SOLID WASTE LEACHATE TREATMENT THROUGH CONSTRUCTED WETLAND

By

Syed Muhammad Usman Ali

(2011-NUST-MSPhD-EnvS-04)

A thesis submitted in partial fulfillment of requirements for the degree of
Master of Science

in

Environmental Science

Institute of Environmental Sciences and Engineering (IESE)
School of Civil and Environmental Engineering (SCEE)
National University of Sciences and Technology (NUST)
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It is certified that the contents and forms of the thesis entitled

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Submitted by

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Has been found satisfactory for the requirements of the degree of
Master of Science in Environmental Science

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This thesis is dedicated to my Supervisor

Dr. Muhammad Anwar Baig & my Parents

For their endless affection, support and encouragement

ACKNOWLEDGEMENTS

This study was completed under the guidance and the help of many individuals, who contributed generously during the course of this research.

*I shall always be indebted and obliged to my supervisor Prof**. Dr. Muhammad Anwar Baig** (Head of Department Environmental Sciences, IESE, SCEE, NUST), who provided me with his valuable technical assistance, constant guidance and encouragement. **Dr. Ishtiaq A. Qazi** has always been my source of inspiration as I moved towards the completion of my research and my MS journey. Many thanks also go to **Dr. Muhammad Arshad** and **Dr. Muhammad Ashraf** who had always been very considerate and supportive in my research work especially in the area of Plants.*

I am also thankful to Engr. Kashif Nadeem, Mr. Usman Hanif, Hamid Iqbal, Malik Muhammad Hassan and Salman Ahmed for their unfailing support.

*The IESE Labs personnel, especially **Mr. Basharat** and **Mr. Muhammad Yasir**, were very accommodative to all my queries during the experimental work and I am grateful to them for this.*

I cannot forget the support of my friends including Asim Waris, Yasir Shabbir, Fasil Raza & others who helped me when required.

Syed Muhammad Usman Ali

TABLE OF CONTENTS

CONTENTS

LIST OF ABBREVIATIONS

COD	Chemical Oxygen Demand
CWs	Constructed Wet Land
EPD	Environmental Protection Department
SWM	Solid Waste Management
US EPA	United States Environmental Protection Agency
MSW	Municipal Solid Waste
TOC	Total Organic Carbon
Cl^-	Chloride
EC	Electrical Conductivity
DOC	Dissolved Organic Carbon
TN	Total Nitrogen
TDS	Total Dissolved Solids
TP	Total Phosphorous
NEQS	National Environmental Quality Standards
DM	Dried Mass

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Solid Waste disposal in open dumps/landfills results in generation of highly contaminated liquid, called leachate. This is extremely harmful to environment, water bodies, humans & animals. To study the leachate constituents & possible treatment, a subsurface-flow type wetland was constructed at pilot scale at the Institute of Environmental Sciences & Engineering, NUST Islamabad, to demonstrate its use as a viable, simple & low-cost treatment option at small landfill sites.

Four native wetland plant species (*Typha latifolia*, *Ipomoea carnea var. Fistulosa*, *Phragmtis karka*, and *Ricinus communis*) were cultivated in monoculture. The objective was comparison of effectiveness of these plants for nutrient removal in controlled wetland microcosms. Fresh municipal waste was collected from Rawalpindi and leachate was generated in closed drums for three weeks and was analysed for COD, TDS, EC, TOC, TN, Chloride & Sulphate etc. When applied to various selected plants it was observed that for COD & chloride removal *Typha latifolia* performed better. For TOC, Phosphate & TN, *Ricinus communis*, had better performance as compared to other plant species. *Phragmitis karka* reduced TDS & EC values more efficiently, while *Ipomoea carnea var. Fistulosa* was good at normalizing pH of the influent.

Chapter 1

1 INTODUCTION:

Solid Waste Management is referred as a field correlated with handling of waste generated by various sources including domestic, commercial & industrial, its collection & storage mechanism, transport and transfer for processing and end disposal of solid waste in such manner which are according to the best practices & principles of engineering, aesthetics, public health, conservation, economics, environmental ethics and other environmental considerations (Tchobanaglous, G. et al, 1997).

Solid Waste is a major problem in rural & urban areas all over the world. The waste generated from different anthropogenic activities including industrial and domestic facilities, if not effectively and efficiently managed, results in health problems in particular and have a negative impacts on the environment in general. To build an effective and appropriate waste management system for a particular society the understanding of waste generation, resources availability and the environmental condition of particular society are most important factors which must be considered.

1.1 Waste Disposal Practices

1.1.1 Landfills

The 'landfill' is referred to elaborate a unit operation for end disposal of 'Municipal Solid Waste' on the ground, constructed and designed with aims of minimum environmental impacts by installing essential components such as leachate control system, gas control system, closure and post-closure plan and environment monitoring system. The term landfill incorporates other terms like 'engineered landfills' and 'secured landfill' which are commonly referred and applied experience to waste disposal units in municipalities.

1.1.2 Open Dumping

Any other type of practice than sanitary landfill is generally termed as open dumping method of waste disposal which is most popular and broadly practiced in the world because of its economic advantages in term of capital cost and management for waste disposal (Renoua et al. 2008).

Furthermore, there are environmental advantages under controlled conditions in terms of waste decomposition till its stabilization are also obvious. But a major disadvantage is production of leachate, which contains high contamination of numerous pollutants with high concentration. These pollutants are extremely hazardous for health of humans, animals, plants & surrounding environment. (Aziz et al, 2004).

1.2 Leachate Composition and Generation

Natural moisture & rainwater percolating in the solid waste degrade organic components of waste into simpler constituents through a series of biological and chemical reactions that involve oxidation, hydrolysis, dissolution and reduction. An unpleasant odour or foul smelling black liquid caused by putrefaction of garbage and natural decomposition is called as percolated liquid or leachate that looks similar to domestic waste water, but with much higher contamination concentration. Rainwater plays an important role in leachate generation. It act as a catalyst when leaches down with contaminants of solid waste layers and generate high proportion of leachate which in volume is far greater from the proportion of moisture content of solid waste. Therefore it is most important engineering phase to divert the rainwater from landfill or any other dumpsite where the waste is being collected. Otherwise the operational phase will effect badly and there would be toxification in the water bodies, water ways, water sources and groundwater through the nearby wells (Robinson *et al*, 1982; Ehrig, 1982; Fetter, 1993). Table 1.1 below shows characteristics of leachate generated from landfill and open dumps.

Table 1.1 Range of Landfill Leachate Characteristics from Various Countries

Sr No.	Parameters	UK	Germany	America
1	pH	6.2-7.4	1-8.0	5.4-7.2
2	Total Dissolved Solids (mg/L)	-	-	2180-25900
3	BOD (Biological Oxygen Demand) (mg/L)	<2-8,000	180-13,000	100-29,200
4	TOC (Total Organic Carbon) (mg/L)	21-4,400	-	427-5,890
5	NH_3-N (Ammonia-nitrogen) (mg/L)	5-730	741	26-557
6	TP (Total phosphorous) (mg/L)	<0.02-3.4	5.7	0.3-117
7	Cl^- (Chloride) (mg/L)	70-2	2-119	180-2,650
8	(Fe) Iron(mg/L)	0.1-380	15-925	2.1-1,400
9	(Mn) Manganese(mg/L)	0.3-26.5	0.7-24	.03-25.9
10	(Ca) Calcium(mg/L)	165-1,150	80-1,300	200-2,100
11	(Mg) Magnesium(mg/L)	12-480	250-600	120-780

1.3 Environmental Problems from Leachate

Solid Waste leachate may be referred as a type of waste water which is a composite of highly concentrated pollutants which results in severe environmental impacts (Li *et al*, 1995). If the leachate is left unattended, it can pollute the surface water as well as ground water by percolating through top soil and sub soil layers (Tatsi *et al*, 2003).

Organic compounds in municipal solid waste are highly responsible for direct and indirect spread of ailments. Human health could be affected via groundwater contamination by leachate. When the ground water (also referred as aquifer/ water table) is contaminated, then its extent is much larger and is very hard to treat. Groundwater is the source of drinking water for entire populations, therefore special attention is to be paid. If the polluted sources are not adequately treated, they can lead to deterioration of human health as well as increased treatment costs. When the surface water bodies become enriched with the nutrients supplied by leachate, eutrophication occurs. It severely damages the aquatic habitats including lakes, causing algal blooms resulting the death of fish, producing unpleasant odours, and destroying the aesthetic beauty of the rivers. Due to eutrophication, these water sources are no more suited for consumption of local inhabitants for drinking purposes (Kaseva, 2004).

1.4 Proposed Solution

Natural wetlands are proved solution for the treatment of different waste water streams and also for polishing of waste water, but some issues such as operational drawbacks in hydraulic control and vegetation management are associated with them (Katayonet al, 2008). But these natural systems have been used and suggested for waste water treatment from many years (Babatunde et al, 2008).

Constructed wetlands are also called artificial wetlands or engineered wetlands. They are made by mimicking natural wetlands which mimic the functions of natural wetlands. They are designed, constructed and operated for various purposes such as providing new or restoring existing habitat for indigenous migratory birds and animals to perform natural wetland functions (Kropfelova et al, 2009). The artificial or constructed wetlands provide habitat to diverse species of microorganisms to survive with other species and therefore they are highly efficient in waste water treatment especially biological oxygen demand (BOD5) removal. Due to soil media the constructed wetlands provide most suitable conditions for filtration, sedimentation, ion exchange & adsorption etc. (Cothren et al, 2002).

1.5 Leachate Treatment Situation in Pakistan

There are mostly simple dumping grounds present in Pakistan which are situated without any environmental site assessment and mitigation measures. The leachate generated from that waste is discharged without any treatment and directly goes into the water bodies and pollute them badly which ultimately disturb the whole ecosystem particularly in those areas where land fill is situated directly up the water stream (Iqbal, et al, 2015).

1.6 Objectives of Study

Keeping in view the type of municipal waste, leachate generation, its characteristics and wetland system, following objectives have been conceived:

- Leachate generation and characterization from fresh municipal waste and its application to constructed wetland system for its treatment.
- Comparison of the potential of four different native wetland plants for treatment of leachate using subsurface flow system.

CHAPTER 2

2 LITERATURE REVIEW

With the increasing production of solid waste, leachate is a growing concern because of this toxic effects on the ecosystem, mainly due to its uncontrolled discharge in surface water and ground water systems. Many natural systems have been considered for the purpose of leachate treatment and their use for resource conservation in comparison to the traditional leachate treatment systems which are energy intensive and involve use of chemicals (Chu et al, 1994).

Natural wetland systems perform the role of earth's kidneys by filtering pollutants from water as it passes through lakes, streams and oceans. Wetlands rely on combination of flora and fauna treatment abilities in their natural treatment system, utilizing very low energy to treat leachate & remove the pollutants. Wetland system are very cost effective and efficient specially undeveloped and developing countries, where economy and simplicity are of paramount importance. Although it has been scientifically proven that the constructed wetlands have enormous potential for application in developing countries but still this concept has not found its proper propagation in those countries (Kivaisi, 2001). Pakistan, as an emerging country has a great potential for adaptation of this much simpler, economically acceptable, efficient, easy to maintain and operate leachate treatment system.

2.1 Constructed Wetlands

Following the concept of natural wetlands, scientists and engineers from all over the world have successfully developed the replicas of natural wetland systems known as constructed or artificial wetlands. These constructed wetlands are designed to filter wastewater & leachate using natural processes found in natural wetland ecosystems mainly run by vegetation, soil and microorganisms related to wetland biota (Bulc, et al, 1997).

2.2 Need of Constructed Wetlands

Constructed wetland are designed and engineered by mimicking natural wetland systems for wastewater treatment, comprising of number of compartments packed with permeable media with native wetland plants species such as reeds, cattails and bulrushes grown in monoculture or poly culture. They are developed to mimic and amplify physical, chemical and biological mechanisms of natural wetland systems to treat the leachate in terms of reducing the BOD, TSS, TN, phosphorus and other contaminants, as wastewater streams gradually through the vegetated subsurface. Other phenomenon like bioaccumulation (accumulation of substances in plants & other organisms), biotransformation (changing of form of a substances from one chemical to another by a certain internal chemical reaction) and biodegradation (chemical dissolution of substances by biological processes) of metals can be observed (Pendleton et al, 2005).

2.3 Leachate Treatment & Constructed Wetlands

Unplanned landfill sites, which may or may not be operational, pose a permanent threat of polluting surface water & aquifers because of leachate generation. The landfill sites are assumed safe when their resultant products are continuously collected and treated properly from the start of decomposition process till it becomes dormant. Leachate poses diverse hazards to the environment as the waste, which is responsible for its generation, has diverse composition & characteristics (Johnson et al, 1998).

As waste generation trends and composition varies geographically, the leachate generated at different geographical landfill sites have distinct characteristics and contaminants. Other factors that are responsible for variable leachate characteristics include the composition of solid waste, its age, dumping mechanism, and climatic conditions. Moreover deviating from standard leachate sampling techniques and handling practices can also result in variation of leachate characteristics (Hernandez et al, 1999; Kjeldsen et al, 2002).

Decomposition of waste involves acid and methanogenic phase. In these phases, decrease of ammonia nitrogen concentration level is mostly not easy and is considered as one of the major goal of treatment system (Robinson et al, 1998). Conventional techniques including in situ treatment & ex situ treatment are not desirably practiced as the transportation involves risks and cost implications while in situ facilities are capital and energy intensive and can result in unmanageable by products from the processes (Higgins, 2000; Bowman etal., 2002).

Despite the above argument on disadvantage of in situ treatment of leachate, it is comparatively low energy, economical & easy to maintain & operate solution without significant environment risks mostly associate with transportation (Higgins, 2000). Among one of very good in situ treatment option, constructed wetlands leachate treatment system has been mostly adopted in various countries with a range of success levels (Vrhovˇsek et al, 1996, 2000; Johnson et al, 1998). As a relatively new concept in terms of a green technology than the traditional technologies, constructed wetlands will be recognized as a sustainable solution for landfills in near future. The operational performance of constructed wetlands have been monitored over course of years to determine its potential limitations and it is assessed with reference to its effectiveness (Christens et al, 2001).

Leachate treatment using constructed wetland involves low capital investment and maintenance cost, less energy and resource consumption and is simple to apply. Constructed wetlands have been recognized as an effective substitute for the treatment of solid waste leachate. Wetland plants can easily be grown in the vicinity of landfills or open dumps with almost negligible capital investment and can be run by relatively less skilled personals (Tuladhar et al, 2008).

Even in the developed industrialized countries, constructed wetlands are being used due to their immense economic and environmental benefits and potential to meet effluent discharge standards. Constructed wetlands can act as sinks for many pollutants, by various mechanisms involving sedimentation, filtration, plant uptake, microbial oxidation and reduction etc., hence protecting the downstream ecosystems (Cooper et al, 1996).

Currently these constructed wetlands are used to treat storm water runoff, sewage, wastewater from agricultural activities, coal mine drainage, waste water of petroleum refineries, leachate from compost piles and landfills, waste water from fish ponds and from industries including pulp and paper mills, tanning industries, textile units and marine food processing units. These constructed wetlands are effectively used as the sole treatment for certain waste water streams and in some cases are a critical component in array of treatment methods (Constructed wetland Handbooks, US EPA).

If planned and maintained properly, constructed wetlands, apart from treating polluted water, can promote water reclamation & reuse, restoring wildlife habitat, and utilization for public interest. Futuristic planning approach, sustainable design, reliable construction practices & tested operating techniques can avert the claimed harmful ecosystem effects which may include variation in natural hydrology, introduction of nonnative opportunistic species, and disruption of native animal & plant species populations (Cooper et al, 1996).

2.4 Categories of Constructed Wetlands

There are several processes involved in constructed wetlands which contribute in wastewater & leachate treatment. Their design is sometimes distinct in different countries to take advantage of site specific leachate treatment requirement and desired level of control. The basic classification of these constructed wetlands is determined by flow regime of water, i.e. free water surface flow system, sub-surface horizontal and vertical flow systems (Kadlec and Knight, 1996).

Table 2.1 Categories of Constructed Wetlands and their Practices in the World

Sr. No.	Categories of Wetlands	Country	Reference
1.	Free Water Surface System (FWS)	USA	(Bigambo and Mayo, 2005)
2.	Sub Surface Flow systems (SFS)	West Germany	(Vohla et al, 2007)
3.	Horizontal Flow Systems (HFS)	West Germany	(Garcia et al, 2004, Luedertz et al, 2001)
4.	Vertical Flow Systems (VFS)	England	(Moshiri, 1993; Haberl, 1999)

2.5 Materials for Wetland

a) Sand: This is a granular material of fine minerals consisting of particles or pellets ranging in diameter from 0.06 to 2 mm. Sand is classified in five sub classes depending on its size, i.e.

- very fine sand (0.05 - 0.1 mm)
- fine sand (0.1 - 0.25 mm)
- medium sand (0.25 - 0.5 mm)
- coarse sand (0.5 - 1.0 mm)
- very coarse sand (1 - 2 mm)

The major component of sand is silica (SiO_2), which is commonly in the form of quartz which, due to chemical inertness and considerable hardness, is resistant to weathering (Kjeldsen et al, 2002).

Intermittent sand filter may have the potential to treat dairy parlour washings effectively and has been used in the dewatering of swine wastewater to increase settlement of suspended solids (SS) and organic compounds (Vanotti *et al*, 2005) and in the treatment of detergent and milk fat wastewaters (Liu *et al*, 1998, 2000, 2003). As mentioned above, previous experimental work provides important information about the suitability of sand for use as media in constructed wetlands (Arias *et al*, 2001).

b) Gravel: Gravel is rock that is at least two millimeters (2mm) in diameter and is mostly in the form of creek rocks which are generally rounded, semi-polished stones, potentially of a wide range of types, which are dredged or scooped from river beds and creek beds. It is also often used as concrete aggregate material (Arias *et al*, 2001).

Gravels in wetlands provide an attachment surface for the microorganisms and for ion-exchange process thus promotes settling of suspended solids and filtration of larger particles. Constructed wetlands have a small ecological footprint, utilize “low-tech” technology, and have an aesthetic value similar to that of natural wetlands. The application of wetland technology for treating landfill leachate is still developing. There has been a call by academics and professionals alike for a better understanding of the movement, transformation, and removal of contaminants in these treatment systems through extensive and long-term studies (Mulamoottil et al, 1998).

2.6 Principle of Constructed Wetlands

Leachate passes through the vegetation cover, which slows it down and significant amount of suspended solids are entangled by vegetation which settles soil media. As a result of biological process, other contaminants in the leachate undergo biotransformation and changed into less harmful substances or they are made inactive. The rhizomes in constructed wetland plants provide suitable conditions & habitat to micro flora, which transform and remove the contaminants from leachate through an array of complex mechanisms.

Some nutrients including nitrogen and phosphorous, which are carried by storm water runoff into wetlands, which originated from agricultural lands sprayed with fertilizers or animal manure or the septic fields which are leaking. Nitrogen and phosphorous are very important for plants growth, and once they are broken down to useable, inorganic forms (NO_3 and NH_4) by microorganisms, they are taken up by the plants which convert them in food or release them in the form of atmospheric gasses.

2.7 Role of Plants in Constructed Wetlands

Constructed wetlands plants are referred to as emergent macrophytes (aquatic angiosperms, bryophytes and pteridophytes etc.). These plants are hydrophytes as they are adopted to living in water with leaves and flowers above water surface in contact with air. The roots and rhizomes stay under water or soil media (Kadlec and Knight, 1996). Usually these plants have large root network, which facilitates them to interact with the influent and hence more contaminants are taken up by microorganisms in rhizomes and plants. *Typha* & *Phragmitis* are two of the most used plants worldwide in sub-surface flow constructed wetlands. Some angiosperms are also grown in constructed wetland systems but they are not proved very efficient and therefore, they have less use (US EPA, 1993). Moreover, it was observed that the angiosperms species are not well adopted in hydrophilic conditions (Nerallaet al, 2000).

The advantages of wetland plants are far more than their disadvantages. Many of plants functions are studied in detail while there are still many functions which need extensive research. Among one of the well-established facts, it is obvious that these wetland plants increase the aesthetic value of the land by spreading over the entire wetland bed, which not only limits the odour from releasing in the surrounding but this cover provide a base for habitat of several bird and animal species serving their breeding ground and repels the insects and mosquitos from settling down and laying eggs (Wood, 1995). The root network and rhizomes of the plants facilitate growth of microorganisms and also trap the solids in the waste water streams.

Another benefit of extensive root network of the plant is that they ensure the provision of oxygen to microorganisms found in the rhizosphere which use this oxygen to degrade the organic matter in aerobic conditions and carry out nitrification process (Brix, 1987). This oxygen is essential for respiration, cell growth and prevention of phytotoxins production in roots. The transfer mechanism of oxygen to root zone and rhizosphere is done by above ground parts including leaves through the airways. Oxygen is critical for plant growth and survival. When the oxygen leaks from these parts, distinct areas establish around the roots and rhizomes of wetland plants, which are called aerated microzones (Brix, 1987). Once these areas are oxidized, they facilitate aerobic biological transformation, where anaerobic environment could have existed. It is evident by many studies that these microzones are responsible for major aerobic biodegradation and nitrification of organic components in the leachate & other wastewater streams.

It was found out by Hiley et al. (1995) that low oxygen demand in rhizosphere is cause of noticeable amount of leaking oxygen. But usually, there is very high demand of oxygen in wetland plants rhizosphere where waste water is passing; due to this fact, considering the quantitative aspect there are very small amount of oxygen leaks to the surrounding by roots and rhizomes. It appears that the wetland plants need roughly all the oxygen which is sent to roots for respiration process and their growth (Kadlec and Knight, 1996).

If the soil sediments are saturated and rich with organic material, the wetland plants may not aerate the rhizosphere significantly (Wetzel, 1993). The wetland bed, rich with organic matter, may range from 0.3 meters to 0.6 meters in depth, and in some cases up to 0.84 meters deep. The rhizosphere cannot extend to this depth even if significant amount of oxygen is released (US EPA, 1993). The roots of almost all the wetland plants very rarely reach below the depth of 0.3 meters in a functional system. The water surface provides supply of oxygen to aquatic plants (Hiley et al, 1995), which is controlled by interfacial transfer of air-water-media

(Kadlec and Knight, 1996). This results in development of excellent aerobic conditions only at the top most part of the wetland soil bed. These aerobic conditions improves the overall treatment performance throughout the rest of rhizosphere positively.

Furthermore, the wetland plants in subsurface flow wetlands have a strong effect on stabilization of hydraulic conductivity of wetland bed media. This effect is significantly observed when the wetland bed media has small sized particles such as the soil, which in isolation reduce the hydraulic conductivity. But the wetland plants grown in soil media disturb and loosen the soil media through the development of their roots and rhizomes enhancing the soil porosity, creating better flow conditions for water around the roots and rhizomes (Reed et al, 1988). Brix (1987) stated that even if construct reason, ed wetland system is established using less porosity media, the growth of plant roots and rhizomes can loosen the soil, thereby increasing soil porosity. Due to this the hydraulic conductivity rate may become equivalent to that of soil from a couple of years to five years.

2.8 Types of Plants

Typha latifolia, *Ricinus communis*, *Phragmitis karka*, *Ipomoea carnea var. Fistulosa* are species commonly found in many natural wetlands of Pakistan. Their potential for leachate treatment is not yet documented for Pakistan. Leachate characteristics such as COD, BOD, TSS, NH_3/NH_4, phosphorous, electrical conductivity etc. are important. The table 2.2 compares the adoption of various plant species for removal of contaminants.

Table 2.2 Various Plant Species and Their Pollutants Removal Efficiency

Sr. No.	Name of Species	Contaminants Removal Efficiency	Study	Country
1.	*Typha* latifolia	N and P removal	(Sundberg et al, 2007)	Northern Hemisphere
2.	*Ricinus communis*	Cd accumulation	(Bauddh and Singh, 2012)	India
3.	*Phragmitis karka*	---------	(Pantip and Nitisoravut, 2005)	Malaysia
4.	*Ipomoea carnea var. Fistulosa*	175 to 200mg kg-1 body weight	(Oleveira, et al, 2014)	American Tropics

2.9 Methods of Leachate Treatment

Several methods of leachate treatment are practiced throughout the world considering various factors including availability of suitable plants adopted to local climatic conditions, availability of land, economic considerations etc.

One of the methods is Leachate transfer, where leachate is recycled and is treated along with the municipal sewage streams.

Biodegradation of leachate is also common through aerobic and anaerobic processes. Certain chemical and physical methods for leachate treatment are also practiced such as chemical oxidation, adsorption, chemical precipitation, coagulation/flocculation, sedimentation/flotation and air stripping

2.10 Leachate Treatment Efficiency through Wetlands

These CWs require low maintenance and designed for 5 years while the up flow filter media required regular replacement. After saturation of media with phosphorus, it can be used as fertilizer for plant production. In addition to this, subsurface wetlands are being used for treatment of various wastewater streams as mentioned in the table 2.3

Table 2.3 Treatment of Different Wastewater Streams though Constructed Wetlands

Sr.#	Study	Wastewater type	Pollutant Removal Efficiency %						
			BOD	COD	TSS	N	P	Cl^-	Fe
1.	Heistad et al, 2006	Domestic Wastewater	97	-	70	30	99	-	-
2.	Bulc et al,1997	Landfill Leachate	59	50	-	51	53	35	84
3.	Chen et al, 2006	Industrial Wastewater	89	61	81	56	35	-	-
4.	Burgoon et al, 1999	Potato wastewater	-	-	-	65	-	-	-
5.	Mhlum and Stinacke, 1999	Abattoir wastewater	75	-	-	60	90	-	-
6.	Lin *et al*, 2003	Aquaculture system	24	-	71	90	5	-	-
7.	Geary and Moore, 1999	Dairy parlor waters	61	-	-	43	28	-	-

2.11 Summary

The review of literature shows that these constructed wetlands have proved successful in developed countries for the domestic wastewater, landfill leachate and processing wastewater treatment by using different reeds. This constructed wetland technology had been established as most economical and self-sustainable Eco technology.

This type of treatment technology is highly required in developing countries but designs being developed in developed countries cannot be replicated in developing counties as such because these countries have different flora & fauna and climatic conditions. Therefore there is need of research on local plant species and wetland design parameters which can best perform in Pakistan climatic conditions. Therefore for this study, local plant species including *Phragmitis karka*, *Typha latifolia, Ricinus communis, and Ipomoea carnea* has been tested for the treatment of leachate.

Chapter 3

3 MATERIALS AND METHODS:

This study was conducted at IESE, NUST following the below sequence.

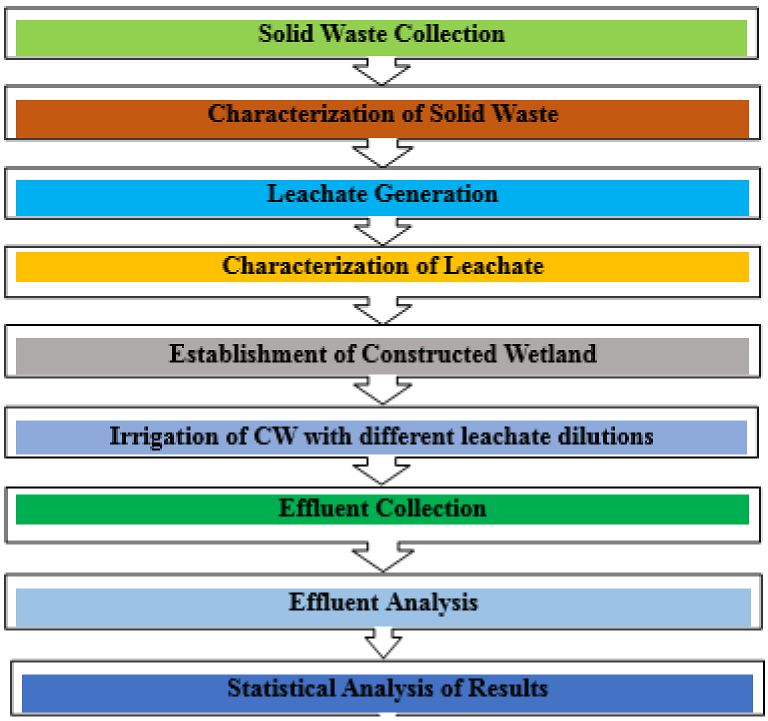


Figure 3.1 Flow Diagram of Sample Preparation and Lab Analysis

3.1 Solid Waste Collection

For the present study, solid waste was collected from curbside containers placed near Chandni Chowk, Rawalpindi through Municipal Staff and filled in specially designed Plastic Drums. The Waste comprised of Domestic Waste, Restaurant Waste and Mixed Waste Streams representing the Rawalpindi Municipal Waste. Mobile Lab of IESE was used in this activity as shown in figure 3.2.

Figure 3.2 Solid Waste Collection & Characterization

3.2 Characterization of Solid Waste:

The Collected waste was characterized using standard coning and quartering method (ASTM-D5231-92). The Solid waste was piled into a conical heap and then spread out into circular cake. This was divided into quarters. Two diagonally quarters were taken as the sample and the remaining two were rejected. The selected two quarters were piled into cone and the procedure of coning and quartering was repeated until the desired volume was obtained.

3.3 Leachate Generation

The waste drums were selected keeping in view the requirements of the study. For convenient collection of leachate, taps were installed in the bottom of drums. Waste drums were placed on specially designed iron stands with height of 8 inches. This height was maintained to place the leachate collection bottles under the waste drums. This arrangement made possible the collection of leachate without disturbing the waste in the waste drums. Drums were sealed with polythene sheet to prevent any moisture entry from outside as well as to trap the moisture from the waste evaporating. Leachate was produced from the natural moisture of waste.

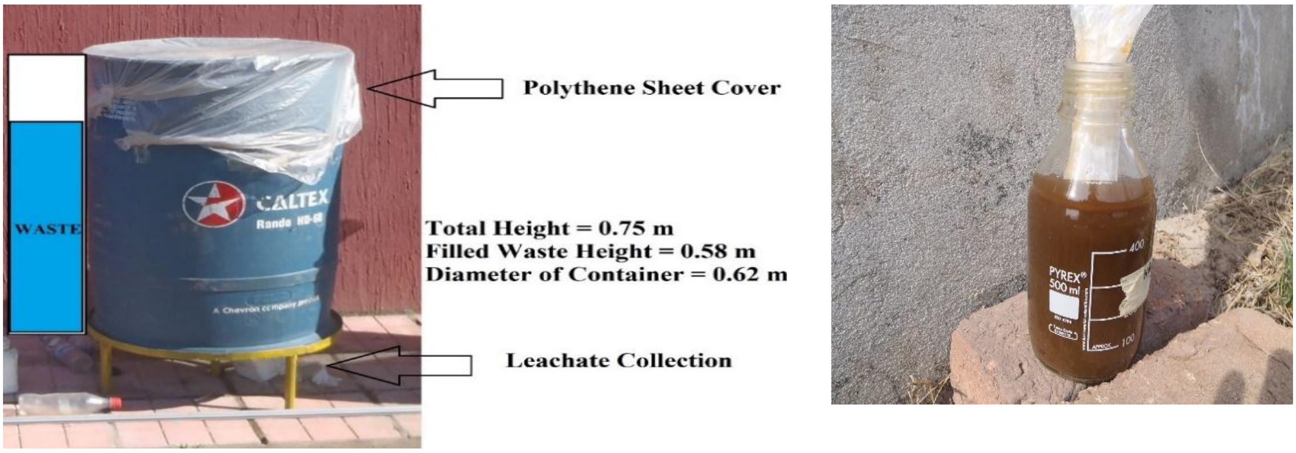


Figure 3.3 Attributes of the Waste Drum & Leachate Collection

The leachate generation commenced on 23rd December 2012 and leachate generation started from the 3rd day of commencement of study till 35th to 50th day (8th February 2013). The leachate generation arrangement and one of leachate samples is shown in figure 3.3.

3.4 Characterization of Leachate

Leachate was collected daily and immediately analysed for pH, EC, TDS. It was refrigerated and later analysed for the remaining parameters including Chemical oxygen demand (COD), total dissolved solids (TDS), total nitrogen (TN), Phosphate (PO_4), Total organic carbon (TOC) and Chloride (Cl^-). All the parameters were determined according to Standard Methods for Examination of Water & Waste Water 20th Edition.

3.5 Establishment of Constructed Wetland

Four Plant Species were selected as the aquatic plant to be planted in the lab scale constructed wetland. Used plastic bottles were collected from Rumi Hostel Mess, washed and cut from bottom and filled with constructed wetland material. The bottles were inverted and filled with gravel at the base, sand in the middle and soil on the top to provide growth environment to plants and better percolation of moisture, where soil was the growing medium for plants and sand with crushed gravel was placed at the bottom of container to avoid clogging as shown in the following figures.

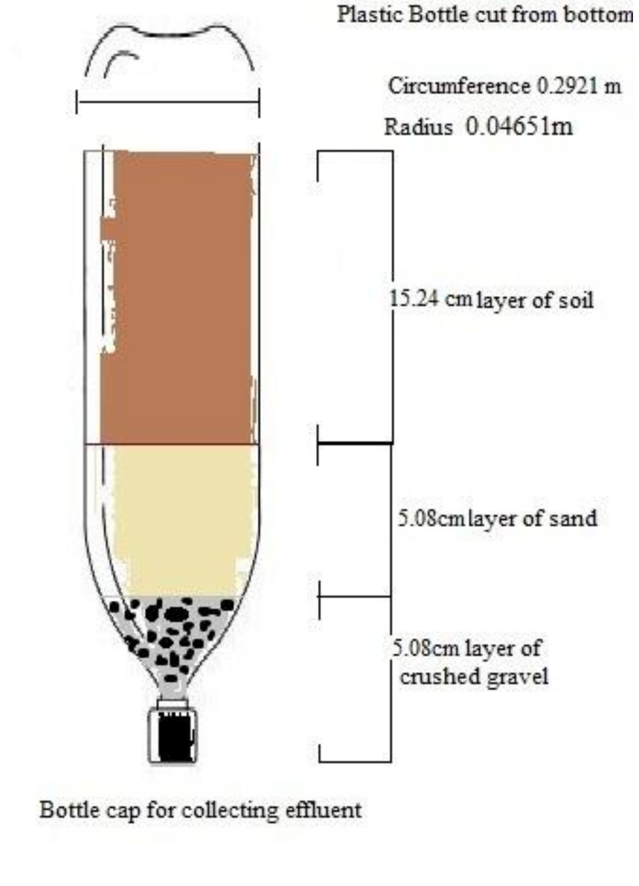
Figure 3.4 Constructed Wetland with the Fill Material

The prepared bottles were erected in Styrofoam rack placed at bricks for convenient collection of effluent.

Figure 3.5 Establishment of Lab Scale Constructed Wetland

The fill material characteristics are tabulated in table 3.1.

Table 3.1 Characteristics of the Fill Material

<table>
<tr><th>Gravel Specifications</th><th>Sand Specifications</th><th>Soil Analysis</th></tr>
<tr><td>Size- 12-25mm</td><td>Coarse Texture</td><td>Moisture content- 41.04%</td></tr>
<tr><td>NUST H-12</td><td>NUST H-12</td><td>pH- 8.64</td></tr>
<tr><td>2 inch layer was laid</td><td>2 inch layer was laid</td><td>6 inch layer was laid (1338.67 g)</td></tr>
<tr><td colspan="2" rowspan="10">
</td><td>Volume of the Soil 0.0010697 m3</td></tr>
<tr><td>Density of Soil 1064.47 kg/m3</td></tr>
<tr><td>Phosphorus (mg/kg)- 5.2611</td></tr>
<tr><td>Nitrogen (mg/kg)- 0.7628</td></tr>
<tr><td>Percentage of Silt in Soil 23.8%</td></tr>
<tr><td>Percentage of Clay 11.9%</td></tr>
<tr><td>Percentage of Sand 64.3%</td></tr>
<tr><td>Textural Class Sandy Loam</td></tr>
<tr><td>EC of Soil (dS/m) 0.44</td></tr>
<tr><td>Percentage of Organic Matter 0.8</td></tr>
</table>

Some of the factors considered during construction included the substrate which must had good porosity to prevent logging and must possess special capabilities to filter and absorb pollutants.

3.6 Irrigation of CW with different leachate dilutions

Initially tap water from IESE was applied to plants for adaptation and growth. After one week, the leachate concentration was being applied. The change was carried out by completely draining out water through the valve at the base of container to ensure full drainage.

This was to prevent unintentional dilution of leachate if not properly drained. Thereafter, diluted leachate samples were added into the constructed wetland with different dilutions for plants adaptation before the commencement of the experiment.

Experimentation commenced from highly diluted leachate with gradually increasing the concentration. Each leachate dosage was daily applied with measured amount of 100ml per day making total volume of 300 ml for 3 days. The effluent was collected at the end of 3rd day before applying the next dilution. The experiment continued from 9th May 2013 to 30 May 2013.

Leachate Dilution for different doses are tabulated below.

Table 3.2 Application of Leachate Dilutions

Date	Dilution Factor	COD concentration (mg/L)
9-May-13	490	100
14-May-13	196	250
18-May-13	98	500
21-May-13	65	750
24-May-13	33	1500
27-May-13	17	3000
30-May-13	10	5000

Outlet valve of the constructed wetland's bottle was vertically positioned to maintain the uniform water level above the bed.

3.7 Effluent Collection & Analysis:

The effluent was collected in the evening of the third day by opening the bottom valve of the container. Each sample was given unique ID and was analyzed immediately. The methods and instruments used for analysis are listed in Table 3.3 below:

Table 3.3 Tests of Leachate Analytical Analysis Using Different Methods and Instruments

Parameters	Symbol	Units	Method/Type	References
pH	pH	--	pH/Cond 720 inoLab	4500 H+ B
Conductivity	EC	µS/cm	pH/Cond 720 inoLab	2510 B
Chemical Oxygen Demand	COD	mg/L	Closed reflux method	5220C
Phosphates	PO_4	mg/L	Vandomolybdo Phosphoric acid colorimetric method	4500-P C.
Total Organic Carbon	TOC	mg/L	Analytik-jena, TOC analyzer multi N/C UV HS	5310C
Total nitrogen	TN	mg/L	Analytik-jena, TOC analyzer multi N/C UV HS	5310C
Chloride	Cl^-	mg/L	Argentrometry	4500Cl- B
Total Dissolved Solids	TDS	mg/L	sensION+ MM150 Portable pH/ORP/EC Multi-Meter	2540C

3.8 Statistical Analysis of Results:

The results were recorded after the effluent examination and were analyzed to draw conclusion. Multiple Criteria Decision Analysis was used for evaluation of overall plant performance as given in the table 3.4.

Table 3.4 Ranking Criteria for Plant Performance

Criterion	Maximum Score	Remarks
COD	10	0-10% = 1 mark 11-20% = 2 marks 21-30% = 3 marks 31-40% = 4 marks 41-50% = 5 marks 51-60%= 6marks 61-70% = 7 marks 71-80% = 8 marks 81-90%= 9 marks 91-100%= 10 marks
TDS	10	Same as above
TOC	10	
Phosphate	10	
TN	10	
EC	10	
Cl^-	10	
pH (Normalization)	10	7.75-8.0 =1 mark 7.5-7.75= 3 marks 7.25-7.5=5 marks 6.75- 7.25= 10 marks 6.5-6.75 = 5 marks 6.25-6.5=3marks 6.0-6.25= 1 mark

Chapter 4

4 RESULTS & DISCUSSION:

4.1 Waste Composition

Three streams of municipal solid waste were used in this study to generate leachate. The composition of the wastes is given below.

4.1.1 Household waste:

The total mass of this waste was 48.8 kg with water content of 3.17 g of DM. The waste was 100% organic with density of 274kg/m^3. It was composed of Fruit & vegetables (58 %), grass clippings (26.84%) & Shrubs and twigs (15%) as shown in the figure 4.1.

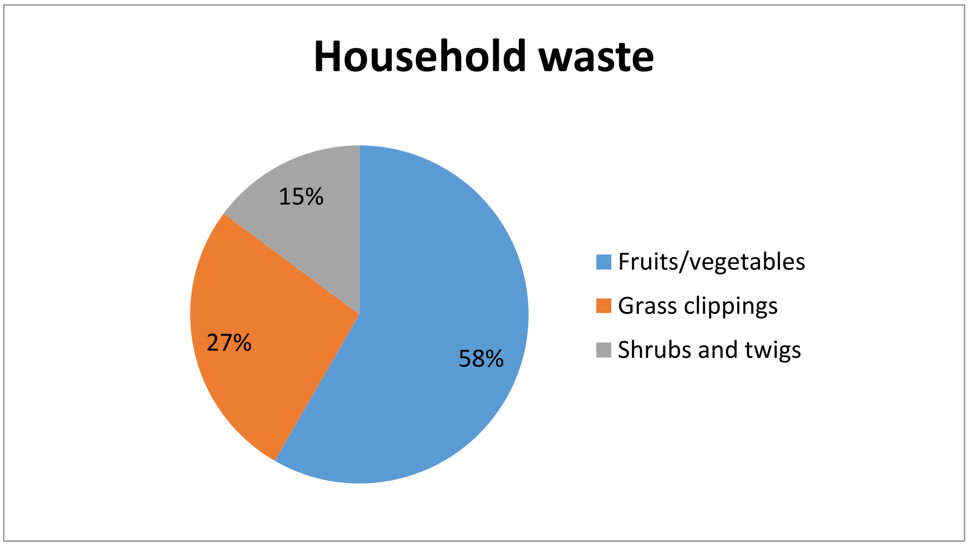


Figure 4.1 Household Waste Composition

4.1.2 Restaurant Waste:

The total mass of this waste was 63.7 kg with water content of 2.02 g of DM. The waste was 95% organic with density of 399 kg/m^3. It was composed of Fruit & vegetables 32%, rice

& snacks (14%), meat & bones (17%), mixed left over food with disposable crockery (32%), plastics (5%) as shown in the figure 4.2.

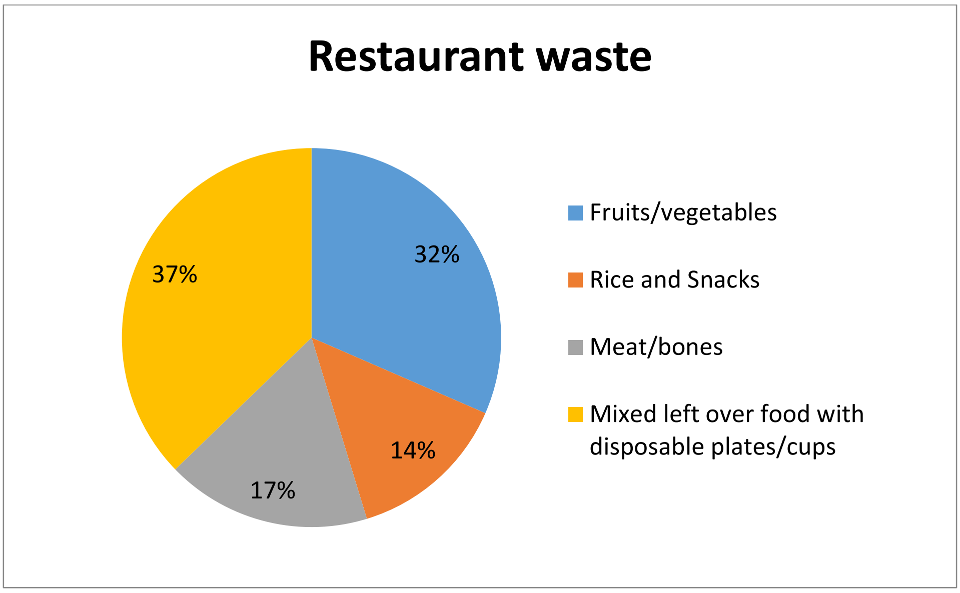


Figure 4.2: Composition of Restaurant Waste

4.1.3 Mixed Waste

The total mass of this waste was 55.5 kg with water content of 1.74 g of DM. The waste was 82 % organic with density of 348 kg/m^3. It was composed of Fruit & vegetables 50%, grass clippings (15%), shrubs and twigs (12%), meat and bones (1%), fabric (4%), construction and demolition (18%) as shown in the following graph.

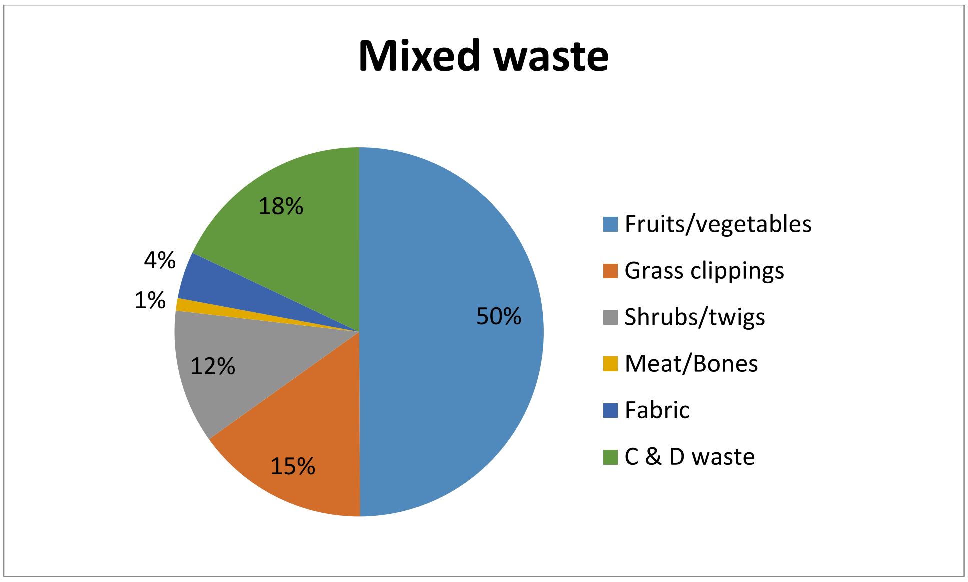


Figure 4.3 Composition of Mixed Waste

Household waste was all degradable, while restaurant waste had some slowly degradable materials and mixed waste contained an inert fraction along with degradable waste. The volume of waste reduced after degradation & loss of moisture is given in the fig 4.4.

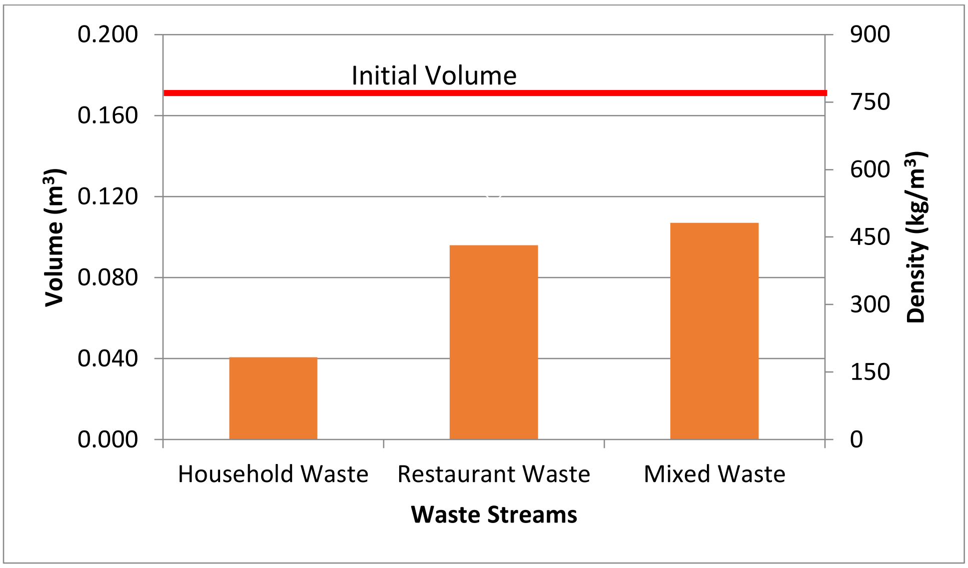


Figure 4.4 Volume Reduction of Waste after Degradation & Loss of Moisture

Initially the density of waste was less, but with time, it increased as the volume reduced. Figure below shows the leachate fluxes (mm/day) from different waste streams plotted against time elapsed after filling the waste containers.

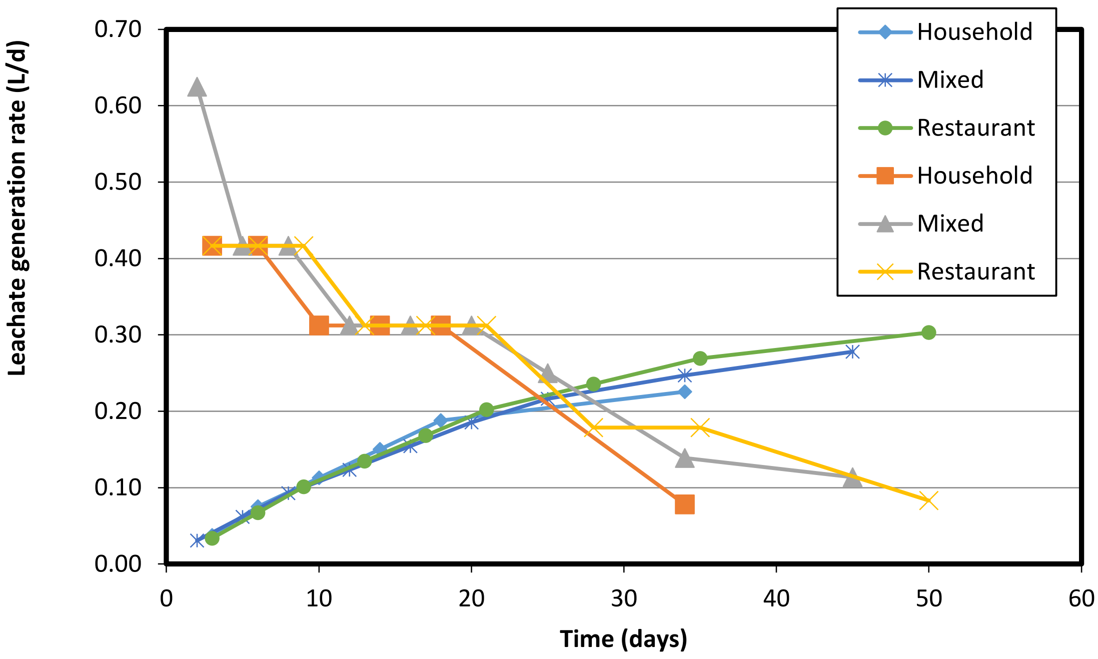


Figure 4.5 Leachate Fluxes of Different Waste Streams with Time

In the beginning, leachate fluxes were high for all wastes, but then the fluxes decreased until the leachate generation eventually ceased. The total volume of leachate generated by household waste, mixed waste, and restaurant waste was 7.5 L, 11.25 L, and 11.25 L, respectively. Drainage ceased after 34, 45, and 50 days for household waste, mixed waste, and restaurant waste, respectively. The cumulative leachate was normalized with the initial water content to measure the amount of volume leached.

The total leachate volume ranged from 20 to 30% of the initial moisture content. Some of the initial moisture of municipal solid waste is likely used for biological degradation and oxidation/reduction reactions (Pommier and Lefebvre, 2009).

The leachate generation rates tend to decrease in drier areas. However, as our results here show, the waste itself produces a measurable amount of leachate without any other source of water entering into the waste. The initial leachate fluxes from the waste itself can be substantial (Figure 4.5), although over longer periods of time the average leachate fluxes diminish, as the leaching ceases.

Initially, the bulk density of the waste was low, but as the waste settled, the density increased and the proportion of smaller pores increased. This leads to an increasing moisture holding capacity of the waste (Wu et al, 2012). The unsaturated hydraulic properties of waste with respect to waste depth and age was studied by Wu et al. (2012), and they found that over time, the residual water content and the field capacity of organic waste increased. Kjeldsen et al. (2002), in their review article on composition of landfill leachate, pointed out that leachate discharges are high in the beginning when settlement of waste occurs. In our experiments, a significant reduction in waste depth was observed during the leaching period. The settlement of municipal solid waste leads to higher leachate volumes especially in fresh wastes (Kjeldsen et al, 2002). Dixon and Jones (2005) reviewed the mechanical behavior of municipal solid waste. They concluded that heterogeneity of waste and rate of decomposition strongly affect the settlement behavior. As there was no external pressure applied for settlement in our experiments and if we assume that the total height of the waste is uniform, the settlement can be quantified by a coefficient of compression (Cα) from a one dimensional consolidation model (El-Fadel et al, 1999).

$$C\alpha = St / [Ho \log(t/tr)]$$

Where Cα is the coefficient of compression, St is the settlement (m), t is the settlement time (days), tr is a reference time (days) and Ho is the initial waste thickness (m).

The reference time (tr) used to calculate Cα was 1 day, as suggested by El-Fadel et al. (1999). In our study, Cα represents overall compression during the leachate drainage period. Household waste, having the highest organic proportion, had the highest Cα value (Cα = 0.48), which is consistent with the findings of El-Fadel et al. (1999), who attributed the higher values of Cα as a consequence of enhanced biodegradation of organic waste. The Cα values of the other two waste types were within the typical range (Cα = 0.02 to 0.35) reported by Babu et al. (2010). The volume reduction in restaurant and mixed waste was not as significant as in the household waste due to the presence of bulky materials like construction and demolition waste and plastics.

Following table shows the water quality parameters of the leachate in comparison with the Pakistan National Environmental Quality Standards (NEQS) for wastewater discharge.

Table 4.1 Comparison of Leachate Quality Parameters with Pak- NEQs

Parameters	(Minimum, Maximum) Average ± Standard Deviation						NEQS
	Household Waste		Mixed Waste		Restaurant Waste		
	Range	Avg ± Std	Range	Avg ± Std	Range	Avg ± Std	
pH	5.5-5.9	5.6 ± 0.1	4.2-6.2	5.3 ± 0.6	3.8-5.6	4.5 ± 0.6	6—9
TDS (g/L)	3.6-13.7	8.9 ± 2.3	9.4-16	12.8 ± 1.9	11.9-15	13.2 ± 1	3.50
EC (mS/cm)	13-23.5	17.6 ± 3.6	15.2-33	22.1 ± 5.5	20.7-32	24.4 ± 4.1	na
COD (g/L)	26.7-43.2	33.3 ± 5.9	62.4-93.6	76.2 ± 12.1	66-94.8	81.1 ± 9.7	0.15
DOC (g/L)	8.5-28.3	14.2 ± 7.1	22.5-64.8	37.5 ± 16.2	30.1-55.5	45.5 ± 7.4	0.01
TN (g/L)	0.2-2.9	1.3 ± 1.1	0.3-10.2	3.9 ± 3.7	1.7-4.4	2.8 ± 1.2	0.04

The pH of the leachates was acidic and below the environmental quality standard. Leachate from restaurant waste was the most acidic (average pH 4.5), and it generally also contained the highest amounts of metals. The low pH dissolves metals in waste (Kjeldsen et al, 2002), thereby causing the highest concentrations of metals in the restaurant leachate. EC values are not under the scope of Pakistan National Environmental Quality Standards.

The leachate contained large amounts of organics, which was evident by DOC and COD having values exceeding the environmental quality standards by up to 800 times. Higher values of both COD and DOC are indicative of initial phases of waste degradation with an elevated rate of decomposition (El-Fadel et al, 2002). Our results were similar to those of Zhao et al. (2013) who analyzed leachates from fresh wastes. COD and DOC were highest in the restaurant waste. Restaurant waste generally has high density and high proportion of organic material, resulting in elevated COD and DOC values in its leachate. As COD is a composite parameter for the oxygen requirement of both organics and inorganics in a solution, the representation of organics can be depicted by the ratio of DOC/COD.

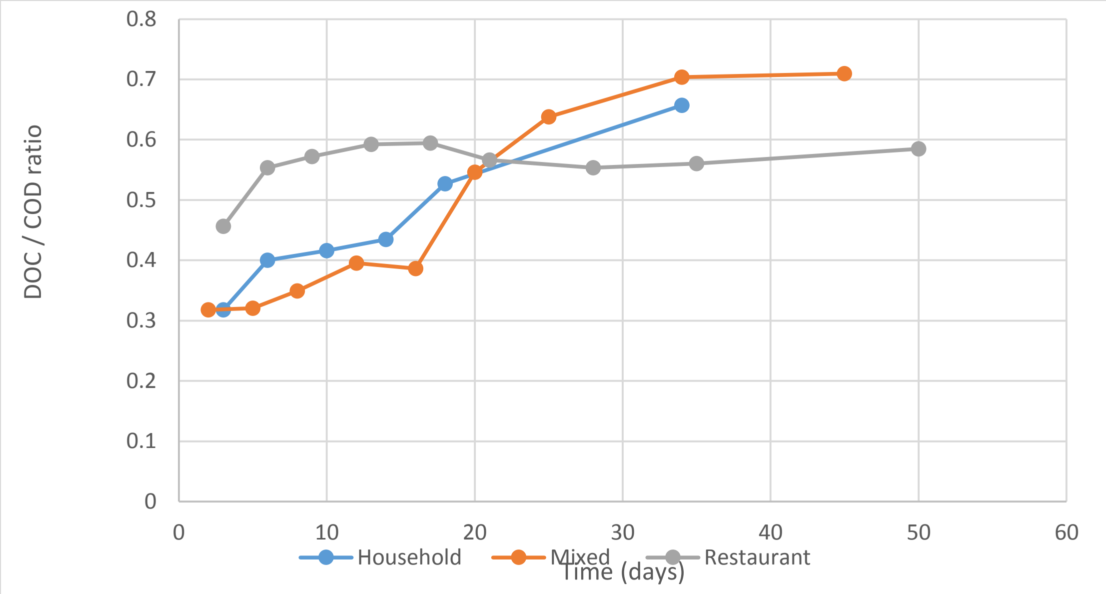


Figure 4.6 DOC/COD Ratio of Different Waste Streams

This indicates that during the experimental time, degradation processes converted organic material more and more into DOC. On the contrary, the restaurant waste showed rather constant DOC/COD ratios, probably because of higher levels of non-carbon oxygen-demanding substances initially present in waste or due to slowly degradable organics that retard the degradation process.

Ziyang et al. (2009) assessed the long-term variation in components of COD in the different phases of the degradation process and concluded that organic carbon is the major portion of COD in the early stage of degradation. Chloride exceeded the environmental quality standards in household and restaurant waste leachates; however, remained within the limits in the mixed waste leachate.

The amount of total dissolved solids in the leachates from three waste types was almost three times higher than the environmental quality standard, which itself is even more saline than seawater. The contribution of chloride in TDS is less than ten percent, and other species like carbonates, sulfates, nitrates, and phosphates have major influence on the salinity of leachates.

Total nitrogen also exceeded the environmental quality standards in all waste types. High nitrogen concentrations in leachate are common. Cheng and Chu (2011) even proposed to use leachates high in nitrogen as fertilizer. Total phosphorus showed high values of 0.25, 0.48 and 0.26 g/L for household waste, mixed waste, and restaurant waste, respectively. No environmental quality standards for phosphorus are available in Pakistan, but our measured concentrations exceed standards of point source phosphorus discharges in the US by a factor of 200 to 500.

4.2 Leachate Characteristics

The leachate from all waste streams was combined to produce a composite sample as the landfill leachate is composite of domestic, restaurant & other mixed wastes. The characteristics of composite sample of leachate were examined using standard methods. The leachate characteristics are given in the table 4.2 below.

Table 4.2 Leachate Characteristics

Sr.#	Parameter	Value	Unit
1.	COD	49000	mg/L
2.	TDS	13690	mg/L
3.	EC	23.50	mS/cm
4.	TN	3940	mg/L
5.	Phosphate	650	mg/L
6.	TOC	15000	mg/L
7.	pH	7.9	-
8.	Cl	4600	mg/L

4.3 Characterization of Effluent from CW

The effluent from the pilot scale monoculture containers was collected every three days after the application of leachate concentration.

The effluent passed through filtration, microbial action zone, vegetative uptake & various other natural processes in the constructed wetland.

4.4 Analysis of effluent

The effluent was analyzed for the selected parameters and the results are discussed in the following section.

4.4.1 Chemical Oxygen Demand

The Chemical Oxygen demand was an important parameter in this study. COD of effluent was compared with the influent to determine the percentage removal. It was observed that all the four plants showed high removal efficiency when the influent concentration was very low. Removal efficiency gradually decreased as the COD concentration was increased.

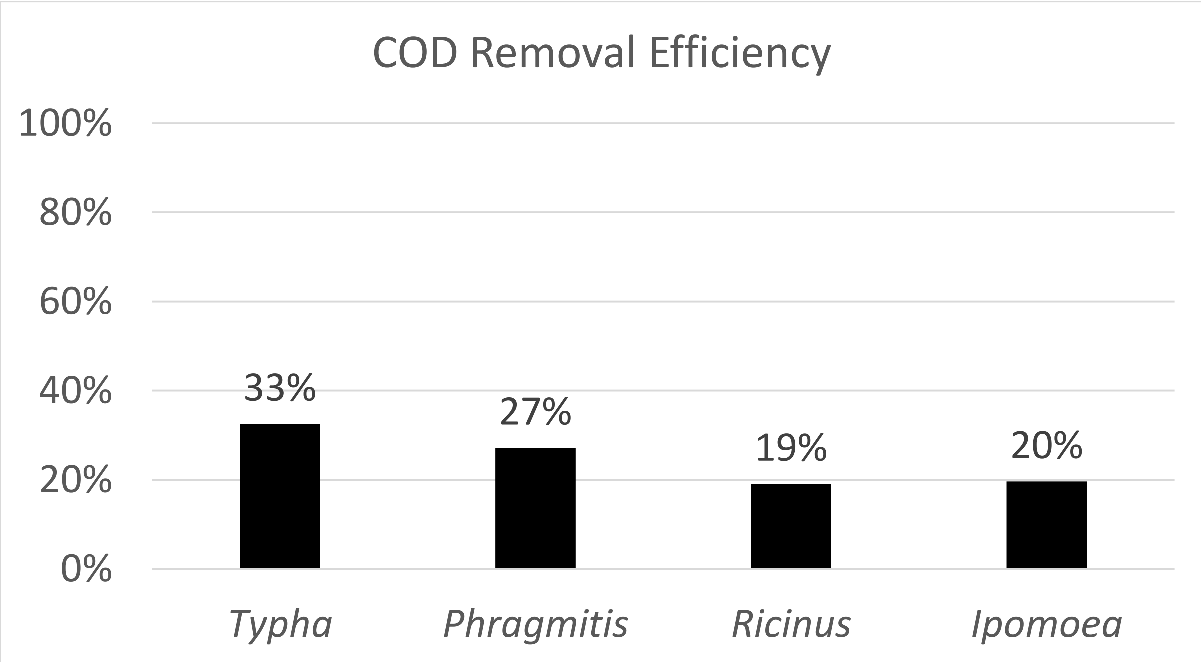


Figure 4.7 Comparative Analysis of Plants for COD

Typha latifolia was found to have the highest average removal efficiency (32.6%) while the lowest average removal efficiency was observed for *Ricinus communis* (19.1%). *Phragmitis karka* showed stability of removal efficiency at higher concentrations as compared to other plant species. *Ricinus* & *Ipomoea* were less tolerant to higher concentrations of COD & their leaves started to turn yellow & falling earlier than *Typha latifolia* & *Phragmitis karka* which were comparatively more tolerant to COD concentration as high as 5g /L.

4.4.2 Total Dissolved Solids:

Initially the TDS count was higher when less concentration of TDS was applied due to the reason that the plants were initiating their root development and influent was accumulating TDS from the soil. After 18 days of high TDS values in the effluent, all the four plant species improved their removal efficiency significantly.

Phragmitis & *Ipomoea* showed better performance in TDS removal than other plants.

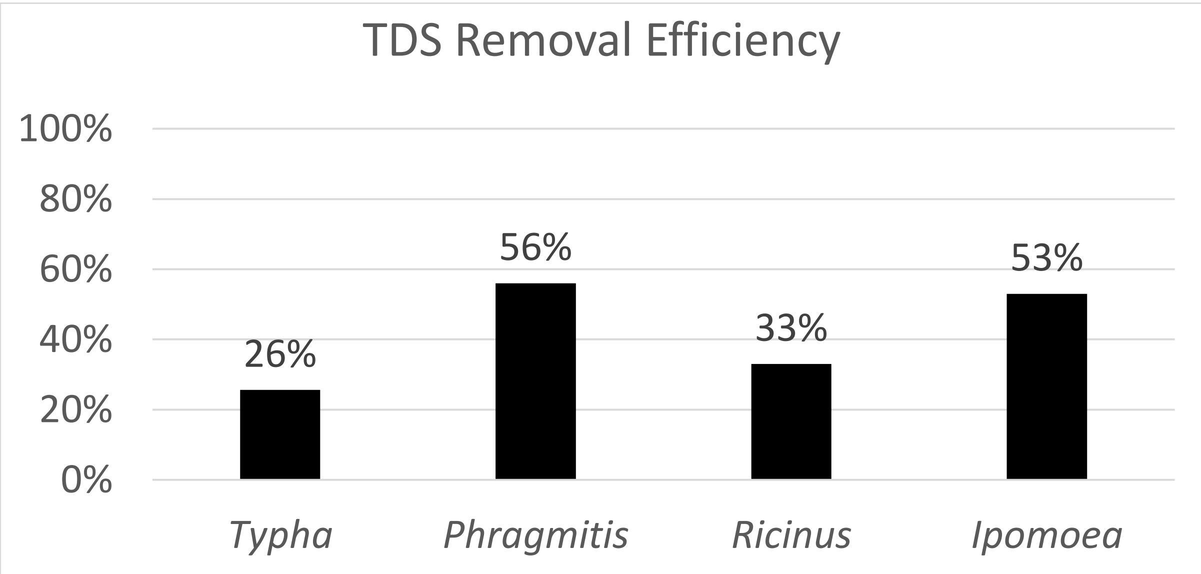


Figure 4.8 Comparative Analysis of Plants for TDS

4.4.3 Total Organic Carbon (TOC):

TOC analysis of the effluent showed that all the four plant species had removal efficiencies above 65%. It was found out that *Ricinus* had maximum removal efficiency of 76% as compared to *Typha* (66%), *Phragmitis* (65%), and *Ipomoea* (67%). The graph showing the TOC removal efficiencies is shown in figure 4.9.

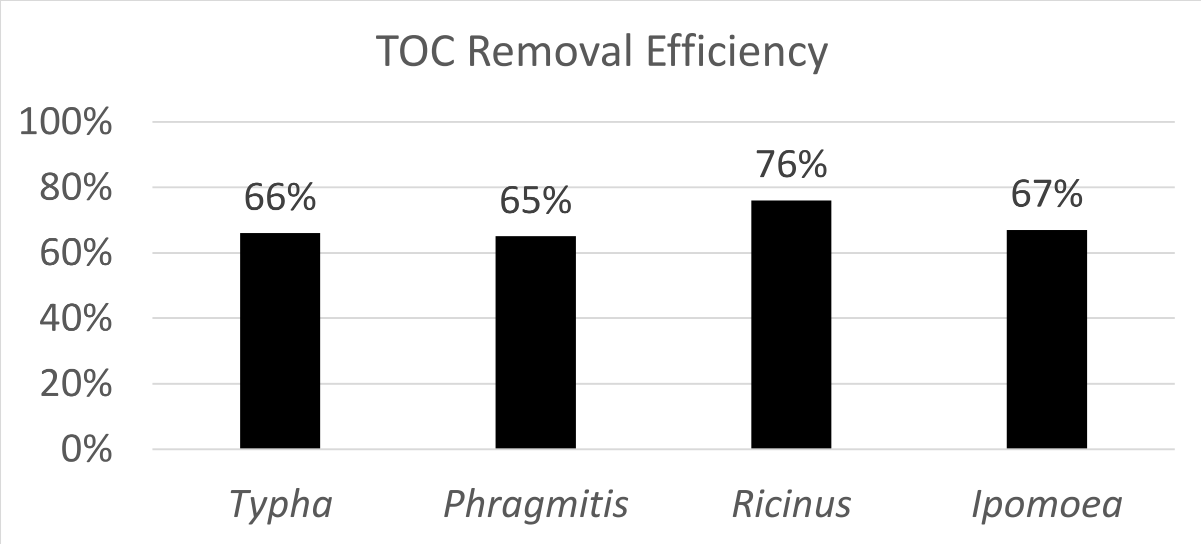


Figure 4.9 Comparative Analysis of Plants for TOC

4.4.4 Phosphate:

All the four plant species didn't remove the phosphate for the first 12 days, as the plants were still developing their roots and there was already natural phosphate in the soil media. The situation improved gradually as the trend started to appear when the plants stabilized. *Ipomoea* performed better at lower concentrations while *Ricinus* performance improved at higher concentrations of Phosphate.

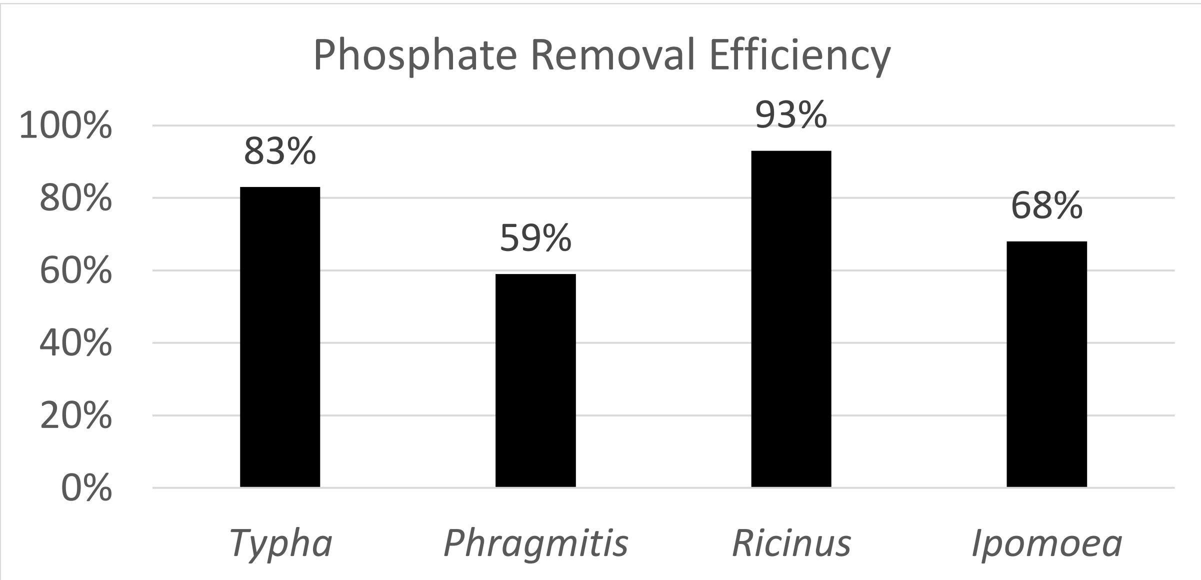


Figure 4.10 Comparative Analysis of Plants for Phosphate

Ipomoea performed better at lower concentrations while *Ricinus* performance improved at higher concentrations of phosphate in the influent.

4.4.5 Total Nitrogen:

Due to natural nitrogen in soil media and developing roots in first 12 days , the effluent concentration of total nitrogen were higher than the influent as explained for phosphate above.

This trend normalized in preceding days, when the removal efficiency of nitrogen was improved in all the four plants.

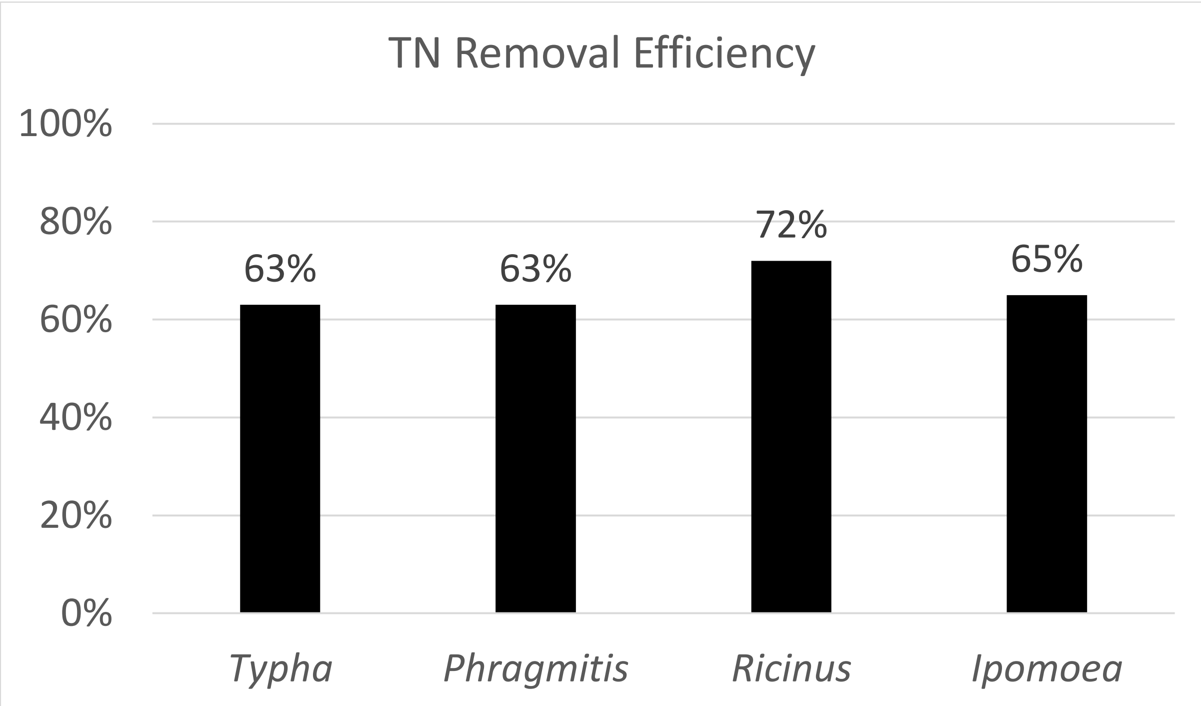


Figure 4.11 Comparative Analysis of Plants for TN

It was found out that *Ricinus* had the maximum removal efficiency of 72 % as compared to *Ipomoea* (65%) &*Typha* & *Phragmitis* (63%).

4.4.6 Electrical Conductivity (EC):

Following the trend of Phosphate & Total Nitrogen, Electrical conductivity varied considerably in first 12 days and the EC values in effluent were higher than the influent's.

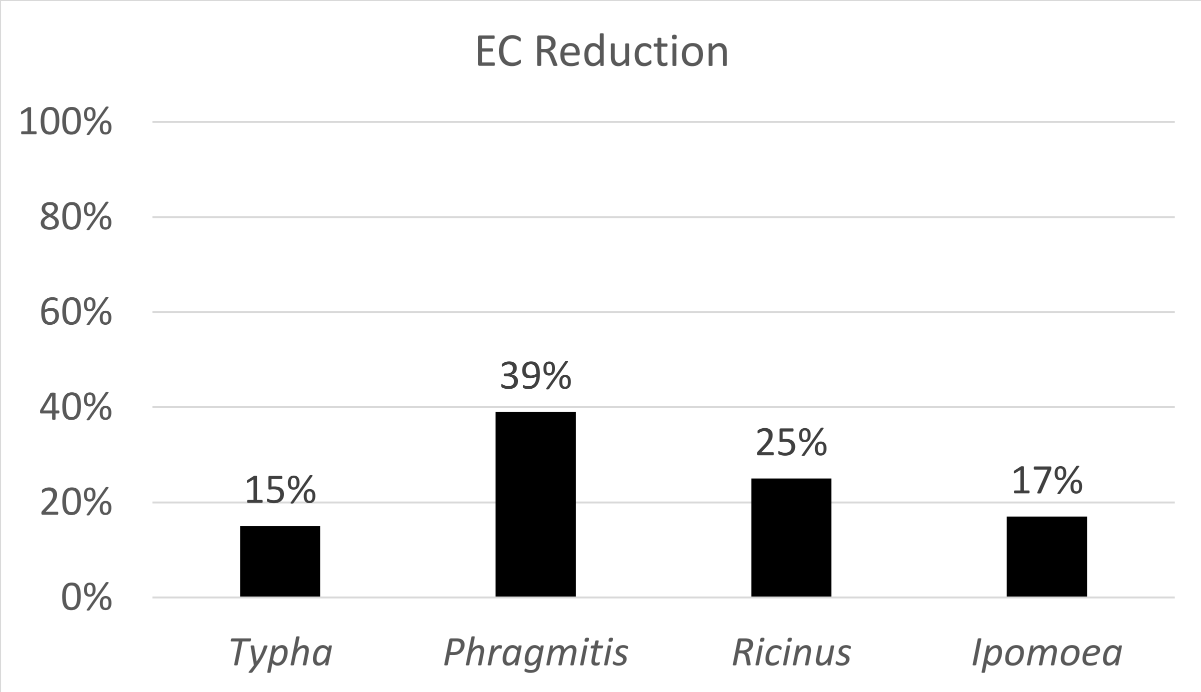


Figure 4.12 Comparative Analysis of Plants for EC

The last 9 days study inferred that *Phragmitis* performed better than rest of the plant species along with *Ricinus*. *Typha* showed consistent performance at higher concentrations without significant variation. *Ipomoea* reduced the EC values but the difference between effluent and influent values started decreasing with increase of influent EC values.

4.4.7 Chloride:

It was observed that the plants did not had any effect on chloride values at lower concentration while the chloride in soil media kept leaching, increasing the effluent value much greater than in influent's. The selected plant species faced difficulty in reducing the chloride in the influent, Only *Typha* could give significant chloride removal.

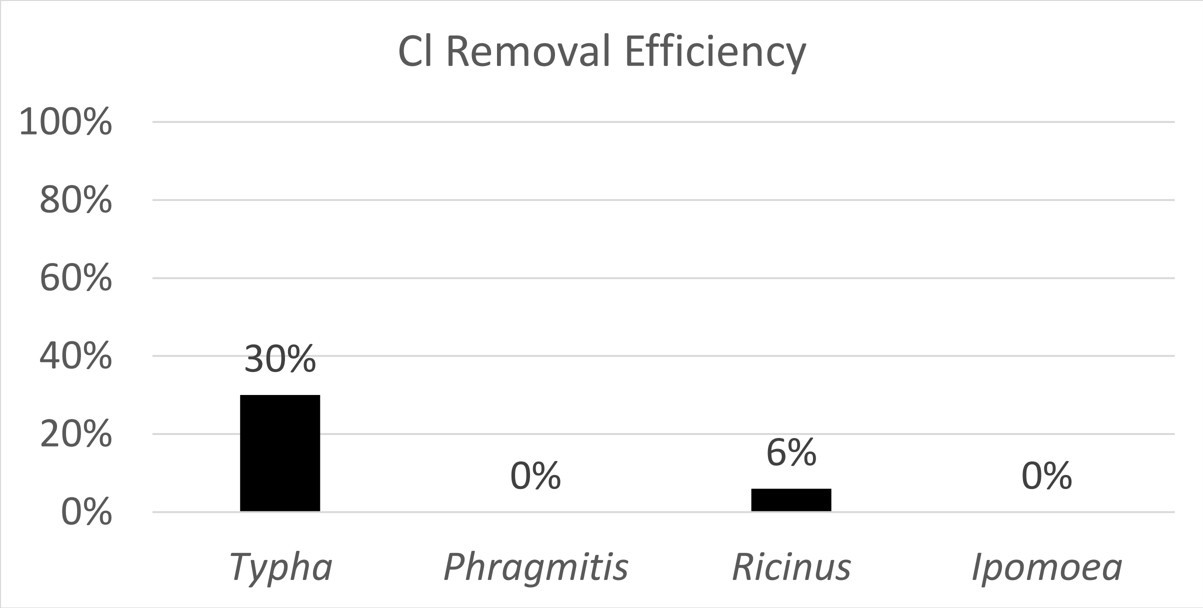


Figure 4.13 Comparison of Plants for Chloride

4.4.8 pH:

The pH of the effluent was initially basic as of soil media but with influent pH value moving towards more basic, the effluent value remained close to 7.0 as observed in the following graph.

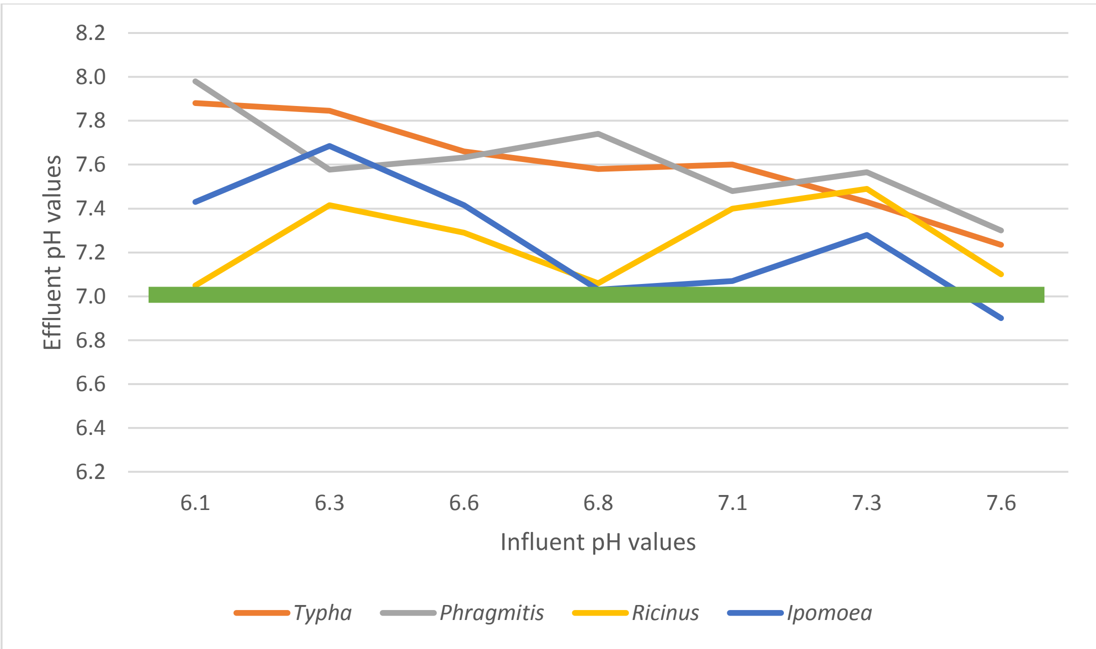


Figure 4.14 Analysis of Plants for pH

Ipomoea performed better in regulating the pH at higher pH values of the effluent while *Ricinus* performed better at lower pH values of the effluent.

4.4.9 Evapotranspiration in Constructed Wetland:

Out of total 300ml of influent, an average of 1.7 ml of effluent was obtained after three days. The graph shows that *Typha* had the least evapotranspiration rate followed by the other three plant species. The evapotranspiration rate is varied significantly due to the temperature change and amount of sun shine.

All the four plants showed varied amount of evapotranspiration and the effluent obtained is shown in the following chart.

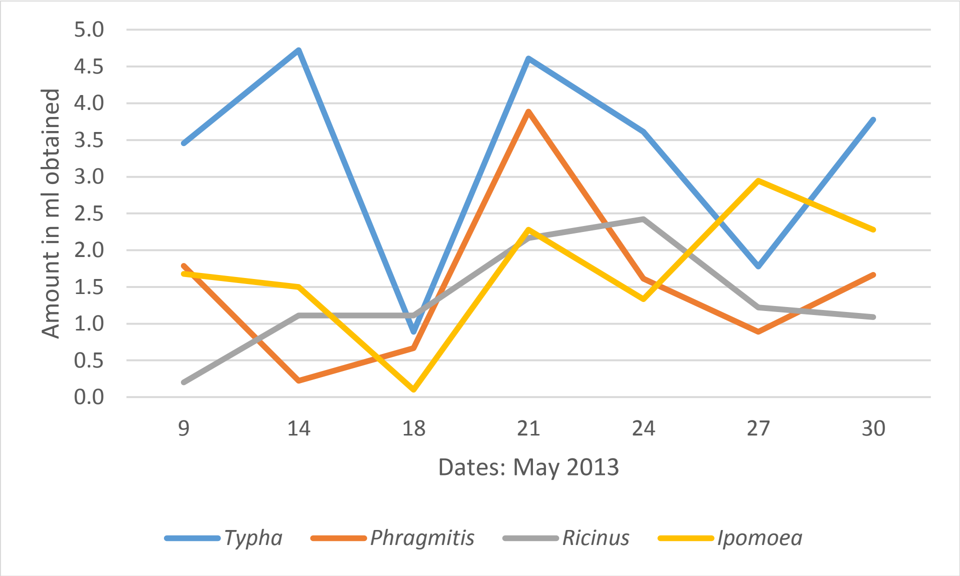


Figure 4.15 Percentage of Effluent Volume Collected after Evapotranspiration

Chapter 5

5 CONCLUSIONS & RECOMMENDATIONS:

5.1 Conclusions:

An attempt was made to evaluate the performance efficiency of constructed wetland with plants in treating leachate generated from Municipal Solid Waste. The tests result showed that all parameters tested experienced considerable reduction in their concentrations. A single plant could not have highest removal efficiency for all the parameters. Each plant was effective for treatment of specific parameters. The average removal efficiencies are shown in the following table.

Table 5.1 Average Removal Efficiencies of Plants (%age)

Plants	COD	TDS	TOC	Phosphate	TN	EC	Cl	pH (Scale)
Typha latifolia	32.6	25	66	83	64	14	30	7.2
Phragmitis karka	27.2	56	65	59	64	39	-	7.3
Ricinus communis	19.1	33	76	93	72	25	6	7.1
Ipomoea carnea var. Fistulosa	19.6	53	67	68	66	17	-	6.9

This table suggests that parameter specific plant should be grown in constructed wetland for better treatment. Our native plant species are efficient in Leachate contaminant removal

- *Typha latifolia* proved most efficient in COD & Chloride Removal
- *Phragmitis karka* was good at removing TDS & EC reduction.
- *Ricinus communis* efficiently removed TOC, Phosphate & TN from leachate.
- *Ipomoea carnea var. Fistulosa* was good at pH Normalization.

Overall plant performance is given in the following table. *Typha latifolia* & *Ricinus communis* were found to be better when compared using multiple decision analysis criteria.

Table 5.2 Comparison of Overall Performance of Wetland Plants

Plants	COD	TDS	TOC	Phosphate	TN	EC	Cl^-	pH	Total (80 marks)
Typha latifolia	4	3	7	9	7	2	4	10	46
Phragmitis karka	3	6	7	6	7	4	0	5	38
Ricinus communis	2	4	8	10	8	3	1	10	46
Ipomoea carnea var. Fistulosa	2	6	7	7	7	2	0	10	41

The above table suggests that parameter specific plant should be grown in constructed wetland for better treatment.

The wetland plants, have been proven a very reliable plant in treating leachate by the results of this study. Also, from the overall performance of the sub-surface flow wetland constructed, it is established that this method is efficient in removing significant percentage of the parameters tested from the leachate sample.

5.2 Recommendations

Sand and gravel materials also proved suitable for plant growth medium from the results of this study. This study suggests the use of constructed wetlands in the vicinity of open dumps all over Pakistan. This solution proves to be very economic, simple, easy to develop and maintain. This system does not require any specialized or trained operator so anyone with some agricultural background and basic training can operator and maintain this system.

Further research can enable these wetlands system for waste water treatment on site. It is recommended that more native plant species to be tested to find the most efficient species for leachate treatment. The use of plant types other than Cyprus such as cattails, reeds and bulrushes should be investigated to determine if optimum species exists. The use of other specialized media such as zeolite, to improve the porosity and penetration of plant root and avoid clogging from occurring is suggested.

A single plant could not had highest removal efficiency for all the parameters. Therefore wetland plants are to be selected carefully as per requirement for the treatment parameter.

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