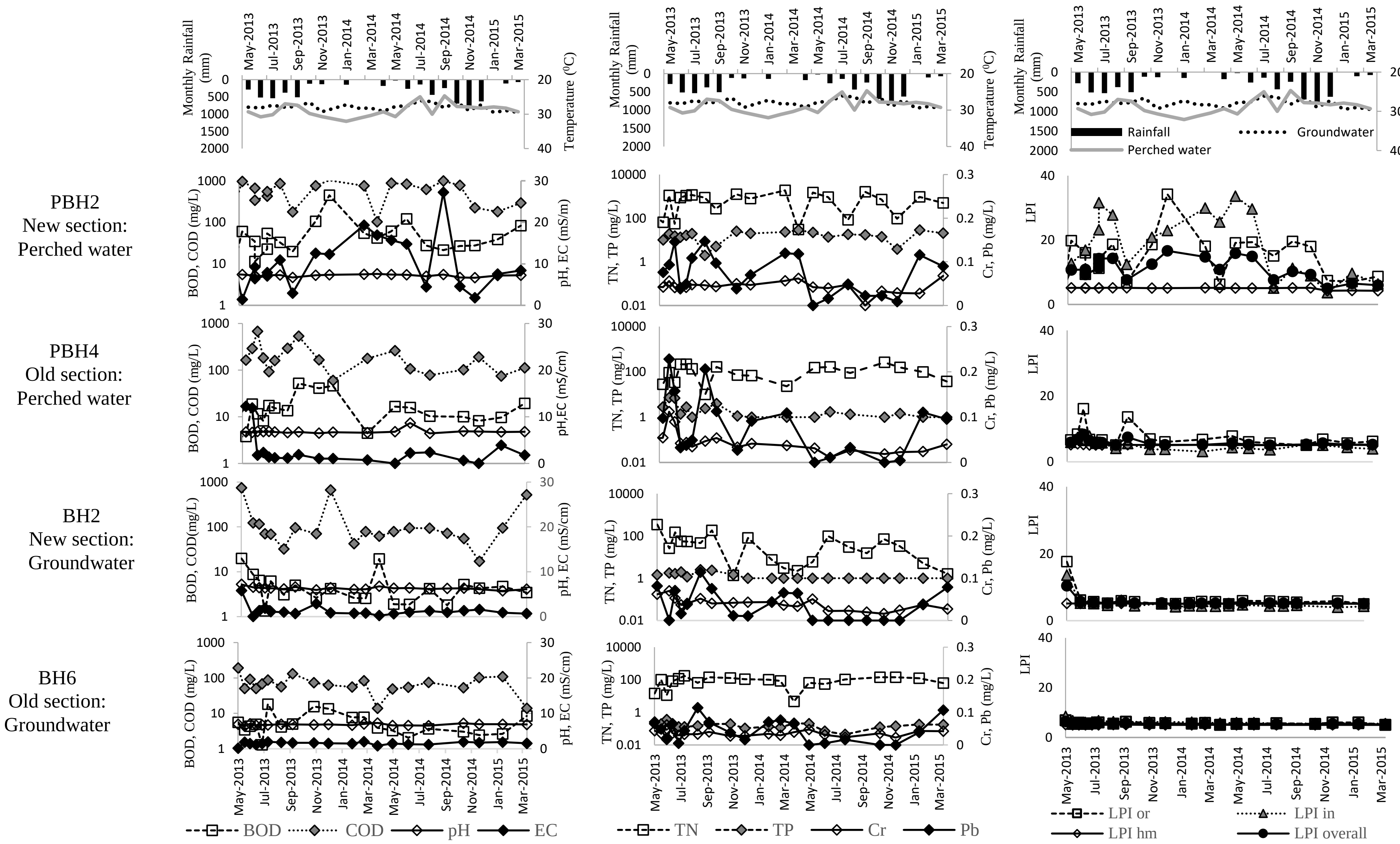
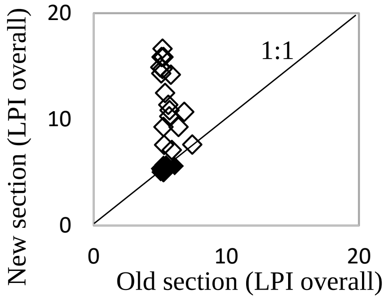


Fig.3 Temporal variability of meteriological parameters, water quality variables, and leachate pollution indices of monitoring boreholes

In order to examine the effect of waste age, measured LPI$_{overall}$ values of perched water at the Old section (PBH4) and New section (PBH2) and in groundwater at the Old section (BH6) and New section (BH2) are plotted in Fig. 4.



◇PBH4 (Old section : Perched water) vs. PBH2 (New section : Perched water)
◆BH6 (Old section : Groundwater) vs. BH2 (New section : Groundwater)

Fig.4 Relationships between LPI$_{overall}$ in monitoring wells

In the figure, the variations in LPI$_{overall}$ at the Old section were narrow compared to those at the New section: the LPI$_{overall}$ in perched water at the New section (PBH2) varied with the range of 5–18, whereas the other values were scattered around 5. Based on the result, it can be said that 1) the dumped waste at lower layer in the Old section (PBH4) was fully washed out by rainwater and surface water after the dumping (probably without the mixing with groundwater) and then its water qualities were almost equal to those of groundwater, and 2) the perched water and groundwater persisted as two independent water bodies (without connectivity) at the site in this study, suggesting the risk of groundwater contamination at the site is currently low.

Correlations between water quality parameters (BOD, EC, LPI$_{overall}$, Pb), and monthly rainfall for the perched water (New section: PBH2) and groundwater (New section: BH2) are shown in Fig. 5.

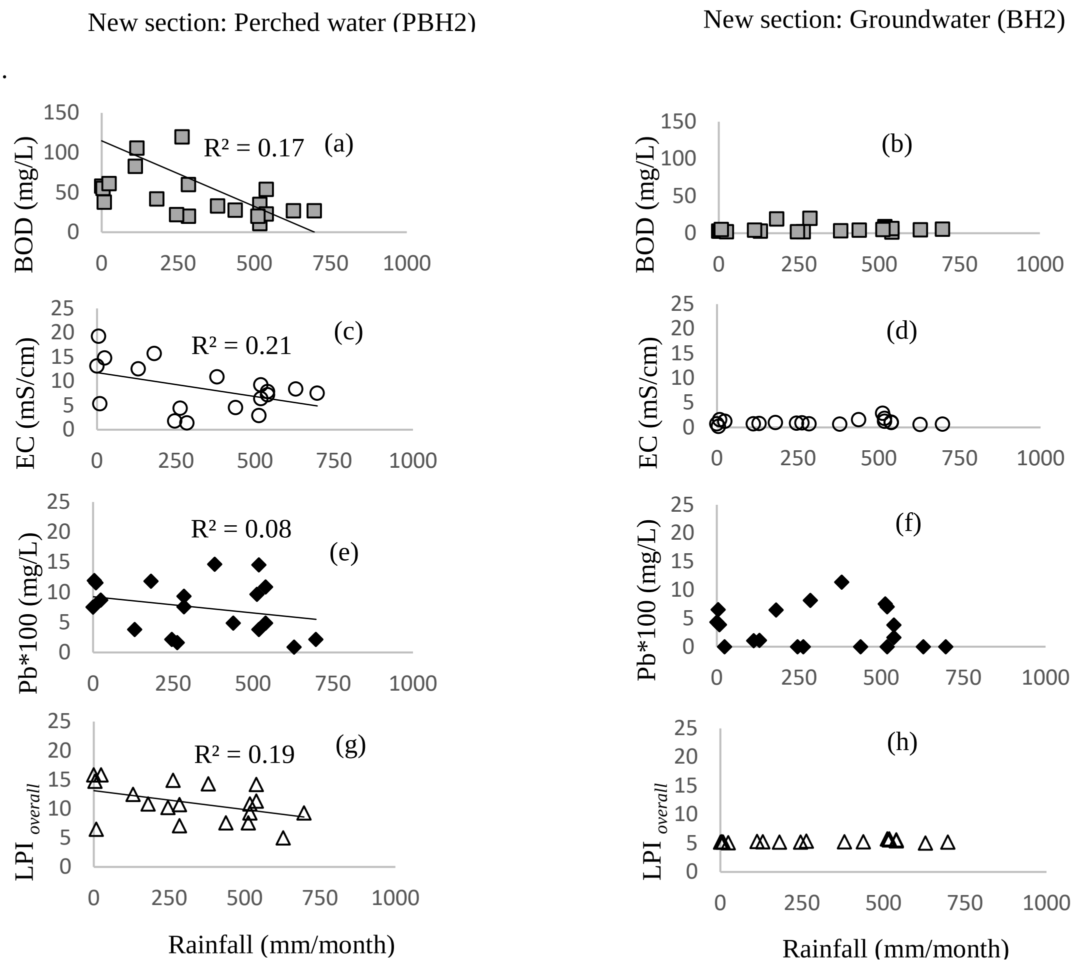


Fig.5 Monthly Rainfall vs major parameters ofPBH2 (Perched water: New section), [(a), (c), (e), (g)], and BH2 (Groundwater : New section), [(b), (d), (f),(h)]

For the perched water, all parameters tended to decrease with increasing monthly rainfall as illustrated in the figure. Similar observations were reported at another waste dumpsite close to our monitored site in Sri Lanka [13]. This is probably that the dilution of perched water retained inside the waste layer caused by the intrusion of rainwater during the period of rainy season. For the groundwater, on the other hand, there were no correlations between water quality parameters and rainfall, suggesting low rainwater intrusion into the groundwater aquifer at this site

3.2 Correlations between major equivalent cations/anions and EC in perched water

Major cations found in perched water were Na^+, K^+, Mg^{2+}, Ca^{2+}, and the major anion was Cl^- since municipal solid waste contains higher proportions of domestic waste in Sri Lanka. A similar result was found in a previous analysis of landfill leachate quality in Sri Lanka [14].Using the monitored water quality data, major equivalent cations calculated by a sum of Na^+, K^+, Mg^{2+}, Ca^{2+}, and NH_4^+ and major equivalent anions calculated by a sum of NO_3^-, SO_4^{2-}, Cl^-, and HCO_3^-. Total HCO_3^- concentration was calculated with respect to total dissolved inorganic carbon (IC). Since the observed pH of perched water and groundwater samples varies at around natural pH, Eq. (3) was used to convert IC to HCO_3^-[15].

$$HCO_3^- \left(\frac{\text{mg}}{\text{L}}\right) = 0.8 * IC \left(\frac{mg}{L}\right) * \frac{61.0\ \left(\frac{g}{mol}\right)}{12.0\ \left(\frac{g}{mol}\right)} \qquad (3)$$

Total equivalent cations and anions were related against EC values and illustrated in Fig. 6. Both major equivalent cations and anions correlated well to the EC values, indicating that EC, which is an easy and portable measurement in the field, is a good indicator to assess the release of major cations and anions under the degradation process at waste dumping sites.

Compared to the major equivalent cations, on the other hand, major equivalent anions were slightly lower in this study. This is partially because our study did not consider organic anions such as acetate, propionate, butyrate, anions of fatty acids, amino acids, and other anion compounds in perched water. Several previous studies reported that the organic anions are a major factor that contributes to the total equivalent anions in landfill leachate [16]. Further studies are needed to characterize the total anions in perched and groundwater at the waste dumping site.

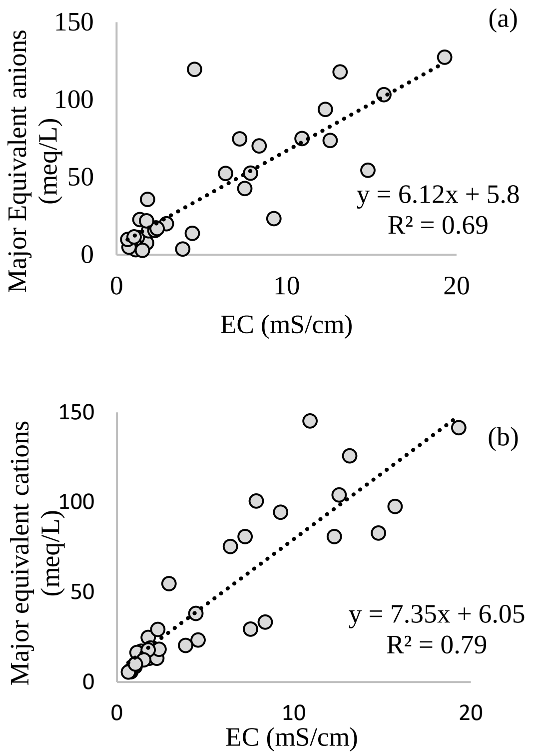


Fig.6 (a) Major equivalent anions vs. EC and (b) Major equivalent cations vs. EC

4. CONCLUSIONS

Water qualities of perched and ground water at two sections, Old and New, of an abandoned waste dumping site in Sri Lanka were monitored for two years from 2013 to 2015. LPI was used to quantify the leachate contamination potential of the landfill site. Except for LPI_{hm}, LPI_{in}, LPI_{or}, and $LPI_{overall}$ in perched water of the new section became 3-4 times higher than those of the other monitoring wells. The perched water and groundwater seem to persist as two independent bodies in both Old and New sections. Besides, the dumped waste in lower layer in the Old section was fully washed out by rainfall and surface water after waste dumping and carries a low risk of groundwater contamination. Based on the results from correlations between major equivalent cations/anions and EC, EC is a simple and accurate indicator to assess the release of major cations during the degradation process at a waste dumping site.

5. ACKNOWLEDGEMENT

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