Addis Ababa University
School of Graduate Studies
Environmental Engineering Program

A Thesis on:

Constructed Wetlands for Greywater Treatment:

The Case of Spa Service Enterprise

Thesis Submitted to the School of Graduate Studies of the Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Environmental Engineering

By: Girum Feleke

June, 2011

ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
ADDIS ABABA INSITUTE OF TECHNOLOGY
DEPARTMENT OF CHEMICAL ENGINEERING

CONSTRUCTED WETLANDS FOR GREYWATER TREATMENT:

THE CASE OF SPA SERVICE ENTERPRISE

A thesis submitted to the Research and Graduate School of Addis Ababa University, Addis Ababa Institute of Technology, Department of Chemical Engineering in partial fulfillment of the requirements for the attainment of the Degree of Masters of Science in Chemical Engineering under Environmental Engineering Stream.

By: Girum Feleke Wolde

Approved by the Examining Board:

_______________________________________ ____________________

Chairman, Department's Graduate committee

Dr. Tassisa Kaba

_______________________________________ ____________________

Advisor

_______________________________________ ____________________

Internal Examiner

_______________________________________ ____________________

External Examiner

ACKNOWLEDGEMENTS

I would like to express my heartfelt thanks to my advisor, Dr Tassissa Kaba, for his excellent academic guidance, advice, encouragement and continuous support throughout the Project. His warm personality and friendship have encouraged me and furthered my development as a scientific researcher.

I would also like to thank Mr. Mesele , the Finance and Administration of AAiT, Mrs. Trsit and Mr. Demsie, staff memebers of AAiT, Mr. Shimelse, Head of Technique Department of SSE, all members of the Technique Department of SSE, Mr. Tariku, Head of Security of SSE, Mr. Gemechu, Head of Jije analytical laboratory branch Office, Mr. Yossan Teshome, laboratory assistant at Environmental lab.

I would also like to extend my very special thanks to my family and all friends, who have supported and encouraged me through all phases of my study period. Special thanks to Abbageda Temesgen Retebo and his family, Zelalem Abatkun, Yisak Bekele, Degefe Desalegn, Demere Tafesse, and Chibo Fikre.

I would also like to sincerely thank those who were management committees of Hadiya Zone Trade and Industry Depatment, specially Mr. Nigatu Lodamo, the then Head of the Department.

Last but for not least, I want to thank GOD ALMIGHTY for helping me to complete my thesis in due time and for His endless Kindness. You are so good to me. Next to GOD, Very special thanks to my Family and Emebet, who have supported and encouraged me through all phases of the study.

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ABBREVIATIONS

AAiT	Addis Ababa Institute of Technology
ANOVA	Analysis of variance
APHA	American Public Health Association
BOD	Biological oxygen demand
COD	Chemical oxygen demand
CWs	Constructed Wetlands
DO	Dissolved oxygen (mg/l)
EC	Electrical conductivity
FWS CWs	Free water surface flow
HFBs	Horizontal Flow Beds
HRT	Hydraulic retention time
O&G	Oil and grease
SF	Surface flow
SSF CWs	Subsurface flow
TN	Total Nitrogen
USEPA	United States Environmental Protection Authority
U.S.	United States
VFBs	Vertical Flow Beds

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ABSTRACT

Wetlands have long played a significant role as natural purification systems, and have been effectively used to treat domestic, agricultural and industrial wastewater. However, very little has been done on the use of constructed wetlands as treatment option for greywater especially in Ethiopia. Six experimental CW cells have been designed and constructed in order to evaluate the performance of constructed wetland and generate information about the effects of substrates (gravel, sand and scoria) and substrate-plant combination, by planting two types of plants (V.anagallis-aquatica and C.bengahllnsis). In addition the two plants were immersed in grey water for about a day in order to evaluate if any significant removal efficiency is shown. A total of 27 samples were collected and analyzed for selected wastewater quality parameters. Comparing the removal efficiencies of the three substrates without plantation, the highest scores were achieved by cells containing sand and scoria. The sand cell showed the best performances for orthophosphate (67.54%) and BOD5 (74.64%), and the scoria cell showed highest removal for Na (66.6%) and COD (61.1%). The only parameter that showed to be statistically significant ($p<0.05$) were sodium removal in the scoria cell. In the case where the cells were planted with V.anagallis-aquatica the sand performance for orthophosphate (72.89%) and BOD5 (76.87%), the scoria achievement for COD (59.86%) and sodium (60.51%), and the gravel cell score for NO_3-N (65.38%) and Mg (29.3%) were the highest for each parameters. On the hand of substrates that were plated with C.bengahllensis the cells with scoria media showed best results for Na (56.39%), COD (53.19%), and BOD5 (66.88%); the sand cell performed highest for orthophosphate (75.55%) and NO_3 (82%); and the gravel cell the first of the three in removal of Mg (29.3%). Finally, from the two plants, which were immersed in greywater in two separate bottles, V.anagallis-aquatica showed the better efficiencies for orthophosphate (43.99%), COD (36.36%) and Mg(88.9%). All of the results showed not to be statistically significant ($p<0.05$). Generally, it can be concluded the study implicated the potential use of CW as an alternative system for greywater treatment.

CHAPTER ONE

INTRODUCTION

Extensive research work has been carried out on treatment of wastewater in constructed wetlands. Constructed wetlands have proved to be a promising treatment facility in treating wastewater originating from a variety of sources; in addition to broader application, they work in both warm and cold climates. Although, constructed wetlands are low cost and low energy treatment method graywater treatment using constructed wetlands has not been much emphasized.

This project focuses on constructed wetland function to treat graywater. So, this project can serve as an initial input for future work in this area. The greywater used in the study was taken from the effluent of Addis Ababa Spa Service Enterprise (SSE).

1.1. BACKGROUND

Water covers 71% of the Earth's surface, and is vital for all known forms of life. On Earth, it is found mostly in oceans and other large water bodies, with 1.6% of water below ground in aquifers and 0.001% in the air as vapor, clouds (formed of solid and liquid water particles suspended in air), and precipitation. Oceans hold 97% of surface water, glaciers and polar ice caps 2.4%, and other land surface water such as rivers, lakes and ponds 0.6%. A very small amount of the Earth's water is contained within biological bodies and manufactured products (Wikipedia, 2010).

Clean drinking water is essential to human and other life forms. Access to safe drinking water has improved gradually and considerably over the last decades in almost every part of the world. There is a clear correlation between access to safe water and GDP per capita. However, some observers have estimated that by 2025 more than half of the world population will be facing water-based vulnerability. A report of November 2009 (cited in Wikipedia, 2010) suggests that by 2030, in some developing regions of the world, water demand will exceed supply by 50% (Wikipedia, 2010). Water plays an important role in the world economy, as it functions as a solvent for a wide variety of chemical substances and facilitates industrial cooling and transportation (Wikipedia, 2010).

Water is becoming a rare resource in the world. It is therefore, essential to reduce surface and ground water use in all sectors of consumption, to substitute fresh water with alternative water resource and to optimize water use efficiency through reuse options. These alternative resources include rainwater and greywater (National Environmental Engineering Research Institute and United Nations Children's Fund [NEERI & UNICEF], 2007).

Greywater does not include wastewater from toilets, and urinals. This is referred to as blackwater (water containing human excrement) (National Water Commission Razing National Waters Standards Program [NWCRNWSP], 2008). All wastewater produced in the home except toilet waste (urine and faeces) is called greywater. Greywater from washing dishes, showers, sinks and laundry comprises the largest part of residential wastewater (Peter, 2004). Since greywater is a reflection of house hold activities, its characteristics strongly depend on factors such as cultural habits, living standard, household demography, type of household chemicals used etc.

The choice of a greywater management strategy is highly dependent on the end use of the effluent produced. Greywater management strategies should therefore, be adapted to a specified purpose, such as generating an effluent suitable for agricultural reuse or whose quality allows its safe discharge into inland or coastal waters. The very basic objective of greywater management is to protect public health and the environment in a socio-culturally and economically sustainable manner. Furthermore, greywater should whenever possible be considered as a valuable resource (Morel & Diener, 2006).

A constructed wetland system for domestic wastewater treatment is designed to mimic the natural wetland treatment processes by Mother Nature. This system uses plants and microbes to improve the wastewater quality. Natural wetlands generally have visible water in the system. However, for constructed wetlands it depends on the designer's (constructor) interest to choose surface or subsurface system.

1.2. PROBLEM STATEMENT

- The Addis Ababa Spa Service Enterprise (SSE) discharges a lot of greywater in to the river every day. An estimated total amount of 810,226.1L (810.23m^3) greywater is produced each day from SSE (Girmay, 2010). Taking this number and calculating the yearly ejection resulted in 295,732,526.5L (295,732.53m^3) of greywater is discharged in to the river each year.
- Since the greywater enters in to river (Ghion river) the quality of the water deteriorates from day to day. Not only the water body, but the community on the countryside who may use the polluted water for different purpose is also expected to be exposed to waterborne diseases.
- The world's population is growing by about 80 million people a year, implying increased freshwater demand of about 64 billion cubic meters a year. Most population growth will occur in developing countries, mainly in regions that are already experiencing water stress and in areas with limited access to safe drinking water and adequate sanitation facilities (NNWWDR, 2009).
- The urban population is expected to double between 2000 and 2030 in Africa and Asia. By 2030 the towns and cities of the developing world will make up an estimated 81% of urban humanity (NNWWDR, 2009).

1.3. OBJECTIVES

1.3.1. General objectives

- The general objective of this study is to assess the performance of constructed wetlands for greywater treatment. In this paper the greywater, which has a great reuse potential and that can alleviate fresh water stress in different sectors, was treated using constructed wetlands and the quality of the treated water were evaluated.

1.3.2. Specific objectives

- Characterization of the greywater from SSE by measuring the following parameters BOD, COD, NO_3-N, TN, Na, Mg, Ca, pH, DO, EC, and Temperature.
- Constructing microcosms and determining removal efficiency for selected water quality parameters; BOD, COD, TS, NO_3-N, TN, Na, Mg, Ca, pH, DO, EC, and Temperature of greywater, taking SSE as a case study
- Evaluating the treated discharge water quality and the potential for further use.

CHAPTER TWO

LITERATURE SURVEY

Before studying the details of constructed wetlands (CWs) it is important to begin with the definition of the term wetlands. According to United States Environmental Protection Agency [USEPA] (2000) they are those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs and similar areas (Davis, 1994; USEPA, 1993, 2000). Wetlands are transitional areas between land and water. All wetlands - natural or constructed, freshwater or salt - have one characteristic in common: the presence of surface or near-surface water, at least periodically (Davis). Wetlands are natural water or wastewater purification systems that use low cost and low energy methods to improve water quality. They also require low operational attention (Anurita, n.d.).

Wetlands mean different things to different people with different backgrounds. To some, wetlands are important habitats for numerous kinds of waterfowl and fish whereas to others they are the “kidneys of the earth” and for some a leading “green” infrastructure of the 21st century (Eke, 2008).

There are many different terms for description of wetland such as temporary shallow water bodies, marshes, swamps, lake margins (littorals), large river floodplains, coastal beaches, salt marshes, mangroves, peat, bogs, fens, sloughs, ponds, coral reefs, riparian area, pocosin, wet pasture, channel, seep, taiga, bay lands, river, prairie pothole, wet meadow, intertidal mudflats, gulf, tundra, lagoon, lake, spring, estuary, sponge, stream, salt flat, creek, reservoir and beds of marine algae or sea grasses Kadlec & Knight (cited in Eke, 2008). The term "wetland" appears to have been adopted as a euphemistic substitute for the term "swamp" Wright (cited in Eke, 2008).

They provide reliable pollutant removal, long life, adaptability to a variety of developmental sites and habitat, food, and breeding areas to a variety of plant and animal species. They also provide educational and aesthetic values (Anurita, n.d.). Anurita also described their importance in flood and erosion prevention as wetlands help in flood and erosion control by functioning as natural sponges, storing water and releasing it slowly. This naturally occurring filtration process is so effective that many communities are looking for wetland protection and mitigation. However, natural wetlands are getting dewatered because of land development practices which have resulted in larger quantities of pollutants entering the water bodies which in turn deplete the water quality (Anurita, n.d.).

Most wetlands support a dense growth of vascular plants adapted to saturated conditions (Davis, 1994). Wetlands are neither terrestrial nor aquatic and cannot easily be classified as an intergrades between tile two Vynaza (cited in Hunt, 1997). Like many other "ecological edges" wetlands are neither wet nor dry and offer these intermediate characteristics chemically, physically, and biologically (Hunt, 1997).

The hydrological, biological and biogeochemical functions impart wetlands various values. Vymazal *et al.* & Denny cited in Eke (2008) summarized some of the values of the wetlands as follows:

1. Hydrological and hydraulic functions (erosion and flood control; recharge of groundwater aquifers; floodplain hydrodynamics),

2. Climatic effects (buffer global warming; carbon fixation and CO_2 balance; micro-climatic influences),

3. Biodiversity functions (wildlife enhancement; breeding grounds for waterfowl, fish and invertebrates like shrimps, crabs, oysters, clams, mussels; preservation of gene pools; conservation of flora and fauna),

4. Mining activities (getting peat, sand, gravel),

5. Usage of plants (staple food plants; grazing land; timber; paper production; roofing; agriculture, horticulture, fertilizers, fodder),

6. Development of aquaculture and integrated systems (fishing, hunting, fish cultivation combined with rice production),

7. Energy production (hydroelectric; solar energy; heat pumps; fuel as gas, solid and liquid),

8. Educational uses (training; nature studies; research activities)

9. Recreational and reclamation uses (sightseeing/ aesthetic benefits; sailing; swimming; canoeing and other water sports).

10. Relatively low capital and operating costs, simplicity of operation (low requirement for operator supervision) and seen as a natural and therefore “green” process.

The natural and constructed wetlands share similarities. However they differ in some aspects (Anurita, 1994):

1. The soil in a natural wetland may be formed as a result of weathering of rocks and minerals over a period of many years. These soils are rich in organic matter. Whereas in constructed wetlands the soil may not be as rich in organic matter as in natural wetlands.

2. In constructed wetlands plants are either seeded or planted. The vegetation in constructed wetlands is less diverse when compared to the natural wetland.

3. The type of microorganisms that thrive in a constructed wetland depends on the wastewater that is being treated in the wetland. Constructed wetlands are designed to provide an ideal habitat for the microbes to grow and perform their functions.

Constructed wetlands have been defined as ‘‘engineered systems, designed and constructed to utilize the natural functions of wetland vegetation, soils and their microbial populations to treat contaminants in surface water, groundwater or waste streams” (Hoffmann & Platzer, 2010). Constructed wetlands are artificial wastewater treatment systems consisting of shallow (usually less than 1 m deep) ponds or channels which have been planted with aquatic plants, and which rely upon natural microbial, biological, physical and chemical processes to treat wastewater (Anurita, 1994; USEPA, 2000). They are wastewater treatment systems composed of one or more treatment cells in a built and partially controlled environment designed and constructed to provide wastewater treatment (USEPA). A “constructed wetland” is defined as a wetland specifically constructed for the purpose of pollution control and waste management, at a location other than existing natural wetlands (USEPA, 1993).

Although main distinction between constructed wetlands and natural wetlands is the degree of control over natural processes the treatment systems of constructed wetlands are based on ecological systems found in natural wetlands (USEPA, 2000). Constructed wetlands, however, are defined as wetlands which are created for a beneficial use in areas where wetlands did not previously exist, at least at the time of construction Reed (cited in Hunt, 1997).

Constructed wetlands are used to treat petroleum refinery wastes, compost and landfill leachates, fish pond discharges, urban runoff, municipal, agricultural, industrial, animal waste and acid mine drainage and pretreated industrial wastewaters to uphold the deteriorating environmental conditions (Anurita, n.d., Davis, 1994). For some wastewaters, constructed wetlands are the sole treatment; for others, they are one component in a sequence of treatment processes (Davis).

Wetlands are being used extensively to treat wastewater because of their three basic functions Anurita, n.d.):

1. Physical entrapment of pollutants through sorption in the surface soils and organic litter.

2. Utilization and transformation of elements by microorganisms.

3. Low energy and low maintenance requirements to attain consistent treatment levels.

2.1. HISTORICAL DEVELOPMENT OF CONSTRUCTED WETLANDS

Despite poor documentation of this technology at early stage of development, there were several indications that wetlands were used for decades in many different forms and applications (Eke, 2008). Kadlec and Knight (cited in Eke) give a good historical account of the use of natural and constructed wetlands for wastewater treatment and disposal. As they point out, natural wetlands have probably been used for wastewater disposal for as long as wastewater has been collected, with documented discharges dating back to 1912. Research studies on the use of constructed wetlands for wastewater treatment began in Europe in the 1950’s and in the United States (U.S.) in the late 1960's. Research efforts in the U.S. increased throughout the 1970's and 1980's, with significant Federal involvement by the Tennessee Valley Authority (TVA) and the U.S. Department of Agriculture in the late 1980's and early 1990's (USEPA, 2000).

Historically, natural wetlands have been used as convenient sewage and wastewater discharge site. This was mainly done as a means of disposal rather than treatment. This trend has led to many wetlands, such as marshes, being saturated with nutrients and experiencing environmental degradation (Hoffmann & Platzer, 2010).

CWs have been used for wastewater treatment for over 40 years in nearly all regions of the world. Seidel (1965) conducted the first experiments on the possibility of wastewater treatment by wetland plants in 1952 at the Max Planck Institute in Plön, Germany. A major increase in the number of CWs took place in the 1990s as the application expanded to different kinds of wastewater. Today subsurface flow wetlands are quite common in many developed countries such as Germany, England, France, Denmark, Austria, Poland, Italy etc. (Hoffmann & Platzer, 2010).

2.2. COMPONENTS OF A CONSTRUCTED WETLAND

A constructed wetland consists of a properly designed basin that contains water, a substrate, and most commonly, vascular plants (Davis, 1994). The water, soil and vegetation are basic components for the characterization of a wetland (Eke, 2008). These components can be manipulated in constructing a wetland. Other important components of wetlands, such as the communities of microbes and aquatic invertebrates, develop naturally (Davis).

2.2.1. Water

A wetland can be built almost anywhere in the landscape by shaping the land surface to collect surface water and by sealing the basin to retain the water. Hydrology is the most important design factor in constructed wetlands because it links all of the functions in a wetland and because it is often the primary factor in the success or failure of a constructed wetland (Davis, 1994).

2.2.2. Substrates, Sediments, and Litter

Substrates used to construct wetlands include soil, sand, gravel, rock, and organic materials such as compost. Sediments and litter then accumulate in the wetland because of the low water velocities and high productivity typical of wetlands. The substrates, sediments, and litter are important for several reasons (Davis, 1994):

- they support many of the living organisms in wetlands
- substrate permeability affects the movement of water through the wetland
- many chemical and biological (especially microbial) transformations take place within the substrates
- substrates provide storage for many contaminants
- the accumulation of litter increases the amount of organic matter in the wetland. Organic matter provides sites for material exchange and microbial attachment, and is a source of

carbon, the energy source that drives some of the important biological reactions in wetlands

2.2.3. Vegetation

Plant is an important component of a wetland system (Eke, 2008). Both vascular plants (the higher plants) and non-vascular plants are important in constructed wetlands. Vascular plants contribute to the treatment of wastewater and runoff in a number of ways: they stabilize substrates and limit channelized flow they slow water velocities, allowing suspended materials to settle they take up carbon, nutrients, and trace elements and incorporate them into plant tissues they transfer gases between the atmosphere and the sediments leakage of oxygen from subsurface plant structures creates oxygenated micro sites within the substrate their stem and root systems provide sites for microbial attachment they create litter when they die and decay (Davis, 1994).

According to Hoffmann & Platzer (2010) for the selection of plants, the following recommendations can be used:

- Use local, indigenous species and do not import exotic, possibly invasive species.
- Use plant species which grow in natural wetlands or riverbanks because their roots are adapted to growing in water saturated conditions.
- Plants with an extensive root and rhizome system below ground are preferable; they should be able to withstand shock loads as well as short dry periods.

2.2.4. Microorganisms

Microorganisms include bacteria, yeasts, fungi, protozoa, rind algae. The microbial biomass is a major sink for organic carbon and many nutrients. Microbial activity (Davis, 1994):

- transforms a great number of organic and inorganic substances into innocuous or insoluble substances
- alters the reduction/oxidation (redox) conditions of the substrate and thus affects the processing capacity of the wetland
- is involved in the recycling of nutrients.

2.3. REMOVAL MECHANISMS OF A CONSTRUCTED WETLAND

Constructed wetlands are highly complex systems that separate and transform contaminants through several mechanisms as the wastewater flows through (Eke, 2008).

The predominant mechanisms and their sequence of reaction are dependent on the external input parameters to the system, the internal interactions, and the characteristics of the wetland (Eke, 2008). The external input parameters most often of concern include the wastewater quality and quantity and the system hydrological cycle (USEPA, 2000).

A natural wetland acts as a watershed filter, a sink for sediments and precipitates, and a biogeochemical engine that recycles and transforms some of the nutrients. A constructed wetland performs the same functions for wastewater, and a constructed wetland can perform many of the functions of conventional wastewater treatment trains (sedimentation, filtration, digestion, oxidation, reduction, adsorption, and precipitation). These processes occur sequentially as wastewater moves through the wetland, with wastewater constituents becoming comingled with detritus of marsh plants (USEPA, 2000).

A wetland is a complex assemblage of water, substrate, plants (vascular and algae), litter (primarily fallen plant material), invertebrates (mostly insect larvae and worms) and an array of microorganisms (most importantly bacteria). The mechanisms that are available to improve water quality are therefore numerous and often interrelated. These mechanisms include: (Davis, 1994)

- settling of suspended particulate matter
- filtration and chemical precipitation through contact of the water with the substrate and litter
- chemical transformation
- adsorption and ion exchange on the surfaces of plants, substrate, sediment, and litter
- breakdown and transformation of pollutants by microorganisms and plants
- uptake and transformation of nutrients by microorganisms and plants
- Predation and natural die-off of pathogens. The most effective treatment wetlands are those that foster these mechanisms.

Table 2.1 Overview of pollutant removal processes in subsurface flow CWs, grouped by pollutant (Hoffmann & Platzer, 2010)

Pollutant	*Process*
Organic material (measured as BOD or COD)	Particulate organic matter is removed by settling or filtration, and then converted to soluble BOD. Soluble organic matter is fixed by biofilms and removed due to degradation by attached bacteria (biofilm on stems, roots, sand particles etc.).
Suspended solids (TSS)	Filtration Decomposition by specialized soil bacteria during long retention times
Nitrogen	Nitrification and denitrification in biofilm Plant uptake (only limited influence)
Phosphorus	Retention in the soil (adsorption) Precipitation with calcium, aluminum and iron Plant uptake (only limited influence)
Pathogens	Filtration Absorption Predation (“feeding”) by protozoa Die-off due to long retention times
Heavy metals	Precipitation and adsorption Plant uptake (only limited influence)

Organic contaminants	Adsorption by biofilm and clay particles Decomposition due to long retention times and specialized soil bacteria (not predictable)

2.4. TYPES OF CONSTRUCTED WETLANDS

CW can be classified based on different criteria. These include macrophyte, size and according to their flow type (Firew, 2010).

Types of CW according to the dominating macrophyte

Wetland treatment system use different water tolerant plant species. According to Thiyagarajan *et al*., (cited in Firew, 2010) these systems can be classified with respect to the life form of dominating macrophytes into:

- Free-floating macrophyte-based system
- Submerged macrophyte-based system
- Rooted emergent macrophyte-based system

Types of CWs according to size

According to Brisson & Chazarenc, (cited in Firew, 2010) experimental wetlands can be classified by their size (surface area) into:

- Microcosms – CW whose surface area are less than $0.5m^2$ (for example; columns, buckets).
- Mesocosms – CW with size ranging from 0.51 up to $5m^2$
- Pilot-scale and full-size – CW with surface area greater than $5m^2$

Types of CWs according to flow type

There are two types of constructed wetlands, characterized by the hydrology Reed, (cited in Hunt, 1997). Constructed wetlands are classified according to the water flow regime: free water surface flow (FWS) and subsurface flow (SSF). Different types of constructed wetlands may be combined with each other (so called hybrid systems) in order to exploit the specific advantages of the different systems. For urban applications, SSF CWs are more commonly used than FWS CWs, as they have higher treatment efficiency and need less space (Hoffmann & Platzer, 2010).

Surface flow wetland

Surface flow (SF) treatment wetlands mimic the hydrologic regime of natural wetlands, where water flows over the soil surface from an inlet point to an outlet point or, in few cases, is totally lost to evapotranspiration and infiltration within the wetland (Eke, 2008). SF wetlands are sometimes called free water surface wetlands, if they are for mine drainage, aerobic wetlands. The advantages of SF wetlands are that their capital and operating costs are low, and that their construction, operation, and maintenance are straightforward. The main disadvantage of SF systems is that they generally require a larger land area than other systems (Davis, 1994).

Subsurface Flow Wetland

Subsurface Flow (SSF) Wetlands are generally constructed with a porous material such as soil, sand, or gravel for a substrate. SSF also known as reed beds, rock-reed wetlands, gravel beds, vegetated submerged beds, and the root method (Davis, 1994; Eke, 2008). Reed beds and rock-reed wetlands use sand, gravel, or rock as substrates, while the root method uses soil (Eke).

The advantages cited for SSF wetlands are greater cold tolerance, minimization of pest and odor problems, and possibly, greater assimilation potential per unit of land area than in SF systems. It has been claimed that the porous medium provides greater surface area for treatment contact than is found in SF wetlands, so that the treatment responses should be faster for SSF wetlands which can, therefore, be smaller than a SF system designed for the same volume of wastewater (Davis, 1994).

2.5. BASIC DESIGN RECOMMENDATIONS

Interest in, and the utilization of, constructed wetlands for treatment of a variety of wastewaters has grown rapidly since the mid 1980s. However, a lack of consensus has resulted in the use of different, and often conflicting, criteria and guidance for the design of these systems (USEPA, 1993).

2.5.1. Design life

Constructed wetlands can be expected to have a design life at least as long as other wastewater treatment systems, such as high-rate aerobic processes or ponds. The longest operating constructed wetlands have now been in operation for about 20 years and are still producing good effluent quality. There are no theoretical reasons which would indicate that constructed wetlands would stop working after a certain length of time (at least for removal of organic matter, nitrogen and pathogens) (Hoffmann & Platzer, 2010).

The major components of a constructed wetland are an influent pump (for VFBs; not required for HFBs), plastic pipes, plastic lining, gravel and sand. Therefore, the design life is determined by the design life of these major components. The pumps and feeding pipes can easily be replaced if necessary. The gravel and sand will never need replacement. The exact design life of the plastic lining is unknown and the condition of the plastic lining can also not be verified in an operational constructed wetland (Hoffmann & Platzer, 2010).

Data from few constructed wetland systems that have provided long term data show that treatment performance for pollutants that are broken down in wetlands, such as BOD_5, total suspended solids (TSS), and nitrogen, does not decrease as long as loadings are reasonable, and the wetland system is designed, built, and maintained with care. For pollutants that are retained within a wetland, such as phosphorous and metals, the capacity of the wetland to remove and store the pollutants may decrease over time. The buildup of these substances must be monitored periodically to assess the wetland's performance (Davis, 1994).

2.5.2. Design parameters

There are several design parameters or approaches for subsurface flow CWs which are used at different points in the design calculations, depending on the type of wastewater and climate (Hoffmann & Platzer, 2010):

- Area per person (in m^2/p.e.)
- Organic loading per surface area (in g BOD or g COD/(m^2 d))
- Hydraulic load (in mm/d or m3/(m2·d))
- Oxygen consumption and input.

The retention time should not be used for design purposes. There is no commonly accepted design approach which uses the retention time.

Despite a large amount of research and published information, the optimal design of constructed wetlands for various applications has not yet been determined. Among the systems that have been monitored, performance has varied and the influences of the diverse factors that affect performance, such as location, type of wastewater or runoff, wetland design, climate, weather, disturbance, and daily or seasonal variability, have been difficult to quantify. Mitsch cited in Davis, (1994) suggests the following guidelines for creating successful constructed wetlands:

- Keep the design simple. Complex technological approaches often invite failure.
- Design for minimal maintenance.
- Design the system to use natural energies, such as gravity flow.
- Design for the extremes of weather and climate, not the average. Storms, floods, and droughts are to be expected and planned for, not feared.
- Design the wetland with the landscape, not against it. Integrate the design with the natural topography of the site.
- Avoid over-engineering the, design with rectangular basins, rigid structures and channels, and regular morphology. Mimic natural systems.
- Give the system time. Wetlands do not necessarily become functional overnight and several years may elapse before performance reaches optimal levels. Strategies that try to short-circuit the process of system development or to over manage often fail.
- Design the system for function, not form. For instance, if initial plantings fail, but the overall function of the wetland, based on initial objectives, is intact, then the system has not failed.

2.5.2.1. Site Selection

The site should be located as close to the source of the wastewater as possible, and down gradient if at all possible so that water can move through the system by gravity. A site that is well suited for a constructed wetland is one that (Davis, 1994):

- is conveniently located to the source of the Wastewater
- Provides adequet space

- is gently sloping, so that water can flow through the system by gravity
- contains soils that can be sufficiently compacted to minimize seepage to groundwater
- is above the water table
- is not in a floodplain
- does not contain threatened or endangered species
- does not contain archaeological or historic resources.

2.5.2.2. Structures cells

Wetlands can be constructed by excavating basins, by building up earth embankments (dikes), or by a combination of the two. An emergency spillway should be provided. Bottom slopes are generally not critical. An exception may be mine drainage wetlands that use subsurface flow through deep beds of compost to induce sulfate reduction; these cells should slope about 1 - 3% upstream. Bottoms should be relatively level from side to side (Davis, 1994).

2.5.2.3. Liners

Constructed wetlands must be sealed to avoid possible contamination of groundwater and also to prevent groundwater from infiltrating into the wetland. On-site soils can be used if they can be compacted to permeability of <10.6 cm/sec (<108 ft/sec). Soils that contain more than 15% clay are generally suitable. Synthetic liners include asphalt, synthetic butyl rubber, and plastic membranes (for example, 0.5 to 10.0 mil high density polyethylene). The liner must be strong, thick, and smooth to prevent root attachment or penetration. The liner should be covered with 3 - 4 inches of soil to prevent the roots of the vegetation from penetrating the liner (Davis, 1994).

2.5.2.4. Physical Facilities

The site topography is of important concern in determining the wetland location. The site topography dictates the shape and configuration of the wetland. Steep slopes are to be avoided as they deter the plant growth in the wetland. Also, this leads to increased construction costs, harvesting and maintenance problems (Anurita, n.d.).

The aspect ratio (AR) is the average length divided by the average width of a wetland system. The higher the length to width ratio of the wetland short circuiting is minimized. The higher AR allows the wetland to closely perform plug flow hydraulics.

2.5.2.5. Vegetation

The vegetation in the wetland must be able to remove pollutants and nutrients present in the graywater and provide a diverse habitat within the constructed wetland. Plants with high growth rates, can establish large surface areas and can withstand winters must be used. Regular harvesting of the vegetation in the wetland stimulates the growth of plant species and in turn helps in the removal of accumulated nutrients and excess organic matter. The vegetation in the wetland attracts wildlife (Anurita, n.d.).

The most common plants used in constructed wetlands are bulrushes (Scirpus), spikerush (Efeocharis), and other sedges (Cyperus). Rushes (Juncus), common reed (Phragrnites), and cattails (Typha). Any species of plant that grows well and establishes dense vegetation may be selected to treat wastewaters (Anurita, n.d.).

2.5.3. Criteria for the design of subsurface flow CWs

Subsurface flow CWs are usually designed for the removal of:

- Organic matter (measured as BOD_5 or COD)
- Suspended Solids (measured as TSS)
- Nutrients (nitrogen and phosphorus)

There are some general considerations about planning and constructing of subsurface flow CWs, which are generally adhered to by most engineers when designing these types of constructed wetlands (Hoffmann & Platzer, 2010):

- A 15 cm freeboard for water accumulation is recommended.
- The surface must be flat and horizontal to prevent unequal distribution or surface run off.
- A basic design has to take into account suspended solids (TSS) and organic load (BOD or COD).
- The design of the inlet area has to assure uniform distribution of the wastewater, without allowing short circuits of the flow.
    - In this context the selection of filter material is crucial.

- The wastewater is distributed via distribution pipes which usually have small holes in certain distances along the length of the distribution pipes.

- Plants play an important role in reed beds, and have to be adapted to the special local conditions, but the main treatment process is a combination of microbial degradation and chemical processes.
- Plastic liner, clay or concrete can be used to seal the filter bed at the base. For HFBs this is always necessary. For VFBs it is only necessary when the effluent will be reused or when the authorities require the sealing of the base of the filter (or when the groundwater table is high and groundwater is used for drinking water purposes).

2.6. OPERATION AND MAINTENANCE

Periodic monitoring and maintenance of the wetlands will ensure the environmental integrity, aesthetic enhancement and wildlife benefit for future generations. The key maintenance considerations of a constructed wetland system are the flow and the vegetation. Weed control and debris removal are the important jobs to be performed. For the constructed wetland to perform successfully following factors must be considered (Anurita, n.d.):

- Flow must be uniformly distributed throughout the wetland.
- The wastewater being treated must be in sufficient contact time with the vegetation and the microbial community in the wetland.
- A healthy ecosystem must be maintained in the wetland ecosystem.

Important information about the quality and functioning of the filter bed can be gained by checking the effluent of the constructed wetland for visual appearance and odour: (Hoffmann & Platzer, 2010)

Monitoring of a constructed wetland system is very important to ensure sound performance of the system. Monitoring will help in identifying the problems in the wetland and thereby improve the treatment facility. Monitoring of the constructed wetland indicates the integrity of the wetland ecosystem. Since the wetlands form an interface between the land and water environments they require regular monitoring and surveying techniques (Anurita, n.d.).

2.7. COST CONSIDERATIONS

The following points can be made regarding cost comparisons between constructed wetlands and other treatment processes (Hoffmann & Platzer, 2010):

- For large-scale treatment plants (more than 10,000 p.e.) in areas where land is available cheaply, ponds have lower capital costs than constructed wetlands.
- The construction costs for aerobic high-rate treatment processes depend on the local conditions but can be similar to those of constructed wetlands, especially for larger plant sizes (more than 2 000 p.e.).
- Constructed wetlands do not have "economies of scale" to the same degree that aerobic high-rate treatment plants have. For small plants (up to 500 p.e.), constructed wetlands may be cheaper than aerobic high-rate plants but for larger plants, they are often more expensive (in terms of capital costs).
- Constructed wetlands have significantly lower operation and maintenance costs compared to high-rate aerobic processes (in terms of energy use and operator time). This is an important consideration for the financial sustainability of a wastewater treatment plant.
- Financial decisions on treatment processes should not be made based on capital costs alone, but rather on net present value (or whole-of-life costs), which includes the annual costs.

2.8. GREYWATER

2.8.1. What is greywater?

As per the definition of Australian Government National water Commission Razing National Waters Standards Program [AGNWCRNWSP] (2008) greywater is the wastewater from:

(a) Washing machines

(b) Laundry tubs

(c) Showers

(d) Basins

(e) Baths

(f) Kitchen

Greywater does not include wastewater from toilets, urinals, or bidets. This is referred to as blackwater (water containing human excrement) (AGNWCRNWSP, 2008; Anurita, n.d.; Ridderstolpe, 2004). Most graywater systems do not use water from kitchen sink and dishwasher due to high solid concentration (Anurita, n.d.).

Since greywater is a reflection of house hold activities, its characteristics strongly depend on factors such as cultural habits, living standard, household demography, type of household chemicals used etc. Nonetheless, specific greywater sources have specific characteristics as summarized below (Morel & Diener, 2006):

Kitchen greywater: contains food residues, high amounts of oil and fat, including dishwashing detergents. In addition, it occasionally contains drycleaners and bleach. Kitchen greywater is high in nutrients and suspended solids. Dishwasher greywater may be very alkaline (due to builders), show high suspended solids and salt concentrations.

Bathroom greywater: is regarded as the least contaminated greywater source within a household. It contains soaps, shampoos, toothpaste, and other body care products. Bathroom greywater also contains shaving waste, skin, hair, body-fats, lint, and traces of urine and faeces. Greywater originating from shower and bath may thus be contaminated with pathogenic microorganisms.

Laundry greywater: contains high concentrations of chemicals from soap powders (such as sodium, phosphorous, surfactants, nitrogen) as well as bleaches, suspended solids and possibly oils, paints, solvents, and non biodegradable fibers from closing laundry greywater can contain high amounts of pathogens when nappies are washed (Morel & Diener, 2006).

2.8.2. What are the risks of using greywater?

The world is facing a crisis in water availability due to reduced rainfall, increased evaporation, changing lifestyle, urbanization and a large demand for freshwater from the population. In order to solve this problem extensive research is going on in the field of wastewater treatment, recycle and reuse in both developed and developing countries. These days importance is being given for recycle and reuse of graywater as it is less polluted and hence the treatment is easier. However, health aspects and environmental perspectives have to be considered (Erikkson *et al*., cited in Anurita, n.d.).

Compared to other aspects of environmental sanitation, such as toilet wastewater or solid waste, greywater traditionally receives the least attention. In urban and peri-urban areas of low and middle-income countries, greywater is most often discharged untreated into stormwater drains or sewers, provided they exist, from where it mainly flow into aquatic system. This leads to oxygen depletion, increased turbidity, eutrophication as well as microbial and chemical contamination of the aquatic systems (Morel & Diener, 2006).

Reuse of greywater for irrigating home gardens or agricultural land is widespread, especially in regions with water scarcity or high water prices such as the Middle East, parts of Africa and Latin America. Greywater is thus perceived and recognized as a valuable resource, but potential drawbacks of such practices are often not taken into account. Untreated greywater, although less contaminated than other wastewater sources, does contain pathogens, salts, solid particles, fat, oil, and chemicals. If reuse practices are inappropriate, these substances may potentially have a negative effect on human health, soil and groundwater quality (Morel & Diener, 2006).

The risks associated with greywater potentially impact on the following:

(a) *Human health*—Greywater can contain large numbers of disease-causing organisms (human Pathogens such as bacteria, viruses, and protozoa).

(b) *Environment*—Greywater can also include a number of contaminants including fats and oils, food scraps, nutrients, salts, sodium, phosphorus, detergents, cleaning products, and personal care products. Long-term watering with greywater containing these contaminants can affect sensitive plants and soil.

2.8.3. Greywater characteristics

The graywater quality is less than the quality of tap water and is unsafe because of the presence of pathogens. The total graywater fraction has been estimated to about 75% by volume of the combined residential sewage (Erikkson *et al*., cited in Anurita, n.d.).

Greywater is generated by any residential premise that is occupied, and as such the water can be recycled to provide a reliable source of water for activities that do not require drinking water quality (e.g., irrigation, toilet flushing and washing). The characteristics of greywater produced by a residential premise will vary according to the number, age, lifestyle, health status and water usage patterns of the household's occupants (NWCRNWSP, 2008).

2.8.3.1. Greywater composition

Graywater composition depends on the water source, plumbing system, living habits and personal hygiene of the users. The main sources of graywater are households which include water from bathtubs, showers, sinks, and washing machines. The characteristics of gray water will be influenced by: cleaning products used, dishwashing patterns, laundering practices, bathing habits, and disposing of household chemicals. The physical, chemical and biological characteristics of gray water and when it is used varies greatly among families and businesses (Anurita, n.d.).

The composition of greywater mainly depends on quality and type of available water supply and household activities. Cooking habits as well as amount and type of soap and detergent used significantly determine the level of contamination. Greywater may contain soaps, food particles, grease, oil, lint, hair, pathogens, and traces of other chemicals. Greywater also contains high levels of detergents. These contain surfactants (surface active agents), builders, bleaches, enzymes, preservatives, solvents, fillers, etc (Morel & Diener, 2006).

There is a high amount of variability in the chemical and physical quality of greywater produced by any household, which is due to factors such as the source of household water, the water use efficiency of appliances and fixtures, individual habits and products used in the household (e.g., detergents, shampoos, and soaps). The amount of salt (e.g., sodium, calcium, magnesium, potassium and other salt compounds), nutrients, oils, grease, fats, and chemicals in greywater are a direct result of the type of products and foods used within the household. Greywater from laundries and bathrooms will contain some body fats, urine, faeces or blood (NWCRNWSP, 2008).

2.8.3.2. Physical characteristics

Temperature

Greywater temperature is often higher than that of the water supply and varies within a range of 18–30 ^{o}C. These rather high temperatures are attributed to the use of warm water for personal hygiene and discharge of cooking water. These temperatures are not critical for biological treatment processes (aerobic and anaerobic digestion occurs within a range of 15–50 ^{o}C, with an optimal range of 25– 35 ^oC). On the other hand, higher temperatures can cause increased bacterial growth and decreased $CaCO_3$ solubility, causing precipitation in storage tanks or piping systems (Morel & Diener, 2006).

Suspended solids

Food, oil and soil particles from kitchen sinks or hair and fibers from laundry can lead to high solids content in greywater. These particles and colloids cause turbidity in the water and may even result in physical clogging of pipes, pumps and filter used in treatment process. Especially non biodegradable fibers from clothing (polyester, nylon, and polyethylene), powdered detergents and soaps, as well as colloids are the main reasons for physical clogging. Suspended solids concentrations in greywater range from 50–300 mg/l, but can be as high as 1,500 mg/l in isolated cases. The highest concentrations of suspended solids are typically found in kitchen and laundry greywater. Suspended solids concentrations strongly depend on the amount of water used (Ridderstolpe, 2004).

The composition of greywater varies greatly and reflects the lifestyle of the residents and the choice of household chemicals for washing-up, laundry etc. Characteristic of greywater is that it often contains high concentrations of easily degradable organic material, i.e. fat, oil and other organic substances from cooking, residues from soap and tensides from detergents (Ridderstolpe, 2004).

2.8.3.3. Chemical characteristics of grey water

The chemical parameters of relevance are hydrochemical parameters such as pH, alkalinity, electrical conductivity, sodium adsorption ratio (SAR), biological and chemical oxygen demand (BOD, COD), nutrient content (nitrogen, phosphorous), and problematic substances such as heavy metals, disinfectants, bleach, surfactants or organic pollutants in detergents (Morel & Diener, 2006).

pH and alkalinity

The pH indicates whether a liquid is acidic or basic. For easier treatment and to avoid negative impacts on soil and plants when reused, greywater should show a pH in the range of 6.5–8.4. The pH value of greywater, which strongly depends on the pH value of the water supply, usually lies within this optimal range. However, observed pH values of 9.3–10 in laundry greywater, partly as a result of the sodium hydroxide-based soaps and bleach used. Greywater with high pH values alone are not problematic when applied as irrigation water, but the combination of high pH and high alkalinity, a measure of the water's ability to neutralize acidity, is of particular concern. Greywater alkalinity (indicated as $CaCO_3$ concentrations) is usually within a range of 20–340mg/l, with highest levels observed in laundry and kitchen greywater (Morel and Diener, 2006).

Salinity and sodium adsorption ratio (SAR)

Greywater contains also salts, indicated as electrical conductivity (EC, in µS/cm or dS/m). EC measures salinity of all the ions dissolved in grey water, including negatively charged ions (e.g. Cl^-, NO_3^-) and positively charged ions (e.g. Ca^{++}, Na^+). The most common salt is sodium chloride – the conventional table salt. Other important sources of salts are sodium-based soaps, nitrates and phosphates present in detergents and washing powders. The electrical conductivity (EC) of greywater is typically in the range of 300-1500 µS/cm but can be as high as 2700 µS/cm. Salinity of greywater is normally not problematic, but can become a hazard when greywater is reused for irrigation. High EC of irrigation water can considerably reduce yield potential. This problem can be overcome by choosing more salt-tolerant plants (Morel and Diener, 2006).

Biological and chemical oxygen demand

The biological and chemical oxygen demand (BOD, COD) are parameters to measure the organic pollution in water. COD describes the amount of oxygen required to oxidize all organic matter found in greywater. BOD describes biological oxidation through bacteria within a certain time span (normally 5 days (BOD_5)). The main groups of organic substances found in wastewater comprise proteins (mainly from food), carbohydrates (such as sugar or cellulose), fats and oils as well as different synthetic organic molecules such as surfactants that are not easily biodegradable. Discharging greywater with high BOD and COD concentrations into surface water results in oxygen depletion, which is then no longer available for aquatic life. BOD and COD concentrations in greywater strongly depend on the amount of water and products used in the household (especially detergents, soaps, oils and fats). Where water consumption is relatively low, BOD and COD concentrations are high (Morel & Diener, 2006).

The COD/BOD ratio is a good indicator of greywater biodegradability. A COD/BOD ratio below 2–2.5 indicates easily degradable wastewater. While greywater is generally considered easily biodegradable with BOD accounting for up to 90% of the ultimate oxygen demand different studies indicate low greywater biodegradability with COD:BOD ratios of 2.9–3.6. This is attributed to the fact that biodegradability of greywater depends primarily on the type of synthetic surfactants used in detergents and on the amount of oil and fat present. While western countries have banned and replaced non-biodegradable and, thus, troublesome surfactants by biodegradable detergents. Such resistant products may still be used (e.g. in powdered laundry detergents) in low and middle-income countries (Morel & Diener, 2006).

Nutrients

Greywater normally contains low levels of nutrients compared to toilet wastewater. Nonetheless, nutrients such as nitrogen and phosphorous are important parameters given their fertilizing value for plants, their relevance for natural treatment processes and their potential negative impact on the aquatic environment. Especially the high phosphorous contents sometimes observed in greywater can lead to problems such as algae growth in receiving water. If too much greywater is used, nitrogen and phosphorus can move off-site into water bodies where they can cause environmental problems (NWCRNWSP, 2008).

Greywater normally contains low levels of nutrients compared with normal wastewater from water borne system. Levels of nitrogen and other plant nutrients are always low, but in some greywater high concentrations of phosphorous can be found. This phosphorous originates from washing and dish-washing powder, where it is used for softening the water. Washing and dish washing powders without phosphorous are available on the market. In general, these are as cheap and effective as those containing phosphorous, which makes choosing P-free detergents a sensible option. If people use only P-free detergents, the phosphorus content of the greywater should be reduced to levels lower than normally found in an advanced treated wastewater. Some progressive countries (e.g. Norway) and some cities in East Asia have banned washing powder containing phosphorous for water protection (Ridderstolpe, 2004).

In countries where phosphorous-containing detergents have not been banned, dishwashing and laundry detergents are the main sources of phosphorous in greywater. Average phosphorous concentrations are typically found within a range of 4–14 mg/l in regions where non-phosphorous detergents are used. However, they can be as high as 45–280 mg/l in households where phosphorous detergents are utilized (Morel & Diener, 2006).

Levels of nitrogen in greywater are relatively low (urine being the main nitrogen contributor to domestic wastewater). Kitchen wastewater is the main source of nitrogen in domestic greywater, the lowest nitrogen levels are generally observed in bathroom and laundry greywater. Nitrogen in greywater originates from ammonia and ammonia-containing cleansing products as well as from proteins in meats, vegetables, protein-containing shampoos, and other household products. Typical values of nitrogen in mixed household greywater are found within a range of 5–50 mg/l with extreme values of 76 mg/l, as observed in kitchen greywater (Morel & Diener, 2006).

Microbial characteristics of grey water

Greywater may pose a health risk given its contamination with pathogens. However, pathogens, such as viruses, bacteria, protozoa, and intestinal parasites, are assumed to be present in partly high concentrations. These pathogens originate from excreta of infected persons. They can end up in greywater through hand washing after toilet use, washing of babies and children after defecation, diaper changes or diaper washing. Some pathogens may also enter the greywater system through washing of vegetables and raw meat; however, pathogens of fecal origin pose the main health risks (Morel & Diener, 2006).

Faecal contamination of greywater, traditionally expressed by faecal indicators such as faecal coliforms, strongly depends on the age distribution of the household members. High contamination must be expected where babies and young children are present. Average concentrations are reported to be around 103–106 cfu/100 ml. However, contamination can be as high as 107–108 cfu/100 ml in laundry or shower greywater. Since greywater may contain high loads of easily degradable organic compounds, re-growth of enteric bacteria, such as the faecal indicators, are favored in greywater systems. Hence, bacterial indicator numbers may lead to an overestimation of faecal loads and thus risk (Morel & Diener, 2006).

The concentrations of human pathogen hazards in greywater vary over a wide range. In the worst cases, concentrations of faecal microorganisms are almost as high as those found in sewage. The reason for this variation is that pathogens depend on the behavior of people living in or visiting the house, and the control of materials discharged into the greywater. Microbiological quality depends on the amount of faecal material that enters greywater from activities such as washing nappies or other types of soiled clothing, and the health of the individual living in or visiting the house (NWCRNWSP, 2008).

One important conclusion from this discussion is that untreated greywater can be expected to contain far lower densities of pathogens than effluent water from an advanced wastewater treatment plant. Treated greywater can thus be expected to have a much better hygiene quality than any kind of mixed wastewater (Ridderstolpe, 2004).

Oil and grease (O & G)

Grey water may contain significant amounts of fat such as oil and grease (O&G) originating mainly from kitchen sinks and dishwashers (e.g. cooking grease, vegetable oil, food grease etc.). Important O&G concentrations can also be observed in bathroom and laundry greywater, with O&G concentrations ranging between 37-78 mg/l and 8–35 mg/l, respectively. The O&G content of kitchen greywater strongly depends on the cooking and disposal habits of the house hold. O&G concentrations ranging between 1,000 and 2,000 mg/l observed in restaurant wastewater. As soon as greywater cools down, grease and fat congeal and can cause mats on the surface of settling tanks, on the interior of pipes and other surfaces. This may cause shutdown of treatment and disposal units such as infiltration treanches or irrigation fields. It is therefore important that O&G concentrations are maintained at acceptable levels < 30 mg/l, to avoid problems with downstream treatment and disposal systems (Morel & Diener, 2006).

Metals and other toxic pollutants

The content of metals and organic pollutants in greywater is generally low, but can increase due to addition of environmentally hazardous substances. The levels of metals in greywater are for most substances approximately the same as in a mixed wastewater from a household, whereas for zinc and mercury the levels are lower. Metals in greywater originate from the water itself, from corrosion of the pipe system and from dust, etc cutlery, dyes and shampoos used in the household. Most organic pollutants in the wastewater are found in the greywater fraction; hence the levels are in the same concentration range as in a mixed household wastewater. Organic pollutants are present in many of our ordinary household chemicals, e.g. shampoos, perfumes, preservatives, dyes and cleaners. They can also be found in furnishing fabrics, glue, detergents and floor coatings. The content of metals and organic pollutants in greywater is heavily affected by human behavior. By using environmentally-friendly household chemicals, and not pouring hazardous substances such as paint, solvents etc. into the washbasin, the levels of metals and organic pollutants in greywater can be kept low (Ridderstolpe, 2004).

During greywater irrigation, toxicity problems may occur if boron ions (similarly to sodium ions) are taken up by plants and accumulate to concentrations high enough to cause crop damage or reduced yield. Detergents are the main sources of boron in greywater. Although boron is an essential micronutrient for plants, excessive amounts are toxic. Boron concentrations reaching 3 mg/l was observed in laundry greywater. The recommended maximum value of boron for irrigation amounts to 1.0 mg/l for sensitive crops such as lemon, onion or bean (Morel & Diener, 2006).

Even though greywater is less polluted than toilet wastewater, it is an undeniable fact that due to the large volumes of greywater produced, its contribution to the total pollution load in domestic wastewater is considerable. According to different studies, greywater makes up on average more than half of the BOD load, up to two thirds of the total phosphorous load (where phosphate containing detergents are used) and one fourth of the total suspended solids load. This clearly reveals the importance of including greywater in sanitation programmes. Focusing only on blackwater will not meet the objective of providing adequate sanitation and reducing public health risks and environmental degradation (Morel & Diener, 2006).

2.8.4. Economic value of greywater

Greywater should be regarded as a valuable resource and not as a waste. Despite the described inadequate greywater management risks, greywater has, nevertheless, a great potential to reduce the water stress currently faced by regions in the world. Greywater reuse is an effective measure for saving water on the domestic level. Where water is scarce and expensive, greywater reuse may lead to considerable economic benefits. Households treating and reusing greywater locally may reach an average annual benefit of USD 376, accounted for by increased product yields, as well as reduced water and fertilizer costs (Morel & Diener, 2006).

CHAPTER THREE

MATERIALS AND METHODS

3.1. DESCRIPTION OF THE STUDY AREA

The Addis Ababa spa had established in 1886, during regime of Emperor Minelik 2^{nd}. Empress Taitu, Queen, wife of the very sovereign, who on one occasion traveled from the then capital, Entoto to Finfinie, the actual site of spa, to bathe in the natural hot springs, date remained to exploit and develop this natural wealth.

The Addis spa center has two major sectors namely the new filwoha and the Finfinie wing, the older segment. The New Filwoha, which was established in 1956 E.C. by Emperor Haile Selassie, is currently the wing with more modern facilities. In addition more than 85% of the showers and bathes are located at this wing. This establishment has a requisite restaurant, cozy bars, bed rooms with cold and warm (hot) baths and showers, a barber a beauty salon, various shops, a physiotherapy treatment and a sauna service.

3.2. EXPERIMENTAL SETUP (MICROCOSMS DESCRIPTION)

The microcosms constructed wetland systems used for the treatment of greywater from SSI in this study were built in the property of Addis Ababa Institute of Technology (AAiT). These microcosms were designed based on the information gained from various literatures.

The system consists of six microcosms each with a dimension of 1 meter length, 0.5 meter width and 0.8 meter depth (surface area of $0.5m^2$) arranged three on one side in parallel and the other three on the opposite side, in the middle there was a space left for collecting sample from the out let of the six microcosms which has a dimensions of 0.4m length, 1.9m width and 0.8m depth. The system was planted with two types of plants the first was Veronica anagallis-aquatica L. and the second one was Commelina benghalensis L.

The microcosms was constructed by digging the surface in the aforementioned dimensions and leaving a 30cm gap, which serves as a separation wall, between each cell. Since it was important to avoid treated water infiltration in to the ground, it was mandatory to use impermeable materials which would block the flow of water out of the system other than the outlet. So, in order to achieve this plastic liner were used as impermeable layer. Once the liner was on place the next thing was to fill the cells with the substrate. In this study there were three types of substrates used; gravel, sand and scoria. These materials were selected as a substrate for the following reasons. According to different literatures covered in this paper, one of the three significant components of CW and which can affect the treatment efficiency highly is the type of media used. Even if, there were no suggestion found on literatures, that were covered on this particular project, mentioning scoria as a substrate for CWs the first two, gravel and sand were the most commonly recommended types of substrates..

Each of the cells has a capacity of about $0.4m^3$ when they are empty. Out of this volume nearly $0.35m^3$ was filled with gravel, sand, and scoria substrate leaving void volume of $0.1225m^3$, $0.105m^3$, and $0.112m^3$ respectively.

The approximate estimate of HRT for this wetland was obtained by using Darcy's formula (USEPA, 1993)

HRT = nLWd /Qav.- 3.1

Where:

n = effective porosity media,

- For gravel of medium size 35%
- For sand 30%, and
- For fine scoria 32%

L = Length of the bed, (1m)

W = Width of the bed, (0.5m)

d = Average depth of liquid in bed, (0.3m)

Qav = the average of the inflow and outflow [(Qi + Qo)/2], (m^3/day),

- Qin = 3.68 m^3/d
- Qout for gravel 5.76 m^3/d, with Qav = 4.72 m^3/d
- Qout for sand 1.02 m^3/d, with Qav = 2.35 m^3/d, and
- Qout for scoria 2.34 m^3/d, with Qav = 3.01 m^3/d

The porosity (n) is used to determine the actual flow velocity in the void spaces in retention time calculation equation. Porosity is equal to void volume/total volume and is expressed as percentage (Birhanu, 2007).

The rate of inflow to the wetland was determined by filling the container, which has a volume of 30L, to its full capacity and recording the time taken that the water to reach the level below the inlet faucet (i.e., outlet point from the sedimentation tank). By doing so repeatedly the average time obtained was 180seconds for about 23L of water. By calculating this, inflow rate of 3.68m^3/d was determined. On the other hand, the outflow rate was calculated by collecting the effluent in a container of defined volume and recording the time taken to collect the obtained amount of water. Based on this, the mean inflow and outflow of the wetland was obtained. The mean depth of water level in the wetland was 0.3 meter. Based on the above data, the calculated hydraulic residence time (HRT) of the microcosms with gravel, sand and scoria were 16.02 min., 27.57 min., and 22.96 min. respectively. Even if there is difference in HRT it is believed not to have significant difference.

To evaluate the performance of microcosms, samples were collected before supplying it to sedimentation tank and, effluent samples were collected at nine sampling position (SP1, SP2, SP3, SP4, SP5, SP6, SP7, SP8, and SP9). SP1 was in the sedimentation tank (for influent of the microcosms), while SP2 to SP7 were at the outlet of each wetland cells (for effluent of each wetland cells). The final two samples (SP8, and SP9) were taken from two small containers, which were proposed to evaluate the capability of pollutant removal efficiency of the selected plants, summing up two samples for each plant a total of four samples were taken in order to evaluate the plants efficiency. The plants had been in contact with the plants for about 24 hours. A total of 27 samples (22 samples from effluent and 5 from influent) were collected throughout the study period.

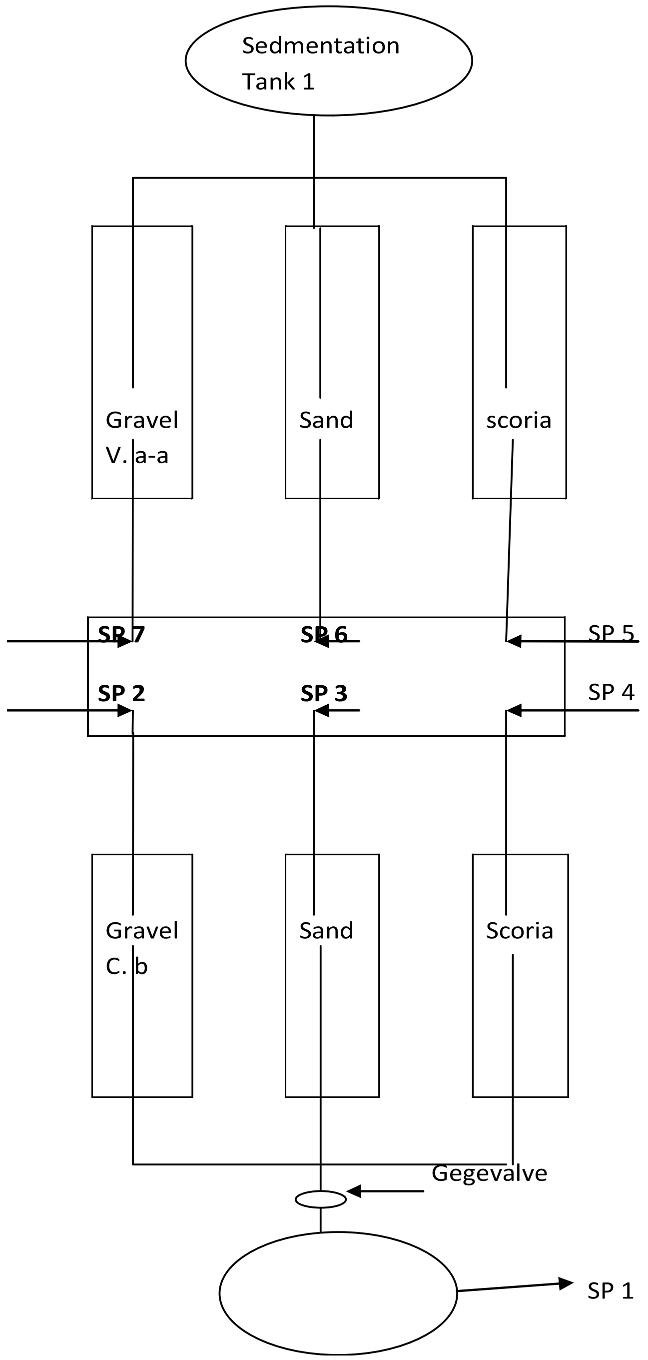

Figure 3.1 the sample collection points

3.2.1. Sedimentation tank

For the whole system there were two sedimentation tanks, one tank for the three cells which lay on one side of the system and the other for three cells on the other side. These tanks, which have a capacity of 30L each, are a place where some of the settleable suspended solids would settle to the bottom of the tank forming some form of sludge. For this reason, the piping networks were connected to the tanks at about 10cm above the bottom which is intended for sludge accumulation.

3.2.2. Piping

The piping system used for the supply and distribution of the greywater was made of ½ inch (1.27cm) diameter galvanized pipes. And the collection pipe system for the treated effluent is made of the same ½ inch (1.27cm) plastic pipe.

3.2.2.1. Inlet Pipes

These are pipes delivering the greyawater into the system. In order to maintain equal distribution throughout each cell the pipes distributing the greywater over each cells were drilled on both sides in a space of 10cm and their tips were covered by tap. This can be taken as the most important part of the system as it determines the flow rate of greywater to be fed in to the system which in turn affects the HRT and the overall treatment efficiency of the whole system. Inside each microcosm, the inlet pipes were set 7cm below the top of the system, all of the three getting water from one source and controlled by one get valve, which is located on the main pipe which receives the grweywater from the tank.

3.2.2.2. Out let pipes

The out let pipes, through which the treated effluent leaves each microcosm, extended about 25cm inside the cells. These pipes were placed 30cm above the bottom of the system and around 40cm below the surface of the media.

3.2.3. Wetland Substrate

Substrates used to construct wetlands include sand, gravel, and scoria. The substrate was filled to the height of 70cm.

3.2.4. Wetland planting and establishment

Plant is an important component of a wetland system. Both vascular plants (the higher plants) and non-vascular plants (algae) are important in constructed wetlands (Eke, 2008). Two types of plant species, Veronica anagallis aquatica L. & Commelina benghalensis L., were used as the CW vegetation. The selection criteria for these plants were based on recommended ways by Hoffmann & Platzer (2010) for selecting plant species for use in a CW.

- Use local, indigenous species and do not import exotic, possibly invasive species.
- Use plant species which grow in natural wetlands or riverbanks because their roots are adapted to growing in water saturated conditions.
- Plants with an extensive root and rhizome system below ground are preferable; they should be able to withstand shock loads as well as short dry periods.

In addition to the above criteria their aesthetic value and their ease of accessibility were considered in identifying the plant types used. Greywater treatment and landscape beautification can be accomplished with the use of such plants on CWs.

By taking the aforementioned criterium in to consideration, the plants were collected from river side of the river which is located around “Afncho ber”, Addis Ababa. And the identification of the species were carried out at Herbarium of Science Faculty.

Brief description of the plants presented below.

Veronica anagallis aquatica L.

Veronica anagallis-aquatica is a species of flowering plant in the plantain family known by the common names water speedwell, blue speedwell, and brook pimpernel. Its true native range is not clear, but the plant is present on most continents, and in most places it is probably naturalized. It occurs in many types of moist and wet habitat, and it is semi-aquatic, often growing in shallow water along streambanks, in ponds, and in other wetland environments. It is a rhizomatous perennial herb with stems growing 10 centimeters to about a meter in maximum length. It may be decumbent, the stem spreading along the ground and rooting where it touches moist substrate, or erect in form. The oppositely arranged leaves are green, smooth-edged or toothed, and sometimes clasping the stem where the leaf pairs meet at the bases. The inflorescence is a raceme of many flowers arising from the leaf axils. Each flower is borne on a short, curving pedicel. The flower corolla is up to a centimeter wide with four lobes, the upper lobe being widest. It is blue, lavender, or violet with purple lines near the base of each lobe. At the center are two small protruding stamens (Wikipedia, 2011).

Annual or perennial herb, glabours or glandular pubescent. Steams erect often with creeping vegetative branches base, thick, hollow (20-)30-60(-100)cm tall. Streams and ponds, 1500-3000m (Hedberga *et al*., 2003).

Uses

Edible Uses:

The leaves of water speedwell are edible, like all members of the genus Veronica, raw or cooked. They are rich in vitamin C. Having a subtle flavor, the leaves can be added to salads or used as a potherb. When used in salads they are reportedly better with a lemon dressing than vinegar. The leaves are often available in winter. As with all edible wetland plants, care should be taken to avoid using plants from polluted water (Wikipedia, 2011).

Medicinal Uses:

The root and the leaves are appetizers and have agents that gradually restore health, and that induce urination. The leaves have been used in the treatment of scurvy, impurity of the blood etc. The plant is bruised and applied externally as a poultice on burns, ulcers, whitlows, etc.

Commelina benghalensis L.

An erector creeping-ascending robust perennial herb with fusiform roots and often with subterranean clistogamous flowers. Stems up to 0.9-2.5m long, rooting at the lower nodes, green with purple tinge, pubescent or rarely hirsute or glabrous; internodes up to 10-13cm long.

In forest, woodland, stream banks rocky hillsides, in partial shade under bushes and weed of cultivation in coffee, cotton, ground nut, pepper, teff etc (Edwards *et al*., 2003).

Commelina benghalensis, commonly known as the benghal dayflower or tropical spiderwort, is a perennial herb native to tropical Asia and Africa. It has been widely introduced to areas outside its native range, including to the neotropics, Hawaii, the West Indies and to both coasts of North America. It flowers from spring into the fall and is often associated with disturbed soils (Wikipedia, 2011).

Uses

In China, the plant is used medicinally as a diuretic, febrifuge and anti-inflammatory. In Pakistan it is used as animal fodder and also eaten by humans as a vegetable. It is also used there medicinally, but with different purported effects, including as a laxative and to cure inflammations of the skin as well as leprosy. The people of Nepal eat the young leaves as a vegetable, use a paste derived from the plant to treat burns, and treat indegestion with a juice produced from the roots Although its roots and tubers are used as a food source, *C. benghalensis* is not cultivated in Ethiopia, where it grows as a weed (Wikipedia, 2011).

3.2.5. Wastewater Feeding and Acclimatization

After the establishment of the plants the microcosms were fed only with tap water for the first three days. Starting from the third day the plants were acclimatized (adapted) with the greywater. This was done by feeding the greywater with different percentage dilutions in to the system.

One of the purposes of acclimatization is to avoid the shock of the plants that could be caused by the high concentration of pollutants in the greywater. It can also enhance the formulation of biofilm that in turn encourages the attachment and growth of microbial population on the substrate and plant root rhizome that plays a role in the biological treatment of the greywater (Firew, 2010).

3.3. SAMPLING

3.3.1. Sampling Strategies and Sample Collection

The grab sample, as the name implies, measures water quality at only one sampling point. Grab samples accurately represent the water quality at the moment of sampling, but say nothing about the quality before or after the sampling. A composite sample is obtained by taking a series of grab samples and mixing them together. In his study composite sampling was used for untreated greywater and grab samples were taken for the treated water.

3.3.2. Sample analysis

Samples were taken in the same day as they were to be analyzed. An exhaustive influent and effluent characterization of all collected samples was carried out for all selected physiochemical and bacteriological wastewater quality parameters. The influent and effluent quality parameters that were determined in this study and the method of testing presented as follows in table 3.1:

Table 3.1 wastewater quality parameters and the test methods followed

S/N	Parameters	Test Methods
1	Calcium	APHA 3500-Ca B. EDTA Titrimetric Method
2	Magnesium	APHA 3500-Mg B. Calculation Method
3	Chemical oxygen demand (COD) and BOD5	APHA 5220 B. Open Reflux Method
4	pH	Potentiometric, electrometric pH meter with glass electrode
5	EC	APHA 2510 Conductivity*#(35)
6	Nitrate	APHA 4500-NO3– B. Ultraviolet Spectrophotometric Screening Method
7	Na	Flame photometry
8	Total nitrogen	APHA 4500-Norg B. Macro-Kjeldahl Method, 4500-NH3 C. Titrimetric Method
9	Ortho P	APHA 4500-P C. Vanadomolybdophosphoric Acid Colorimetric Method
11	Dissolved oxygen	APHA 4500-O G. Membrane Electrode Method

The removal efficiency of the microcosm for each wastewater quality parameters were calculated using the following formula (Firew, 2010)

Removal Efficiency (%) = [(Ci-Ce/Ci)]100……………(3.2)

Wher: Ci = is the concentration of the waste material in the influent

Ce = is the concentration of the waste material in the effluent

Statistical Analysis

Statistical analysis was performed with SPSS package Release 17.00 for windows. The included Mean, Standard Error, and the Analysis of Variance (ANOVA) testes were done using this package.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. RESULTS

In order to characterize the greywater from the SSE and to evaluate the treatment performance of the microcosms, some selected wastewater quality indicating parameters were measured for the effluent of the SSE. These parameters were BOD_5, COD, TN, NO_3- N, EC, PO_4^{3-}, DO, PH, Na, Mg, Ca and greywater temperature. During the entire period of the study, a total of 27 samples were analyzed for each wastewater quality parameter. Out of 27, the large proportion, which is 12, goes for assessing the performance of plant-substrate combination. The remaining samples taken for; 5 for characterization, 6 to assess the performance of the substrate alone, and the remaining 4 were taken from the bottles where the plants where submerged for about a 24 hours.

In the following Table the characteristics of greywater effluent from SSE is presented. On the table, it is presented that the results of five different composite samples which had been taken on different days with that of the average (mean) value.

Table 4.1 characteristics of SSE effluent

Parameter	S1	S2	S3	S4	S5	Mean
pH	8.03	8.11	8.15	8.05	8.19	8.11
EC (dS/m at 25oC)	1.58	1.54	1.68	1.62	1.58	1.6
$NO3^-$ (mg/L)	1.07	0.47	0.78	1.02	1.08	0.884
Ca (mg/L)	19.15	41.48	37.80	24.67	19.59	28.54
Mg (mg/L	1.33	19.02	16.22	10.45	0.98	9.6
Na	414.10	560.70	739.20	450.50	392.70	511.44

(mg/L)						
Ortho P (mg/L)	40.54	70.74	98.65	89.74	64.65	72.86
TN (mg/L)	32.93	125.80	120.53	85.53	16.46	76.25
COD (mg/L)	640.6	185.6	265.5	245.5	210.2	309.48
DO (mg/L)	4.82	1.58	1.72	2.62	5.16	3.18
BOD_5 (mg/L)	88.00	72.0	67.2	100.2	80.0	81.48
T(^oC)	35	33	35	32	34	33.8

On the Table it is presented that the mean concentrations of BOD_5, and COD were 309.48 mg/L and 81.48 mg/L, respectively**.** The average effluent greywater temperature, DO,EC, and pH values were 33.8^{o}C, 3.18 mg/L, 1.6 dS/m, and 8.11 pH units, respectively.

The average values for TN, Na, Ca, Mg, NO_3-N, and Ortho P were found to be 76.25 mg/L, 511.44 mg/L, 28.54 mg/L, 9.6 mg/L, 0.88 mg/L, and 72.86 mg/L respectively.

Table 4.2 influent, mean effluent and removal efficiencies of substrates for Na, Po_4^{3-}, COD, and BOD_5

Parameter	Influent	gravel	**Effi. (%)**	Influent	sand	**Effi. (%)**	Influent	scroia	**Effi. (%)**
Na (mg/L)	414.10	299.95	**27.56**	414.10	186.2	**55.03**	414.10	138.1	**66.65**
Ortho P (mg/L)	40.54	31.52	**22.25**	40.54	13.16	**67.54**	40.54	20.34	**49.83**
COD (mg/L)	640.6	256.1	**60.02**	640.6	251.3	**60.77**	640.6	249.5	**61.05**
BOD_5 (mg/L)	125.00	59.6	**52.32**	125.00	41.8	**66.56**	125.00	50.7	**59.44**

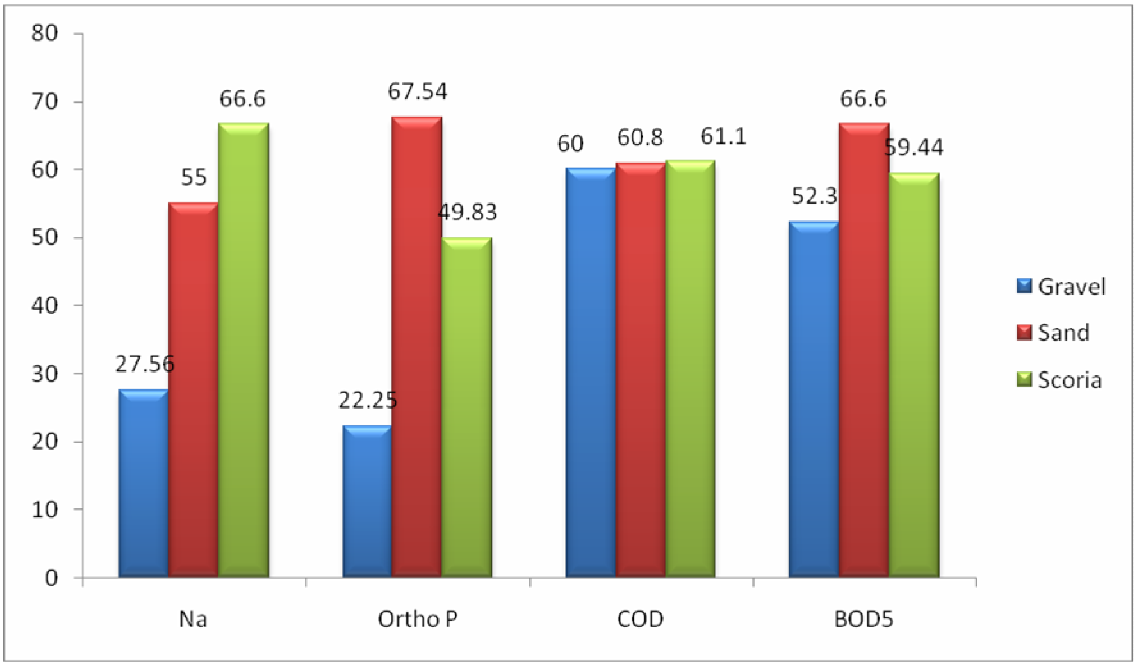

Figure 4.1 removal efficiencies of substrates for Na, Po_4^{3-}, COD, and BOD_5

Since, the character of the influent greywater, which was distributed to all of the components of the constructed wetland system, was assumed uniform the magnitude for the parameters representing the influent were the same.

The column next to the influent one presented the values that show the average results obtained for samples that had been taken from the effluent of three cells which were filled with three different substrates. As presented under the column that represented gravel containing cell, the mean values for Na, Po_4^{3-}, COD, and BOD_5 were 299.95 mg/L, 31.52 mg/L, 256.1 mg/L and 59.6 mg/L, respectively.

On the table it is presented that the CW which was filled with gravel showed an average of 27.56% removal efficiency for sodium. The Ortho phosphate removal capacity for gravel was scored to be 22.25%. For the same media the mean removal efficiency obtained for BOD_5 and COD were 60.02% and 52.32% respectively. However, the removal efficiency for sand 55.03% for Na and 67.54% for ortho phosphate were showed. The COD and BOD_5 were removed with 60.77% and 66.56% where the sand was used as the substrate. The third media, red ash, showed removal efficiency for Na and Ortho phosphate 66.65% and 49.83% respectively. And for COD and BOD_5 were 61.05% and 59.44% respectively.

As it can be seen from the figure the sodium removal efficiency of the scoria, 66.6%, is the highest of the three. Of the remaining two, the better media in treating sodium was that of sand.

The ANOVA test result indicated that the result for scoria was statistically significant ($p < 0.05$).

The removal efficiency of ortho phosphate was found to be highest (67.54%) in the case of sand. Unlike that of sodium removal efficiency the second good performance (49.83%) in the removing ortho phosphate was achieved by the cell filled with scoria. In this case the removal efficiency scored by the three cells were closer than that of sodium.

The third column of the graph showed the removal efficiency comparison of the three cells for COD. Even if, the best recorded of removal efficiency for COD removal was once again scored by the cell containing red ash the removal efficiencies of the three medias were very close. Eventhough the second place was once again held by cell 2(sand) there was almost no difference as it can be seen from the graph.

The final column of the graph presented one of the most important wastewater quality parameters, which is commonly used to evaluate the treatment efficiency of different kinds of wastewater treatment methods. As presented on the figure the sand filled cell takes the first place (74.66%) by taking over the sand. The removal efficiency of the red ash (59.4%) was recorded to be better than the score of the cell with gravel (48.67%).

Overall orthophosphate, COD and BOD performances of the three medias were statistically compared to each other and the results indicates that wetlands performance were not statistically significant ($p>0.05$).

Table 4.3 influent, mean effluent and removal efficiencies of substrates for NO_3^-, Ca, Mg, and TN

Parameter	Influent	gravel	**Effi. (%)**	Influent	sand	**Effi. (%)**	Influent	Scoria	**Effi. (%)**
$NO3^-$ (mg/L)	1.07	1.205	**-12.61**	1.07	4.05	**-278.97**	1.07	1.81	**-69.15**
Ca (mg/L)	19.15	33.18	**-73.26**	19.15	107.65	**-462.14**	19.15	116.95	**-510.70**
Mg (mg/L	1.33	2.69	**-102.6**	1.33	19.39	**-535.5**	1.33	19.12	**-510.5**
TN (mg/L)	32.93	35.67	**-8.32**	32.93	30.72	**6.72**	32.93	22.64	**31.26**

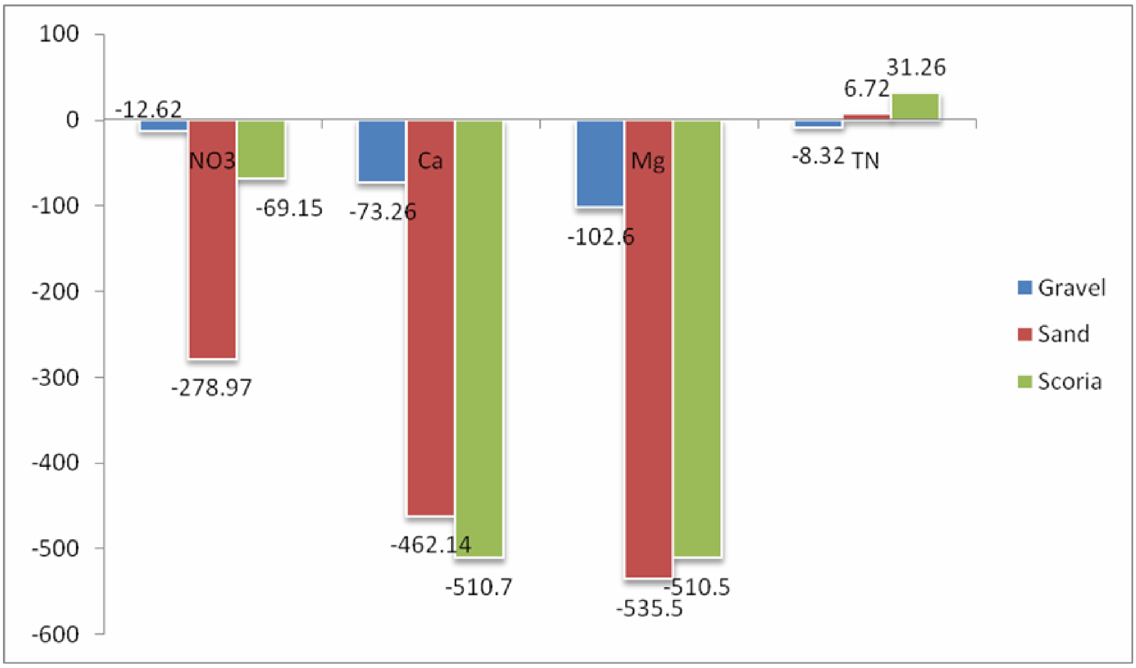

Figure 4.2 removal efficiencies of substrates for NO_3^-, Ca, Mg, and TN

The influent results determined for NO_3^-, Ca, Mg, and TN were 1.07 mg/L, 19.15 mg/L, 1.33 mg/L, and 32.93 mg/L respectively.

The results showed in gravel filled cell for NO_3^-, Ca, Mg, and TN were 1.205 mg/L, 33.18 mg/L, 2.69 mg/L, and 35.67 mg/L respectively. Elsewhere, in the cell which filled with sand as a substrate results determined for NO_3^-, Ca, Mg, and TN were 4.05 mg/L, 107.65 mg/L, 19.39 mg/L, and 30.72 mg/L respectively. In the final cell that containing scoria results determined for NO_3^-, Ca, Mg, and TN were 1.81 mg/L, 116.95 mg/L, 19.12 mg/L, and 22.64 mg/L respectively.

Most of the removal efficiency results presented in table carries negative sign, which implies the increase of the parameters rather than decreasing as the greywater flow through the CW. As showed on the table the CW which was filled with the first media, gravel, gave efficiency of -12.61% and -8.32% results for NO_3 and TN, respectively. And the average removal efficiency for Ca and Mg were -73.26% and -102.6%, correspondingly. On the other hand, the efficiencies scored for the greywater which had been treated using sand as a media resulted in a removal efficiency of -278.97% for $NO3^-$ and 6.72% for TN. The red ash, the other substrate used, resulted in NO_3 and TN removal efficiency of -69.15% and 31.26%**.** And the removal efficiency for Ca and Mg were -510.70% and -1336.47% which was also negative implying the increase in the amount of the parameters after treatment.

The possible reasons for the increase of the above parameters would be discussed in detaile in the discussion part.

Most of the removal efficiencies results presented in the above figure are upside-down which was result of the negative sign carried by the removal efficiency. The inversion implies the increase of the parameters rather than decreasing as the greywater flow through the CW. In this condition there was almost no treatment had happened.

Other-than treatment it can be called “pollution”, if the real increase source were the treatment (passing through) the medias. In order to identify the source of the excess nitrogen and metals the first things to check were the detailed material properties of each media, if there was a likely source out of their composition. Not only the composition, but also their tendencies to release those compounds when they are in contact to water were assessed. In order to make it more brief the properties of the substrates presented as follows.

Scoria is a volcanic rock containing many holes or vesicles. It is most generally dark in color (generally dark brown, black or red), and basaltic or andesitic in composition. Scoria is relatively low in mass as a result of its numerous macroscopic ellipsoidal vesicles, but in contrast to pumice, all scoria has a specific gravity greater than 1, and sinks in water.

Table 4.4 properties of Natural Sand/Gravel

COMPONENT(S) CHEMICAL NAME	% by weight (approx)

Silicon Dioxide*, SiO_2	0-79
Aluminum Oxide, Al_2O_3	0-16
Ferric Oxide, Fe_2O_3	0-5
Ferrous Oxide, FeO	0-3
Magnesium Oxide, MgO	1-22
Calcium Oxide, CaO	3-43
Sodium Oxide, Na_2O	0-2
Potassium Oxide, K_2O	0-4
Calcium Carbonate, $CaCO_3$	0-48

*: The composition of SiO_2 may be up to 100% crystalline silica. Adobted from (Marietta, 2004)

The substrates properties described above imply the probability of the substrates to be a source for Ca and Mg is less.

So, if the media is not the likely source, where did it come from?

In order to answer this question exactly it may requires detailed and inclusive study. But from different literature information on the area and, logical hypothesis the most likely sources of the increased results could be from one or combination of the following factors. The possible situations were discussed as follows.

- As the nitrate graph showed, it is upside-down indicating that there was a net production of nitrate as the wastewater passes through the bed. The source of this “extra” nitrate is believed to be from the aerobic decomposition of the ammonia nitrogen trapped in the bed as particulate matter. Even if the bed is anaerobic, there might be sufficient oxygen available to oxidize this ammonia to nitrate.
- On a study which was carried out in US (November, 2004) the rain water showed to contain nitrate in most cases. Nitrate was found in all but 8 samples (out of 51 samples). The highest concentration was found in Northport, Michigan with 8.16 mg/L. The smallest concentration recorded was 0.13 mg/L in Lake Norden, SD (Root *et al.*,2004). . The results of the study suggest the potential of rain water as a source of nitrate. Since

there was rain coverage on some days before sample collection it can be considered as a potential source for the net production.

- Sampling method, sample collecting bottles, transportation method, sample storage place and storing equipment, test method, equipment accuracy and workability, operators' capacity on the area and so on. All these factors may have their part in the net production of the parameters, even if the significance level was not expected to be as strong as the others.
- In the sodium-magnesium case there may be three possible sources assumed to be the source for the net production. The first is, sludge accumulation. The sludge, which was allowed to settle in the bottom 10cm, is the most likely source. To make it clear, during the experiments the greywater to be treated was allowed to settle for about 10 minutes in sedimentation tank, and then it was released to the beds. After a while the water drains and at the bottom of the container there would be concentrated grey water and little amount of sludge accumulation. As the number of filling and draining were repeated the bottom of the container becomes filled with sludge and the concentration of some parameters becomes higher than the previously fed ones. The outcome of the combination is believed to be the source of the net generation.
- The other experimental limitation, which is also believed to result in net production, is the combined effect of minimum hydraulic retention time (HRT) and the shortage of the time gap between each greywater release to the system. These two parameters have somewhat direct relation, especially in this experimental setup. These parameters have great role in pollutant removal and the effect of both factors increases as their magnitude increases, the longer the HRT and the loading gap the better will be the efficiency. So, if this is the fact about the two factors, how did the shortage of them affect the out come
    - In the case of short HRT the pollutants would not get enough time for bacteriological action, chemical reactions and sedimentation. So, the time needed to treat the more concentrated parameters was very low.
    - The shortage of loading gap basically does not allow the system to dry out. The drying of the system after loading is recommended on literatures, in order to improve the treatment efficiency. Otherwise the pollutants which were adsorbed

on the surface of substrates would be washed out. For this reason the loading gap is also believed to contribute its part on the net production.

The graph showed that for the case of NO_3^- the gravel cell was found to be with smallest negative value, -12.6%. The less magnitude from the remaining two cells was found to be that of scoria cell, which is, -69.15%. This results were compared by ANOVA and the scoria and sand cells showed to be statistically significant ($p<0.05$).

For the calcium and magnesium the results obtained were beyond increment. The values of Ca and Mg were radically increased above 500% on average on both sand and red-ash cells. These results showed extraordinary increase. The results for magnesium removal were tested to be statistically not significant ($p>0.05$) but significant ($p<0.05$) for gravel cell for the calcium.

The only parameter that showed positive results was TN, which showed removal efficiencies of 6.76% and 31.26% for sand cell and red-ash cell respectively. The ANOVA test showed the results for scoria and sand were statistically significant ($p<0.05$)

Table 4.5 influent, mean effluent and removal efficiencies of substrates for Na, Po_4^{3-}, COD, and BOD_5 each of them were planted with veronica onagallis-aquatica L.

Parameter	Influent	gravel	**Effi. (%)**	Influent	sand	**Effi. (%)**	Influent	Scoria	**Effi. (%)**
Na (mg/L)	739.20	472.5	**36.07**	739.20	312.9	**57.67**	739.20	291.9	**60.51**
Ortho P (mg/L)	89.74	27.4	**69.47**	89.74	24.33	**72.89**	89.74	25.93	**71.12**
COD (mg/L)	245.5	143.8	**41.42**	245.5	114.3	**53.44**	245.5	98.5	**59.80**
BOD_5 (mg/L)	76.1	37	**47.44**	76.1	17.6	**76.87**	76.1	25.9	**66.89**

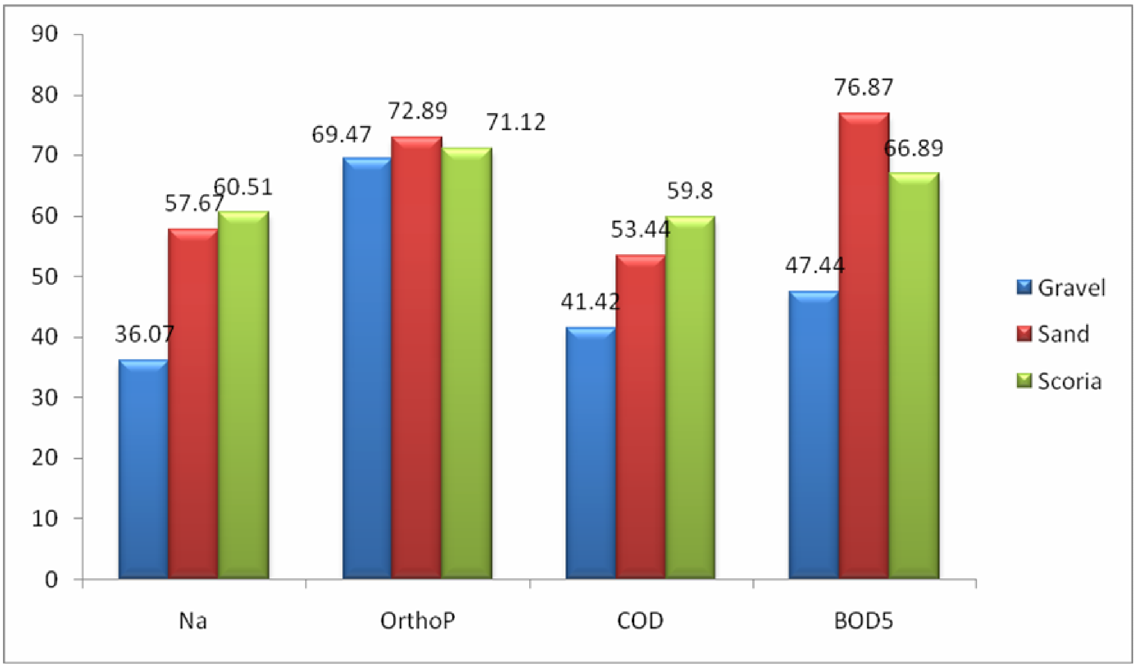

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Figure 4.3 removal efficiencies of substrates for Na, Po_4^{3-}, COD, and BOD_5 each of them were planted with veronica anagallis-aquatica L. estimable

For the same reason mentioned earlier the magnitudes representing the influent were similar. So, the influent quantities for Na, Po_4^{3-}, COD, and BOD_5 were 739mg/L, 89.74mg/L, 245.5mg/L, and 76.1mg/L, respectively.

The average effluent values that were obtained by collecting samples from each cell representing each of the three substrates are presented as follows. The gravel containing cell produced Na, Po_4^{3-}, COD, and BOD_5 value of 472.5 mg/L, 27.4 mg/L, 143.8 mg/L, and 37 mg/L respectively.

As presented on the table the ability of the CW, that filled with gravel as a media and planted with Veronica anagallis-aquatica L., to reduce the quantity of organic loading amount of greywater which was expressed as BOD_5 and COD were 47.44% and 41.42%, respectively. For the other two parameters i.e., for Na and ortho phosphate as presented on the table the efficiency were 36.07% and 69.47%. The same plant was combined with sand and the efficiencies achieved for BOD_5, COD, Na and ortho phosphate were 70.83%, 53.44%, 56.67% and 72.89% respectively. On the other type of media, scoria, which was also planted with veronica onagallis-aquatica L. the variation recorded in removing organic loading, was 66.89% for BOD_5, and 58.04% for COD. And the removal efficiency for Na and ortho phosphate were 60.51% and 71.12% respectively.

In the above figure (Fig. 4.3) the removal efficiencies presented represent the capacity of CW cells in removing the pollutants from the greywater. What makes the scenario different from the earlier presented graph (Fig 4.1) in this case the cells efficiency presented represented the efficiency which is resulted from substrate-plant combination; the plant for this specific case was Veronica anagallis-aquatica L.

As the graph reflects in its first column, the red ash containing cell showed highest removal efficiency of 60.51% in sodium removal, it was followed by 57.67% removal, which was the result of sand filled cell. Like that of sodium, the ortho phosphate highest removal efficiency (72.89%) was achieved by the sand cell. here the scoria cell took the second place by recorded removal efficiency of 71.12%. Although cell-3(the scoria cell) placed second the gap from the first placed cell-2 (the sand cell) was a small.

The third column, which compares the removal efficiency for COD, once again revealed the best substrate, that producing effluent with less pollutant load, was cell-3 with removal efficiency of 59.80%. the second efficient cell was cell-2 with 53.44% efficiency, this time the gap was small.

When the difference among the three cells removal efficiency for BOD_5 is considered at least two things can be discussed in detail .The first, as it is shown on the graph the removal efficiency of cell-2 (the sand cell) which was 76.87% implied that for the first time, out of the four columns, it excelled cell-3 (the red-ash cell), which was performed only 65.97%. The second point is the gap between the two cells was large and the other impressive point to notice in relation to the BOD_5 removal efficiency is the red-ash removal efficiency increased with the plantation and the removal efficiency of the sand cell somehow decreased.

The ANOVA analyses indicate that results for BOD5, COD, Na and orthophosphate were not statistically significant ($p > 0.05$) in any one of the three substrate-veronica anagalsis combination.

Table 4.6 influent, mean effluent and removal efficiencies substrates that were planted with Veronica anagallis-aquatica L. for NO_3^-, Ca, Mg, and TN

Parameter	Influent	gravel	**Effi. (%)**	Influent	sand	**Effi. (%)**	Influent	Scoria	**Efficiency (%)**
$NO3^-$ (mg/L)	0.78	0.27	**65.38**	0.78	0.39	**50.00**	0.78	0.69	**11.53**
Ca (mg/L)	37.80	77.89	**-106.05**	37.80	135.51	**-258.49**	37.80	100.945	**-167.05**
Mg (mg/L	16.22	12.59	**22.37**	16.22	16.22	**0.00**	16.22	29.645	**-82.76**
TN (mg/L)	120.53	130.19	**-8.01**	120.53	137.89	**-14.40**	120.53	132.85	**-10.22**

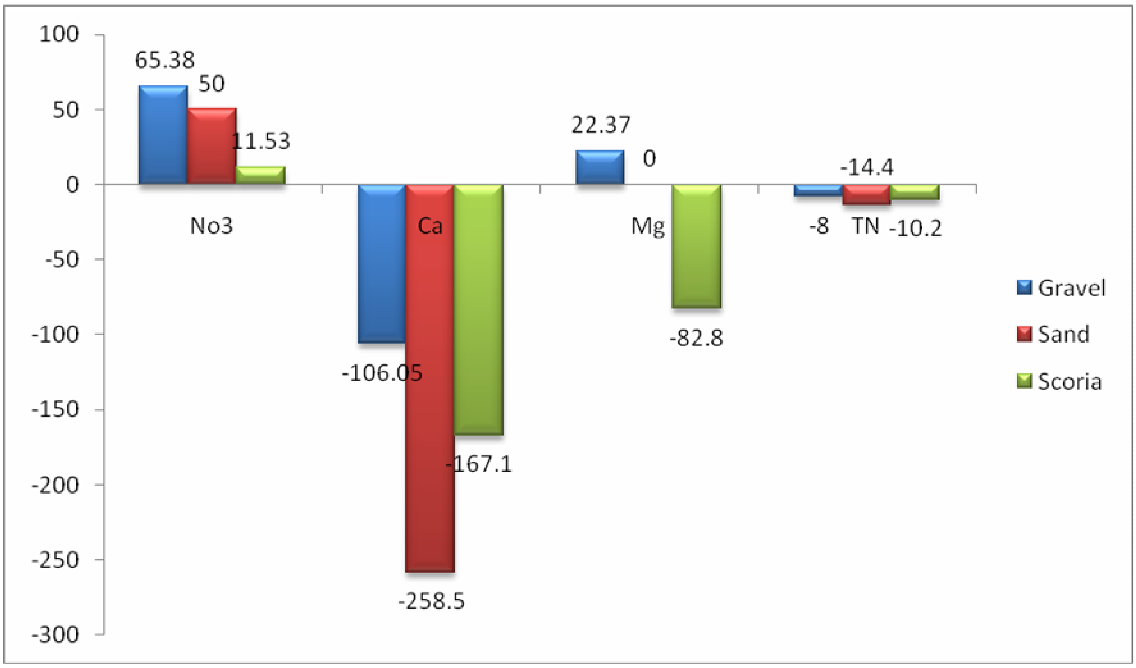

Figure 4.4 removal efficiencies substrates that were planted with veronica onagallis-aquatica L. for NO_3^-, Ca, Mg, and TN

The influent registered for NO_3^-, Ca, Mg, and TN were 0.78 mg/L, 37.8 mg/L, 16.22 mg/L, and 120.53 mg/L, respectively.

The data's which were obtained by calculating the wastewater quality parameters which was measured as influent to the CW with that of the effluent of the system, while the substrate was gravel in combination with Veronica anagallis-aquatica L. the obtained results for the removal efficiencies were 65.38% for NO_3 and 22.37% for Mg. even if the removal efficiencies of the aforementioned parameters were positive, the recorded results for the other two parameters that are showed on the table were negative, which were -82.76% for Mg and -10.22% for TN. On the same table it can be shown that there were negative scores for the other two efficiency columns, which implies the increase in the quantity of the parameters rather than decreasing. The table presented the efficiencies for sand media which were planted with veronica onagallis-aquatica L. showed 50% removal for NO_3 and 0% removal for Mg which means neither deduction nor addition were taken place. The Ca and TN reduction were -167.05% and -10.22% respectively. As presented on the final column, the scoria-veronica onagallis aquatic L. combination had resulted in the removal efficiencies of 11.53% for NO_3^- which was the only positive result in that specific column. The magnitude of removal efficiency for the remaining three, Mg, Ca and TN, were -82.76%, -167.05%, and -10.22%, respectively.

The graph presented above showed the removal efficiency obtained by the cells which were planted with Veronica anagallis-aquatica L.

As it can be shown the removal efficiencies for NO_3^- were positive unlike the other most parameters presented on the graph. The highest nitrate removal efficiency were recorded for the case of gravel cell, that was 65.38%. The next good performance in removing nitrate nitrogen was scored by sand cell, that was 50% efficient the graph implies high amount of increments were obtained in all three cells. This means negative efficiency values were achieved. Among the three cells, the sand cell "produced" an effluent with very high (-258.5%) increments.

The results under magnesium imply the highest and the only positive result of the column was resulted from gravel cell. The Mg removal efficiency in the case of sand cell was nil, which implies the amount of Mg in the influent remained the same at the effluent. The final parameter of discussion in fig 4.4 is TN. The removal efficiency results from all cells were negative. Even though the negative efficiency values of the three cells were nearly the same, the sand cell produced more TN than provided.

Overall NO_3^-, Ca, Mg, and TN performances of the three medias were statistically compared to each other and the results indicates that wetlands performance was not statistically significant ($p>0.05$).

Table 4.7 influent, mean effluent and removal efficiencies of substrates planted with Commellna bengahllensis L. for Na, Po_4^{3-}, COD, and BOD_5

Substrate	Influent	gravel	**Effi. (%)**	Influent	sand	**Effi. (%)**	Influent	Scoria	**Effi.(%)**
Na (mg/L)	739.20	598.5	**19.03**	739.20	548.1	**25.85**	739.20	322.35	**56.39**
Ortho P (mg/L)	89.74	47.67	**46.88**	89.74	21.94	**75.55**	89.74	22.73	**74.64**
COD (mg/L)	245.5	186.5	**41.14**	245.5	146.95	**40.14**	245.5	114.9	**53.19**
BOD_5 (mg/L)	76.1	40	**47.44**	76.1	18.4	**66.49**	76.1	25.2	**66.88**

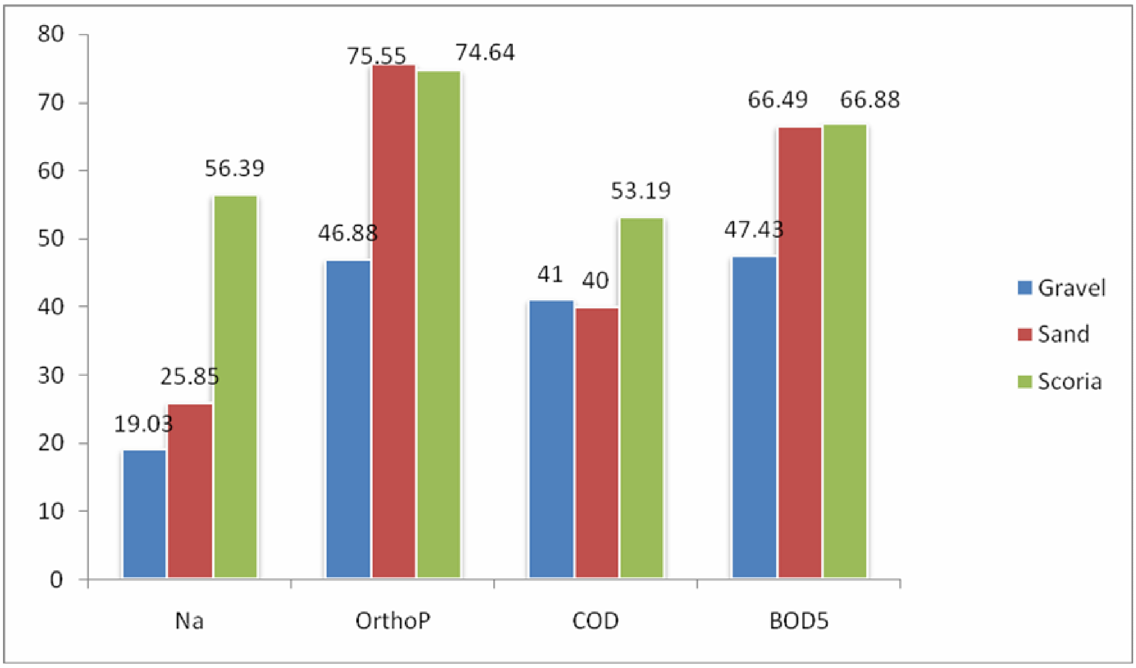

Figure 4.5 removal efficiencies of substrates planted with commellna bengahllensis L. for Na, Po_4^{3-}, COD, and BOD_5

Given that, the character of the influent greywater, which was dispersed the components of the constructed wetland system, was assumed uniform the magnitude for the parameters representing the influent were the same and the amounts for Na, Po_4^{3-}, COD, and BOD_5 were 739.20 mg/L, 89.74 mg/L, 245.5 mg/L, and 76.1 mg/L respectively.

The file next to the column that presented the influent quantities represents the average results obtained for samples that had been taken from the effluent of three cells which were filled with three different substrates. As presented under the column that represented gravel containing cell, the mean values for Na, Po_4^{3-}, COD, and BOD_5 were 598.5 mg/L, 47.67 mg/L, 144.5 mg/L and 40mg/L, respectively. And the average record sand-Commellna bengahllensis L. combination for Na, Po_4^{3-}, COD, and BOD_5 were 548.1 mg/L, 21.94mg/L, 146.95 mg/L, and 18.4mg/L, respectively. The quantity for parameters kelbe oemeasured for the effluent from red ash for Na, Po_4^{3-}, COD, and BOD_5 were 322.35 mg/L, 22.73 mg/L, 114.9 mg/L, and 25.2mg/L, respectively.

On the table it is presented that the CW which was filled with gravel showed an average of 19.03% removal efficiency for sodium. The Ortho phosphate removal capacity for gravel was scored to be 46.88%. For the same media the mean removal efficiency obtained for BOD_5 and COD were 41.14% and 47.44%, respectively. This same table presented the removal efficiency for sand, which is 25.85% for Na and 75.55% for Ortho phosphate. The COD and BOD_5 were removed with 40.14% and 66.49% where the sand was used as the substrate. The third media, scoria, showed removal efficiency for Na and ortho phosphate were 56.39% and 74.67% respectively.

The figure above presented the removal efficiency for the same cells which were discussed previously. But for this particular case the plantation applied on the substrates was Commellna bengahllensis L. Comparing the removal efficiencies of the three cells in removing capacity of sodium, the red-ash cell takes the number one position by 56.39%, followed by the sand cell which has scored 25.85%.

The next column of this graph (fig. 4.5) showed, the orthophosphate and COD column of the first place is owned by sand cell with removal efficiencies of 75.55% for orthophosphate. and by scoria for COD with removal efficiency of 53.19%.

The BOD_5 results shown on the graph implies once again the best performance for this particular parameter was produced from the scoria cell with removal efficiency of 66.88%. And the sand cell was second with 66.49% removal efficiency.

Even if most of the parameters showed good removal efficiency in all substrate cases but the ANOVA analysis implied none of the parameter removal in any of the substrate were statistically significant ($p>0.05$).

Table 4.8 influent, mean effluent and removal efficiencies of substrates planted with Commellna bengahllensis L. for NO_3^-, Ca, Mg, and TN

Substrate	Influent	gravel	**Effi. (%)**	Influent	sand	**Effi. (%)**	Influent	scoria	**Effi. (%)**
$NO3^-$ (mg/L)	0.78	1.20	**-53.84**	0.78	0.14	**82.05**	0.78	0.54	**30.76**
Ca (mg/L)	37.80	65.45	**-73.14**	37.80	75.59	**-99.97**	37.80	113.85	**-201.19**
Mg (mg/L	16.22	11.46	**29.34**	16.22	13.98	**13.81**	16.22	33.83	**-108.63**
TN (mg/L)	120.53	127.73	**-5.97**	120.53	123.38	**-2.36**	120.53	128.00	**-6.20**

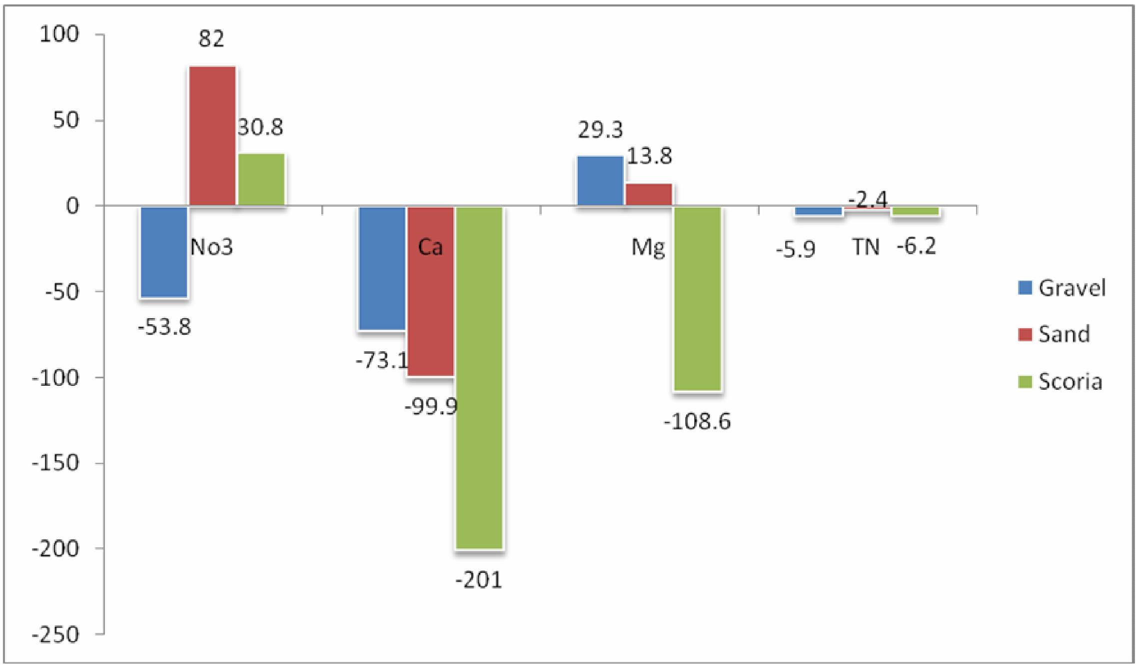

Figure 4.6 removal efficiencies of substrates planted with commellna bengahllensis L. for NO_3^-, Ca, Mg, and TN

The influent registered for NO_3^-, Ca, Mg, and TN were 0.78 mg/L, 37.8 mg/L, 16.22 mg/L, and 120.53 mg/L, respectively.

The results showed in gravel filled cell for NO_3^-, Ca, Mg, and TN were 1.2 mg/L, 65.45 mg/L, 11.46 mg/L, and 127.73 mg/L respectively. Elsewhere, in the cell which filled with sand as a substrate results determined for NO_3^-, Ca, Mg, and TN were 0.14 mg/L, 75.59 mg/L, 13.98 mg/L, and 123.38 mg/L respectively. In the final cell that containing scoria results determined for NO_3^-, Ca, Mg, and TN were 0.54 mg/L, 113.85 mg/L, 33.84 mg/L, and 127.99 mg/L respectively.

Most of the removal efficiency results presented in table carries negative sign, which implies the increase of the parameters rather than decreasing as the greywater flow through the CW. As showed on the table the CW which was filled with the first media, gravel, gave efficiency of -53.84% and -5.97% results for NO_3 and TN, respectively. And the average removal efficiency for Ca and Mg were -73.14% and -29.34%, correspondingly. On the other hand, the efficiencies scored for the greywater which had been treated using sand as a media resulted in a removal efficiency of 82.05% for $NO3^-$ and -2.36% for TN. The red ash, the other substrate used, resulted in NO_3 and TN removal efficiency of 30.76% and -6.28%**.** And the removal efficiency for Ca and Mg were -201.19% and -108.63% which was also negative implying the increase in the amount of the parameters after treatment.

The graph presented above showed the removal efficiency obtained by the cells which were planted with commellna bengahllensis L. for NO_3^-, Ca, Mg, and TN.

The removal magnitude of nitrate nitrogen for cell-2 (the sand cell) was very high, which was 82% removal. The sand cell showed big gap from the next efficient cell, in removal efficiency of nitrate. Like the big interval between the most efficient and the second efficient, there was also much more bigger interval between the second, 30.8% for red-ash cell, and the least, which was negative (-53.8%) for gravel cell.

The results under category two (calcium efficiencies) are all negative. In the negative side of the graph, the red-ash cell showed the largest increment in calcium size than it initially feeded.

The gravel cell showed the best removal performance for that of magnesium, that was 29.3%. Next to cell-1 (the gravel cell), sand cell produced positive efficiency. On the other hand the red-ash cell was far from positive. TN, the parameter whose removal efficiency data's' were assigned on the forth category, showed totally negative efficiencies and the results for the three cells were almost equal.

The ANOVA test results illustrated the only statistically significant change was showed for Mg, in the scoria cell.

Table 4.9 plants exposed to greywater influent, mean effluent and removal efficiencies for Na, Po_4^{3-}, COD, and BOD_5

Substrate	Influent	V. onagallis-aquatica	**Efficiency (%)**	Influent	C. bengahllensis L.	**Efficiency (%)**
Na (mg/L)	560.70	676.2	**-20.59**	560.70	643.65	**-14.79**
Ortho P (mg/L)	89.74	50.25	**43.99**	89.74	63.03	**29.76**
COD (mg/L)	185.6	118.1	**36.36**	185.6	148.8	**19.82**
BOD_5 (mg/L)	80.0	81.1	**-1.37**	80.0	89.2	**-11.5**

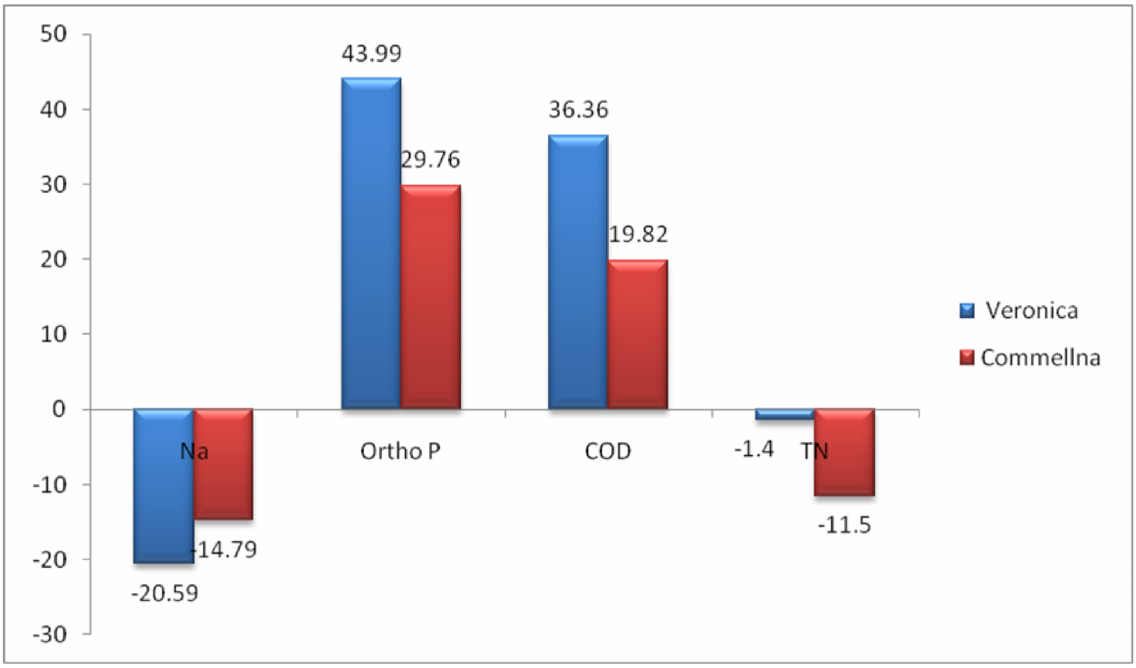

Figure 4.7 plants immersed in to greywater, removal efficiencies for Na, Po_4^{3-}, COD, and BOD_5

Even if, the sample taken as influent in the plant efficiency evaluation system was the same effluent which was collected from SSE, the application method was not by distribution pipe as that of the earlier samples. But in this case the plants were immersed in one liter grey water allowing them direct contact for several hours. The effluent parameters registered before emersion of plants were similar and showed numbers for Na, Po_4^{3-}, COD, and BOD_5 were 560.7 mg/L, 89.74mg/L, 185mg/L, and 80 mg/L, respectively.

The average results of obtained for each plants were presented under columns named p1 (for Veronica anagallis-aquatica L.) and p2 representing Commellna bengahllensis L. the results which had been recorded after the exposure period was over, for Veronica anagallis-aquatica L. showed magnitudes for Na, Po_4^{3-}, COD, and BOD_5 were 676.2 mg/L, 50.26mg/L, 118.1 mg/L, and 81.1 mg/L, respectively. On the other hand the recorded results for the same scenario but different plant (Commellna bengahllensis L.) Obtained extents for Na, Po_4^{3-}, COD, and BOD_5 were 643.65 mg/L, 63.03 mg/L, 148.8 mg/L, and 89.2 mg/L, respectively.

As presented on the table the ability of the Veronica anagallis-aquatica L., to reduce the quantity of organic loading amount of greywater which was expressed as BOD_5 and COD were -1.37%

and 36.36%, respectively. For Na and ortho phosphate as presented on the table the efficiency were -20.59% and 35.79%. for the other plant (Commellna bengahllensis L.) the efficiencies achieved for BOD_5, COD, Na and ortho phosphate were -11.5%, 19.82%, -14.79% and 10.73% respectively.

The above graph presented the change of selected wastewater quality parameters after the greywater had been left in contact with two type of plant species, that were Veronica anagallis-aquatica L. (Veronica) and Commellna bengahllensis L. (Commellna).

In the columns other than the first, which presents result for sodium, the better efficiency results were obtained in the case of veronica. For the ortho phosphate category the Veronica species showed removal percentage of 43.99%, while the Commellna species showed 29.76% removal. In the category of COD the removal efficiency achieved by veronica was 36.36% and the efficiency of the commellna species was registered to be 19.18%.

The last category, which was assigned to represent the BOD_5 removal efficiency, showed negative efficiencies for both plants. Even if both plant species achieved negative efficiency, the veronica species showed a result approximately equal to zero (-1.4%). And that of the commellna species negative efficiency was -11.5%.

Table 4.10 plants exposed to greywater influent, mean effluent and removal efficiencies for NO_3^-, Ca, Mg, and TN

Substrate	Influent	V. anagallis-aquatica	**Efficiency (%)**	Influent	C. bengahllensis L.	**Efficiency (%)**
$NO3^-$ (mg/L)	0.47	1.23	**-161.7**	0.47	1.33	**-182.9**
Ca (mg/L)	41.48	59.92	**-44.45**	41.48	50.7	**-22.22**
Mg	19.02	3.63	**80.91**	19.02	3.35	**82.38**

(mg/L						
TN (mg/L)	125.80	128.21	**-1.91**	125.80	128.22	**-1.92**

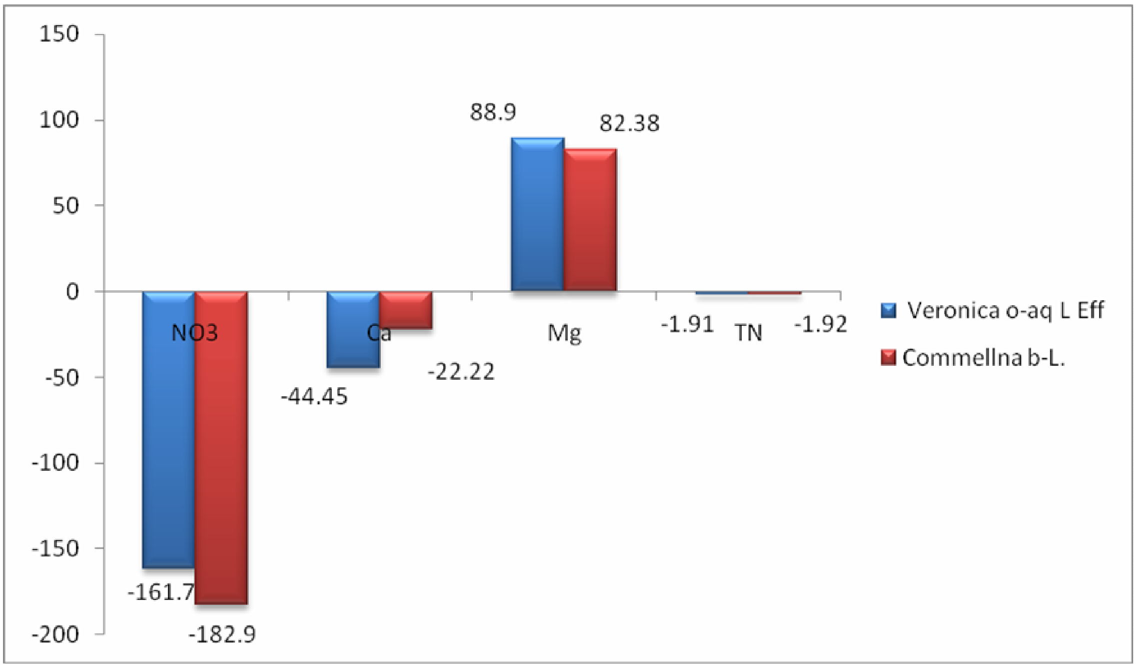

Figure 4.8 plants immersed in to greywater, removal efficiencies for NO_3^-, Ca, Mg, and TN

Like the earlier table (4.9) the effluent parameters recorded before emersion of plants were similar and results gained for NO_3^-, Ca, Mg, and TN were 0.47 mg/L, 41.48 mg/L, 19.02 mg/L, and 125.8 mg/L, respectively.

The mean data in the table showed the magnitudes achieved after the given time for each plants i.e., for Veronica anagallis-aquatica L. and Commellna bengahllensis L. the removal efficiency of the first plant (Veronica anagallis-aquatica L.) for NO_3^-, Ca, Mg, and TN were 1.23 mg/L, 59.92 mg/L, 3.63 mg/L, and 128.21 mg/L, respectively. Besides the other plant (Commellna bengahllensis L.) which was exposed to greywatere for the same time duration, the obtained data for the "effluent" i.e., when the plant was removed from the bottle the average results obtained were 1.33 mg/L, 50.7 mg/L, 3.35 mg/L, and 128.22 mg/L for NO_3^-, Ca, Mg, and TN, respectively.

The above graph presented the change of selected wastewater quality parameters after the greywater had been left in contact with two type of plant species, that were Veronica anagallis-aquatica L. (veronica) and Commellna bengahllensis L. (commellna).

According to literatures one of the pollutants expected to be removed by plants is the nutrient part. Specially, nitrogen and phosphorus are the major nutrients that are estimated to be reduced in exposure to plants. But what category one (NO_3) and four (TN) of the above graph showed was not as that of the expectation. The presented negative efficiency for veronica and commellna were -161.7% and -182.9%, respectively. The efficiencies of TN removal, even if both were on the negative side their magnitude were nearly nil.

The second category, which represented the calcium removal efficiency, showed negative removal efficiencies for calcium. The negative efficiency result obtained for veronica and commellna plant species were -44.45% and -22.22%, respectively.

The magnesium removal efficiencies were the only positive signed results in the givn graph. The veronica plant species showed the bettr performance by rmoving 88.9% and the commellna plant species also showed closer efficiency by removing 82.38%.

The ANOVA analysis implied all of the parameters analyzed for both of the plants were not statistically significant ($p>0.05$).

Overall performance comparisons

In this part the ANOVA test results of the overall experimental results for each parameter were presented.

Table 4.11 summary of ANOVA test results for substrate- plant effect

	G-GV	G-GC	GV-GC	S-SV	S-SC	SV-SC	R-RV	R-RC	RV-RC
BOD5	NS	NS	NS	NS	NS	NS	NS	NS	NS
Na	NS	NS	NS	NS	SS	SS	NS	NS	NS
COD	NS	NS	NS	NS	NS	NS	NS	NS	NS
NO_3	NS	NS	NS	SS	SS	NS	SS	SS	NS
PO_4^{3-}	NS	NS	NS	NS	NS	NS	NS	NS	NS
TN	SS	SS	NS	SS	SS	SS	SS	SS	NS
Mg	NS	NS	NS	NS	NS	NS	NS	NS	NS
Ca	NS	NS	NS	NS	NS	SS	NS	NS	NS
PH	NS	NS	NS	SS	SS	NS	SS	NS	SS
DO	SS	SS	NS	NS	SS	NS	SS	SS	NS
EC	NS	NS	NS	NS	NS	NS	SS	SS	NS

NS- statistically not significant ($p>0.05$) SS- statistically significant ($p<0.05$)

G-gravel, GV-gravel V.anagallisis, GC-gravel-C.benghallsis, S-sand, SV-sand V.anagallisis, SC-sand- C.benghallsis , R-redash(scoria), RV-redash- V.anagallisis, RC-redash- C.benghallsis

As the table above showed BOD5 results showed no statistical significance in any of the comparison. Like BOD5 there were three other parameters which also did not show statically significant in all of the given substrate-plant combination. These parameters were COD, PO_4^{3-}, and Mg.

Out of all the parameters, TN, DO, PH and NO_3-N showed to be statistically significant ($p<0.05$) in a number of cases. For TN the substrate without plantation showed to be statistically significant. Whereas the nitrate nitrogen tests implied the statistically significant results were showed for cells with plantations. The other parameters showed statistical significance for ANOVA test were Na and Ca.

Table 4.12 summary of ANOVA test results for substrate effect

	G-S	**G-R**	**S-R**	**GV-SV**	**GV-RV**	**SV-RV**	**GC-SC**	**GC-RC**	**SC-RC**
BOD5	NS	NS	NS	NS	NS	NS	NS	NS	NS
Na	NS	SS	NS	NS	NS	NS	NS	SS	NS
COD	NS	NS	NS	NS	NS	NS	NS	NS	NS
NO_3	SS	SS	NS	NS	NS	NS	NS	NS	NS
PO_4^{3-}	NS	NS	NS	NS	NS	NS	NS	NS	NS
TN	NS	SS	SS	NS	NS	NS	NS	NS	NS
Mg	NS	NS	NS	NS	NS	NS	NS	SS	SS
Ca	SS	SS	NS	SS	NS	NS	NS	NS	NS
PH	SS	SS	NS	NS	SS	NS	NS	SS	SS
DO	NS	NS	NS	SS	SS	SS	SS	SS	NS
EC	NS	NS	SS	NS	NS	NS	NS	NS	NS

The table presented that the BOD5, COD, and PO_4^{3-} like on the previous table 4.10 these parameters were not statistically significant ($p>0.05$) in any of the substrates.

Out of the ANOVA test results performed for sodium, red ash (scoria) based cells showed to be statistically significant ($p<0.05$). For PH and DO there were a number of statistically significant differences were shown for different combinations. For the case of NO_3 ANOVA test, the results implied statistically significant results for both red ash and sand. For TN, the statistically significant result was showed for the cell containing red ash. Finally, the test for calcium and magnesium showed statistically significant results for gravel filled cells.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1. CONCLUSION

Since the study was focused on assessing the performance of constructed wetland as greywater treatment option, different factors which were believed to affect the treatment efficiency were investigated on experimental microcosm cells. These factors were type of substrate, state of plantation, and type of plant. As a result of this the conclusions are somewhat grouped in categories. The key conclusions resulting from this study are summarized as follows:

The results obtained by treating the greywater by microcosm cells, in different combinations, lead to the following conclusions:

- Comparing the performance among the three substrates used the results of each cell were tested using ANOVA. The result implied the mean difference for BOD5, COD and orthophosphate were not statistically significant ($p>0.05$). From this it can be concluded that the type of substrate does not affect the treatment of COD, BOD and orthophosphate.
- Comparing the removal efficiencies of the three substrates without plantation, the highest scores were achieved by cells containing sand and scoria. The sand cell showed the best performances for orthophosphate (67.54%) and BOD5 (74.64%), and the scoria cell showed highest removal for Na (66.6%) and COD (61.1%). The only parameter that showed to be statistically significant ($p<0.05$) were sodium removal in the scoria cell. This implies that scoria has great performance in sodium removal than sand and gravel.
- In the case where the cells were planted with V.anagallis-aquatica the sand performance for orthophosphate (72.89%) and BOD5 (76.87%), the scoria achievement for COD (59.86%) and sodium (60.51%), and the gravel cell score for NO_3-N (65.38%) and Mg (29.3%) were the highest for each parameters. But the only statistically significant ($p<0.05$) difference were showed for NO_3-N. It can be concluded that the effect of V.anagallis-aquatica on the treatment is very small.
- On the hand the out of substrates that were plated with C.bengahllensis the cells with scoria media showed best results for Na (56.39%), COD (53.19%), and BOD5 (66.88%); the sand cell performed highest for orthophosphate (75.55%) and NO_3 (82%); and the gravel cell the first of the three in removal of Mg (29.3%). Once again the scoria

containing cells showed to be best for most of the parameters. When the results were tested by ANOVA to compare with the unplanted cells, the differences that were statistically significant ($p<0.05$) were observed only for NO_3 in the sand and scoria cells. From this one can conclude that generally the C.bengahllensis plant did not showen good contribution for pollutant removal.

- Finally, from the two plants, which were in two separate bottles, V.anagallis-aquatica showed the better efficiencies for orthophosphate (43.99%), COD (36.36%) and Mg (88.9%). All of the results showed not to be statistically significant ($p<0.05$). It can be concluded that the two plants do not have difference in treating capacity.
- Generally, taking the very short HRT and the results obtained for this very short HRT, it can be concluded that the study implicated the potential use of CW as an alternative system for greywater treatment.

5.2. RECOMMENDATION

- The results obtained in this study showed that the scoria can be used as a substrate in the constructed wetlands. As it was shown in most cases the best removal efficiency and at the same time most of the statistically significant ($p<0.05$) results for ANOVA tests were obtained in this same substrate. This implies it has great potential to be used as a substrate. So, further detailed and inclusive studies on the use of scoria as a CW substrate are recommended.
- As it has been discussed on the material and method part the plants used in this study were collected from river side of the local river, although the results did not showed high performance, the need for such method of assessment is recommended. It has to be explored further in order to get indigenous, easily accessible and local wetland plant species.
- Since a lot of greywater has been continued to be discharged in to the river, the river is continued to be polluted. In order to protect the river and also to use its potential as a substitution for fresh water, it needs to be studied further.
- The use of a multi-stage or integrated wetland system with short HRT may be an option for treating a lot of water in short time and with better efficiency
- As the results for the ANOVA test showed the plantation did not showed to be statistically significant ($p>0.05$). These results were obtained for very short HRT and after a very short plant age, so it is recommended to study the plant effect for longer HRT and for longer plantation period.

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APPENDIX

Partial photographic description of the microcosms constructing process

The area before cleanup

During cleaning (left) and ready space for digging (right)

Digging

One of the microcosm cells (left) and the distribution pipe installation

The six microcosms as the syetem is ready for the first test

Water outflow from the distribution system

After the plants were planted V. anagallis-aquatica (left) and C. benghalensis L. (left)

Watering the plants

DECLARATION

I declare that the thesis for the M.Sc. degree at the University of Addis Ababa, hereby submitted by me, is my original work and has not previously been submitted for degree at this or any other university, and that all resources of materials used for this thesis have been duly acknowledged.

Name: **Girum Feleke Wolde**

Signature: ___________________

Date of Submission:___________________

This thesis has been submitted for examination with my approval as a university advisor.

Name: **Dr. Tassisa Kaba**

Signature: ___________________

Date: ___________________