EVALUATING THE PERFORMANCE OF SUBSURFACE HORIZONTAL FLOW CONSTRUCTED WETLAND FOR TERTIARY TREATMENT OF SANITARY LANDFILL LEACHATE

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Degree of Master of Science

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Abstract

The difficulty in detecting and quantifying the typical composition characteristics of landfill leachate, limit successful treatment of it. High quality effluent that can be discharged to surface waters could be achieved by using the two stage leachate treatment systems with a constructed wetland at the final stage. This pilot scale study was conducted with the aim of evaluating the tertiary treatment of pre-treated leachate obtained from Sanitary Landfill located at Dompe, by a subsurface horizontal flow constructed wetland comprising *Phragmites karka* and Calicut tiles as substrate. The removal efficiency of BOD_5, COD, TSS, NO_3^--N and PO_4^{3-}-P was evaluated. The study period was from June to August 2017. Sixty liters of diluted pre-treated leachate (i.e. Containing 80% of the pre-treated leachate by volume) was fed per day with a hydraulic retention time of 1 day. Concentration based average removal efficiency of the system was 63% for BOD_5, 62% for COD, 96% for TSS, 49.11% for NO_3^- -N and 85.28% for PO_4^{3-}-P. Long term research is necessary to examine the effects of continuous feeding and shock loadings on the growth response of *Phragmites karka*.

Key words: Horizontal Subsurface Flow, *Phragmites karka,* Removal Efficiency

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LIST OF ABBREVIATIONS

Abbreviation	Description
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
FWS	Free Water Surface System
HF	Horizontal Flow
HRT	Hydraulic Retention Time
HSSF	Horizontal Sub-Surface Flow constructed wetland
NH_4-N	Ammoniacal Nitrogen
NO_2-N	Nitrite as Nitrogen
NO_3-N	Nitrate as Nitrogen
P	Phosphorus
PO_4-P	Phosphate as phosphorus
SSFS	Subsurface Flow System
TDS	Total Dissolved Solids
TKN	Total Kjeldal Nitrogen
TP	Total phosphorus
TS	Total Solids
TSS	Total Suspended Solids
VF	Vertical Flow
VSF	Vertical Subsurface Flow

LIST OF APPENDICES

CHAPTER 1: INTRODUCTION

In a rapidly urbanizing global society today, solid waste generation becomes a key challenge faced by the entire world. In developing countries, its management has become a major concern due to increasing population, economic development and rapid urbanization. The pollution caused by indiscriminate dumping of solid waste is one of the major causes of ill health of the population and poor quality of the environment. Thus, in waste management, environmentally and economically sustainable disposal options are in priority.

Although there are several methods, the most popular way to dispose municipal solid wastes is Landfilling (Sogut et al., 2005). Among the total worldwide collection of municipal solid waste, around 95% are disposed to Landfills (Akinbile et al., 2012). Currently leakage and leachate management in landfill is documented as one of the important problems linked with the environment. Landfill leachate is a liquid produced by the infiltration of fluid into refuse and comprises materials dissolved in water and other liquid disposed of within the refuse. Within the landfill this liquid collects in areas as it drains through the refuse (Alker et al., 1995). In a contained site like sanitary landfill this liquid encounters an impermeable barrier and is channeled towards a collection point from where it is usually pumped away for treatment. The leachate from landfills usually has high content of pollutants, i.e. inorganic macro components, Xenobiotic organic compounds, dissolved organic matter and heavy metals, many of which are toxic to humans and aquatic life (Alker et al., 1995; Yalcuk & Ugurlu 2009). Therefore, it needs to be treated before discharge into the environment.

Further, when comparing with landfilling and incineration, composting is identified as more environmentally effective. But leachate is produced from the composting process too, as a result of water retained in the organic waste and added in the shredding process. Its disposal becomes one of the important problems if not treated prior to the disposal as it could pollute water. It contains high content of pollutants, i.e. dissolved and colloidal organic matter, inorganic components and trace heavy metals. This itemizes the need for leachate purification before discharge into the environment (Ibezute et al. 2014).

Constructed wetlands present an environmental friendly, cost effective and promising alternative for either treating or polishing the landfill leachate; good quality effluent that could be discharged to surface waters could be achieved by using the two stage leachate treatment systems with constructed wetland as the final stage (Wojciechowska et al., 2010). Also, when compared with conventional treatment systems, these systems are enabled to cope with variable contaminant concentrations and inconsistent water flow rates (Akinbile et al., 2012). Rani et al. (2011) pointed out that subsurface flow constructed wetlands have a specific capacity to absorb and retain nutrients, particulate matters and other pollutants and are useful in treating effluents including landfill leachate that requires removal of suspended solids, nitrate, high concentrations organic materials, pathogens and other pollutants; Also, it is stated that the subsurface flow constructed wetland is often significant for developing countries with tropical climates.

In Sri Lanka, disposal of solid waste has become a national concern and a priority environmental issue. With growing quantities of waste materials and changing consumption patterns, the volume of solid waste has exceeded the present capacity for adequate and effective waste management. The total generation of municipal solid waste is over 9000 MT/day (Fernandopulle, 2017). Although ‘National Strategy for Solid Waste Management’ highlights the importance of waste recycling over disposal, still open dumping remains to be the most common disposal method of municipal solid waste. Absence of proper system for management of solid waste, including lack of technical standards of both collection and final disposal leads to long term human health and environmental problems. Landfills become a prominent source of pollution that contaminates ground and surface water if it does not have leachate treatment facilities and proper management (Wimalasuriya et al., 2011). Therefore, in Sri Lanka as an integrated waste management solution for municipal solid waste, sanitary landfills are being developed as a final disposal facility.

Sanitary landfill located at Maligawatte, Dompe in Gampha district serves as the final disposal site for Dompe Pradeshiya Sabha area, managing 10 tons of waste per day. This final disposal facility encompasses a composting yard where the short term biodegradable component of the received waste, are composed. Long term bio-degradable and non-biodegradable wastes are landfilled. The generated leachate from landfill and compost yard are collected through a system, treated using a Sequencing Batch Reactor followed by a constructed wetland prior to the disposal to an existing canal network which finally meets up with ‘Pugoda ela’ and eventually the Kelani river. However, although a constructed wetland has been developed for tertiary treatment of leachate, the effectiveness of the technology of using plants for in situ remedying treatment of leachate had not been investigated in this site.

Reed beds are environmentally friendly systems for polishing of pre-treated leachate that can consistently and reliably meet demanding discharge consent conditions for disposal to watercourse (Barr & Robinson, 1999). Also *Phragmites karka* is identified as a one of the promising emergent aquatic plants for sustainable use in wastewater treatment due to its rapid growth (Chavan & Dhulap, 2012). Hence this study aims to evaluate the performance of subsurface horizontal flow constructed wetland (HSSF) comprising *Phragmites karka* and Calicut tiles as substrate in tertiary treatment of leachate (i.e. Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Nitrate (as Nitrogen) (NO_3^--N) and Phosphate (as Phosphorus) (PO_4^{3-}-P)) at sanitary landfill, Dompe.

1.1. Problem statement

A major constraint for the successful treatment of landfill leachate is the difficulty in identifying and quantifying their typical composition characteristics (Sogut et al., 2005). Generally, chemical quality and the expected volume of a landfill leachate is highly site specific and can vary with time (El-Gendy et al., 2005). Hence, although various physicochemical methods for treatment of landfill leachate are feasible, these methods may not be able to consistently meet permissible discharging standards; it may be need continued supervision and sometimes pose operational problems. Also, it is costly and energy intensive. It is stated in Wojciechowska et al. (2010) that high quality effluent that can be discharged to surface waters could be achieved by using the two stage leachate treatment systems with a constructed wetland at the final stage. Hence, essentially the plants in this constructed wetland should be able to cope with the variable contaminant concentrations and fluctuating water flow rate of the secondary effluents and providing additional treatment of secondary effluents ensuring that they consistently meet demanding discharge consent conditions for disposal to watercourse and also serve as economical substitutes for tertiary filters. However, although a constructed wetland has been developed for tertiary treatment of leachate generated from landfill and compost yard in a sanitary landfill at Dompe, the effectiveness of using plants for in situ tertiary treatment had never before been investigated in this site.

Even though there are literature available in the area of phytoremediation potential of aquatic plants in the global context a little amount of research has been carried out on the phytoremediation potential of aquatic plants in Sri Lanka. It has been stated in Nilusha et al. (2015) and Jayasena et al. (2013) that constructed wetland is a freshly minted term in Sri Lanka, thereby most of the research is in the embryonic stage. Many of the reported studies are limited to investigating the phytoremediation potential of aquatic plants such as reeds and sedges on municipal wastewater and floating aquatic plants for industrial wastewater under different conditions. In Sri Lanka wetlands are not commonly used for leachate treatment (Jayasena et al., 2013) and the literature on research work related to phytoremediation potential of plants to treat landfill leachate is limited within the context of Sri Lanka. Also conducting this type of pilot scale research in order to explore the effectiveness of available local native plants in tertiary treatment of leachate shall be helpful in view of applying the outcome of this research in future developments.

The present pilot study focused on the subsurface flow systems because they are reported as causing fewer problems arising from public exposure, odors or insects, which are thus appropriate to treat landfill leachate (Yalcuk & Ugurlu, 2009; Vymazal, 2009). Also a horizontal subsurface flow wetland is successfully used for both secondary and tertiary treatment (Vymazal & Kropfelova, 2009). Further, it uses low-cost Sorbent material Calicut tile that could be utilized as a medium for constructed wetlands (Jayaweera, 2013). BOD, COD, TSS and nutrient removal from landfill leachate has become particularly important as this element causes water quality problems in surface waters and ground waters.

1.2. Objectives

This pilot scale study was aimed to evaluate the performance of subsurface horizontal flow constructed wetland comprising *Phragmites karka* and Calicut tiles as substrate in tertiary treatment of leachate at sanitary landfill, Dompe.

The objective of the study was,

1. To evaluate the removal efficiency of BOD_5, COD, TSS, NO_3^--N and PO_4^{3-}-P.

CHAPTER 2: LITERATURE REVIEW

2.1. Phytoremediation

Contaminations of the environment through anthropogenic and industrial activities have led to the development of mechanisms to reduce contamination and bio-remediation is identified as an important mechanism in reducing contamination of the environment.

Phytoremediation is defined as the use of green plants to remove, contain or render harmless environmental contaminants or the set of technology that uses plants to clean contaminated sites (Sogut et al., 2005). It includes all plants-influenced chemical, physical and biological processes that aid in the uptake, sequestration, degradation and metabolism of contaminants, either by plants or by the free-living organisms that constitute in the plant rhizosphere (Hinchman et al., n.d.). Mechanisms of phytoremediation are as follows (Jayaweera et al., 2002; U.S. Environmental Protection Agency, 2000):

1. Phytoextraction: Uptake of contaminants by plant roots and translocation within the plants.
2. Rhizofiltration: Adsorption or precipitation onto plant roots or absorption into the roots of contaminants that are in solution surrounding the root zone, due to biotic or abiotic processes.
3. Phytostabilization: Immobilization of a contaminant in soil through absorption and accumulation by the roots, adsorption onto roots or precipitation within the root zone of plants and the use of plants and plant roots to prevent contaminant migration via wind and water erosion, leaching, and soil dispersion.
4. Rhizodegradation: Breakdown of an organic contaminant in soil through microbial activity that is enhanced by the presence of the root zone.
5. Phytodegradation: Breakdown of contaminants taken up by plants through metabolic processes within the plant, or the breakdown of contaminants external to the plant through the effect of compounds (such as enzymes) produced by the plants.

6. Phytovolatalization: Uptake and transpiration of a contaminant by a plant, with release of the contaminant or a modified form of the contaminant to the atmosphere from the plant through contaminant uptake, plant metabolism, and plant transpiration.

It is a natural, inexpensive and in situ remediation method. It can reduce the movement of pollutants towards groundwater, prevent the loss of soil resources and enhance the soil quality (Oh et al., 2014). The bio-degradation and mineralization rates depend on contaminant concentration, contaminants' nature, surrounding air/soil temperature, pH, moisture, bio-availability of soil elemental contents and the supporting microbial media (Zhang et al., 2010). Phytoremediation could be enhanced by application of chelating agents or surfactants, utilization of genetically engineered plants, using agricultural work techniques and by using microbe-plant-combination systems (Cunningham & Ow, 1996; Oh et al., 2014; Gratao et al., 2005).

However, there are concerns about contaminations of groundwater by the enhanced mobility of metals in soil (Cunningham & Ow, 1996). Also Gratao et al. (2005) pointed out that possible risks of using transgenic plants such as the uncontrolled spread due to interbreeding with population of wild relatives, transformation of metals into forms more bio-available could increase exposure of wildlife and metals should be considered.

2.2. Aquatic treatment systems

Role of aquatic plant species in cleaning water bodies was discovered with the realization of the importance of clean water as a basic necessity for life. United States Environmental Protection Agency & Centre for Environmental Research Information (2000) mention about three categories of aquatic treatment systems. They are natural wetlands, constructed wetlands and aquatic plant systems. It has been realized that natural wetlands are always not able to efficiently function in achieving required standards of water quality. Thus, constructed wetlands were developed for wastewater treatment. Aquatic plant systems are stated as the shallow ponds with floating and submerged vegetation.

A constructed wetland is an artificial wetland that uses the natural processes involving wetland vegetation, soils, and their associated microbial assemblages assist in waste treatment (Zhang et al., 2010). It is classified as free water surface system (FWS) and subsurface flow system (SSFS). In SSFS wastewater flows underneath and through the plant rooting media and water level is maintained below the tip of the substratum. In the horizontal flow systems (HF), the wastewater flows under the surface of the bed in a more or less horizontal path. In the vertical flow systems (VF), the wastewater is fed on the whole surface area through a distribution system and passes the filter in a more or less vertical path (Yalcuk & Ugurlu, 2009).

As per the Akinbile et al. (2012), constructed wetland systems are especially suitable for developing countries because of its ability to withstand fluctuating contaminant concentrations and volumes.

It is stated in Yalcuk & Ugurlu (2009) that BOD_5, COD, TSS removal is possible to a high degree in subsurface flow constructed wetland systems due to a long retention time of the wastewater, normally 80–90% in an HF system and more than 90% removal can be achieved by Vertical Subsurface Flow (VSF). Due to the mostly aerobic conditions in a VF system, oxygen requiring nitrifying bacteria are favored and nitrification can be achieved in these systems; however de-nitrification may not take place to a large extent. Nitrogen reduction is not significant in HF system, but fully nitrification is limited due to lack of oxygen that is characteristic of this kind of systems. Further, it is stated that total nitrogen and phosphorus removal in constructed wetland systems can be as high as 98–99%, respectively.

Brisson & Chazarenc (2009) pointed out about the container and edge effects in microcosm experiments; hence they are especially useful in examining the mechanisms and patterns. But, it is needed to validate the results in realistic conditions.

2.3. Landfill leachate treatment using phytoremediation

A major constraint for the successful treatment of landfill leachate is the difficulty in identifying and quantifying their typical composition characteristics. El-Gendy et al. (2005) said that, the expected volume and chemical quality of a landfill leachate is highly site specific and can change over time. It is stated in Sogut et al. (2005) that, the chemical quality of leachate varies with composition of solid wastes, particle size, degree of compaction hydrology of the site climate and age of the dumpsite. As per the Yalcuk & Ugurlu (2009) and Jones et al. (2006), young leachate contains low pH, high BOD_5 and COD values, whereas old landfills are more stable with low BOD/COD ratio. Ammonia is the major long-term pollutant that does not decrease with landfill ages. Young leachate is extremely toxic to life (Jones et al., 2006). Therefore, it is needed to be managed in an environmentally safe manner.

Mukherjee et al. (2015) states that monitoring of leachate generation and release into the environment, hazard identification associated with it and its treatment prior to disposal into the environment are the stage of the leachate management; since leachate quality and volume are fluctuating over the time its management strategy needed to be changed according to the existing conditions.

2.3.1. Landfill leachate treatment studies around the world

Landfill leachate treatment, including treatment of heavy metals such as Cd, Cr, Pb, Cu, Zn, Co, Ni, Se and Cs has been extensively studied in several countries. Batch type constructed wetlands (Sogut et al., 2005; El-Gendy et al., 2005; Mojiri et al., 2013), horizontal subsurface flow wetlands (Akinbile et al., 2012; Yalcuk & Ugurlu, 2009; Chiemchaisri et al., 2009), vertical subsurface flow wetlands (Yalcuk & Ugurlu, 2009) and hybrid systems (Justina & Zupancic, 2009) have been used.

It is pointed out in Grisey et al. (2012) that organisms living in landfill leachate treatment systems should be able to tolerate high loads of organics, nutrients and heavy metals. Various wetland plants are screened for heavy metal accumulation from the landfill leachate by several scientists. Such as *Cyperus haspan* (Akinbile et al., 2012), *Pennisetum clandestinum* (Sogut et al., 2005), *Eichhornia crassipes* (Water hyacinth) (El-Gendy et al., 2005) *Typha latifolia* (Cattail) (Chiemchaisri et al., 2009; Yalcuk & Ugurlu, 2009), *Typha domingensis* (Southern cattail) (Mojiri et al., 2013) and *Phragmites australis* (Common reed) (Justina & Zupancic, 2009). Grasses like *Vetiveria zizanioides* (Vetiver grass) (Ibezute et al., 2014) have been tested for pollution removal from compost leachate.

Alker et al. (1995) have studied the metal ion content of landfill leachate, says that certain metal ions are associative: Zinc and lead often occur together, as do copper and cadmium.

It is stated in Yalcuk & Ugurlu (2009) that Zeolites is good for removal of heavy metals such as lead, zinc, cadmium, nickel, iron and manganese; also the vertical flow system having Zeolite as bed material with *Typha latifolia* is advantageous in ammoniacal nitrogen (NH_4–N) removal and metal removal is higher.

The subsurface flow systems are recommended as good for treating landfill leachate since it causes less problems generated by public exposure, odors and insects (Yalcuk & Ugurlu, 2009; Vymazal, 2009).

A study on the leachate treatment in the subsurface horizontal flow constructed wetland, using young leachate & partially stabilized leachate using *Typha angustifolia* revealed that, high nitrogen in the stabilized leachate negatively affected the treatment performance and vegetation in the system (Chiemchaisri et al., 2009).

2.3.2. Landfill leachate treatment studies in Sri Lanka

In Sri Lanka, studies on treatment of landfill leachate are still in pilot scale and limited. Richardson et al. (2016) has studied total nitrogen removal of municipal solid waste leachate using hybrid constructed wetlands containing *Cyperus alternifolius* (umbrella farm), *Scirpus atrovirens* (green bulrush) and *Typha angustifolia* (narrow leaved cattail), demonstrated that hybrid wetlands provided a suitable environment for microorganisms to decompose or transform pollutants to assist in nitrogen removal in leachate.

Leachate treatment by vertical flow constructed wetlands containing different media i.e. gravel, coir and *Typha* sp., was tested by Jayasena et al. (2013) has demonstrated that the plantation and the media have no significant role in removing BOD, COD and ammonia in constructed wetlands.

The growth performance of the bulrush plant in soil and coir mixed media was studied by Sasikala et al. (2005) and found that harvesting at the time when the growth rates are highest would promote a greater number of shoots and increase in the number of tillers and the harvesting should be done in a staggered manner along the length of the constructed wetland for constant BOD reduction.

2.4. Use of *Phragmites karka* in wastewater treatment

Phragmites karka is promising emergent plant for sustainable use in wastewater treatment due to its rapid growth (Chavan & Dhulap, 2012). It is used in India, Pakistan and Indonesia (E.g. Billore et al., 1999; Billore et al., 2001; Kurniadie, 2011). Jha & Bajracharya (2014) stated that it is used in Nepal too. It has been used in the treatment of different kind of wastewater (E.g. Billore et al., 1999; Billore et al., 2009; Sengupta et al., 2004) and polishing different kind of pretreated wastewater (Singh et al., 2010; Billore et al., 2001; Vipat et al., 2008).

Chavan & Dhulap (2012) states that the root zone using *Phragmites karka* is suitable for the treatment of wastewater and is quite efficient for the pollution reduction in terms of Solids, BOD, COD, organic, inorganic materials and other physicochemical parameters. Further the use of *Phragmites karka* for wastewater (sewage) treatment using HSSF has resulted clear and odorless treated wastewater and Total Solids (TS) concentration reduction by 61.64%, Total Dissolved Solids (TDS) by 60.37%, TSS by 63.19%, Hardness by 57.15%, Nitrate by 94.69%, Phosphate by 92.95%, BOD by 61.47% and COD reduction by 64.74% after 96 hours of Hydraulic Residence Time.

Sengupta et al. (2004) examined the impact of water depth on nutrient removal by *Phragmites karka* and *Thysanolaena maxima* and found that with the water depth nutrient removal was increased.

It is stated by Billore et al. (2008) that nutrient uptake, ammonia volatilization and oxygen release from reed root coir matrix may be regarded as chief mechanisms in reduction of nitrogen species, BOD reduction and increase in dissolved oxygen in both the artificial floating island experiments done using *Phragmites karka.*

Sharma et al. (2005) has screened 10 aquatic plants for the treatment of textile dye waste water and found that only *Phragmites karka* was growing better than the control plants in dye wastewater, i.e. in acidic-azo water (pH 4.3-6.2), neutral-azo (pH 7) and silicate waters (pH 9-10).

Polishing of primary treated diluted spent wash in the batch fed down flow constructed wetlands planted with *Phragmites karka* has showed that the concentrated spent wash (COD>5000 mg/l) was found toxic to shoots resulting in their etiolation in dose dependent manner (Singh et al., 2010).

The field scale HSSF with gravel and *Phragmites karka* used to treat the pre-treated (settling tank) domestic wastewater for the eighteen months study period, has shown the overall removal efficiency of 100% of organic nitrogen, 79.0% for TSS, 77.8% for COD, 8.9% of Total Kjeldal Nitrogen (TKN), 65.7% for BOD, 62% for Nitrate Nitrogen and 53.3% of ammonium nitrogen. The treated effluents Dissolved Oxygen (DO) levels have increased by 139% indicating existence of aerobic conditions in Rootzone bed (Vipat et al., 2008).

It is reported by Billore et al. (2001) that the horizontal flow constructed wetland with *T. latifolia* and *P. karka*, may be a suitable tertiary treatment option for distillery wastewaters.

The treatment performance of a field-scale HSSF with *Phragmites karka* on municipal wastewater is tested by Billore et al. (1999) and has recorded effluent DO levels raised to 34% indicating prevalence of aerobic conditions in the root zone and removal efficiency above 50% for BOD, NH_4–N, TKN, and Phosphorus (P).

Phragmites karka has been used in vertical subsurface flow constructed wetland to treat wastewater from the farmhouse in Indonesia and it has been revealed that it effectively removed nutrients, organics and pathogens (Kurniadie, 2011).

Comparison of removal efficiencies of major pollutants present in the domestic gray water was studied in the sub-surface horizontal flow constructed wetlands using three types of commonly available varieties of reeds (Common reed, narrow leaf cattail and bulrush) by Pathiraja & Perera (n.d.). In that study highest propagation was observed in Common Reed while the lowest was observed in Bulrush; it was observed that with 2.6 days retention time is sufficient to treat the wastewater up to the inland surface waters discharged limits and removal efficiencies were 93-97% COD, 87-90% BOD, 99% TSS reductions, 83-97% Coliforms and 91-99% E. coli.

CHAPTER 3: METHODOLOGY

3.1. Study site

Sanitary landfill in Dompe is equipped with the highest level of technology available at the present and is recognized as the first ever state-of-the-art sanitary landfill of Sri Lanka. It is located at Maligawatte in Gampha district, Western province of Sri Lanka; it serves as the final disposal site for ‘Dompe Pradeshiya Saba’ area managing around 10 tons of waste per day. Land extent is around 5 hectares (Figure 3.1). The average yearly temperature is about 80^0F and average rainfall is 1500mm respectively in this area (Pilisaru project, 2009).

Figure 3.1: Aerial photograph of the Sanitary landfill, Dompe

This final disposal facility comprises a composting yard (uses an aerobic windrow method with an approximate capacity of 10 tons per day) where the short term biodegradable component of the received waste are composed. Types of wastes that landfill are: long term bio-degradable, wooden, slaughter house, saw dust, paddy husk, garment waste, polythene and plastics (only a fraction). An approximate capacity of Landfilling area is 90 tons per day.

The generated leachate from landfill and compost yard are collected through a system, treated using a Sequencing Batch Reactor followed by a constructed wetland prior to the disposal to an existing canal network which finally meets up with ‘Pugoda ela’ and eventually the Kelani river.

3.2. Plant description

Phragmites karka (Retz.) Steud. (Sinhala name: ‘Nala gas’), is a perennial reed with creeping rhizomes; culms to 4 m tall. Leaf blades 30-80 cm long, 12-40 mm wide, glabrous, tips stiff and attenuate. Panicles 30-50 cm long and 20 cm wide, the lower branches often whorled, bare of spikelets for some distance from the base; spikelets 9-12 mm long, the rhachilla hairs sparse, 4-7 mm long; lower glume slightly more than half as long as upper, the upper 4-6 mm long, elliptic to narrowly elliptic, acute to subacute; lowest lemma narrowly elliptic, 7.5-12 mm long; lemma of perfect florets narrowly lanceolate, 8.5 –11 mm long (Figure 3.2.a – Figure 3.2.d). It grows along streams and lakeshores, in marshes and moist wetlands. It is distributed in Tropical Africa, Asia, Polynesia and Northern Australia (Dissanayake et al., 1994).

It reproduces sexually from seed & spreads primarily by vegetative means via stolon (creeping aboveground stems) and rhizomes (underground stems). It produces dense monotypic stands of clones or plants that are genetically identical to one another (Frankenberg, 1997). It can be established from seedlings, cuttings and transplanted rhizomes.

This species is classed as Least Concern in IUCN red list as it does not have any major threats, is widespread and can grow in a range of man-made habitats (Lansdown, 2013).

Figure 3.2.a: *Phragmites karka* plants

Figure 3.2.b: Habitat of leafy culms and inflorescences of *Phragmites karka* plants

Figure 3.2.c: Formation of tillers from shoot nodes in *Phragmites karka* plant

Figure 3.2.d: Formation of creeping rhizome and root of *Phragmites karka* plant

Taxonomy

Kingdom	: Plantae
Phylum	: Tracheophyta
Class	: Liliopsida
Order	: Cyperales
Family	: Gramineae
Genus	: *Phragmites*
Species	: *karka*

It can uptake and accumulate nutrients well, because of it has large both above and below ground biomass (Herath & Vithanage, 2015). Also, it is commonly used to trap silt (Frankenberg, 1997) and capable of withstanding high COD concentration, i.e. up to 5000 mg/l (Singh et al., 2010) and a wide range of pH (4-10) (Sharma et al., 2005).

Also, it is a good candidate for preventing soil erosion in river banks and can tolerate heavy flooding (Innes, 1977). It is capable of producing lignocellulosic biomass for bio-ethanol production (Gul et al., 2015). Other uses of this plant are, its older culms are used in preparation of musical instruments, screens, baskets and leaves are used as fodder (Cook, 1996).

3.3. Experimental method

3.3.1. Experimental setup

This experiment was conducted in a subsurface horizontal flow constructed wetland. The system was built on an open field exposed to weather conditions. An above ground, waterproof wetland bed with dimension of 1.5m length, 4 m width and 0.71 m depth was constructed; width is sectioned into 20 columns with an average width of 13 cm, in a way of water flowing in a zig zag manner (Figure 3.3 & 3.4) (Drawing & Design summary is given in Appendix-A & Appendix-B respectively). Used Calicut roof tiles were used as the substrate; the used Calicut roof tiles were collected and washed several times with high pressure tap water in order to remove soluble inorganic salts and any adhering materials. After the wash, the tiles were sun dried and manually crushed into sizes in the range of 25-50mm and filled up to 0.65m of the bed. 20 young plants of *Phragmites karka*, shoot height of 150-170 cm long, were planted; 1 plant was planted in the mid of the each section. Pre-treated leachate (SBR effluent) was supplied to the wetland using an overhead tank (capacity 200 liters). It was filled once in three days after samples of influent and effluent were collected.

Figure 3.3: Front view of the HSSF sectioned into columns and planted with *Phragmites karka*

Figure 3.4: Side view of the HSSF planted with *Phragmites karka* in the mid of the each section

3.3.2. Evaluation of the system

3.3.2.1. Phase 1: Acclimatization phase

The study period was from June to August 2017. Initially the system was acclimatized for a week with tap water previous to the startup of the study. Secondly, pre-treated leachate (i.e. SBR effluent) was introduced in gradually increasing concentration (i.e. Series of dilution by volume accomplished by adding water) and increasing flow rate in order to assess the plants tolerance limits towards concentration and flow rate. SBR effluent of 20% & 40 liters/day, SBR effluent of 40% & 60 liters/day and SBR effluent of 60% & 80 liters/day was fed in 3 days interval. It was observed symptoms of intolerance for SBR effluent of 60% & 80 liters/day (Figures 3.5.a), therefore flow rate was reduced 60 liters/day and system was fed with 80% of SBR effluent for 3 days and then 90% of SBR effluent for 1.5 days. Again, it was observed color changes in plant leaves in 1st & 2nd column

(Figures 3.5.b & 3.5.c). Therefore the concentration of SBR effluent was reduced to 80%. The Influent flow rate was controlled by manipulating a valve.

Figure 3.5.a: Bottom leaves turning to yellowish color in plant in section1 during feeding of 80 l/day & 60% of SBR effluent.

Figure 3.5.b: Yellow patches observed in upper leaves of the plant in section1 during feeding of 60 l/day & 90% of SBR effluent.

Figure 3.5.c: Browning observed in upper leaves of the plant in section2 during feeding of 60 l/day & 90% of SBR effluent.

3.3.2.2. Phase 2: Operation phase

After finding the tolerance limit of concentration and flow rate (i.e. 80% of pre-treated leachate & 60 liters/day), the system was continuously fed with 80% of pre-treated leachate & 60 liters/day and retention period of 1 day.

Plant growth data were recorded, i.e. shoots height (from the bed surface to the tip of the plant), developments of daughter plants & tillers and color changes.

3.4. Sample analysis

Sampling was carried out from the beginning of the feeding of pre-treated leachate into the system. Influent and effluent water samples were collected once in 3 days and transferred to the laboratory. BOD_5, COD, TSS, NO_3^- -N and PO_4^{3-} - P of these samples were tested according to the standard methods for the examination of water and wastewater in the American Public Health Association (1980 & 2012). In table 3.1, the test methods were used for analysis is listed.

Table 3.1: Test methods of parameters analyzed

Parameter	Test method
COD	Open Reflux Titrimetric APHA, 5220-B (APHA, 2012)
BOD_5	Membrane Electrode APHA, 4500 O-G (APHA, 2012)
TSS	Gravimetric APHA, 2540 C (APHA, 2012)
NO_3^- -N	Chromotropic acid method APHA 418D (APHA, 1980)
PO_4^{3-} - P	Ascorbic acid method APHA 4500-PE (APHA, 2012)

3.5. Data analysis

The removal efficiency of the parameters tested, was calculated using the following equation:

$$R = (1- (C_e/C_i)) *100$$

(Where: R, C_e and C_i are the removal efficiency (%), the effluent concentration of testing parameter and Influent concentration of testing parameter respectively).

The paired samples t-test was used to test whether inlet and outlet values of testing parameters of pre-treated leachate from the pilot treatment system were significantly different ($\alpha <. 05$). ‘MINITAB 14’ software was used in the data analysis.

The last 16 samples taken during the operation phase (phase 2) were considered in the statistical analysis of the data.

CHAPTER 4: RESULTS AND DISCUSSION

During this study, pre-treated secondary effluent of the leachate (i.e. SBR effluent) obtained from sanitary landfill, Dompe was treated in horizontal subsurface flow wetland. The system was initially fed tap water with a flow rate of 20l/day. During the study it was revealed that HRT was 4 days. Hence, with the aim of increasing the efficacy of the system, the flow rate was increased gradually together with concentration and tolerance limit of flow rate & concentration of the system was evaluated. It was revealed tolerance limits of the flow rate and feeding concentration of the system was 60 liters per day and 80% of pre-treated leachate.

The SBR treatment system established for pre-treatment of leachate before it enters the constructed wetland was beneficial. It was noticed that the quality of the SBR effluent was not consistent and varied over the study period; this may be due to the variation in the raw leachate quality.

A valve system was used to control the influent flow rate. The flow rate was monitored and adjusted once in 3 days after checking the tank in order to achieve same flow rate. Because it was observed in some days the flow rate was not consistent; it ranged between 160 liters/3days – 180 liters/3days; this might be due to the increase in suspended solids in the influent was clogging the pipeline.

Among the 20 samples obtained, initial 04 samples were taken during phase1 (acclimatization phase) and final 16 samples taken during phase2 (Operation phase). Samples taken during phase 2 were considered for analysis of removal efficiency and statistical analysis. Summary of the descriptive statistics obtained for testing parameters during the operation phase is given in table 4.1.

Means of each tested parameter depict that there was a difference between the influent and effluent to the wetland system; the concentration of the effluent obtained after the treatment of the each tested parameter had decreased in a range comparing with the Influent of the system (Table 4.1).

Table 4.1. Summary of the descriptive statistics obtained for the tested parameters during operation phase

Parameter		**Unit**	**Minimum**	**Maximum**	**Range**	**Mean**	**Average Removal Efficiency (%)**	**Permissible level of discharge into inland surface waters**
BOD_5	In	mg/l	6	26	20	18	63	30 mg/l, max
	Out	mg/l	2	11	9	7		
COD	In	mg/l	61	381	320	183	62	250 mg/l, max
	Out	mg/l	30	98	68	62		
TSS	In	mg/l	29	129	100	60	96	50 mg/l, max
	Out	mg/l	1	4	3	2		
NO_3^- - N	In	mg/l	1.14	19.78	18.64	6.31	49.11	-
	Out	mg/l	0.45	5.03	4.58	2.27		
PO_4^{3-} - P	In	mg/l	0.97	4.65	3.68	2.07	85.28	5 mg/l, max
	Out	mg/l	0.10	0.44	0.34	0.27		

Table 4.2: Summary of the paired T test of the tested parameters during the operation phase

Parameter	**Unit**	**Average Removal efficiency (%)**	**Paired T test _Paired Differences**					
			Mean	**Standard Deviation**	**95% Confidence Interval of the Difference**		**T Value**	**P value**
					Lower	**Upper**		
BOD_5	mg/l	63	11	4	9	14	10.82	.000*
COD	mg/l	62	122	69	85	158	7.04	.000*
TSS	mg/l	96	58	29	43	73	7.98	.000*
NO_3^- -N	mg/l	49.11	2.54	2.26	1.65	3.92	4.58	.000*
PO_4^{3-} - P	mg/l	85.28	1.80	1.07	1.23	2.37	6.73	.000*

*Depicts the significance at $\alpha = 0.05$

As per the Kolmogorov-Smirnova normality test data sets are symmetrical-shaped distributed. Since it was studied the difference between before and after treatment of pre-treated leachate, the paired T test was used to check whether there was a significant difference between the influent and effluent of testing parameters (Appendix C). Summary of the paired T test of the tested parameters during the operation phase is given in table 4.2.

From the p value (<0.05) of the paired T test (Table 4.2) it can be said that there is a statistically significant difference between the mean concentration of the influent and effluent values of the each parameter tested in this HSSF wetland system. Also mean concentration of the each parameter was lower in the effluent of the system compared to the Influent of the system and well below the permissible level of discharge (Table 4.1). Therefore, it can be said that a tertiary treatment has been taking place. The results for removal efficiency obtained reveals that this HSSF system is most effective in the removal of TSS comparing to the rest of the parameters; removal efficiency of TSS is 96%. NO_3^- -N removal efficiency is the lowest compared to the rest of the parameters i.e. 49.11%.

Common reed *Phragmites karka* is especially suitable for the root zone treatment system because of striking deep roots (Up to 0.75m) and rhizomes with large number of the Rhizosphere per unit surface area (Chavan & Dulap, 2012). The important function of the *Phragmites* plant in the constructed wetland is to provide oxygen to the microorganisms in the root zone. Further, it also helps to increase the hydraulic conductivity of the substrate; the plants hold themselves in the substrate through their roots and rhizomes and penetrate through the substrate loosen the substrate creating increased porosity by forming pores & providing air passages through the substrate. In densely rooted bed, the activity of microorganisms increases in terms of both, quality and quantity (Chavan & Dulap, 2012). Further dense stands of the plant decreases the flow velocity of the wastewater and in so doing increase sedimentation; roots of plants stabilize constructed wetland substrate, reducing the potential of re-suspension of already settled materials (Koskiaho & Puustinen, 2005).

The bed filled with substrate act as roofing material for vegetation supporting plants and associated microbial development. It also helps the distribution of flow along the path. The pollutant removal in the substrate is taking place by sedimentation, adsorption and filtration. Further aerobic, anaerobic and anoxic conditions prevailing in the substrate to provide space for pollutant removal by microbial degradation too. Used Calicut roof tiles were reused as the substratum in this study. No clogging was observed during the study period.

It shall be noted that this pilot scale study was carried out as a trial feasibility study in order to determine the applicability of horizontal subsurface flow constructed wetland for tertiary treatment of landfill leachate. No control experiments were carried out.

Further, this system was built above ground and in an open environment. Generally, during rainfall, the water level of the wetland system temporarily increases, pollutants get diluted and the hydraulic retention time decrease; during evapo-transpiration, the water level of the wetland system temporarily decreases, pollutant concentration increases and the hydraulic retention time increases. However, it is stated in United States Environmental Protection Agency (U.S.EPA) (1999) that, “Except in very wet climates, flows from precipitation events will probably not adversely affect performance because vegetated submerged systems have a relatively small area (compared to free water surface wetlands) and effluent control should be sufficient to prevent surfacing”. No surfacing was observed during the study period.

4.1. Removal of organics and suspended solids

Organic matter comprises a mixture of liable and recalcitrant bio-polymers. Its degradation is a multi-step process (Figure 4.1). The microbial metabolism takes an important role in the removal of organic matters. They utilize the dissolved oxygen available in water and uptake organic matter as food for their growth. When the amount of organic matter increases, the demand for dissolved oxygen also increases.

Below reaction depicts the aerobic degradation of soluble organic matter by the aerobic heterotrophic bacteria (Vymazal & Kropvelova, 2009):

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + 12e + \text{energy}$$

Therefore, if untreated organic matters are disposed into water bodies, it could decrease the amount of available dissolved oxygen in the receiving water and adversely affects that aquatic ecosystem. Thus, it is important to treat the organic matter prior to its disposal.

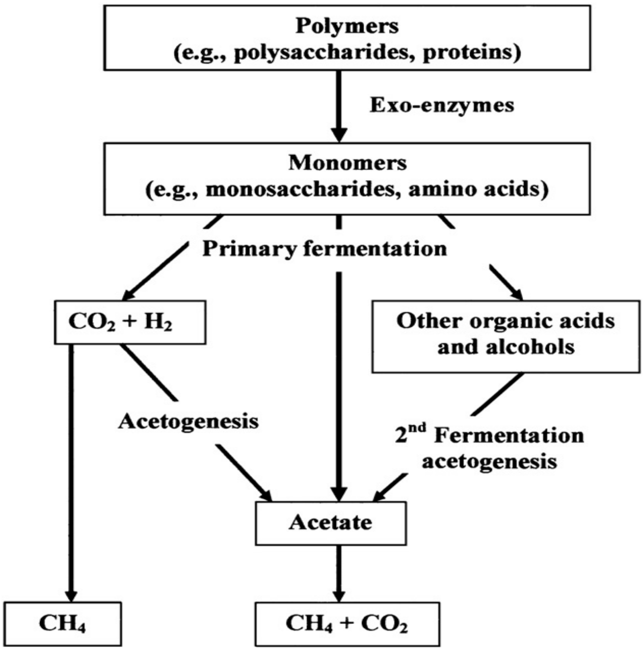


Figure 4.1: Metabolic scheme for the degradation of complex organic matter, culminating in Methanogenesis. From: Megonikal et al. (2004)

In the horizontal subsurface flow constructed wetlands, due to the continuous loading of wastewater through the bed and saturation of it, mostly anaerobic and anoxic conditions prevail; aerobic conditions are prevailing adjacent to the root area. Therefore, organic matter is removed by both anaerobic and aerobic degradation. U.S.EPA (1999) states that the extent of degradation of organic matter has been rather little in a vegetated submerged system wetland since average dissolved oxygen concentrations are less than 1 mg/l; further, it pointed out that in vegetated submerged bed wetlands the predominant metabolic mechanism is anaerobic manner;

it includes Methanogenesis, sulfate reduction and the de-nitrification, which all produce gaseous products. Rather than to this, in horizontal subsurface flow constructed wetlands organic matter removal is taking place by filtration and sedimentation of particulate organic matter too (Vymazal & Kropvelova, 2009; Weragoda et al., 2010; U.S.EPA, 1999).

4.1.1. Biochemical Oxygen Demand (BOD$_5$)

Biochemical Oxygen Demand is the amount of the dissolved oxygen consumed by the microorganisms in the biochemical oxidation of organic matter. It depends on the concentration of nutrients, temperature and the enzymes available to microorganisms. Total BOD is the amount of oxygen required to completely oxidize the organic compounds to carbon dioxide and water through generations of microbial growth, death, decay, and cannibalism; it is of more significance to food webs than to water quality (University of Moratuwa (UoM), 2013). Dissolved oxygen depletion affects the fish, aquatic insects and other aquatic life forms.

Variation in inlet and outlet concentration of BOD$_5$ during the study period is depicted in figure 4.2.

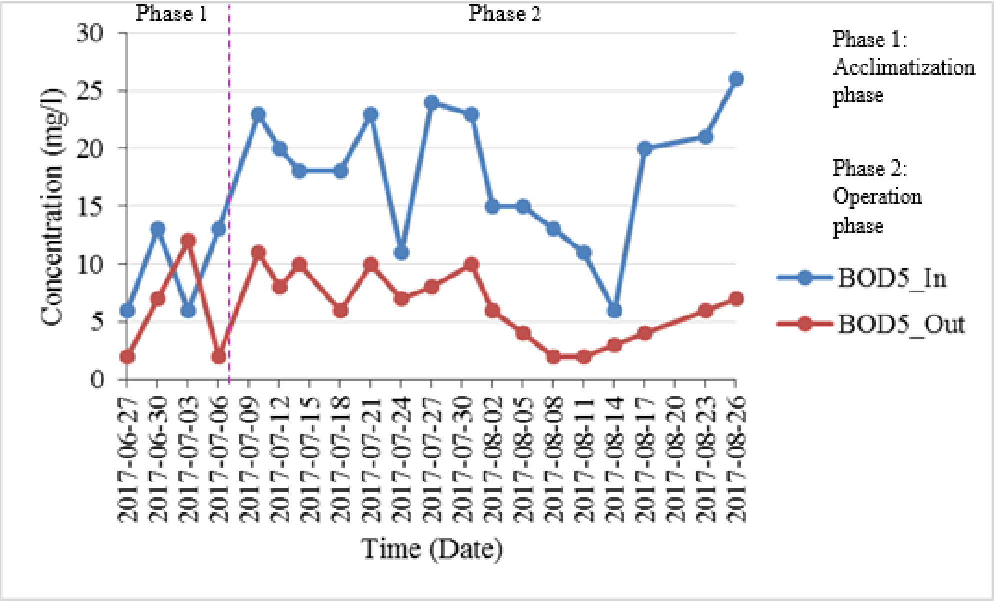


Figure 4.2: Inflow and Outflow concentration of BOD$_5$

4.1.1.1. BOD$_5$ removal in phase1 (Acclimatization phase)

In sample number 3 (Date 2017.07.03) BOD$_5$ concentration was higher in outlet than at the inlet (Figure 4.2). This sample was taken during the evaluation period (phase 1) changing flow rate and changing concentration of the Influent and during the feeding of 60% of pre-treated leachate and 80 liters/day, when plants showed intolerance symptoms. This may be due to the plants and establishing microbial population got stressed during feeding of 80 liters per day. Further, the system needs time for establishment of vegetation, bio-film establishment, acclimatize to the feeding pre-treated leachate and regulate into the treatment process (Vipat et al., 2008). It can be assumed from these results that first 12 days as the establishment period of microbial activity and the system's acclimatization period to pre-treated leachate.

4.1.1.2. BOD$_5$ removal in phase 2 (Operation phase)

During the operation phase BOD$_5$ removal has got regulated (Figure 4.2). In this phase, the mean BOD$_5$ of the Influent was 18 mg/l (range 6-26 mg/l) & the effluent BOD$_5$ was ranged between 2 mg/l and 11 mg/l with a mean value of 7 mg/l. When comparing with influent, effluent BOD$_5$ varied within a smaller range (Table 4.1, Figure 4.2).

The mean BOD$_5$ value of both the influent and effluent were well below the permissible level of discharge of industrial effluents into inland surface waters (i.e. 30 mg/l, max). During the study period BOD$_5$ of the Influent was below the permissible level of discharge, might be because of leachate used in this study had undergone prior treatment. Further, Vymazal & Kropvelova (2009) pointed out that lowest inflow BOD concentrations recorded in landfill leachate systems, because organics in landfill leachate are very often recalcitrant and therefore, not analyzed as BOD but rather COD. There was a significant difference between the inlet and outlet value of mean BOD$_5$ (p value 0.000, at 95 % confidence interval).

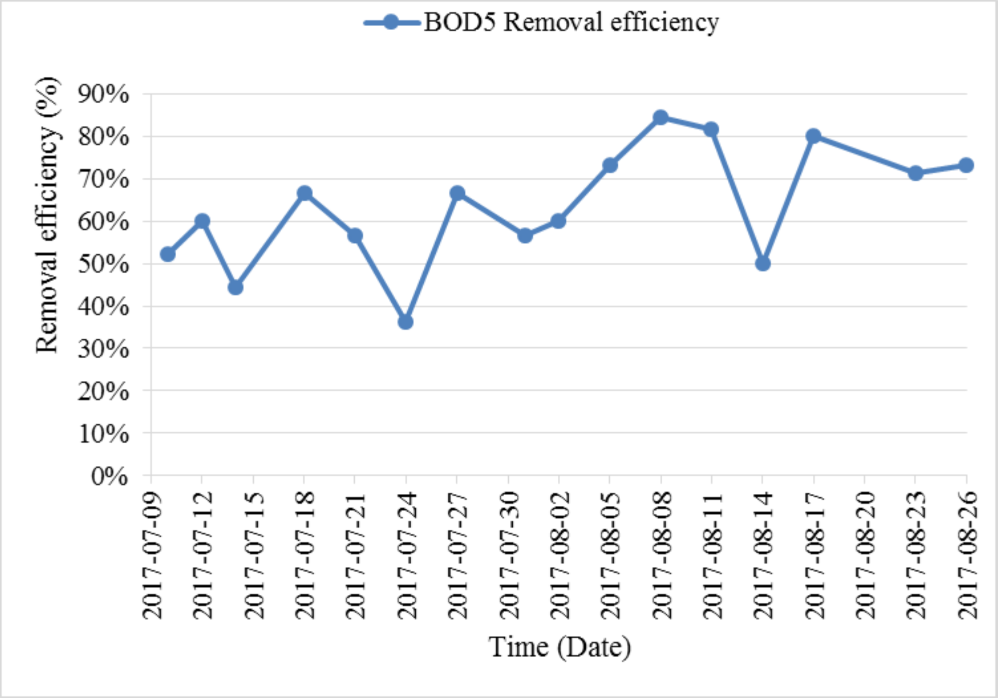


Figure 4.3: Removal efficiency of BOD_5 during the operation phase

As per the results obtained during the study period wetland was better at removing BOD_5. The average removal efficiency of BOD_5 of the system was 63%, ranged between 36% and 85%. Average removal efficiency is moderate when comparing with other parameters. Similar results for removal efficiency has been obtained, i.e. 61.47% by Chavan & Dhulap (2012) & 65.7% of Vipat et al. (2008) in an HSSF with *Phragmites karka* on wastewater (sewage) treatment and domestic wastewater treatment, respectively; different type of substrates have been used in those studies.

The removal efficiency of BOD_5 was not consistent and it was fluctuating (Figure 4.3). The major mechanism of BOD_5 removal might be the microbial degradation; BOD_5 removal performance of the system seemed to be improved over the time when the system gets acclimatized to the feeding leachate and the establishment of microbial populations. Dense growth of plants supports BOD removal by adding oxygen in the root zone (Billore et al., 2008; Weragoda et al., 2010). In this system the *Phragmites* growth was not much denser during the study period; due to the continuous loading of wastewater and saturation of the bed, aerobic degradation would have restricted to small area nearby roots and rhizomes. Plants might have performed as a support role for microbial decomposition in attached bio-film. Other physical and chemical mechanisms such as filtration and sedimentation would have supported the BOD_5 removal in this system.

4.1.2. Chemical Oxygen Demand (COD)

Chemical oxygen demand is used as a tool to indicate organic pollution in water. It is stated in UoM (2013) that, the efficiency of the treatment process is indicated by it. Variation in inlet and outlet concentration of COD during the study period is depicted in figure 4.4.

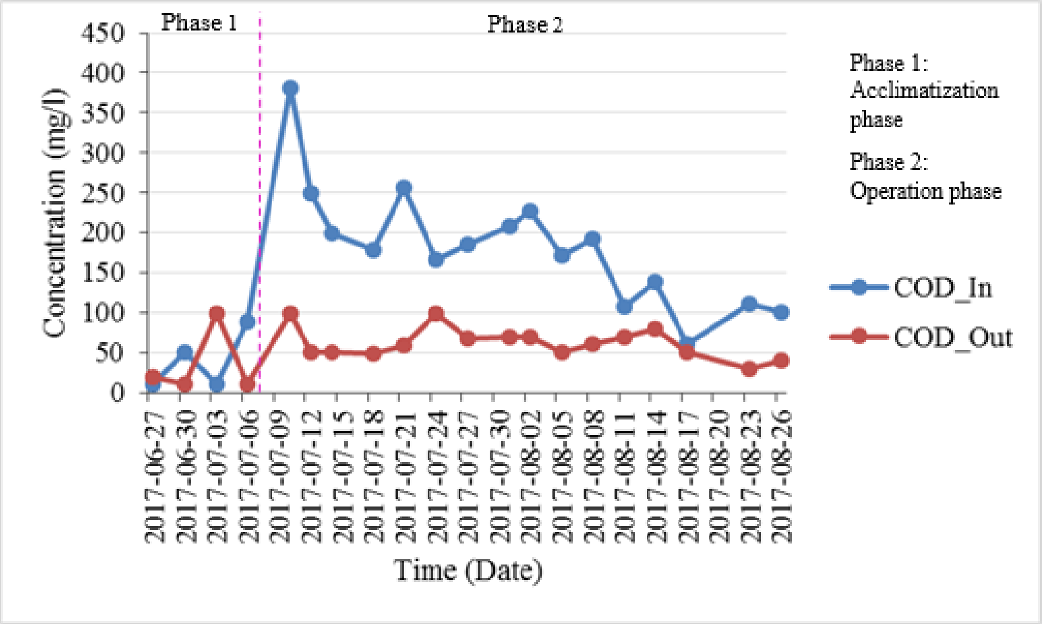


Figure 4.4: Inflow and Outflow concentration of COD

4.1.2.1. COD removal in phase1 (Acclimatization phase)

In the sample number 1 (Date: 2017.06.27) and in sample, number 3 (Date 2017.07.03) COD concentration was higher in outlet than at the inlet (Figure 4.4). As in BOD, this may be due to the changing flow rate and concentration of the Influent during this phase. Also 3rd sample was taken during the feeding of 60% of pre-treated leachate and 80 liters/day, when plants showed intolerance symptoms to increase flow rate and concentration. Also, as explained in section 4.1.1.1, the system needs time to acclimatize to the feeding pre-treated leachate and regulate into the treatment process. Plants and establishing microbial population also would have got stressed to the changing conditions. From these results further it can be assured that first 12 days as the establishment period of microbial activity and the system's acclimatization period to pre-treated leachate.

4.1.2.2. COD removal in phase 2 (Operation Phase)

In this phase, the mean COD of the Influent was 183 mg/l (range 61-381 mg/l) & the effluent COD was ranged between 30 mg/l and 98 mg/l with an average value of 62 mg/l. When comparing with influent, effluent COD varied within a smaller range (Table 4.1, Figure 4.4).

Although wastewater used in the experiment had undergone prior treatment, COD of the Influent was exceeding the permissible limit of discharge few times, i.e. 250 mg/l, max (Figure 4.4). This may be because organics in landfill leachate are very often recalcitrant and chemically stable (Vymazal & Kropvelova, 2009; Tanaka et al., 2006). It depicts the need of a tertiary treatment system to support the treatment of leachate, to ensure final effluent is in good quality and consistently meet the permissible discharge standards. However, after the treatment with this wetland system the mean COD value of effluent was well below the permissible level of discharge of industrial effluents into inland surface waters. There is a significance difference between the mean of the inlet and value of COD (p value 0.000, at 95 % confidence interval).

In general wetland performance was good in removing COD. The average removal efficiency of COD of the system was 62% & ranged between 18% and 80%. Average removal efficiency is moderate when comparing with other parameters. A similar result for average removal efficiency has been obtained by Chavan & Dhulap (2012) in a subsurface horizontal flow constructed wetland with *Phragmites karka* on wastewater (sewage) treatment.

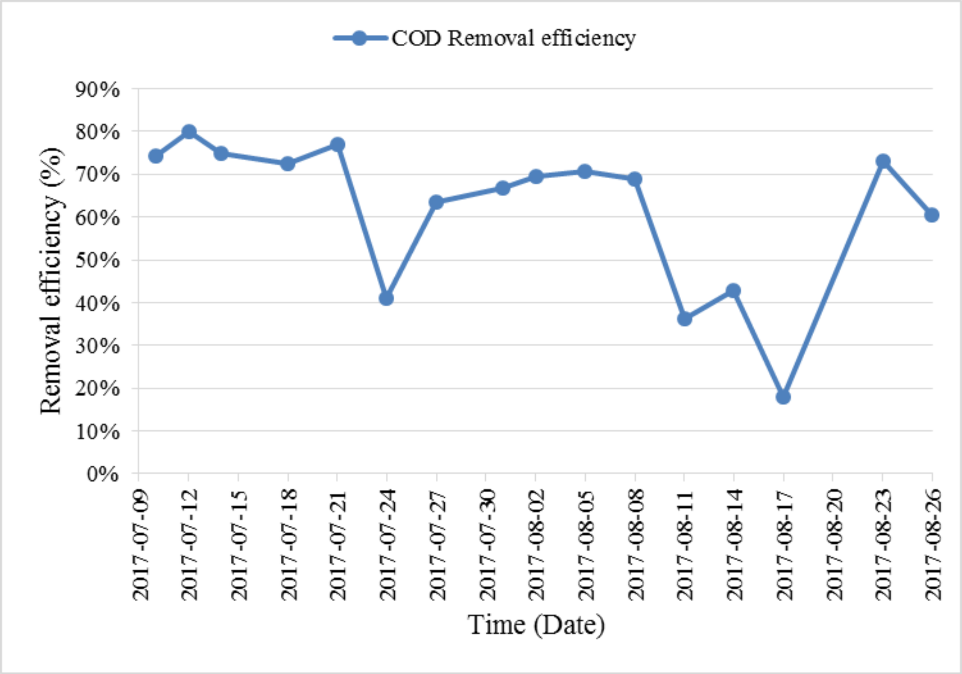


Figure 4.5: Removal efficiency of COD during the operation phase

The removal efficiency of was fluctuating (Figure 4.5). Both the aerobic and anaerobic microbial decomposition and adsorption of solid particles and dissolved organics into the Calicut tile substrate might have played a major role in the removal of COD. Tanaka et al. (2006) says that, “mineralization of soluble and fine particulate material might occur readily in a bio-film, whereas the mineralization of coarse particulate organic matter might take place primarily in sediments”. The Influent of the HSSF system might have contained recalcitrant & non-biodegradable organic compounds, that the performance of COD removal during the operation was moderate.

The treated effluent was clear, odorless and reduced in color. Aziz et al. (2007) stated that, “color in landfill leachate was mainly due to the presence of high organic matters (measured as COD) that associated with suspended solids and turbidity”.

Therefore, it can be said that the removal of COD by this wetland would have contributed to the color reduction also.

4.1.3. Total Suspended Solids (TSS)

Total Suspended Solids is solids in water that can be trapped by a filter; it is descriptive of inorganic and organic particulate matter in wastewater (Weragoda et al., 2010). High concentration of suspended solids in water bodies can adversely affect the aquatic organisms. As the amount of TSS increases in water, the turbidity also increases.

Vegetated submerged bed wetlands are effective for the removal of suspended solids as it has a large amount of media surface area and the velocity of the flowing wastewater is low; the principal mechanisms for suspended solid removal are straining, adsorption onto plant media, and gravity settling (U.S.EPA, 1999). But in order to achieve a proper suspended solid removal and reducing clogging effects, it is necessary to select different type of media. Variation in inlet and outlet concentration of TSS during the study period is depicted in figure 4.6.

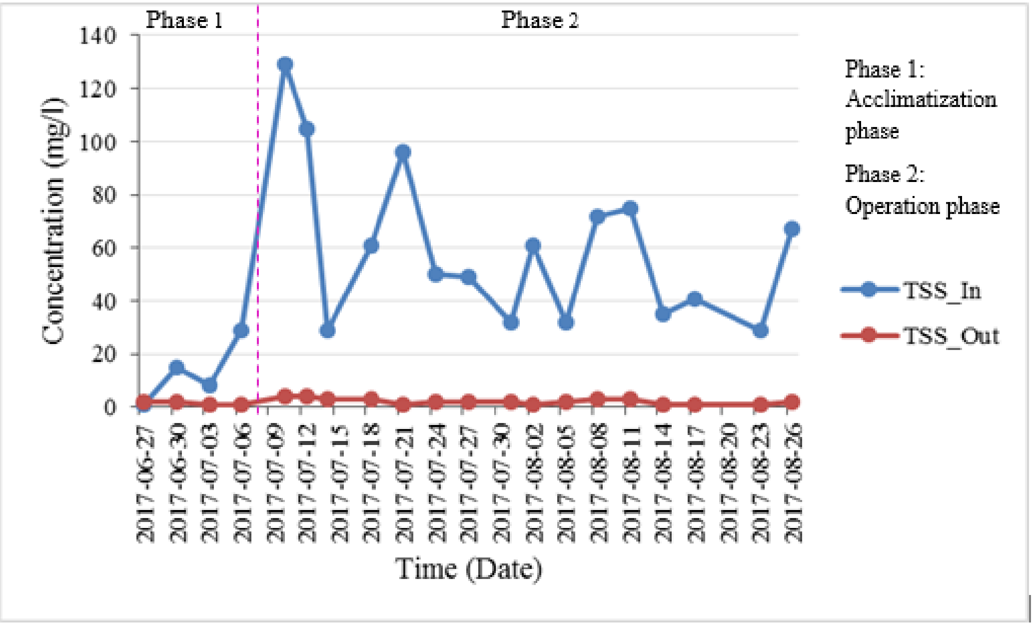


Figure 4.6: Inflow and outflow concentrations of TSS

4.1.3.1. TSS removal in Phase 1 (Acclimatization phase)

In the sample number 1 (Date: 2017.06.27) TSS concentration was slightly higher in outlet than at the inlet (Figure 4.6).

4.1.3.2. TSS removal in Phase 2 (Operation Phase)

The mean TSS of the Influent was 60 mg/l (range 29-129 mg/l). The maximum and minimum values of TSS in effluent for the study period were 4 mg/l & 1 mg/l, respectively with a mean value of 2 mg/l. When comparing with influent, effluent TSS varied within a narrow range (Table 4.1, Figure 4.6). Although the mean TSS of the Influent exceeds the permissible level of discharge few occasions i.e. 50 mg/l, max (Figure 4.6), the mean TSS value of effluent was well below the permissible level of discharge of industrial effluents into inland surface waters. The difference in mean TSS concentration between inlet and outlet was significant (p value 0.000, confidence interval 95%).

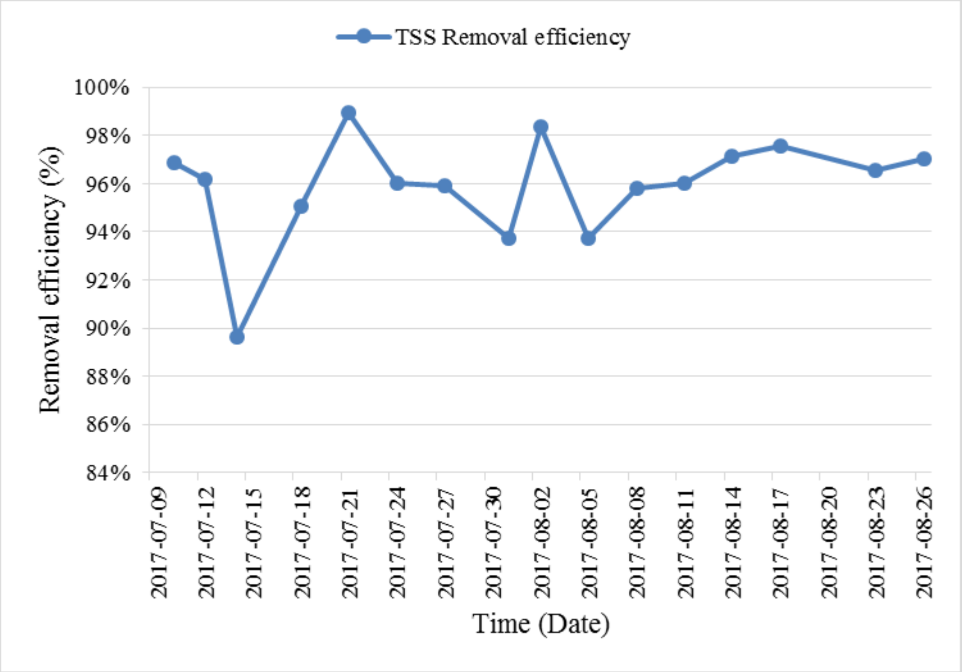


Figure 4.7: Removal efficiency of TSS during the operation phase

Figure 4.8: Removal of TSS (sample taken on 2017.08.26)

The removal of TSS was quite satisfactory and the system has performed very well. Removal efficiency varied from 90% to 99%, with an average of 96%. This system acted as good tertiary filter (Figure 4.8). A similar reduction is reported by Akinbile et al. (2012) for leachate treatment; the significant reduction in TSS in the cell with lower HRT was recorded; further they said that when the hydraulic retention time increased, the removal of TSS becomes insignificant related to the re-mobilization of solids in constructed wetlands with longer hydraulic retention time. The results are in agreement with Yalcuk & Ugurlu (2009) statement that 80%-90% TSS removal can be achieved in horizontal flow wetlands.

It can be seen from figure 4.7 that the removal efficiency of TSS was not consistent and fluctuating. Gravity settling, incorporation into the Calicut tile substrate & sedimentation might had a significant role in the removal of TSS. Plants also might support in filter or settle out suspended solids. The TSS concentrations reduced significantly in this HSSF system with lower hydraulic retention time.

4.2. Removal of nutrients

Nutrients are the important elements of water body that are required for the growth of aquatic plants and animals. Nitrogen and phosphorus are the elements that are naturally available in the aquatic body; but if these are disposed too much into the water receptors water get polluted, and consequently has an impact on humans who utilizing these resources. Increasing concentration of nitrogen and phosphorus lead to the development of algal bloom which drastically reduces the dissolved oxygen, resulting fish killing and water quality deterioration. So it is needed to treat them prior to discharge into the environment.

4.2.1. Nitrate (NO_3^- -N)

Removal of nitrogen is one of the important issues faced in wastewater treatment. 'Blue baby' syndrome and Eutrophication are some of the major problems arise due to the increasing concentration of nitrates in water.

Total nitrogen (dissolve inorganic nitrogen, particulate organic nitrogen and dissolved organic nitrogen) is an important indicator of nutrient loading to a watercourse. The nitrification process converts ammonia to nitrate and it depends on factors such as HRT, temperature, pH, alkalinity and dissolved oxygen availability (Tanaka et al., 2006). Jayasena et al. (2013) explains the process: it consists of two steps; they are oxidation of ammonia (NH_4^+) to nitrite (NO_2^-) and subsequent oxidation of Nitrite to nitrate (NO_3^-):

$$NH_4^+ + 1\frac{1}{2}\, O_2 \rightarrow NO_2^- + 2H^+ + H_2O$$

$$NO_2^- + \frac{1}{2}\, O_2 \rightarrow NO_3^-$$

The total reaction of nitrification is,

$$NH_4^+ + 2O_2 \rightarrow NO_3^- + 2H^+ + H_2O$$

After the nitrification, Nitrate is converted to nitrogen gas in the de-nitrification process. The de-nitrification is the reduction of oxidized nitrogen compounds. The final product of the complete de-nitrification process is nitrogen gas (N_2). The de-nitrification is ran stepwise, from the most oxidized to the most reduced compounds:

$$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$$

The resulting reaction of de-nitrification:

$$2\, NO_3^- + H^+ + \text{Organic matter} \rightarrow N_2 + HCO_3^-$$

The de-nitrification is performed by heterotrophic bacteria, which use organic material as carbon source. The common denitrifying bacterial groups responsible for de-nitrification are *Bacillus, Aerobacter, Micrococcus, Pseudomonas and Spirillum* (Metcalf & Eddy, 2014). For de-nitrification to takes place, the following conditions should be prevail in a constructed wetland: presence of nitrate, acceptable pH conditions, acceptable temperature, Anoxic conditions and an adequate carbon source must exist. Carbon is significant in enhancing de-nitrification rates because it supports requirements for both energy and cellular synthesis for the heterotrophic bacteria that are considered to be most responsible for utilizing nitrogen oxides as electron acceptors in the absence of oxygen. Adding an external carbon source to the wetlands such as methanol or alternative carbon sources that are easily degraded such as mulch, grass clippings, or harvested wetland plants can stimulate the de-nitrification; additions should be higher than the theoretical methanol/ nitrogen ratios due to the losses of the carbon fraction to aerobic decomposition, as well as resistance to degradation of the Lignin fraction of the biomass (Gersberg et al., 1983). The most favorable pH for de-nitrification lies between 7 and 9 (Jayasena et al., 2013).

Variation in inlet and outlet concentration of NO_3^- -N during the study period is depicted in figure 4.9.

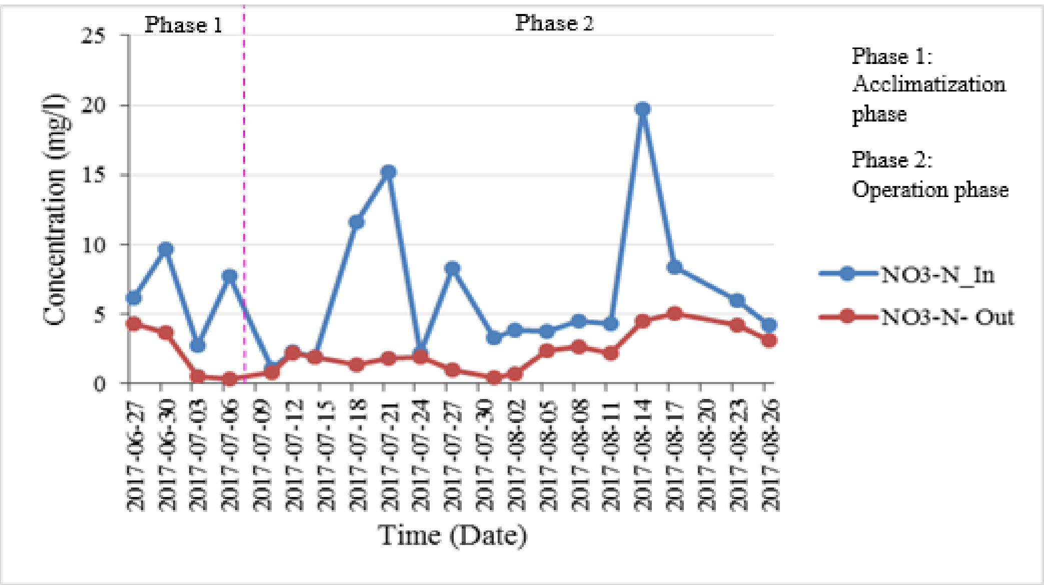


Figure 4.9: Inflow and Outflow concentration of NO_3^- -N

4.2.1.1. NO_3^- - N removal in phase 1 (Acclimatization phase)

From the beginning, removal of NO_3^- - N was taken place (Figure 4.9). This may be due to the plants were acclimatized for a period of one week with tap water and then pre-treated leachate was fed. Plants might be in need of acuring nutrient for growth of them and establishment of microbial populations.

4.2.1.2. NO_3^- - N removal in Phase 2 (Operation phase)

During the operation period, the mean NO_3^- -N of the Influent was 6.31 mg/l (range 1.14 – 19.78 mg/l) & the effluent NO_3^- -N was ranged between 0.45 mg/l and 5.03 mg/l with a mean value of 2.27 mg/l. Variation in effluent NO_3^- -N range was smaller compared to the Influent range (Table 4.1, Figure 4.9). There is no standard has been developed for NO_3^--N discharge of industrial effluent into inland surface waters. However, the difference in mean NO_3^- -N concentration between inlet and outlet was significant (p value 0.000, 95% confidence interval).

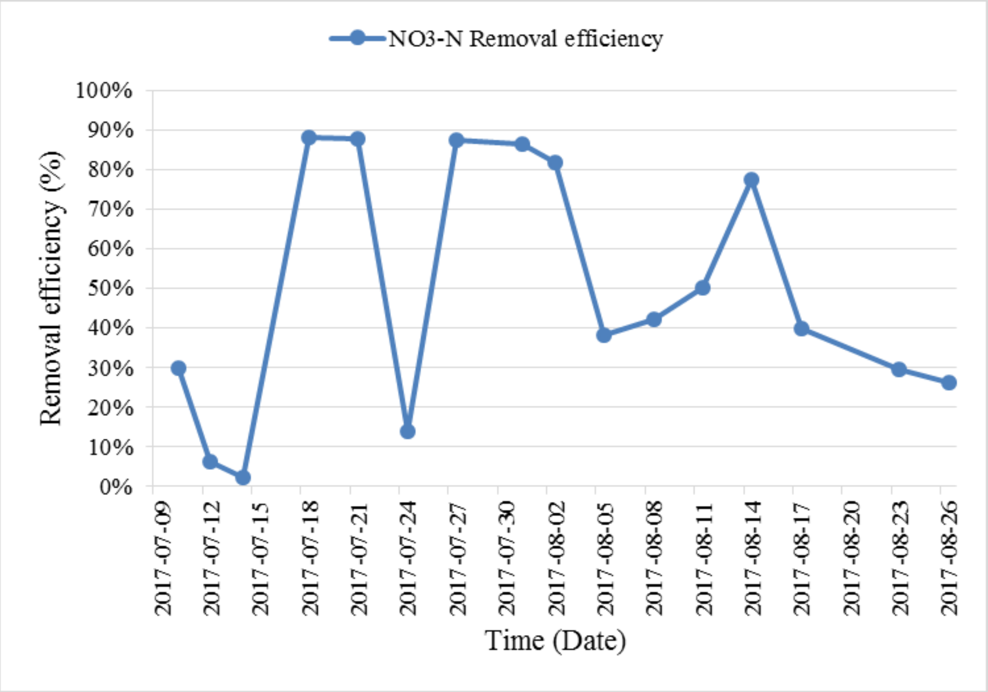


Figure 4.10: Removal efficiency of NO_3^- -N during the operation phase

The average removal efficiency of NO_3^- -N of the system was 49.11% and ranged between 2.07% and 88.10%. Among the tested parameters average removal efficiency of NO_3^- -N was the lowest. This HSSF wetland system was not performing well in the removal of NO_3^- -N. It was noted that removal efficiency was not steady and fluctuating (Figure 4.10).

Direct plant uptake would have contributed to the removal of NO_3^- -N to a smaller extent because plant growth was not dense during the study period; also they provide attachment sites for microbes to grow in and accumulating nutrient. The Denitrification might have occurred predominantly in the Calicut tile substrate due to higher possibility for the formation of anoxic conditions in the substrate. Average removal efficiency of NO_3^- -N was low, might be the specific microbial activity was low during this study period that might need time to reach enough population and plant rhizosphere aeration might built up aerobic conditions adjacent to the rhizosphere and stimulate aerobic decomposition processes; further carbon is identified as significant for enhancing denitrification rates because it supports requirements for both energy and cellular synthesis for the heterotrophic bacteria that are considered to be most responsible for utilizing nitrogen oxides as electron acceptors in the absence of oxygen. Accordingly availability of carbon might have an impact in the removal; it needs further study on evaluating the impacts of these factors in nitrate removal.

4.2.2. Phosphate (PO_4^{3-} - P)

Phosphorus is considered to be the controlling nutrient of Eutrophication in ecological systems because nitrogen can be fixed from the atmosphere, whereas phosphorus has no other route of entry than inflow. The uptake by plants, precipitation with metals (Fe, Al, Mn), adsorption of phosphates into bottom sediments, bacterial synthesis of poly-phosphates and incorporation into organic matter (mainly as part of nucleic acid) could contribute to the removal of phosphorus from wastewater (Tanaka et al., 2006; Weragoda et al., 2010; Akinbile et al., 2012).

Variation in inlet and outlet concentration of PO_4^{3-} - P during the study period is depicted in figure 4.11.

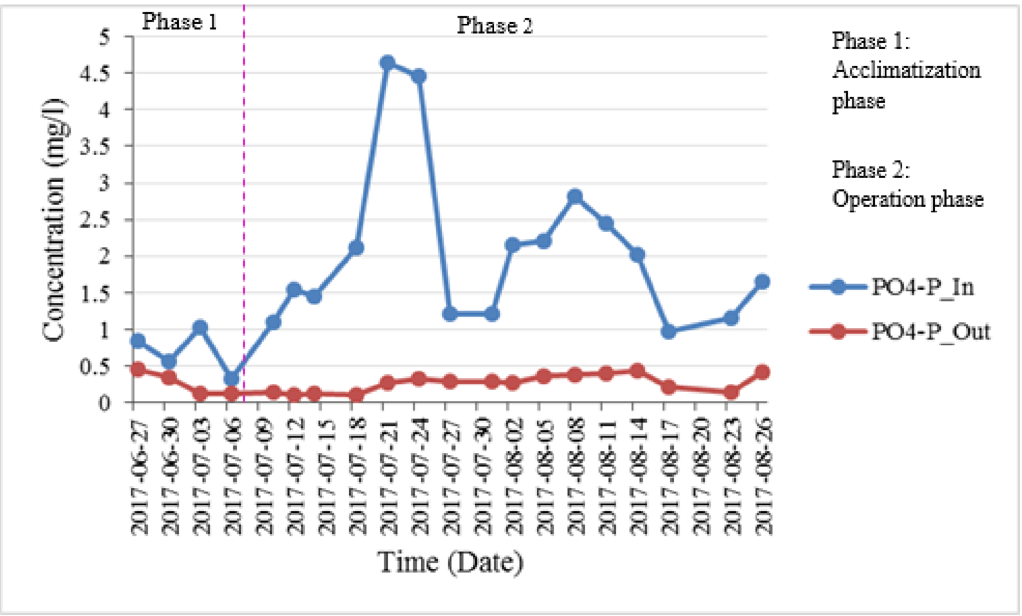


Figure 4.11: Inflow and Outflow concentration of PO_4^{3-} - P

4.2.2.1. PO_4^{3-} - P removal in Phase 1 (Acclimatization phase)

From the beginning, removal of PO_4^{3-} - P has taken place (Figure 4.11). This may be due to the plants were acclimatized for a period of one week with tap water and then pre-treated leachate was fed. Plants might be in need of obtaining nutrients for growth of them and establishment of microbial populations.

4.2.2.2. PO_4^{3-} - P removal in Phase 2 (Operation phase)

PO_4^{3-} - P concentration in the pre-treated leachate was reported in a minor level; the mean PO_4^{3-} - P of the Influent was 2.07 mg/l (range 0.97-4.65 mg/l) & the effluent PO_4^{3-} - P was ranged between 0.10 mg/l and 0.44 mg/l with a mean value of 0.27 mg/l. When comparing with influent, effluent PO_4^{3-} - P varied within a narrow range (Table 4.1, Figure 4.11). The mean PO_4^{3-} - P concentration in both influent and effluent were well below the permissible level of discharge of industrial effluents into inland surface waters (i.e. Dissolved phosphate (as P) - 5 mg/l, max). Also, the difference in mean PO_4^{3-} - P concentration between inlet and outlet effluent was also significant (p value 0.000, 95% confidence interval).

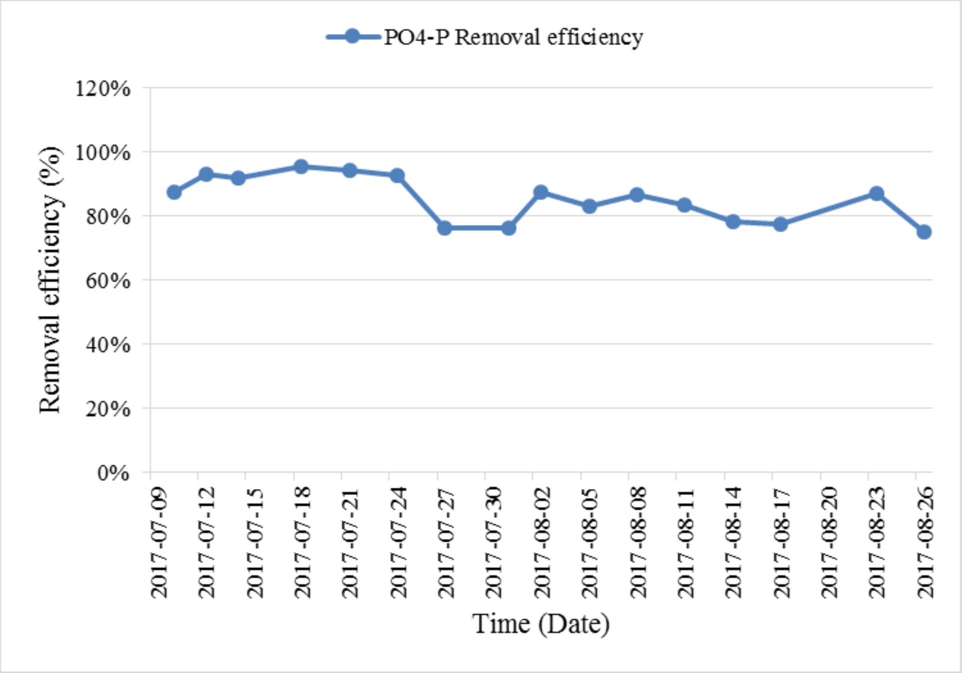


Figure 4.12: Removal efficiency of PO_4^{3-} - P during the operation phase

The removal of PO_4^{3-} - P was quite satisfactory and system was performed well in removing PO_4^{3-} - P during the study period. The average removal efficiency of PO_4^{3-} - P of the system was 85.28% & ranges between 75.15% and 95.26%. It was noted that the removal efficiency of PO_4^{3-} - P is less fluctuating (Figure 4.12). Adsorption and precipitation in the Calicut tile substrate, possibly the major mechanism of removal of phosphate while plant uptake also would have supported the process. It is stated in Koskiaho & Puustinen (2005) that, as the contact area between the influent wastewater and phosphorus adsorption substrate increase, the phosphorus removal by adsorption also increases.

4.3. Plant density

In this experiment, Calicut tile bed was planted with *Phragmites karka* at a density of 1 plant per column with an average width of 13cm with the aim of minimizing the edge effect on plant growth. In the acclimatization phase, initially the system was acclimatized with tap water (i.e. 20 l/day) for a week. During this period, it was observed that plants in sections near to the outlet showed dry & wilting signs; this was possibly because it took time for water to reach the outlet through the media and filled up to the water level elevation. During the evaluation of plants tolerance limits towards gradually increasing flow rate and concentration of pre-treated leachate as explained in section 3.3.2.1 & as in figures 3.5.a, 3.5.b & 3.5.c the plant near to the inlet, especially plants in section 1 & 2 showed intolerance signs for increasing flow rate & concentration; this was possibly due to plants near the inlet were facing load of pollutants instantly and initially and it gradually decreases when passing through the wetland bed towards the outlet. During phase 1, no new tillers and new daughter plant formations were observed.

During the operation phase, once started feeding of 80% of pre-treated leachate & 60 l/day formation of tillers and daughter plants were observed. This depicts that system, including plants has taken time to establish and adapt to the feeding pre-treated leachate. It confirms that this HSSF system’s efficient feeding flow rate & concentration are 80% of pre-treated leachate & 60 l/day. The availability of nutrients in pre-treated leachate favors the growth of plants with the development of more tillers and daughter plants over the time during the study**.**

Plants spreading and density was not much higher during the study period (Figure 4.13). Plants in section 2, 3, 4, 8, 10, 11, 12, 14, 18 and 19 were given rise to tillers from the shoot’s node. There were 4 tillers in plants in section 2, three tillers in plants in section 10, two tillers in plant in section 12 and 1 tiller in remaining plants in the sections mentioned above; height of tiller’s were between 6cm to 178cm. Daughter plants were observed in section 1-14 and 20; height of daughter plant’s ranged from 10 cm-165 cm from the wetland bed surface. Plants in section 15, 16 and 17 only were not given rise to any new daughter plants or tillers during the study period. Plant height has increased; height recorded from the wetland bed surface ranges between 180 cm to 288 cm. That was possibly due to enhanced nutrient uptake by plants with the addition of pre-treated leachate to the system. Plants in final treatment zone given rise to new plants initially; gradually plants in initial treatment zone produced new tillers and plants.

It was observed during the end of the study period that, the tip of the plants in section 2, 10 and 16 died and fallen off. It was observed that bottom leaves (2-4 in numbers) of plants of most of the sections tuned to yellowish brown.

However HSSF system allowed incoming pre-treated leachate to be polished to a level allowing discharge in compliance with the general standards for the discharge of industrial effluents into inland surface waters of Sri Lanka.

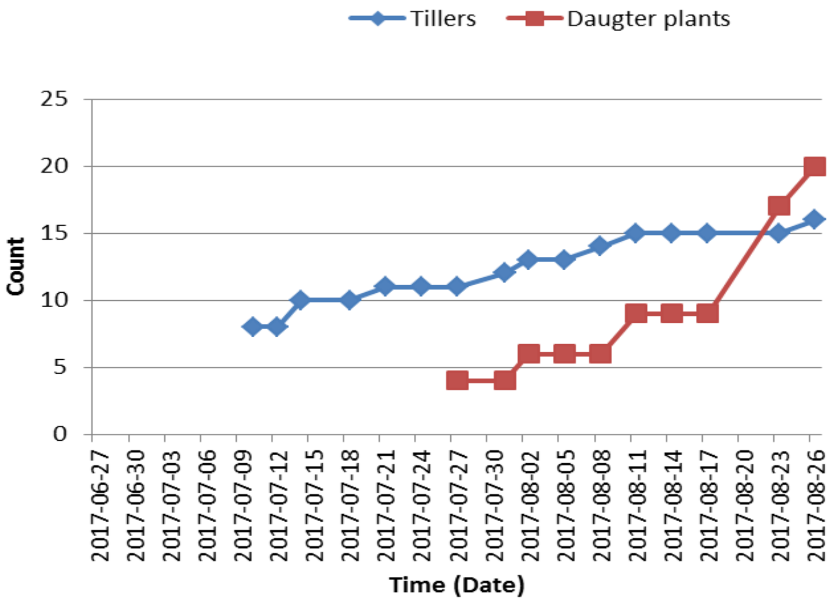


Figure 4.13: Growth of tillers and daughter plants during the study period

CHAPTER 5: CONCLUSIONS

- This study depicts the need of a tertiary treatment system to support the treatment of sanitary landfill leachate, to ensure final effluent is in good quality and consistently meet the permissible discharge standards, since some parameters (i.e. COD and TSS) in pre-treated leachate (i.e. SBR effluent), occasionally exceed the permissible discharge limits. During the study period the mean TSS (60.19 mg/l) of the Influent exceeds the permissible level of discharge into inland surface water bodies, that is 50 mg/l, max. However the pre-treatment of the leachate using sequencing batch reactor facilitated the function of the system by reducing the pollutant load to a considerable extent adding to system efficacy during the study period.

- The overall performance of this HSSF system predicted that this system performed efficiently in tertiary treatment of landfill leachate; there was a significant reduction of mean concentration of the tested parameters in the outlet compared to the inlet of the system. A significant percentage of the most of the tested parameters was removed from the leachate sample; the concentration based average removal efficiency of the system reveals that:
  - This HSSF system is most effective in the removal of TSS comparing to the rest of the parameters; removal efficiency of TSS is 96%.
  - Removal efficiency for BOD_5, COD and PO_4^{3-} -P are 63%, 62%, and 85.28% respectively.
  - This system was not performing well in NO_3^- -N removal; Its removal efficiency is the lowest compared to the rest of the parameters i.e. 49.11%.

CHAPTER 6: RECOMMENDATIONS

- This study was carried out using the pre-treated, secondary effluent of the leachate, from the SBR plant because of the constructed wetland in the landfill receives the effluent of the SBR plant. Therefore the operation of SBR is having a key role in the overall leachate treatment process. The proper operation, continuous monitoring and maintenance of the SBR are important to avoid the shock loadings and impacts on the survival of the plant introduced into the constructed wetland; because of, the leachate quality of the landfill varies with composition of solid wastes dumped, climate and with the degree of stabilization with the age of the dumpsite. Therefore, ensuring the proper maintenance and operation of this plant, together with monitoring is important to obtain a good quality effluent from this two stage treatment process.

- It shall be noted that this study was conducted as a trial pilot scale in order to check the applicability of HSSF for tertiary treatment of leachate. Further long term research is necessary to examine the effects of continuous feeding, climatic variations and shock loadings on the growth response of plants. Such long-term study will enable a more definite understanding of the performance of *Phragmites karka* plants in tertiary treatment of leachate.

REFERENCE LIST

01 Akinbile, C.O., Yusoff, M.S., & Zuki, A.Z.A. (2012). Landfill leachate treatment using sub-surface flow constructed wetland by *Cyperus haspan. Waste Management*, *32*(7), 1387–1393.

02 Alker, S.C., Sarsby, R.W., & Howell, R. (1995). The composition of leachate from waste disposal sites. In Sarsby (ed.), *Waste Disposal by Landfill-GREEN'93.* Balkema, Rotterdam.

03 American Public Health Association. (1980). *Standard methods for the Examination of Water and Wastewater* (15th ed.). American Public Health Association.

04 American Public Health Association. (2012). *Standard methods for the Examination of Water and Wastewater* (22nd ed.). American Public Health Association.

05 Aziz, H.A., Alias, S., Adlan, M.N., Faridah, Asaari, A.H., & Zahari, M.S. (2007). Colour removal from landfill leachate by coagulation and flocculation processes. *Bioresource Technology*, *98*(1), 218–220.

06 Barr, M.J., & Robinson, H.D. (1999). Constructed wetlands for landfill leachate treatment. *Waste Manage Res*, *17*, 498-504.

07 Billore, S.K., Prashant, & Sharma, J.K. (2008). Restoration and conservation of stagnant water bodies by gravel-bed treatment wetlands and artificial floating reed beds in tropical India. In Sengupta, M. and Dalwani, R. (Editors), *Proceedings of Taal 2007: The 12th World Lake Conference* (981-987).

08 Billore, S.K., Prashant, & Sharma, J.K. (2009). Treatment performance of artificial floating reed beds in an experimental mesocosm to improve the water quality of river Kshipra. *Water Science and Technology, 60* (11), 2851-2859.

09 Billore, S.K., Singh, N., Ram, H.K., Sharma, J.K., Singh, V.P., Nelson, R.M., & Das, P. (2001). Treatment of a molasses based distillery effluent in a constructed wetland in central India. *Water Sci. Technol., 44* (11/12), 441–448.

10 Billore, S.K., Singh, N., Sharma, J.K., Dass, P., & Nelson, R.M. (1999). Horizontal subsurface flow gravel bed constructed wetland with *Phragmites*

karka in Central India. *Water Science and Technology*, *40* (3), 163-171.

11 Brisson, J., & Chazarenc, F. (2009). Maximizing pollutant removal in constructed wetlands: Should we pay more attention to macrophyte species selection? *Science of the Total Environment*, *407* (13), 3923-3930.

12 Chavan, B.L., & Dhulap, V.P. (2012). Designing and testing of wastewater in constructed wetland using *Phragmites karka*. *International Journal of Physical and Social Sciences, 2* (12).

13 Chiemchaisri. C., Chiemchaisri, W., Junsod, J., Threedeach, S., & Wicranarachchi, P.N. (2009). Leachate treatment and greenhouse gas emission in subsurface horizontal flow constructed wetland. *Bioresource Technology*, *100*, 3808–3814.

14 Cook, C.D.K. (1996). *Aquatic and Wetland Plants of India*. Oxford, Oxford University Press.

15 Cunningham, S.D., & Ow, D.W. (1996). Promises and Prospects of Phytoremediation. *Plant Physiol.*, *110*, 715-719.

16 Dissanayake, M.D., Fosbery, F.R., & Clayton, W.D. (1994). *A revised handbook to the flora of Ceylon* (Volume VIII, Page 373-374). New Delhi.

17 El-Gendy, A.S., Biswas, N., & Bewtra, J.K. (2005), A floating aquatic system employing water hyacinth for municipal landfill leachate treatment: effect of leachate characteristics on the plant growth. *J. Environ. Eng. Sci*. *4*, 227–240.

18 Fernandopulle, L. (2017, July 9). Waste to energy plants in the pipeline, garbage issue cannot be trashed any more. Retrieved from www.sundayobserver.lk.

19 Frankenberg, J. (1997). Guidelines for growing *Phragmites* for erosion control, Murray-Darling Freshwater Research Centre, Albury.

20 Gersberg, R.M., Elkins, B.V., & Goldman, C.R. (1983). Nitrogen removal in artificial wetlands. *Water Res.*, *17* (9), 1009–1014.

21 Gratao, P.L., Prasad M.N.V., Cardoso, P.F., Lea, P.J., & Azevedo, R.A. (2005). Phytoremediation: green technology for the cleanup of toxic metals in the environment. *Braz. J. Plant Physiol. 17* (1), 53-64.

22 Grisey, E., Laffray, X., Contoz, O., Cavalli, E., Mudry, J., & Aleya, L. (2012). The bioaccumulation performance of reeds and cattails in a constructed treatment wetland for removal of heavy metals in landfill leachate treatment (Etueffont, France). *Water Air Soil Pollut, 223*(4), 1723–1741.

23 Gul, B., Abideen, Z., Qasim, M., Rasheed, A., Adnan, M.Y., & Khan, M.A. (2015). Antioxidant activity and polyphenolic content of *Phragmites karka* under saline conditions. *Pak. J. Bot., 47*(3), 813-818.

24 Herath, I., & Vithanage, M. (2015). *Phytoremediation in Constructed Wetlands.* DOI: 10.1007/978-3-319-10969-5_21.

25 Hinchman, R.R., Negri, M.C., & Gatliff, E.G. (n.d.). Phytoremediation: using green plants to clean up contaminated soil, groundwater, and wastewater. Retrieved from: http://treemediation.com.Technical._Phytoremediation_1998 .pdf.

26 Ibezute, A.C., Tawari-Fufeyin, P., & Oghama, O.E. (2014). Analysis of pollution removal from compost leachate by Vetiver grass (l.) Nash plant (*Vetiveria zizanioides*). *Resources and Environment*, *4*(6), 268-273

27 Innes, R.R. (1977). *A manual of Ghana grasses* (With a key to species by W. D. Clayton). Surbiton, UK: the Ministry of Overseas Development, Land Resources Division, *14* (02), 265.

28 Jayasena, W.D.G., Jinadasa, K.S.B.N., Jayamal, A.N., Jayasinghe, R.G.D.P., Mohamed, A., & Tanaka, N. (2013). Leachate treatment by Constructed wetland System. *ACEPS-2013*.

29 Jayaweera, M., Annacchatre, A., & Guo, Z. (2002). Treatment options for heavy metal containing wastewaters. *Asian Regional Research Programme on Environmental Technology,* 86-119

30 Jayaweera, M.W. (2013). *Wetland Sri Lanka: Heavy metal adsorption by low coat mineral substrates incorporated in constructed wetlands*, CEA, 43-44.

31 Jha, A.K., & Bajracharya, T.R. (2014). Wastewater treatment technologies in Nepal. *Proceedings of IOE Graduate Conference*, 76-81.

32 Jones, D.L., Williamson, K.L., & Owen, A.G. (2006). Phytoremediation of landfill leachate. *Waste Management*, *26*, 825–837.

33 Justina, M.Z., & Zupancic, M. (2009). Combined purification and reuse of landfill leachate by constructed wetland and irrigation of grass and willows. *Desalination*, *247*, 158–169.

34 Koskiaho, J., & Puustinen, M. (2005). Function and potential of constructed wetlands for the control of N and P transport from agriculture and peat production in boreal climate. *Journal of Environmental Science and Health*, *40*, 1265–1279.

35 Kurniadie, D. (2011). Wastewater treatment using vertical subsurface flow constructed wetland in Indonesia. *American Journal of Environmental Sciences*, *7* (1), 15-19.

36 Lansdown, R.V. (2013). *Phragmites karka: The IUCN red list of threatened species 2013.* Retrieved from http://dx.doi.org/10.2305/IUCN.UK.2013-1. RLTS.T168955A1256797.en.

37 Megonikal, J.P., Hines, M.E., & Visscher, P.T. (2004). Anaerobic metabolism: linkage to trace gases and aerobic processes. In Schlesinger WH, editor. *Biogeochemistry* (p. 317–424). Oxford, U.K.: Elsevier-Pergamon.

38 Metcalf, & Eddy. (2014). Wastewater engineering treatment & reuse (4th edition). McGraw Hill Education (India) Private Limited.

39 Mojiri, A., Aziz, H.A., Zahed, M.A., Aziz, S.Q., & Selamat, M.R.B. (2013). Phytoremediation of heavy metals from urban waste leachate by Southern Cattail (*Typha domingensis*). *International Journal of Scientific Research in Environmental Sciences (IJSRES)*, *1*(4), pp. 63-70.

40 Mukherjee, S., Mukhopadhyay, S., Hashim, M.A., & Gupta, B.S. (2015). Contemporary environmental issues of landfill leachate: Assessment and remedies. *Critical Reviews in Environmental Science and Technology*, *45*(5), pages 472-590.

41 Nilusha, R.T., Dissanayake, D.M.H.S., & Fonseka, W.R.K. (2015). Preliminary study on nutrient removal of dairy wastewater by pilot scale subsurface horizontal flow constructed wetland planted with *Schoenoplectus grossus. International Journal of Recent Research in Interdisciplinary Sciences* (IJRRIS), *2*(3), 38-44.

42 Oh, K., Cao, T., Li, T., & Cheng, H. (2014). Study on application of phytoremediation technology in the management and remediation of contaminated soils. *Journal of Clean Energy Technologies, 2*(3).

43 Pathiraja, P.M.G., & Perera, N.P.T. (n.d). Pilot scale study: use of subsurface flow constructed wetlands for domestic wastewater treatment in Sri Lanka'. Retrieved from http://dl.lib.mrt.ac.lk/handle/123/8947.

44 Pilisaru Project. (2009). *Initial Environmental Examination report for Proposed Final Disposal Facility at Maligawatte, Dompe.*

45 Rani, S.H.C., Chelliapan, S., Mohd. M.F.M.D., & Yusof, B.M. (2011). Overview of Subsurface Constructed Wetlands Application in Tropical Climates. *Universal Journal of Environmental Research and Technology*, *1*(2), 103-114.

46 Richardson, V.P., Meetiyagoda, T.A.O.K., Jinadasa, K.B.S.N., & Gamage, P.D. (2016). Total nitrogen removal of municipal solid waste leachate using hybrid constructed wetlands. *ACEPS-2016.* Retrieved from http://www.dcee.ruh.ac.lk/ images/donaimage/ACEPProceeding2016/Total%20Nitrogen%20Removal%20 49of%20Municipal%20Solid%20Waste%20Leachate.pdf>

47 Sasikala, S., Mowjood, M.I.M., & Basnayake, B.F.A. (2005). Formulation of harvesting regimes from bulrush (*Scirpus grossus* Lf.) growth responses to MSW leachate in constructed wetlands with coir-based media. *Tropical Agricultural Research. Vol. 17,* 12S -134.

48 Sengupta, S., Gopal, B., & Das, S.N. (2004). Effect of nutrient supply and water depth on nutrient uptake by two wetland plants. *Bull.Nat.Inst.Ecol, 14*, 55-60.

49 Sharma, K.P., Sharma, K., Kumar, K., Sharma, S., Grover, R., Soni, Bhardwaj, S.M., Chathurvedi, R.K., & Sharma, S. (2005). Response of selected aquatic macrophytes towards textile dye wastewater. *Indian Journal of Biotechnology, 4*, 538-545.

50 Singh, P.K., Sharma, K.P., Sharma, S., Swami, R.C., & Sharma, S. (2010). Polishing of biomethanated spent wash (primary treated) in constructed wetland: A bench scale study. *Indian Journal of Biotechnology*, *9*, 313-318.

51 Sogut, Z., Zaimoglu, B.Z., Erdogan, R., & Sucu, M.Y. (2005). Phytoremediation of landfill leachate using *Pennisetum clandestinum. Journal of Environmental Biology, 26* (1), 13-20.

52 Tanaka, N., Jinadasa, K.B.S.N., Werellagama, D.R.I.B., Mowjood, M.I.M., & Ng, W.J. (2006). Constructed tropical wetlands with integrated submergent-emergent plants for sustainable water quality management. *Journal of environmental Science and Health, Part A, 41*, 2221-2236.

53 United States Environmental Protection Agency & Centre for Environmental Research Information. (2000). *Design Manual: Constructed Wetlands and Aquatic Plant Systems for Municipal Wastewater Treatment.* Cincinnati.

54 United States Environmental Protection Agency. (1999). *Constructed Wetlands Treatment of Municipal Wastewater.* Cincinnati, Ohio.

55 University of Moratuwa. (2013). *World bank Metro-Colombo urban development project report on sediment & water quality analyses at selected locations.* Uni-Consultancy Services. University of Moratuwa.

56 Vipat, V., Singh, U.R., & Billore, S.K. (2008). Efficacy of root zone technology for treatment of domestic wastewater: Field scale study of a pilot project in Bhopal. (MP), India. *Proceedings of Taal2007: The 12th World Lake Conference,* 995-1003.

57 Vymazal, J. (2009). The use constructed wetlands with horizontal sub-surface flow for various types of wastewater. *Ecological engineering, 35,* 1-17

58 Vymazal, J., & Kröpfelová, L. (2009). Removal of organics in constructed wetlands with horizontal sub-surface flow: A review of the field experience', *SCIENCE OF THE TOTAL ENVIRONMENT, 407,* 3911–3922.

59 Weragoda, S.K., Tanaka, N., Sewwandi, B.G.N., & Mowjood, M.I.M. (2010). Efficiency of coconut coir-pith as an alternative substrate in the treatment of submerged macrophyte wetlands systems in tropical conditions. *Chemistry and Ecology*, *26*(6), 445-452.

60 Wimalasuriya, K.M.D.D.C., Chandrathilake, T.H.R.C., Liyanage B.C., & Gunathilake, J. (2011). In-situ water quality and economical leachate treatment

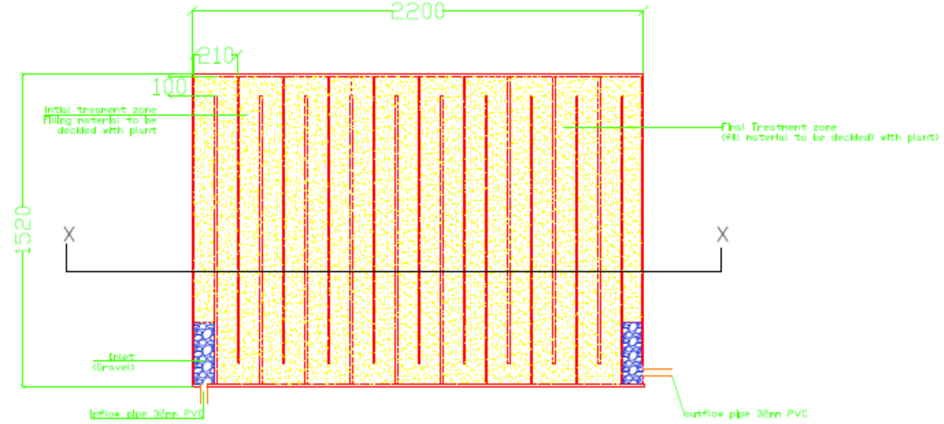
system for Gohagoda dumping site, Sri Lanka', *IESL-SSMS Joint International Symposium*,189-198

61 Wojciechowska, E., Gajewska, M., & Obarska-Pempkowiak, H. (2010). Treatment of Landfill Leachate by Constructed Wetlands: Three Case Studies. *Polish J. of Environ. Stud.*, *19* (3), 643-650.

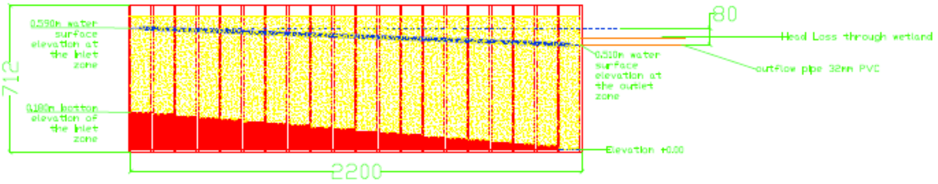
62 Yalcuk. A., & Ugurlu, A. (2009). Comparison of horizontal and vertical constructed wetland systems for landfill leachate treatment. *Bioresource Technology*, *100*, 2521-2526.

63 Zhang, B.Y., Zheng, J.S., & Sharp, R.G. (2010). Phytoremediation in engineered wetlands: Mechanisms and applications. *Procedia Environmental Sciences*, *2*, 1315–1325.

APPENDIX-A: DRAWINGS OF THE DESIGN



Elevation of the Wetland



X-X Cross section of the Wetland

APPENDIX-B: SUMMARY OF THE DESIGN

The design summary for the constructed wetland when flow is 0.02 m^3/d.

Design Summary			
The Surface Area for the initial Treatment Zone (Asi)	=	0.10	m^2
The Surface Area for the final Treatment Zone	=	0.23	m^2
Width of VSB	=	0.01	m
Length of initial Treatment zone	=	10.95	m
Length of final treatment zone	=	25.56	m
Elevation at bottom outlet	=	0.00	m
Elevation of bottom at beginning of the Final Treatment	=	0.13	m
Elevation of bottom of the inlet	=	0.18	m
Water Surface Elevation			
At inlet	=	0.59	m
At beginning of the final Treatment zone	=	0.53	m
At outlet	=	0.51	m
Outlet zone*	=	0.50	m
Inlet zone*	=	0.50	m
Media elevation	=	0.65	m
Media Depth	=	0.60	m
Water depth at Inlet	=	0.51	m

The requirement of the Calicut tiles = 2.405 m^3

Standard

*In these zones large, well-sorted gravel is used

**standard is 0.3 to 0.7m

APPENDIX-C: STATISTICAL ANALYSIS OF THE DATA

Since data of Influent BOD$_5$, Effluent BOD$_5$, Influent COD, Effluent COD, Influent TSS, Effluent TSS, Log of NO_3^- -N_ Influent & Log of NO_3^- -N_ Effluent, Influent PO_4^{3-} -P and Effluent PO_4^{3-} -P are normally distributed, paired sample T-test is carried out to check the difference between mean values of influent and effluent of each tested parameter separately.

- Null hypothesis:

  H_0: $\mu_{IN} - \mu_{OUT} = 0$ (The difference between the mean concentration of the inlet and outlet of the particular tested parameters is equal to 0)

  Vs

  Alternative hypothesis:

  H_1: $\mu_{IN} - \mu_{OUT} \neq 0$ (The difference between the mean concentration of the inlet and outlet of the particular tested parameters is not equal to 0)

- α =0.05

1. Paired T-Test and CI: BOD5_In, BOD5_Out

```
Paired T for BOD5_In - BOD5_Out

             N     Mean   StDev  SE Mean
BOD5_In     16  17.9375  5.6388   1.4097
BOD5_Out    16   6.5000  2.9212   0.7303
Difference  16  11.4375  4.2264   1.0566


95% CI for mean difference: (9.1854, 13.6896)
T-Test of mean difference = 0 (vs not = 0): T-Value = 10.82  P-Value = 0.000
```

As the *p*-value is less than 0.05, it can be concluded that there is a statistically significant difference between the mean BOD$_5$ concentration of Inlet and Outlet of the HSSF wetland. According to the results, mean BOD$_5$ concentration was lower in outlet compared to the inlet. 95% confident that difference between BOD$_5$ concentration in inlet and outlet range between 9 and 14.

2. Paired T-Test and CI: COD_In, COD_Out

```
Paired T for COD_In - COD_Out

            N     Mean   StDev  SE Mean
COD_In      16  183.313  76.088   19.022
COD_Out     16   61.750  18.849    4.712
Difference  16  121.563  69.089   17.272


95% CI for mean difference: (84.747, 158.378)
T-Test of mean difference = 0 (vs not = 0): T-Value = 7.04  P-Value = 0.000
```

As the *p*-value is less than 0.05, it can be concluded that there is a statistically significant difference between the mean COD concentration of Inlet and Outlet of HSSF wetland. According to the results, mean COD Concentration was lower in outlet compared to the inlet. 95% confident that difference between mean COD concentration in inlet and outlet range between 85 and 158.

3. Paired T-Test and CI: TSS_In, TSS_Out

```
Paired T for TSS_In - TSS_Out

            N     Mean    StDev  SE Mean
TSS_In      16  60.1875  29.6630   7.4158
TSS_Out     16   2.1875   1.0468   0.2617
Difference  16  58.0000  29.0861   7.2715


95% CI for mean difference: (42.5011, 73.4989)
T-Test of mean difference = 0 (vs not = 0): T-Value = 7.98  P-Value = 0.000
```

As the *p*-value is less than 0.05, it can be concluded that there is a statistically significant difference between the mean TSS concentration of Inlet and Outlet of HSSF wetland. According to the results, mean TSS Concentration was lower in outlet compared to the inlet. 95% confident that difference between mean TSS concentration in inlet and outlet range between 43 and 73.

4. Paired T-Test and CI: Log NO3_N_In, Log NO3_N_Out

```
Paired T for Log NO3_N_In - Log NO3_N_Out

               N      Mean     StDev   SE Mean
Log NO3_N_In   16  0.676640  0.337384  0.084346
Log NO3_N_Out  16  0.271620  0.297808  0.074452
Difference     16  0.405020  0.353410  0.088352


95% CI for mean difference: (0.216701, 0.593339)
T-Test of mean difference = 0 (vs not = 0): T-Value = 4.58  P-Value = 0.000
```

Results are transformed into anti-log forms.

```
AntiLogMeanNO3_N_Influent
4.74941

AntiLogMeanNO3_N_Effluent
1.86905

AntiLogMeanNO3_N_Difference
2.54109

AntiLogMeanNO3_N_Difference_ StDev
2.25637

AntiLogMeanDifLow_NO3_N
1.64703

AntiLogMeanDifHigh_NO3_N
3.92048
```

As the *p*-value is less than 0.05, it can be concluded that there is a statistically significant difference between the mean NO_3^- -N concentration of Inlet and Outlet of HSSF wetland. According to the results, mean NO_3^- -N concentration was lower in outlet compared to the inlet. 95% confident that difference between mean NO_3^- -N concentration in inlet and outlet range between 1.65 and 3.92.

5. Paired T-Test and CI: PO4-P_In, PO4-P_Out

```
Paired T for PO4-P_In - PO4-P_Out

            N     Mean    StDev  SE Mean
PO4-P_In    16  2.07125  1.10536  0.27634
PO4-P_Out   16  0.26813  0.11623  0.02906
Difference  16  1.80313  1.07208  0.26802


95% CI for mean difference: (1.23185, 2.37440)
T-Test of mean difference = 0 (vs not = 0): T-Value = 6.73  P-Value = 0.000
```

As the *p*-value is less than 0.05, it can be concluded that there is a statistically significant difference between the mean PO_4^{3-} -P concentration of Inlet and Outlet of HSSF wetland. According to the results, mean PO_4^{3-} -P concentration was lower in outlet compared to the inlet. 95% confident that difference between mean PO_4^{3-} -P concentration in inlet and outlet range between 1.23 and 2.37.