CHARACTERIZATION OF LANDFILL LEACHATE FROM MUNICIPAL SOLID WASTES LANDFILLS IN SRI LANKA

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Abstract

Open dumping of municipal solid waste (MSW) is the most common way of handling solid waste in Sri Lanka due to high cost involved with advanced technologies for landfilling, lack of technical capacity, lack of know-how to manage landfill sites, and so on. Landfill leachate generated from the MSW landfill sites must be treated before dispose into the environment as it creates many social and environmental problems. Characterization of landfill leachate is important to identify the most critical pollutants present in the leachate and thereby to introduce suitable and applicable treatment technologies such as *in-situ* permeable reactive barrier technologies for contaminant remediation. Therefore, the objective of this research is to characterize landfill leachate collected from several MSW landfills in Sri Lanka. The leachate samples were collected from 12 landfill sites located in Matale, Hambantota, Kataragama, Bandaragama, Kolonnawa, Gampola, Gohagoda, Wennappuwa, Rathnapura, Negombo, Galle, and Matara. For the collected samples, general water quality parameters (pH, EC, DO, ORP, and SS), organic pollutants (BOD_5, COD, TOC, IC, TN, TP), typical anions and cations (Cl^-, SO_4^{2-}, NH_4^+, K^+, Mg^{2+}, Ca^{2+}, etc), and heavy metals (Cr, Mn, Fe, Se, Pb, etc) were measured. The results showed that most of the pollutants (F^-, Cl^-, PO_4^{3-}, NH_4^+, Fe, Se, Pb, BOD_5, and COD) exceeded the maximum tolerance limits in Sri Lankan Standards. It was found that the BOD_5/COD ratio ranged from 0.01 to 0.6 for the most samples and the highest value of 0.6 was observed in the Kolonnawa sample. Measured EC values for all samples were high and varied ranging from 4.5 to 38.3 mS/cm, indicating the biological treatment system alone would not be effective in reducing the pollutants especially for heavy metals. The results of this study will be used in developing site specific remediation technologies in landfill leachate treatment.

Key words: landfill leachate, municipal solid waste, open dumping, water quality, heavy metals

1. Introduction

Landfills are the most common way of disposing municipal solid wastes in developing countries due to the higher capacity of landfills at lower cost than other waste management techniques. In the case of Sri Lanka, almost all the landfills are operated as unmanaged and uncontrolled open dumpsites as a result of lack of technology, high cost of operation and maintenance and running out of capacity etc.

There are several forms of landfill emissions as gaseous emissions of volatile organic compounds, airborne particulate matter and landfill leachate (Slack et al., 2005). Among them, landfill leachate generation is a serious environmental problem associated with open dumpsites since landfill leachate is highly contaminated with different types of pollutants. The composition of landfill leachate varies from time to time and site to site due to the differences in waste composition, amount of precipitation, moisture content, climatic changes, site hydrology, waste compaction, interaction of leachate with the environment etc. (Kulikowska and Klimiuk, 2008; Umar et al., 2010).

Landfill leachate consists of organic matter (biodegradable and non-biodegradable), inorganic pollutants and hazardous substances (Slack, et al., 2005; Umar, et al., 2010). Hazardous substances in MSW are in the form of paints, mercury containing wastes, batteries, pharmaceuticals, vehicle maintenance products and many other diffuse products (Slack, et al., 2005). Thus, the disposal of landfill leachate prior to the treatment is a source of hazard to receiving water bodies.

Landfill leachate characterization is necessary to have a proper treatment facility since the composition of landfill leachate is varied from site to site. This will facilitate the introduction of site specific technologies such as in-situ permeable reactive barriers for the treatment of landfill leachate. Therefore, the objective of this study is to characterize landfill leachate collected from several MSW landfills in Sri Lanka.

2. Materials and Methods

2.1. Sampling of landfill leachate

Landfill leachate were collected from several landfill sites (open dumpsites) located in different areas of Sri Lanka to represent Wet and Dry zones of Sri Lanka (Fig. 1). All the selected landfill sites are in active operation. Samples were collected in polypropylene bottles and leachate was collected as to minimize the headspaces in the bottles to prevent aeration of the samples. Landfill leachate sampling was carried out from November 2011 to August 2012. The collected samples were transported to the laboratory and stored at $4^{o}C$ until analysis of the samples.

2.2. Leachate characterization

Mainly, four groups of pollutants, general water quality parameters, anions and cations, organic pollutants and heavy metals were measured in collected leachate samples using standard methods. Dissolved oxygen (DO), pH, oxidation reductive potential (ORP), electrical conductivity (EC), suspended solids, total nitrogen (TN) and total phosphorous (TP) were measured as general water quality parameters. DO, pH, ORP and EC were analyzed using DO meter (DKK-TOA coorparation, Japan), pH meter (DKK-TOA coorparation, Japan), ORP meter (DKK-TOA coorparation, Japan) and EC meter (DKK-TOA coorparation, Japan), respectively. Suspended solids were measured by filtration followed by oven drying. TN and TP were analysed using colorimetric method (UV mini 1240, Shimadzu, Japan).

Ion chromatography technique was used to measure the anions and cations in landfill leachate. Anions, F^-, Cl^-, NO_2-N, NO_3-N, SO_4^{2-} and PO_4^{3-} and cations, NH_4^+, Mg^{2+} and Ca^{2+} were analyzed in collected landfill leachate samples using CLASS-VP software (Shimadzu, Japan).

The amount of organic pollutants in landfill leachate was measured in terms of biochemical oxygen demand for five days (BOD_5), chemical oxygen demand (COD), total organic carbon (TOC), inorganic carbon (IC) and total carbon (TC). TOC analyzer (TOC-V CSH, Shimadzu, Japan) was used to measure the TOC and IC. TC was calculated from IC and TOC results for each sample. Standards methods were used to analyze BOD_5 (Water test kit, Kyoritsu chemical check lab, corp., Japan) and COD (HACH DRB 200, USA) in leachate samples.

Landfill leachate was characterized by total heavy metal availability. Total concentrations of Cr, Mn, Fe, Ni, Cu, Zn, As, Se, Sr, Cd, Sb and Pb were measured in Inductively coupled plasma mass spectrometer (ICPM-8500, Shimadzu, Japan). Concentrations of pollutants were compared among landfill sites as well as with the maximum tolerance limit of each pollutant based on Sri Lankan Standards.

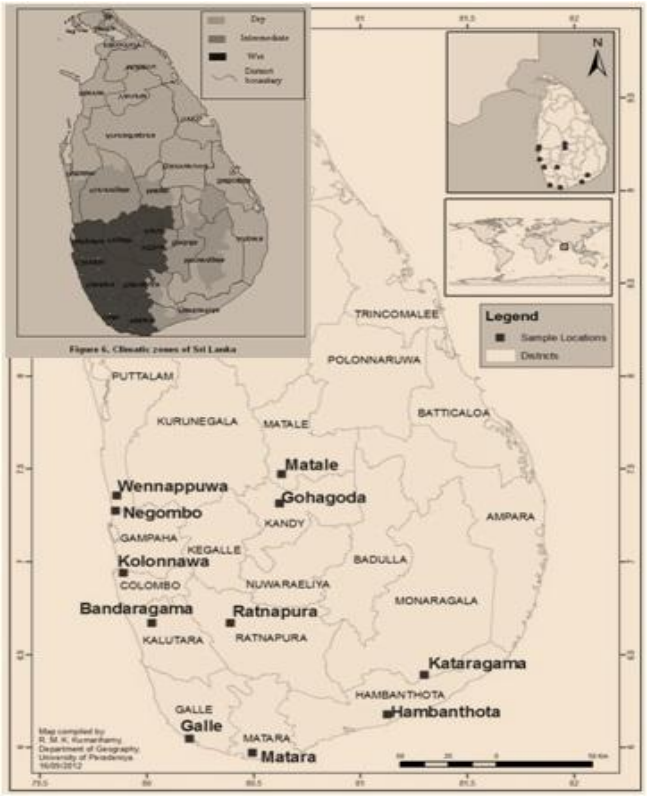

Figure 1: Landfill leachate sampling sites

3. Results and Discussion

Leachate quality is affected by environmental factors (temperature, moisture content), climatic factors (precipitation, drought), and factors related to the wastes (composition of wastes). Thus, the quality of

leachate changes with time and the location of the dumpsite. Selected open dumpsites for leachate collection are located in different areas of Sri Lanka. Most of them are located in the Wet Zone (Matale, Bandargama, Kolonnawa, Gampola, Gohagoda, Wennappuwa, Rathnapura, Negombo and Galle) of Sri Lanka while Hambantota and Kataragama are located in the Dry Zone. Open dump site located in Matara belongs to the Intermediate Zone of Sri Lanka.

3.1. Variation of general water quality parameters

General water quality parameters in landfill leachate are illustrated in Fig. 2. Almost all the leachate samples show a basic pH value ranging from 7.5 to 8.6 except for Rathnapura and Kolonnawa samples. The pH of leachate from Rathnapura and Kolonnawa dumpsites showed an acidic pH, 5.7 and 6.24, respectively. Generally, the fresh landfill leachate shows an acidic pH than matured leachate. Chen (1996) has observed the same variation in a study carried out to assess leachate characteristics. He has found that the pH of landfill leachate is increased with the age of the landfill due to the biological decomposition of organic N into ammonium N. The result in this study also shows the same tendency as that indicated by Chen (1996).

All the landfill leachate samples have a very low DO concentration which shows an anaerobic condition. This is also verified by the negative ORP values of the leachate samples. Electrical conductivity of all the samples ranged from 450 to 3830 mS m^{-1}. The highest EC was reported from Kolonnawa leachate sample which indicates that the dissolved ion content in landfill leachate from Kolonnawa site is higher over the other sites.

Total residue on evaporation represents the sum of both suspended and dissolved solids including colloidal materials in leachate. Kolonnawa leachate sample has the higher total residue among all the samples. Other samples had more or less similar concentration of total residue. However, approximately equal amount of suspended solids concentration were observed in all the samples. Therefore, the rest of the total residue is dissolved solids (DS) and the DS concentration is much higher in Kolonnawa sample than that in the other leachate samples.

3.2. Anions and cations in landfill leachate

Nitrogenous pollutants in landfill leachate

Figure 3 shows NH_4-N, NO_2-N NO_3-N and TN concentrations variation in landfill leachate from different dumpsites. Landfill leachate samples from Hambantota and Kataragama show very low concentrations of nitrogenous pollutants compared to other samples. Moreover, almost all the samples show very low concentrations of NO_2^- and NO_3^- as well as a high concentration of NH_4^+. Nitrite and nitrate concentrations were varied from 0 to 58.29 mg L^{-1} and 2.19 to 132 mg L^{-1}, respectively. On the other hand, ammonium concentration in leachate samples studied varied from 34 to 2753 mg L^{-1}. The highest concentration of NO_2^- and NO_3^- were shown in landfill leachate from Gohagoda and Negombo open dumpsites, respectively. As shown in Figure 3, the lowest and the highest NH_4^+ were shown in leachate from Kataragama and Matale dumpsites, respectively. However, for some landfill leachate samples, NH_4^+ concentrations show a higher value than TN concentration. This can be due to the changes occurred in the landfill leachate

from collection to the time of measurement, as the measurements of both parameters were not carried out simultaneously.

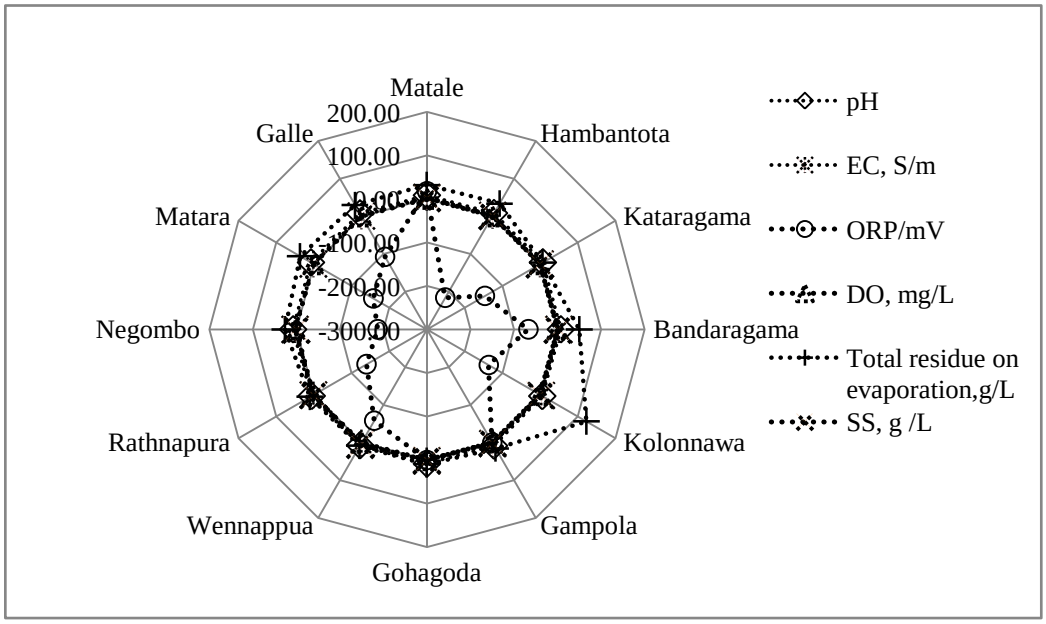

Figure 2: Variation of general water quality parameters in landfill leachates from different dumpsites

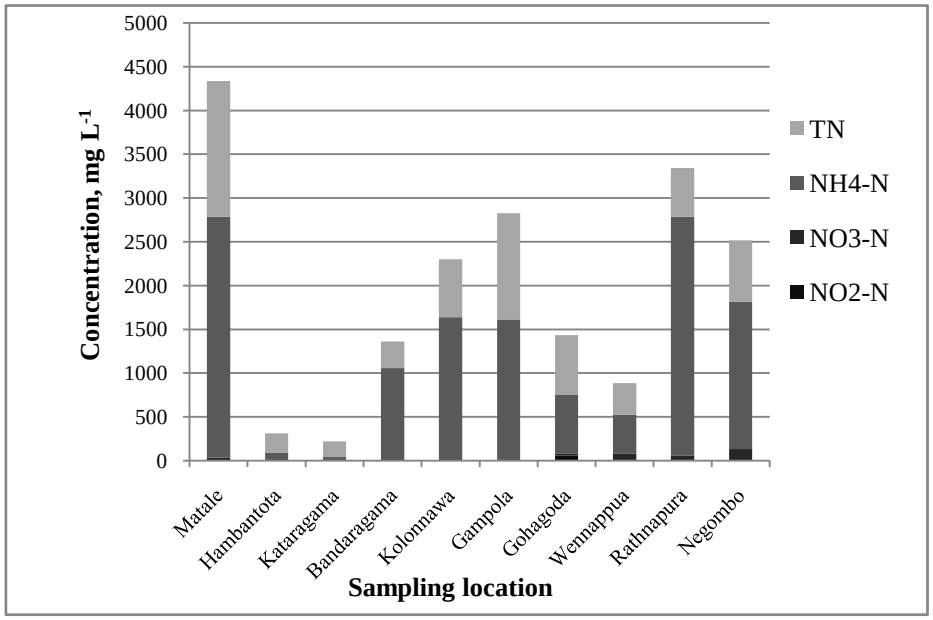

Figure 3: Nitrogenous pollutant variation in landfill leachate

In the case of nitrogenous pollutants, total ammonia, which has two forms as ammonium ion (NH_4^+) and free ammonia (NH_3) is important (Sri Shalini and Joseph, 2012). From the two forms, NH_3 is the active substrate and the most important N compound in surface water and other ecosystems. Ammonia concentration in landfill leachate varies with the age of the dumpsite ranging 100-5500 mg L^{-1} (Renoui et al., 2008). Sri Shalini and Joseph (2012) have stated that four groups of NH_3 as, beneficial (50-200 mg L^-

^{1}), detrimental (200-1000 mg L^{-1}), inhibitory (1500-3000 mg L^{-1}) and toxic (>5000 mg L^{-1}). However, in this study ammonia was not estimated as free ammonia in leachate and it was measured as NH_4^+. Most of the samples show a high concentration (>1000 mg L^{-1}) of NH_4^+ which indicates that the leachate is from old landfills and the high concentrations are resulted from hydrolysis and fermentation of the nitrogenous fractions of biodegradable substrates (Carley and Mavinic, 1991). Only leachate from Hambantota and Kataragama sites showed very low concentrations of NH_4^+ and it further suggests that landfill leachatefrom new landfills has very low NH_4^+ concentration.

Other anions and cations in landfill leachate

Analysis of F^-, Cl^-, SO_4^{2-} and PO_4^{3-}, Mg^{2+} and Ca^{2+} in leachate was carried out. Fluoride concentration was not detectable in the leachate from Gampola and Gohagoda dumpsites. Very high concentrations compared to maximum permissible level (2 mg L^{-1}) of F^- in wastewater to discharge in to inland surface water were observed from other dumpsites. Among them, landfill leachate from Kolonnawa showed a very high concentration of F^- (117 times higher than max. permissible limit) than other sites.

Chloride concentration in leachate in sites except for Kataragama is ranged from 3 to 6 times higher than the maximum permissible level and the highest concentration was observed in Kolonnawa leachate sample. The high concentrations of F^- and Cl^- in Kolonnawa landfill leachate could be due to the dumping of specific type of solid waste that contains F^- and Cl^-.

Sri Lankan standards for portable water was used to compare PO_4^{3-}, SO_4^{2-}, Mg^{2+} and Ca^{2+} ions in landfill leachate. Based on that, maximum permissible levels of PO_4^{3-}, SO_4^{2-}, Mg^{2+} and Ca^{2+} are 2.0, 400, 150 and 240 mg L^{-1}, respectively. Even though, the other pollutants are higher in Kolonnawa leachate sample, PO_4^{3-} was not detectable. Some sites showed a higher concentration than maximum permissible level. Very low concentrations of SO_4^{2-} were shown in landfill leachate from Matale, Kataragama and Bandaragama dumpsites. It was varied from 1.4 to 5.3 times higher than the maximum permissible level (400 mg L^{-1}) in other sites studied.

Only three sites, Matale, Hambantota and Bandaragama showed higher concentrations of Mg^{2+} than maximum permissible level in landfill leachate. On the other hand, very low concentrations of Ca^{2+} were observed in all the sites. These two cations, $Mg^{2+}$and Ca^{2+} are important in water quality as they cause hardness in water creating many problems such as formation of soap scum, galvanic corrosion etc.

3.3. Organic pollutants

Total organic carbon and inorganic carbon in leachate

Total organic carbon and inorganic carbon content variation in landfill leachate are illustrated in Fig. 4. Total carbon content in leachate is illustrated together with TOC and IC (Fig. 4). Accordingly, TC content is very high in Kolonnawa leachate sample than the other samples. In addition, IC content is very low in Kolonnawa, Matara and Galle leachate samples than the other sites and those were 50, 80 and 49 mg L^{-1}, respectively. Thus, almost all the TC in that leachate is organic carbon. Therefore, the wastes disposed in these landfill sites could be organic in nature. On the other hand, IC content is higher than the TOC content in landfill leachate from Wennanppuwa, Rathnapura and Negombo sites.

Other organic pollutants in leachate

Maximum permissible levels of BOD_5 and COD are 30 and 250 mg L^{-1}, respectively based on Sri Lankan standards. Both lowest BOD_5 and COD have resulted from Gohagoda landfill leachate and the highest BOD_5 and COD have resulted from Kolonnawa landfill leachate (Table 1). Both BOD_5 and COD in Kolonnawa landfill leachate are extremely higher than the other leachate samples and the concentrations are 49600 and 82577 mg L^{-1}, respectively. Kolonnawa landfill site is located near the Capital of Sri Lanka and the disposal of industrial wastes near Colombo area could be the reason for the high concentration of BOD_5 and COD.

Biodegradability of wastes can be measured by the ratio of BOD_5/COD (Kulikowska and Klimiuk, 2008). In this study, the ratio of BOD_5/COD varies from 0.01- 0.6 which indicates that the amount of biodegradable wastes are different in dumpsites studied. The highest amount of biodegradable wastes is in Kolonnawa landfill leachate followed by Rathnapura leachate. The ratio of BOD_5/COD in Kolonnawa and Rathnapura landfill leachates are 0.6 and 0.27, respectively. All the other samples show very low values of BOD_5/COD ratio which indicates a considerable amount of biologically inert materials in leachates. Moreover, it has shown that the ratio of 0.1 or lower is resulted from old landfill leachate (Kurniawan et al., 2006).

In contrast, the TN showed a higher concentration in leachate from Matale and Gampola landfill sites and the TP concentrations were low in all the leachate samples.

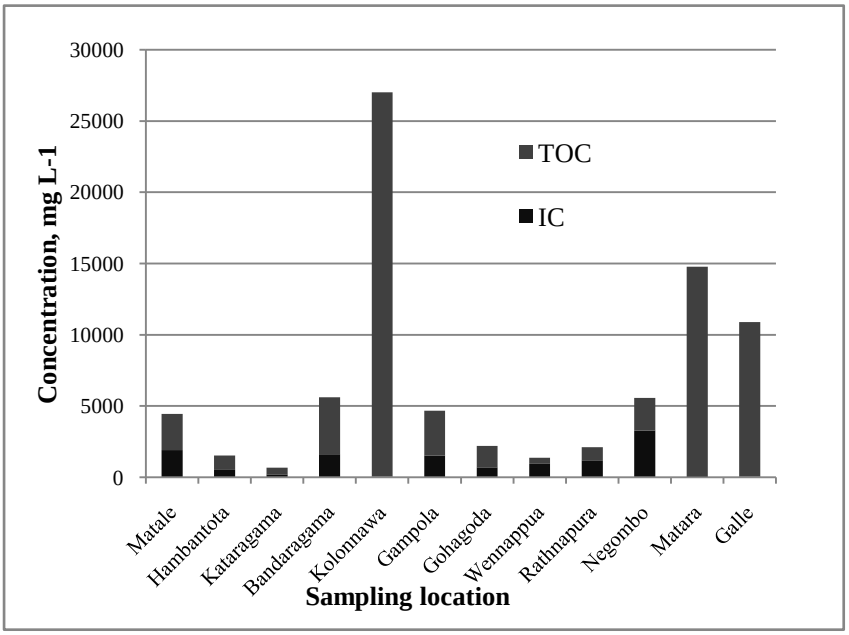

Figure 4: Variation of TOC and IC in landfill leachate

3.4. Heavy metals in landfill leachate

Heavy metals in landfill leachate were determined as total metal concentration. Heavy metal concentrations were compared with the maximum permissible level of heavy metal in wastewater to be discharged in to inland surface water (CEA, 1990). Comparison was carried out by calculating quality

rating scales as per the eq.1 (Ramakrishnaiah et al., 2009). Heavy metal concentrations and the respective quality rating scales (QRS) are listed in Table 2 and 3, respectively.

$$q_i = \frac{C_i}{S_i} \times 100 \qquad (1)$$

Where,
q_i = Quality rating scale (%)
C_i = Concentration of heavy metal in leachate (mg L^{-1})
S_i = Tolerance limit/maximum permissible level of heavy metal (mg L^{-1})

Table 1: Biochemical oxygen demand, chemical oxygen demand, total nitrogen and total phosphorous content in leachate

Sample	*BOD_5*	*COD*	*BOD_5/COD*	*TN*	*TP*
Matale	*71*	*4236*	*0.02*	*1549*	*43*
Hambantota	*49*	*2475*	*0.02*	*224*	*12*
Kataragama	*38*	*1047*	*0.04*	*180*	*20*
Bandargama	*938*	*9279*	*0.10*	*305*	*24*
Kolonnawa	*49600*	*82577*	*0.60*	*664*	*11*
Gampola	*41*	*1249*	*0.03*	*1212*	*6*
Gohagoda	*19*	*714*	*0.03*	*684*	*8*
Wennappuwa	*86*	*2405*	*0.04*	*361*	*18*
Rathnapura	*3757*	*13951*	*0.27*	*558*	*35*
Negombo	*294*	*18328*	*0.02*	*703*	*86*

The impact of heavy metal is different from each other and accordingly the maximum permissible level is different. Therefore, it is important to consider a common factor like QRS to study the impact of heavy metals. Table 2 shows the maximum permissible level of heavy metals based on Sri Lankan standards for wastewater to be discharged in to inland surface waters (CEA, 1990). Accordingly, maximum permissible levels of As, Cr, Cd and Pb are lower than the other metals.

Even though, the concentrations of those metals are low, the impact of them is higher which is shown by the QRS (Table 3). Most of the heavy metals studied showed a higher concentration in Kolonnawa leachate sample which could be a result of dumping industrial wastes in to the Kolonnawa dumpsite since it is located near to the industrial area.

Landfill leachate from Kataragama landfill shows only high concentration of Pb and the concentration of other metals are lower than the maximum permissible level. It was observed that most of the wastes dumped in the Kataragama landfill are food wastes from the nearby temple. It can be the reason for low levels of other pollutants also in Kataragama landfill leachate.

Even though, the concentrations of Ni and Cu are higher in most of the leachate samples, the impact is very low compared to other metals. The highest QRS for Ni (149%) was obtained for Kolonnawa leachate sample and none of the QRS values of Cu exceeded 100.

Among the heavy metals studied in this study, Cr, Fe, As, Se and Cd show higher QRS for most of the samples. However, some researchers have mentioned that Fe is not considered as a heavy metal and that falls onto the group called inorganic macrocomponents which occur at high concentrations (Slack, et al., 2005).

4. Conclusions

The results of the study showed clearly the complex nature of landfill leachate from different sites due to the differences in waste composition, moisture content, climatic conditions etc. the effect of each pollutant was different from site to site as the concentration of each pollutant varies with the site. It was noted that the most of the pollutants, BOD_5, COD, TOC and some heavy metals are much higher in landfill leachate from Kolonnawa site while nitrogenous pollutants are higher in landfill leachate from Matale dumpsite. The highest concentrations of BOD_5, COD, TOC are 49600, 82577 and 26970 mg L^{-1}, respectively. Landfill leachate from Matale, Bandaragama, Hambantota and Kolonnawa are polluted with heavy metals, Cr, Zn, As, Se, Ni and Pb than the leachate from other sites. According to the results of the study, it is clear that the leachate from MSW dumpsites is loaded with different kinds of pollutants. Therefore, the characterization of landfill leachate is important before deciding the leachate remediation methods for a particular MSW dumpsite. The results of this study will be used to develop a permeable reactive barrier in landfill leachate treatment in Sri Lanka.

Table 2: Heavy metal concentrations in landfill leachate and the maximum tolerance limits of heavy metals. Values are in μg L^{-1}

Sample	*Cr*	*Fe*	*Ni*	*Cu*	*Zn*	*As*	*Se*	*Cd*	*Pb*
Matale	*345*	*60762*	*115*	*573*	*6876*	*522*	*1935*	*100*	*1777*
Hambantota	*80*	*5341*	*226*	*166*	*19909*	*678*	*2522*	*172*	*492*
Kataragama	*11*	*1117*	*89*	*58*	*638*	*106*	*400*	*50*	*123*
Bandargama	*329*	*7167*	*912*	*227*	*5362*	*722*	*2607*	*90*	*479*
Kolonnawa	*1968*	*346930*	*4473*	*55*	*11759*	*705*	*2443*	*15*	*421*
Gampola	*220*	*5546*	*335*	*734*	*462*	*164*	*461*	*4*	*34*
Gohagoda	*139*	*3004*	*331*	*334*	*389*	*148*	*465*	*1*	*19*
Wennappuwa	*363*	*2501*	*399*	*431*	*409*	*939*	*2812*	*53*	*87*
Rathnapura	*439*	*56343*	*1311*	*627*	*1685*	*1551*	*4922*	*52*	*168*
Negombo	*330*	*20111*	*666*	*535*	*2062*	*846*	*2184*	*51*	*333*
Matara	*830*	*7528*	*571*	*464*	*500*	*1219*	*3705*	*48*	*60*
Galle	*486*	*15477*	*673*	*564*	*593*	*1796*	*5947*	*52*	*169*
Max. permissible level	***100***	***3000***	***3000***	***3000***	***5000***	***200***	***500***	***100***	***100***

Table 3: Quality rating scale values of heavy metals for leachate samples. Values are in percentages.

Sample	QRS_{Cr}	QRS_{Fe}	QRS_{Ni}	QRS_{Cu}	QRS_{Zn}	QRS_{As}	QRS_{Se}	QRS_{Cd}	QRS_{Pb}
Matale	***345***	***2025***	*38*	*19*	***138***	***261***	***387***	***100***	***1777***
Hambantota	*80*	***178***	*8*	*6*	***398***	***339***	***504***	***172***	***492***
Kataragama	*11*	*37*	*3*	*2*	*13*	*53*	*80*	*50*	***123***
Bandargama	***329***	***239***	*31*	*8*	***107***	***361***	***521***	*90*	***479***
Kolonnawa	***1968***	***11564***	***149***	*2*	***235***	***352***	***488***	*15*	***421***
Gampola	***220***	***185***	*11*	*24*	*9*	*82*	*92*	*4*	*34*
Gohagoda	***139***	***100***	*11*	*11*	*8*	*74*	*93*	*1*	*19*
Wennappuwa	***363***	*83*	*13*	*14*	*8*	***469***	***562***	*53*	*87*
Rathnapura	***439***	***1878***	*44*	*21*	*34*	***775***	***984***	*52*	***168***
Negombo	***331***	***670***	*22*	*18*	*42*	***423***	***437***	*51*	***333***
Matara	***831***	***251***	*19*	*16.*	*10*	***609***	***741***	*48*	*60*
Galle	***486***	***516***	*22*	*19*	*12*	***898***	***1189***	*52*	***169***

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