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Design and Development of Bio-Reactors and Leachate Barricades for landfill Leachate Treatment

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Abstract: The treatment of leachate from open dump sites/landfills is a challenging task due to its complexity and high pollutant loads. In recent years, new technologies have been developed on leachate treatment however, most of them are expensive and complex to conduct. Anaerobic ammonium oxidation of nitrite to N_2(ANAMMOX) has gained recent attention to treat high ammonia wastewaters. At the same time, Biochar (BC) pyrolyzed by the biowaste of municipal solid waste (MSW) has shown a promising capacity in removing nutrients, heavy metals, total solids and organics including volatile organic compounds (VOCs) in landfill leachate.Hence, the objectives of the study are to treat nitrogen rich leachate through anammox and biochar barricades followed by a biochar embeddedsubsurface constructionwetland.

Characterization of landfill leachate was done for the leachate from the Karadiyana dump site for various parameters indicated that the leachate was highly contaminated from solids both total and volatiles (6000-25000 mg/L), low nitrate however with high ammonia-N (900 mg/L), high Chemical Oxygen Demand (COD) (6000 to 20000 mg/L) and high heavy metals/metalloids such as Zn, As etc. Initially anammox bacteria were incubated in laboratory scale. Biochar production was taken place at the dump site using the barrel method for the residue from composting by slow pyrolyzing process.The discharge of leachate was measured using a v-notch.The pre-filter columnshaving both wood biochar and MSW biochar were strong enough to remove COD considerably and ammonia, nitrate and EC at initial stage. However, the removal efficiency continues to drop over the time. The pre-treatment unit showed a potential removal of contaminants from leachate and based on that designs were done for the pilot scale treatment train for the site.

Keywords: Open dump, Leachate, ANAMMOX reactor, biochar barricades, Constructed Wetlands

1. Introduction

The practice of open waste dumping is a significant issue in Sri Lanka. Municipal Solid Waste (MSW)—more commonly known as trash or garbage—consists of everyday items we use and then throw away, such as product packaging, grass clippings, furniture, clothing, bottles, food scraps, newspapers, appliances, paint, and batteries. This comes from our homes, schools, hospitals, and businesses. Current global MSW generation levels are approximately 1.3 billion tonnes per year and are expected to increase to approximately 2.2 billion tonnes per year by 2025 [1]. This represents a significant increase in per capita waste generation rates, from 1.2 to 1.42 kg per person per day in the next fifteen years whereas in Sri Lanka it is estimated to be slightly less than 1 kg [2]. However, global averages are broad estimates only as rates vary considerably by region, country, city, and even within cities, Analysis of data has revealed that the amount of MSW per capita per day on average was 0.85 kg in Colombo Municipal Council, 0.75 kg in other Municipal Councils, 0.60 kg in Urban Councils, and 0.40 kg in PradeshiyaSabhas [1]. Between 1999 and 2009, the amount of solid waste generated daily rose from an estimated 6,500 metric tons to 7,500 metric tons [3]. Of this waste, as much as 85 percent is deposited at open dumpsites each day [4]. In Sri Lanka, solid wastes are collected and disposed in mixed state and being dumped in places like road

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sides, marshy lands, low lying areas, public places, forest and wild life areas, wet lands, water courses (Karadiyana, Manampitiya, Bloemendhal, Gohagoda waste dumping sites, etc). It leads to various harmful environmental impacts such as ground and surface water pollution, air, visual/aesthetic pollution. Further, these places are ideal for breeding of disease vectors such as mosquitoes [5]. Managing waste properly is essential for building sustainable and livable cities, but it remains a challenge for many developing countries and cities. Effective waste management is expensive, often comprising 20%–50% of municipal budgets. Operating this essential municipal service requires integrated systems that are efficient, sustainable, and socially supported [2,6].Further, leachatereleased from decomposing waste is contaminating soil and waterways while biodiversity and ecosystem health is threatened by the location of these dumpsites in ecologically sensitive areas [7].

Modern landfills are always designed to prevent liquid fromleaching out and entering the environment. However, if they are not properly managed, the groundwater at a risk for pollution by mixing with leachatewhich can have polluting effects on surface water and groundwater. Hence, the characterization of landfill leachate is important to identify the complexity [8].

The landfill leachate can be generally categorized into four main groups of compounds namely dissolved organic matter (COD, TOC including CH_4, volatile fatty acids and more refractory compounds), Inorganic macro components (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, NH^{4+}, $Fe^{2+}/^{3+}$, Mn^{2+}, Cl^{-}, SO_4^{2-}, and HCO_3^{-}), heavy metals (As, Hg, Cd, Cr, Cu, Pb, Ni and Zn) and xenobiotic organic compounds (XOCs) [9].High content of nitrate and phosphate cause eutrophication in lakes Whereas heavy metals are highly reactive and often toxic at low concentrations, they may enter soils and groundwater, bioaccumulation in food webs, and adversely affect biota, which can then lead into irreversible changes in the body especially in the central nervous system [10-11]. Therefore direct discharge of leachate causes significant threat to water bodies.

2. Present status

In Sri Lanka, urban areas are identified as Municipal council (MC) and Urban council (UC) areas, accordingly there are 23 and 41 MCs and UCs respectively. Waste collection and disposal is happening in all the above MCs and UCs. It is estimated that over 6400 tons/day of solid waste are generated in Sri Lanka[12]. The most common practice in almost all municipalities in Sri Lanka are open burning, land filling (not technical) and open dumping of wastes. These methods are not considered as environmental friendly. About 85 % of collected waste in Sri Lanka is subjected to open dumping. Further, there are very good SWM system has been established in most of the councils in Sri Lanka. However, operation, maintenance, monitoring and evaluations are not properly implementing by these local authorities which leads for so many solid waste issues in urban areas of Sri Lanka. Further, today SWM issues are become a major environmental problem and also a national issue [13].

For the last 2 decades government institutions have attempted to figure out the best waste management strategy for the country. While some policies and actions supported sanitary landfills, some initiatives were driven towards waste to energy projects. In 2008, CEA initiated a 10 year Waste Management Programme named “Pilisaru Programme” with the goal of “Waste Free Sri Lanka by 2018”. Unfortunately, the lack of a unified coherent strategy has led to inconsistent and ineffective practices [14].

Previous studies have reported leachate quality in few open dump sites in Sri Lanka including Karadiyana however, focus have been only on few main inorganic parameters [15-16]. Not many studies have been conducted to investigate the organic pollutants present except Volatile Organic Compounds (VOCs) where the studies revealed the most common VOCs in few Sri Lankan dump sites [17].

Treatment of landfill leachate was focus mainly on physical-chemical methods for landfill leachate treatment. The physical-chemical ways for landfill leachate treatments are Chemical precipitation, Chemical Oxidation, Coagulation–Flocculation, Membrane filtration, Ion exchange, Adsorption and Electrochemical treatment [18]. Some researchers have reviewed various leachate treatment technologies such as adsorption by reverse osmosis [19], activated carbon, biological treatment, constructed wetlands [18], howeverthere treatment efficiency depending on the leachate characteristic and operational conditions. In Sri

Lanka, previous researches conducted experiments using two stages biological treatment processes and Sequencing Batch Reactor to treat the leachate [20]. If persistent biological compounds remain in the wastewater, activated carbon filters and/or ozonisation are employed to remove these contaminants. But high-tech solutions applied for leachate treatment such as reverse osmosis or ozonation are expensive and energy consuming [21], thus they are not affordable to developing countries like Sri Lanka. Hence, the objectives in this study are to design and develop an economical, basic leachate treatment train in order to minimize the contamination of water bodies.

3. Methodology

3.1 Leachate quality and quantity

The leachate discharge was measured using a v-notch to determine parameters of basin while the quality was assessed for many different parameters.Solid content of the leachate (TSS, VSS, TS, and VS) was obtained by membrane filter paper techniques. The general parameters of DO, EC, BOD, NH_3 were measured by Orion 5 star meter, (Thermo Scientific, USA) equipped with electrode system. Portable data logging colorimeter (Model DR/ 890, HACH, USA) were used in measuring COD while carbon type was obtained by the TOC analyser (Shimadzu Japan).Cations and heavy metalcontent was determined using an Inductive couple plasma emission spectrometer (ICP-OES 7000 Thermo, USA) as well as anions by Ion chromatograph (Shimadzu CDD 10A). Quantitative analysis of VOCs were performed using static headspace equipped gas chromatography coupled mass-spectrometer (Shimadzu QP 2010)(Table 3).

3.2 ANAMMOX reactor

Anammox bacteria are currently incubating in laboratory to populate in anaerobicdigester with anammox bacteria. Activated sludge was used to incubate anammox bacteria in an anaerobic digester with temperature 35˚C. Synthetic medium was used to feed, containing $NaNO_2$(30mg N/L), NH_4Cl (30 mg N/L), $NaNO_3$ (0–14 mg N/L), $KHCO_3$ (0.4 g/L), KH_2PO_4, (0.040 g/L), $MgSO_4$_7H2O (0.25 g/L) and $CaCl_2$ (0.30 g/L) and micro-nutrients dissolved in demi water [22].

3.3 Designing treatment process

Treatment tanks will be designed with respect to maximum discharge to treat the leachate to remove the pollutants from the leachate. High concentrations of ammonia in the leachate may become a hindrance to the effective functioning of bioreactor landfills. Thus, the stabilization of landfill leachate with respect to ammonia is very important. Therefore, initially leachate was passed through annomox tank in order toreduce nitrogen component. Thereafter, biochar barricades, finally through the constructed wetland.

3.4 Design of constructed wetland

Constructed wetland was designed based on leachate quality according to test results.The constructed wetland inlet was designed to increase aeration of the lagoon effluent. It was composed PVC pipe at the top of the berm. The wastewater will be aerated as it cascades down a rip-rap slope as shown in figure 1.

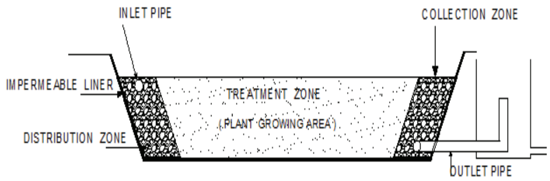

Figure 1 – Proposed constructed wetland

3.5 Biochar Production

The biochar production was carried out using organic waste in Karadiyana open dump site under various fractions of oxygen ranging from 0% to 11% by heating to a temperature range about 600-700°C. It was made by two 200 litre steel barrels and two 60 litre steel barrels. Small holes were cut into bottom of one large barrel and it was used as pyrolyzer drum. It was filled with chopped wood pieces. An ample amount of air was allowed in to the larger barrel and there wasn't any hole in smaller one. The biomass was stocked into the smaller barrel as tight as possible, with the whole inverted into the larger barrel. The space between the barrels filled with wood and ignited. The lid of the small barrel was cut with small openings, so the gases producing during pyrolysis process can escape. Then it was covered with a large barrel with a 30cm diameter hole cut on top of the barrel, which was used as chimney drum. The next small barrel was fixed on top of chimney drum to facilitate emission.

Then the pyrolyzer drum was allowed to burn for three hours. If necessary, more wood was inserted to the pyrolyzer drum. The setup is shown in figure 2.

Figure 2- Biochar production technique (left) and the resulted MSW biochar (Top right) and wood biochar (Bottom right)

After burning completed, water was poured to drums as it was cooldown. The small drum which filled with municipal solid waste was opened and it was quenched with water. The advantage of this method is that you generate a batch of high temperature gasifier wood biochar and use the heat given off to generate a second small of MSW char.
The biochar was allowed to dry on sunlight for one day to remove the moisture. Then it was crushed and sieved. Particle size less than 5mm and greater than 1.18mm was collected to fill up the biochar column.

3.6 Preparation of biochar columns
An anaerobic digester was used to prepare the biochar columnin order to quantify the removal of pollutants. The biochar was added in small layers while adding water. Every layer was compacted with a tamping rod to remove air voids. After fill up with biochar, a layer of laterite (particle size range 3.5mm – 14mm) was placed and compacted. The biochar: laterite weight ratio was kept as 1: 2. Then water was pumped until one pore volume of voids completely filled with water. Then water was replaced with leachate. Figure 3 shows the experimental set up for testing this leachate.Retention time of leachate in biochar column was adjusted to 24 hours.

Figure 3 – Experimental set up for testing leachate treatment with biochar columns

3.7 Design of biochar tank
The proposed biochar embedded leachate barricade for Karadiyana dump siteis shown in figure 4. This was designed based on the biochar column test results.

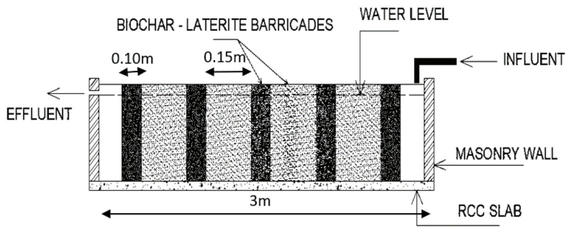

Figure 4 – Proposed biochar tank

3.8 Testing the effluent
Samples were taken from effluent pipe after every pore volume is replaced with leachate. Samples were tested for pH, Electrical conductivity, COD, NO_3^- and ammonia nitrogen. Same tests were done to influent leachate.

4. Results & Discussion

Physical and chemical properties of raw leachates in Karadiyana Open Dump Site was tested and the results are shown in table 1.The discharge of leachate was measured using a v-notch in order to determine parameters of basins.

Figure 5 shows the variation of leachate discharge with time & the variation of rainfall with time. It could be seen that the leachate discharge varies from 2.4 l/s to 0.02 l/s in rainy to dry period respectively. Maximum leachate discharge shows when the rainfall is maximum, 8mm. Landfill leachate quality were influenced from the waste composition, the age of landfill, waste amount, rain intensity as well as the category of municipal landfill solid waste [23].

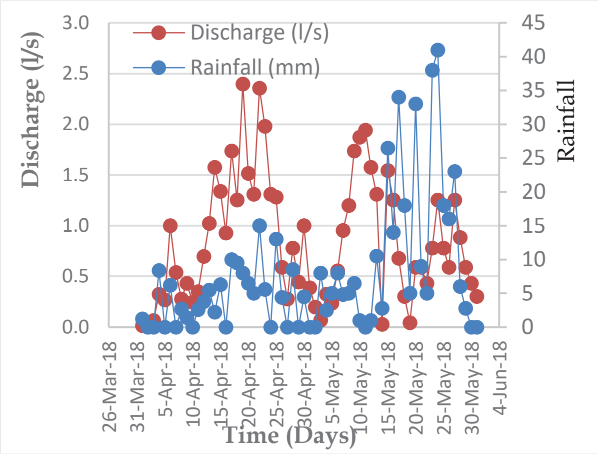

Figure5 – The graph of Leachate discharge Vs Time & Rainfall Vs Time fromApril 2018

Therefore, the concentrations of each parameter differ because of rainfall. However the generation of leachate quantity is quit high in the rainy days with compare to dry period.

Table 1 – Water quality parameters of leachate and treated water of lab scale permeable bio reactor with MSW biochar

Parameter	pH	COD	NH_3-N	EC	NO_3^--N
Unit	-	mg/l	mg/l	mS/cm	mg/l
Influent	8.73	4110	780	13.08	126
Sample 1 (42 hrs)	9.3	824	40	3.099	11
Sample 2 (66 hrs)	8.82	1300	360	5.129	25
Sample 3 (90 hrs)	8.52	1600	500	10.93	26
Sample 4 (114 hrs)	8.42	1080	680	10.93	24
Sample 5 (139 hrs)	8.39	1640	760	12.23	45
Sample 6 (163hrs)	8.42	1550	760	12.83	17

The results of testing for MSW biochar are denoted in table 1. Two biomass input materials were selected for this study, wood & Municipal Solid Waste. Differences in pH can be observed for the biomass types: biochar produced from wood has an average lower pH in solution than the values for the other feedstocks produced by MSW. The pH of the biochar is likely to be correlated with the presence of oxygen functionalities in the biochar: during thermochemical conversion with lower process intensity, more labile – and more oxygenated – carbon is retained. Consequently, at higher pyrolysis severity, the amount of carboxyl groups in the resulting biochar has been reduced and/or the acidic groups have become deprotonated to the conjugate bases resulting in more alkaline pH of the biochar in suspension. Another contributing factor to the rise in pH at more severe pyrolysis conditions is the relative increase of ash content in the biochar [24].

Table 2 –Water qualityparameters of leachate and treated water of lab scale permeable bio reactor with wood biochar

Parameter	pH	COD	NH_3-N	EC	NO_3^--N
Unit	-	mg/l	mg/l	mS/cm	mg/l
Influent	8.62	4110	760	9.87	58
Sample 1 (52 hrs)	8.15	19	0.09	0.47	0.7
Sample 2 (80 hrs)	8.29	397	22	3.82	7
Sample 3 (128 hrs)	8.22	2600	560	8.38	27
Sample 4 (169 hrs)	7.84	1359	540	9.07	35
Sample 5 (208 hrs)	7.96	1990	620	9.441	30
Sample 6 (247 hrs)	7.92	2100	660	9.97	51

The variation of COD, EC, NO_3^--N, NH_3-N concentration with time are shown below.

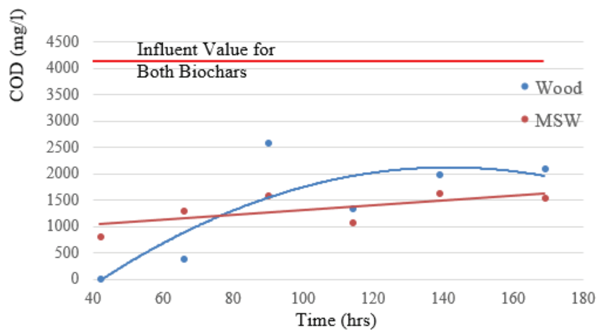

Figure 6 – COD reductionof leachatein the MSW& Wood biochar reactors

The influent COD was 4200 mg/L and after passing through MSW and wood under optimum conditions, the final COD is low in wood biochar compare to MSW as in the figure 6. Also, there is a considerable high reduction in COD in 1st sample compare to the influent and with the time COD value has been increased. It can be concluded the COD reduction is decrease with the time.

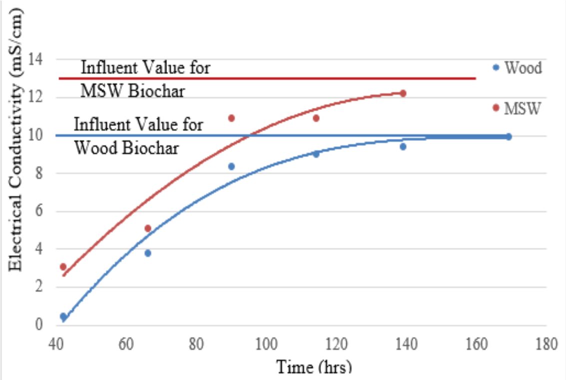

Figure 7 – Reduction of Electrical Conductivity of leachate in the MSW & Wood biochar reactors

Electrical conductivityhas been reduced in both MSW and wood biochar. With the time conductivity has been increased (refer figure 7). This indicates the continuous flow of leachate through biochar reduces removal of EC.

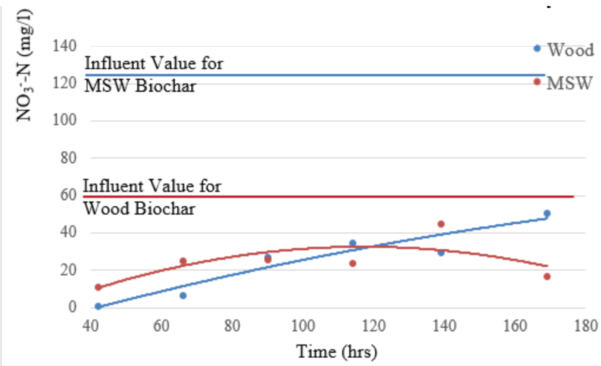

Figure 8 – Reduction of NO_3^--N of leachate in the MSW & Wood biochar reactors

Initially, the concentration of NO_3^- - N is higherwhen comparedto the effluent of wood and MSW reactors. It's revealed that MSW biochar has reduced considerable amount of NO_3- - N in leachate than the wood biochar (refer figure 8). Also, it can be noted that the continuous flow of leachate through biochar has impacted on the removal of NO_3- - N.

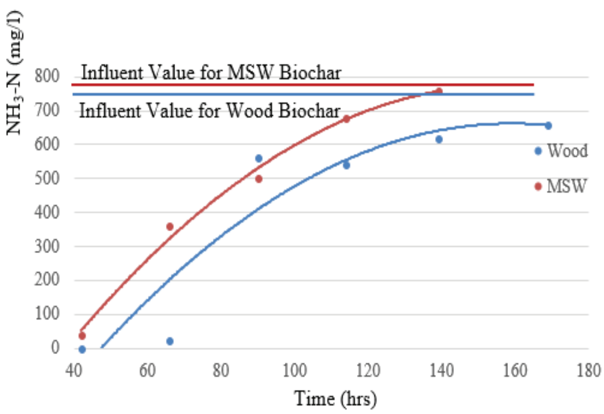

Figure 9 –Reduction of NH_3-N of leachate in the MSW & Wood biochar reactors

Ammonia in leachate is reduced by both wood and MSW biochar. But it can be noted a high reduction of ammonia is shows in wood biochar as shown in figure 9. Also, with the time ammonia removal efficiency has been decreased.

It can be concluded that the continuous flow of leachate through biochar significantly effect for reducing contaminant. Initially each pollutant has been decreased considerably, with the time pollutant removal efficiency is decreased. Also, this concludes the composition of the biochar correlated with the constitution of the biomass used to made biochar. The type of feedstock material is important factor that determines the final application of the biochar because its properties are affected by the nature of the original material.

Anyway MSW biochar has potential as an environmental adsorbent to remove organic and inorganic pollutants from water systems. Because of the relatively low cost and the abundance of biomass materials from waste, biochar is becoming a practical alternative remediation agent for heavy metal (loid) s contaminants in the environment [24, 25].

Leachate is generally found to have pH between 4.5 and 9 [26].Initial low pH is due to high concentration of volatile fatty acids [26]. Stabilized leachate shows fairly constant pH with little variations and it may range between r7.5 and 9 [28]. However, the results indicate a slightly basic pH value for leachate (range: 7.4–8.8), which reveals an initial methanogenic phase. Major landfill sites under the same climatic conditions in Sri Lanka show methanogenic conditions [29].

The BOD & COD values recorded for the leachate samples were above the permissible standard limit. (BOI limits for BOD & COD are 30mg/l & 250mg/l respectively) This may be due to the reason that with time the solid waste material gets. The BOD value highly depends on organic substances that decompose in early stage. For new landfills, BOD values are up to 30000 mg/L; for mature landfills, BOD varies from 100-200 mg/L [30]. BOD/COD ratio shows the degree of biodegradation and gives the information regarding the age of land fill. In this case BOD/COD ratio of the leachate is approximately 0.5, which indicates the majority of the organic compounds present are biodegradable.

Table 3 – Leachate quality in Karadiyana Open Dump

General parameters	pH	8.24
	EC (mS/cm)	21.9
	T (°C)	29.5
	DO (mg/L)	0.56
	TDS (mg/L)	10.95
	COD (mg/L)	5990
	BOD (mg/L)	1022
	TS (mg/L)	24928
	VS (mg/L)	11472
	TSS (mg/L)	3762
	VSS (mg/L)	1692
	ORP (mv)	-316
Anion	PO_4^{3-} (mg/L)	20.62
	Cl^- (mg/L)	3954.22
	NO_2^- (mg/L)	Nd
	Br^- (mg/L)	3
	NO_3^- (mg/L)	6.52
	NH_4^+ (mg/L)	972
Macro elements	Na	6720
	K	2290
	Ca	14
	Mg	19
Trace metals total	Cd (µg/L)	15.14
	Ni (µg/L)	497.27
	Zn (µg/L)	10370.64
	Mn (µg/L)	3158.17
	Cr (µg/L)	1000.88
	Pb (µg/L)	701.15
	Co (µg/L)	167.47
	Cu (µg/L)	1183.79
	As (µg/L)	87.40
	Fe (mg/L)	31422.00
Organics	TC (mg/L)	2410.00
	IC (mg/L)	1080.40
	TOC (mg/L)	1329.60
	TN (mg/L)	1333.40
Biological	total coliform	2100
VOC	Benzene (µg/L)	Nd
	Toluene (µg/L)	19.06
	4-Isopropyltoluene (µg/L)	1.59
	Naphthalene	0.59

Nd = not detected

High organic and inorganic solids contributed to high TSS concentration and the metal salts to high EC. This high value of EC is attributable to high levels of anions and cations in the samples. Also the high values TSS indicate that leachates in this study could be undergoing biodegradation, thereby increasing the solids.

The high phosphate values in leachate may be due to the organic load of the refuse that contains phosphorus. This organic material (mainly phospholipids and phosphoproteins) during its biodegradation releases phosphorus and eventually increases phosphate concentrations [31]. Ammonia nitrogen can have a negative environmental impact, and it is known as one of the major toxicants to living organisms. This can result from the deamination of amino acids during the destruction of organic compounds. Higher concentrations of ammonia are also known to enhance algal growth, promote eutrophication due to decreased dissolved oxygen.Due to its toxicity it can also disrupt biological leachate treatment operations [32].

Selected trace metals, such as Cu, Ni, Cd, Zn, Pb, and Mn concentrationsare higher in raw leachateas it exceeds the permissible limit in each pollutant when it disposes to the natural waterbody. Excessive heavy metal concentration indicates the open dump acid phase or the end of the acid phase and the beginning of the methanogenic phase [33].The biochar embedded subsurfaceconstructed wetland which give promising results [34] was constructed followed by the biochar barricades. In Sri Lanka there are many small-scale dump sitesbelongs to local authorities which are practicing composting as a solution for Solid waste management [35]. During composting the generation of leachate is neglected. The leachate method proposed by this research can be recommended for small scale composting sites.

5. Conclusions

Leachate found to be high in many parameters exceeding the permissible levels of discharge adopted by the Central Environmental Authority.Initially Wood and MSW biochar considerably remove pollutantin leachate. Both wood biochar and MSW biochar has high removal efficiency of COD, ammonia, nitrate and EC at initial stage.However, the removal efficiency continues to drop over time which may be resolved through decreasing the flow rate. The pre-treatment unit showed a potential removal of contaminants from leachate, which indicates its possibility to be used as a pre-filter prior to Anammox treatment system.

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