Grey water treatment by Constructed Wetland

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DECLARATION

I hereby declare that this thesis entitled "**Grey Water Treatment by Constructed Wetland"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

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Certified that this thesis entitled **"Grey Water Treatment by Constructed Wetland"** is a record of research work done independently by **Abhijeet Hindurao Surve** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

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Dedicated to
Never Satiated Dream of
Pollution Free Environment

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Symbols and Accronyms

^{0}	-	degree
-	-	minus
"	-	second(s)
%	-	percent
:	-	is to
‘	-	minute(s)
+	-	plus
$<$	-	less than
$>$	-	greater than
≤	-	less than or equal to
≥	-	greater than or equal to
µS	-	micro siemens
^0C	-	degree Celsius
AEC	-	adenylate energy charge
AIT	-	Asian Institute of Technology
AM	-	anti meridian
ANOVA	-	analysis of variance
APHA	-	American Public Health Association
ASAE	-	American Society of Agricultural Engineers
AW	-	artificial waste water
B	-	Boron
BOD	-	biological oxygen demand
Ca	-	Calcium
cal	-	calculated
cap	-	capita
Cd	-	Cadmium
cfu	-	colony forming unit
CH_3OH	-	Methyl alcohol
CH_4	-	methane
cm	-	centi meter

CO_2	-	carbon di-oxide
COD	-	chemical oxygen demand
Cu	-	Copper
CWAL	-	Central Water Analysis Laboratory
CWRDM	-	Center for Water Resources Development and Management
d	-	day
DO	-	dissolved oxygen
DOF	-	degrees of freedom
E. coli	-	Escherichia coli
EC	-	electrical conductivity
eff.	-	effluent
Eh	-	Redox potential
EPA	-	Environment Protection Agency
et.al.	-	et. Alia (and others)
FC	-	fecal coliform
FCW	-	Free water surface constructed wetland
Fe	-	Iron
fig.	-	figure
g/gm	-	gram(s)
GMF	-	gravel media filter
h	-	hour(s)
H_2S	-	Hydrogen sulphide
ha	-	hectare
HRT	-	hydraulic retention time
HSSF	-	Horizontal Sub-Surface Flow Constructed Wetlands
i.e.	-	that is
ICAR	-	Indian Council for Agricultural Research
inf.	-	influent
KAU	-	Kerala Agricultural University
KCAET	-	Kelappaji College of Agricultural Engineering and Technology
K_s	-	Saturated hydraulic conductivity
l	-	Litre
LOS	-	level of significance

lpd	-	litres per day
LWRCE	-	Land and Water Resources and Conservation Engineering
m	-	meter
m^2	-	square meter
m^3	-	cubic meter
Mg	-	Magnesium
mg/l	-	milligram(s) per liter
ml	-	milli liter
mm	-	milli meter
Mn	-	Manganese
Mo	-	Molybdenum
MPN	-	most probable number
MS	-	mild steel
MW	-	municipal waste water
N	-	nitrogen
n	-	porosity
Na	-	Sodium
NEERI	-	National Environmental Engineering Research Institute
NH_3^+	-	Ammonia
NH_4-N	-	ammonium nitrate
No.	-	number
NO_2^-	-	nitrite
NO_3^-	-	nitrate
NTU	-	Nephelometric Turbidity Unit
OSS	-	on-site sanitation
P	-	Phosphorous
PE	-	people equivalent
Phos.	-	Phosphates
PO_4^{3-}-P	-	orthophosphate
pp.	-	pages
PVC	-	Poly Vinyl Chloride
PW	-	potable water
R^2	-	correlation coefficient

red.	-	reduction
S	-	Sulphur
SC	-	somatic coliphage
SCW	-	subsurface flow constructed wetland
Sl	-	serial
SS	-	suspended solids
SSFW	-	subsurface flow wetland
STE	-	septic tank effluent
STP	-	sewage treatment plant
TC	-	total coliform
TDS	-	total dissolved solids
TKN	-	Total Kjeldahl nitrogen
TN	-	total nitrogen
TOC	-	Total Organic Carbon
TP	-	total phosphorous
TS	-	total solids
TSS	-	total suspended solids
TWPCR	-	Turkish Water Pollution Control Regulation
UASB	-	un-aerobic sludge blanket
USA	-	United States of America
VFW	-	vertical flow wetland
VSS	-	Volatile Suspended Solids
WHO	-	World Health Organization
WPCF	-	Water pollution Control Federation
WW	-	waste water
WWTP	-	waste water treatment plant
yr	-	year
Zn	-	Zinc

Introduction

CHAPTER I

INTRODUCTION

According to Indian mythology, whole universe is made up of five elements viz., Vayu, Jal, Bhoomi, Agni and Akash. These elements are to be respected and considered in planning the progress of any country to avoid disasters. Water is the most precious and prime element in the socio economic development of the nation and can be described as “eco currency”. Many countries in the world including India is experiencing big water scarcity. The volume of available water more or less remains the same and the increasing demand is due to the increase in population, industrialization and growth in agricultural sector.

Water scarcity and security are new agenda in managing water in the world. It is one of the most important resources for socio-economic development and environment management in dry countries and also the key factor in either conflict and war or peace making. In Saurashtra region of the Gujarat state of India many villages like Jodiya in Jamnagar district gets water for only 20 minutes in 12 days in summer. Rivers and aquifers are being hopelessly overexploited and there is an enormous unmet demand for water. Kerala is one of the wettest states of India. But slope of Western Ghats and undulating topography of the state makes it difficult to store water from heavy rains during the monsoon and thus the state experiences acute water shortage in summer.

Actually the idea of water scarcity is absurd-there is scarcity amongst plenty. That is why water tankers supply water to towns even when the streets are flooded with rain water. The available clean water sources are being viciously attacked by pollution and over exploitation which has now become a global threat. Hardly any river or ground water aquifer near a city today escapes the perils of pollution. The Yamuna has no flow in it except the sewage as it passes through the capital of India, New Delhi.

Every community produces both liquid and solid waste. The liquid portion - waste water - is essentially the water supply of community after it has been fouled by variety of uses. From the stand point view of composition and source of generation, waste water may be classified as Grey, Brown, Yellow, Black, Green and Storm water. Grey water is the domestic waste water from the bathroom sinks, laundry water, swimming pool water, wash basin water etc, except water from toilets. About 60 % of domestic waste water is Grey water i.e. the Grey water producing potential is nearly 200 lit/capita/day.

Due to extreme water scarcity, reuse of wastewater for secondary water uses is becoming essential in many parts of world. But there are certain limitations in direct reuse of this ravaged water. Direct handling of waste water can result in bacteria infection, anemia and transmission of cholera (WHO, 2001). Also consumption of vegetables irrigated with raw waste water can transmit typhoid and cholera. Even grazing of cattle on pasture irrigated with raw waste water is not safe as bacterial infection can transmit through this route.

Direct reuse of waste water for landscape irrigation can lead to saline soil conditions. Dissolved salts in waste water can accumulate in the root zone which can reduce the availability of water to crops. The presence of excessive concentration of specific ions like sodium, chloride or boron can lead to burning of leaves, leaf cupping, chlorosis, reduced growth and yield. The suspended solids present in waste water can clog the reuse system and also results in excessive wear of moving parts of pumps and other equipments. Excessive nitrogen in irrigation water can lead to vigorous vegetative growth, delayed or uneven maturity and reduced crop quality. Excessive leaf growth leads to plant lodging or bending.

The excess concentration of phosphates from washing activities and certain industrial effluents in water streams cause “Eutrophication” – a natural ageing process, in which water becomes organically enriched. Eutrophication leads to the increasing domination of aquatic plants like water hyacinth, breeding of vectors such as mosquitoes and snails, generation of foul smell due to gases like hydrogen sulphide (H_2S), ammonia (NH_3), methyl alcohol (CH_3OH), death of aquatic animals and ground water pollution. Eutrophication further results in obstruction to water flow and transport, flooding and transformation to marshy lands.

To overcome the problem of water scarcity and pollution of water sources, some sort of water treatment is necessary. The key challenges before the humanity are not the utilization of the limited freshwater resources, but the reduction in fresh water demand, management and protection of this precious resource. Though pollution cannot be totally prevented it can be definitely controlled to a great extent so that the recipient ecosystems are not drastically affected. As pollution of water is the result of mans activities, the solution too can be man made.

At present there are several waste water treatment methods like evaporation and distillation, electro dialysis, reverse osmosis, freezing, trickle filtering, microfiltration, ultrafiltration, nanofiltration, anaerobic digestion etc. Many of these methods are efficient and usable only for large scale centralized waste water treatment. These methods of wastewater treatment are often costly and thus fall beyond the reach of introduction. Apart from this, these methods require considerable amount of energy, human power and careful maintenance to operate these systems. Thus they are not practicable for on-site waste water treatment. Hence there is the need of easy, simple, cost effective and safe on-site waste water treatment methods.

The best option for on-site waste water treatment is the usage of constructed wetlands also called as artificial wetlands. The wetlands act as the "Kidneys of nature" and work on the same principle as that of natural wetlands. Constructed, also called artificial wetland can be defined as wetland specifically constructed for the purpose of pollution control and waste management, at a location other than existing natural wetlands. The waste water treatment by constructed wetlands can result in positive environmental effect of reducing ground water pollution and demand of fresh water with considerable elimination of awful odour and unsightly water stagnation sites. Also subsurface flow constructed wetlands can reduce the insects like mosquitoes which create discomfort to human life and can lead to dangerous life finale diseases like Dengue or Chikengunya, as is happening for the past few years in some districts of Kerala.

Reutilization of wastewater is an important aspect of water management. Constructed wetland systems have potential for treating wastewater for single houses, villages, small towns, tourist resorts, institutions, farms as well as some industrial areas. They are gaining popularity because of the poor condition of existing small purification plants and high cost of new purification plants. Constructed wetlands are potentially good, cost effective, appropriate technological treatment systems for domestic waste water in rural areas.

Grey water treatment by constructed wetland is accomplished by physical, chemical and biological activities of the micro-organisms. Performance of biological systems is dependent on environmental conditions, influent quality, hydraulic retention time, bacterial composition, filtering media, macrophytes etc. In the past few years the research work carried out in the developed and industrialized countries have resulted in information dissemination and still a lot is yet to be done with reference to the developing countries like India. Hence to assess the performance of constructed wetland in Kerala climatic conditions the present experimental study was conducted with the following objectives-

1) To test the quality of grey water from the selected source for the presence of pollutants.
2) To design and fabricate subsurface flow constructed wetland with suitable media and vegetation.
3) To evaluate the performance of subsurface flow constructed wetland for pollutant removal.
4) To study the effect of hydraulic retention time on performance of pollutant removal.
5) To conduct irrigation trials with treated and untreated grey water and compare effect on crop quality.

Review of Literature

CHAPTER II

REVIEW OF LITERATURE

The increased urbanization and industrialization will lead to increased fresh water demand and hence enhanced ground water exploitation. But the available fresh water quantity is nearly constant. Hence in the near future, some sort of waste water treatment and reuse will be unavoidable. Wastewater treatment will have two major positive effects on environment. It will help to reduce the pollution of water bodies, bad odour, insects like mosquitoes and snails, and also reduce the demand of fresh water. For human, soil, crop and environmental risk-free wastewater reuse, some sort of treatment is necessary. Constructed wetland for on-site waste water treatment is the affordable, easily operable and reliable alternative for the rural as well as urban communities.

Natural processes have always cleansed water as it flowed through rivers, lakes, streams, and wetlands. In the last several decades, systems have been constructed to use some of these processes for water quality improvement. Constructed wetlands are now used to improve the quality of point and non-point sources of water pollution. In this chapter, research and developmental efforts carried out at different parts of the world have been critically reviewed regarding objectives of this study.

2.1. Definitions

2.1.1 Grey water

'Grey water' is the term given to all used water discharged from a house, except for toilet water. It includes shower, bath, hand basin, kitchen sink, dishwasher, washing machine and laundry tub water. This water is called 'grey' water because it turns grey if stored for a while. It also becomes quite smelly if stored for a day or so.

Grey water re-use for garden irrigation should be encouraged in urban and rural households. It utilizes a valuable on-site resource which is otherwise wasted, conserves precious drinking water and reduces the load on wastewater disposal systems (both on-site and centralized). If applied appropriately to gardens, grey water re-use presents minimal health risks and environmental pollution. It conserves fresh water which can remain in natural ecosystems.

An average urban house uses 820 litres of water per day for indoor and outdoor use. This encompasses toilet (140 litre), grey water (340 litre) and outdoor (340 litre) use. Grey water is generated in the bathroom (180 litre), laundry (110 litre) and kitchen (55 litre). Each house varies from these averages depending on appliances and habits, but the volumes indicate that a lot of grey water is generated that generally disappears down the plug-hole never to be seen or re-used again.

Main objectionable constituent of grey water is phosphorous, the main source of which is soap and detergents. Alexander & Stevens (1976) measured the total phosphorus content in wastewater collected from a Northern Ireland city and then calculated the total per capita phosphorus discharge as 1.8 g/cap.d. The authors also surveyed results obtained in various countries and showed that the phosphorus content in excreta and non-detergent household wastes varied between 1.0 and 1.6 g/cap.d (average approximately 1.4 g/cap.d). More objectionable form of phosphorus is coming from detergents. Alexander & Stevens found that the phosphorus input from detergents was between 1.5 and 3.0 g/cap.d while Balmer & Hultman (2004) showed that this value varied within the range of 0.65 - 2.0 g/cap.d. Design manuals from early 80’s Water Pollution Control Federation (WPCF) showed as typical values for domestic wastewater as 2.1 to 4.9 g/cap.d of total P consisting of 0.8 to 1.6 g P/cap.d of organic and 1.3 to 3.3 g/cap.d of inorganic compounds.

Environmental Protection Agency (EPA) (1993) design manual suggests that 20 % excess of aluminum ions (by weight) is necessary if 80 % reduction of phosphorus is desired while 100 % excess is recommended for 95 % P removal.

2.1.2 Constructed wetlands

Wetlands are defined as land where the water surface is near the ground surface long enough to maintain saturated soil conditions, along with the related vegetation. Marshes, bogs and swamps are all examples of naturally occurring wetlands. 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. Artificial wetlands utilize natural processes involving wetland vegetation, soils and their associated microbial assemblies to assist, at least partially, in treating an effluent or other water source. Physical, chemical and biological processes combine in wetlands to remove contaminants from wastewater.

Theoretically, treatment of wastewater within a constructed wetland occurs as it passes through the wetland medium and the plant rhizosphere. A thin film around each root hair is aerobic due to the leakage of oxygen from the rhizomes, roots and rootlets. Decomposition of organic matter is facilitated by aerobic and anaerobic micro-organisms present. Microbial nitrification and subsequent denitrification releases nitrogen as gas to the atmosphere. Phosphorus is precipitated with iron, aluminum and calcium compounds located in the root-bed medium. Suspended solids are filtered out as they get attached to the filter media within subsurface flow wetland cells. Harmful bacteria and viruses are reduced by filtration and adsorption by biological films on the rock media in subsurface flow and vertical flow systems.

There are two basic types of constructed wetlands, the free water surface constructed wetland (FCW) and the subsurface flow constructed wetland (SCW). Both types utilize emergent aquatic vegetation and are similar in appearance to a marsh. The FCW typically consists of a basin or channel with some type of barrier to prevent seepage, soil to support the roots of the emergent vegetation, and water at a relatively shallow depth flowing through the system. The water surface is exposed to the atmosphere, and the intended flow path through the system is horizontal. Figure 1 presents the pictorial view of free water surface constructed wetland

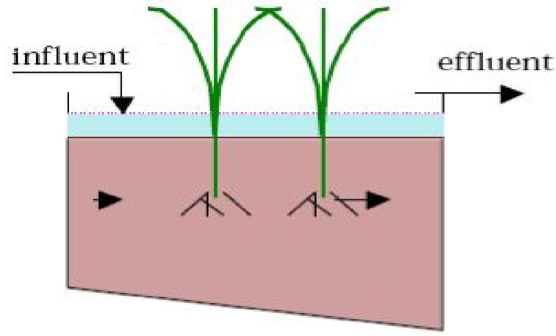

Fig. 1 Free water surface constructed wetland

The subsurface flow constructed wetland system (SCW) also consists of a basin or channel with a barrier to prevent seepage, but the bed contains a suitable depth of porous media.

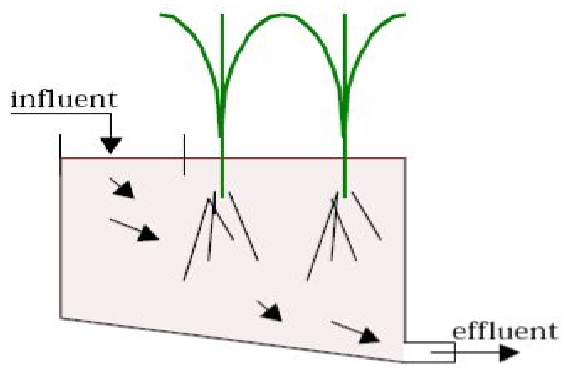

Fig. 2 Subsurface flow constructed wetland

Rock or gravel is the most commonly used media type but fine sand, crushed stones or bricks, marble pieces; gravel etc can also be used. The media also support the root structure of the emergent vegetation. The designs of these systems assume that the water level in the bed will remain below the top of the rock or gravel media. The flow path through the operational systems can be horizontal or vertical. The figure 2 presents the pictorial view of sub surface flow constructed wetland.

Effluent nitrate concentration from the wetland is dependent on maintaining anoxic conditions within the wetland so that denitrification can occur. It found that subsurface flow wetlands were superior to surface flow wetlands in nitrate removal. Results obtained from the vertical flow systems show a significant reduction in both total nitrogen and ammonia (>97 %) when primary treated effluent was applied.

Calculations showed that over 50 % of the total nitrogen going into the system was converted to relatively harmless nitrogen gas.

In freshwater aquatic ecosystems phosphorus has been described as the major nutrient responsible for the unnecessary growth of aquatic plants and algae. Because phosphorus does not have an atmospheric component as does nitrogen, the phosphorus cycle can be characterized as closed. The removal and storage of phosphorus from wastewater can only occur within the constructed wetland itself. Phosphorus may be locked within a wetland system either by

- The binding of phosphorus in organic matter as a result of incorporation into living biomass, or
- Precipitation of insoluble phosphates with ferric iron, calcium and aluminum found in wetland media.

2.2. Harmful effects of raw waste water reuse.

Raw industrial effluents contain many offensive constituents like superfluous nitrogen, sulphates and phosphorous with other nutrients and heavy metals like sodium, chloride, manganese, magnesium, iron, copper, cadmium, selenium, mercury, lead, nickel etc. Hence treatment is unavoidable before safe reuse of waste water. In the following paragraphs the waste water reuse and its effects on soil, crop and human health are reviewed.

Samir *et.al.* (1993) studied the impact of domestic waste water reuse for irrigation on ground water quality. The main objectives of their study were to assess the impact of irrigation with sewage effluent on groundwater. Their study yielded useful recommendations to decrease the impact on groundwater quality and possible risks concerning type and amount of pollution from sewage effluent. It also gave design criteria to control possible spreading of pollutants and finally the use of groundwater in the area. The following comprised the main conclusions of their study-

- Irrigation with sewage effluent had a positive impact on salinity of the initially brackish groundwater. On the contrary, the groundwater quality was negatively affected by sewage effluent with regard to nitrogen contents (ammonium and nitrate), phosphates, heavy metals and fecal coliforms.
- The limit of nitrate for drinking water quality standards was sometimes exceeded. Moreover, fecal coliforms were found in the water from all shallow hand pumps in the area. The general suitability of the groundwater was therefore limited while the use of hand pumps for drinking water purposes should be avoided. High boron content of sewage effluent indicated a risk for crops sensitive to boron.
- The accumulation of heavy metals and phosphorous in the soil adversely affected the soil system.
- Pretreatment of sewage effluent should be improved to limit the pollution of the aquifer. Industrial discharge to sewage effluent should be avoided.
- Groundwater recharge by sewage effluent was mainly collected by drains in or along the border of the area, so spreading of pollutants out of the area was largely controlled.

Albulbasher Shahalam *et.al* (1998) studied the effect of wastewater irrigation on soil, crop and environment. The experimental plots had three crops: alfalfa, radish and tomato which were irrigated with fresh and waste waters. The irrigation water was applied by sprinklers. Each crop was given two sub-treatments: with fertilizer and without fertilizer. The physical and chemical properties of the soil, the crop yield and subsurface drainage were measured. In most of the cases, the yield resulting from the use of wastewater with fertilizer was compatible with those of the use of freshwater with fertilizer. The washings of tomato fruits grown with wastewater were analyzed for fecal coliforms. It appeared that the fruit skins were free of viable fecal coliforms, 24 hours after the wastewater application. Subsurface drainage analyses did not show any alarming levels of constituents irrespective of the source of the water. Wastewater irrigation applied for a season had no significant effect on the silty loam soil. Slight changes in the soil porosity and salinity were observed.

Friedel *et.al.* (2000) studied the effects of long-term waste water irrigation on soil organic matter, soil microbial biomass and its activities. In the Vertisols, where larger amounts of water have been applied than in the Leptosols, TOC contents increased 2.5 times after 80 years of irrigation. In the Leptosols, however, the degradability of the organic matter tended to increase with irrigation time.

Changes in soil microbial communities occurred, as denitrification capacities increased greatly and adenylate energy charge (AEC) ratios were reduced after long-term irrigation. These changes were supposed to be due to the addition of surfactants, especially alkylbenzene sulfonates (effect on denitrification capacity) and the addition of sodium and salts (effect on AEC) through waste water irrigation. Heavy metals contained in the sewage do not appear to be affecting soil processes yet, due to their low availability. Detrimental effects on soil microbial communities can be expected, however, from further increase in pollutant concentrations due to prolonged application of untreated waste water or an increase in mobility due to higher mineralization rates.

Plate 1 depicts the ill effects of raw waste water on Aptos Blue and Roses showing leaf chlorosis, limited growth of young branches and leaf burning. Plate 2 shows the common Canna macrophyte in the natural wetland.

EL-Aila *et.al.* (2002) conducted field study on wastewater treatment for irrigation purpose and its effects on yield and uptake of some nutrients by wheat plant. A field experiment was conducted to use treated and untreated waste water effluent for wheat irrigation as compared to the effects of well water. Results showed that application of untreated sewage effluent simulated the yield as compared to treated and well water. Data revealed that application of untreated sewage water increased total nitrogen, phosphorous and potassium content in both grain and straw. It was observed that treatment of sewage effluents resulted in remarkable decrease in the accumulation of heavy metal in grain and straw as compared to untreated effluents. Results showed that high grain/straw ratio was obtained in case of untreated irrigation as compared to treated and well water irrigation.

(a) (b)

Plate 1 Effects of raw waste water irrigation on (a) Aptos Blue showing leaf chlorosis and limited growth (b) Leaf burning of Roses.

Plate 2 Canna macrophyte in the wetland.

Fasciolo *et.al.* (2002) studied the effects on crops irrigated with treated municipal wastewaters. Two experiments were performed on a pilot plot planted with garlic (1998) and onions (1999) using furrow irrigation with three types of water in 10 random blocks: treated effluent (2.5 x 10^3 MPN Escherichia coli/100 ml, three helminth eggs/l, and Salmonella (positive); and well water (free of microorganisms), with and without fertilizer. Two responses were evaluated: (1) crop yield, and (2) crop microbiological quality for human consumption at different times after harvest. Wastewater irrigation acted like well water with fertilizer, increasing garlic and onion yields by 10 % and 15 %, respectively, compared to irrigation with well water with no fertilizer. Wastewater-irrigated garlic reached sanitary acceptability 90 days after harvest, once attached roots and soil were removed. Onions, which were cleaned immediately after harvest, met this qualification earlier than garlic (55 days). Neither the wastewater-irrigated crops nor the control crops were microbiologically acceptable for consumption raw at harvest.

Grant Poole *et.al.* (2003) reviewed the soil, water and crop production considerations in municipal wastewater application to forage crops. They reported that the municipal wastewater can contain high levels of nitrogen and other constituents that can be detrimental to surface and groundwater supplies if it is not carefully applied. Wastewater application to cropland requires fundamental knowledge of soil salinity and fertility, plant water and nutrient use, and wastewater characteristics to successfully monitor and properly irrigate forage crops. Farm managers and wastewater suppliers who are involved with this application process should have a general understanding of soil, plant, water interactions and the motivation to achieve and maintain adequate agricultural productivity for the operation to be agriculturally and environmentally sound.

Gaspare Viviani *et.al.* (2004) studied the effect of waste water reuse on soil hydraulic properties. He reported that the wastewater TSS concentration affects the saturated hydraulic conductivity, K_s, of clay. A loam soil was investigated on laboratory repacked soil cores by a constant head permeameter. Both municipal wastewater (MW) and artificial wastewater (AW) with different TSS concentration were used, with an aim to evaluate, the effects of biological activity. The development of a surface sealed layer was investigated in loam soil columns supplied with AW and equipped with water manometers at different depths to detect the hydraulic head gradient changes. In the loam soil, K_s reduced to about 80 % of the initial value after infiltration of 175 mm of MW with TSS = 57 to 68 mg/l. Reductions in K_s were more remarkable in clay soil.

Mohammad *et.al.* (2004) studied the forage yield and nutrient uptake as influenced by secondary treated wastewater. Three field experiments were conducted at a farmer's field. Corn (Zea mays) was planted for two seasons as a summer crop while Vetch (Vicia sativa) was planted for one season as a winter crop during 1994-95. Plots were irrigated with either potable water (PW) or wastewater (WW) in amounts according to the following treatments: (i) PW equivalent to 100% class A pan reading (PW); (ii) WW equivalent to 100% class A pan reading (WW1); (iii) WW equivalent to 125% class A pan reading (WW2), and (iv) PW with application fertilizer equivalent to nitrogen (N) and phosphorus (P) content of WW1 (PWF).

Treatments were replicated four times in randomized complete block design. The results indicate that WW irrigation increased the yield of both Corn and Vetch. Supplemental fertilization with the potable water irrigation (PWF) enhanced vetch production and increased grain weight for corn in the second season (1995). The uptake of macronutrients and micronutrients by corn increased with WW irrigation, while the uptake by vetch increased with both WW irrigation and PW supplemented with fertilization. It was concluded that under the conditions of this study, secondary treated WW could be a source of plant nutrients and can be reused for irrigation to increase forage crop production.

Platzer *et.al.* (2004) studied the reuse of treated wastewater for agricultural purposes. They reported that the SSFW-effluent meets all standards established in the national regulations for wastewater reuse in agriculture, except for fecal coliforms, existent at an average concentration of 7×10^4 MPN/100 ml. A conventional surface irrigation method was used to irrigate different crop species selected to establish their risk of contamination.

Ilker Angin (2005) studied the effect of wastewater irrigation on soil properties. He stated that the use of wastewater for irrigation is increasingly being considered as a technical solution to minimize soil degradation and to restore nutrient content of soils. His study describes changes in soil and plant nutrient contents after long-term irrigation with wastewater. Application of wastewater increased salinity and decreased pH. Several beneficial changes were observed including an increase in organic matter, N, concentrations of major cations and heavy metals in soils. Wastewater increased N, P, Fe, Mn, Zn, Cu, B, Mo and Cd contents of Cabbage and Potato plants. In order to avoid undesirable side effects due to salinity and toxic concentrations of metals by the application of wastewater to soil, it is necessary to determine the effects of wastewater concentration in long-term periods.

Alit Wiel-Shafran *et.al.* (2006) studied the potential changes in soil properties following irrigation with surfactant rich grey water. Concentration of surfactants found in grey water effluents range from 0.7 to 70 mg/l and on average is higher than concentrations in raw domestic wastewater. Pollutants such as boron, salt and fecal coliforms are also commonly found in grey water. The capillary rise in sand that was pretreated with a laundry detergent solution was lower than that in sand pretreated with fresh water, and exhibited hydrophobic properties. As with the capillary rise, a flow pattern typical of hydrophobic soil was noted when the imbibitions of fresh water in to sand pretreated with laundry detergent solution was tested.

2.3. Performance evaluation of constructed wetlands.

Wastewater treatment in constructed wetlands is the overall effect of physical, chemical and biological activities of bacteria attached to filter media and plant roots. Performance of SCW in reduction of pollutants depends on many factors like type of filtering media and its size, atmospheric temperature, macrophytes, microorganism composition, hydraulic retention time etc.

Jenseen *et.al.* (1993) studied the potential use of constructed wetlands for waste water treatment in northern environments. He reported that the experience from Norway indicated that significant biological activity occurred at temperature between 0 to 5^0C, and the high removal rates of nutrients and organic matter were achieved in ponds and soil amended with wastewater at these temperatures. Cold climates may require careful installation of larger and deeper system, with longer detention time. Results of 15-month operation of a Norwegian multistage constructed wetland pilot plant optimized for nutrient removal, showed 55 % nitrogen and 98 % phosphorous removal. The large phosphorous removal was obtained by using sand with a high content of iron oxides and a fabricated porous media that had a high phosphorous adsorption capacity. The results indicated that properly designed constructed wetlands operated satisfactorily even in cold climates. When an adequate design criteria was developed, several possible applications exist for these simple low maintenance systems as main treatment systems, or in conjunction with other treatment methods.

Robert Netter (1993) studied the planted soil filter as a wastewater treatment system for rural areas. Three planted soil filters for wastewater treatment (constructed wetlands with subsurface water flow) were investigated over an extended period of time. Each of them was filled with different kinds of soil. The filters were planted with helophytes, and loaded with septic tank effluent, with pretreated combined sewage respectively. The hydraulic surface loading varied from 4 to 60 mm/d and the specific BOD_5 mass loading from 0.9 to 8.7 $g/m^2.d$. The purification efficiency varied between 61 and 99 % with respect to BOD_5 and COD. The elimination of nutrients (N_{total} and P_{total}) varied between 5 and almost 100 %. The removal rate of total bacterial count, coliforms, fecal coliforms and fecal streptococci was significant.

House *et.al.* (1994) studied the treatment of nitrogen and phosphorous by a constructed upland wetland wastewater treatment system. Treatment effectiveness was evaluated from March 1990 to September 1991. The mound provided an aerobic environment those results in complete nitrification and complete reduction of phosphorous. Concentration of total nitrogen (TN) was lowered 64 %, from 44.4 mg/l to 16.0 mg/l by the mound component. Nitrogen in the wastewater dosed in to the mound was in the ammonium (NH_4-N) and organic forms, while essentially all the nitrogen present in water that had passed through the mound was in the nitrate (NH_3-N) form. The mound lowered total phosphorous (TP) concentration 86 %, from 4.4 mg/l to 0.6 mg/l. The wetland cell planted with Phragmites australis was more effective than both the unplanted cell and the cell planted with Typha angustifolia. Concentrations of (TN), primarily NH_3-N, were lowered from 16.0 mg/l to 11.1 mg/l of that entering the cell. Total phosphorous was lowered to 50 %, from 0.6 mg/l to 0.3 mg/l.

Chr. Platzer (1994) has evaluated nitrogen removal at three treatment plants in order to determine the relationship between effluent temperatures, evapotranspiration, substratum, loading rates and the different types of nitrogen. The results showed a very high and almost complete denitrification. In most of the plants nitrification was the limiting factor. Evapotranspiration was found to be one of the strongest factors supporting nitrification. Influence of the effluent temperature was significantly lower. Investigations on influence of the substratum showed better results for nitrification and denitrification on fine material containing clay.

Yang Yang *et.al.* (1995) studied the removal efficiency of constructed wetland. After their three years study on a constructed wetland wastewater treatment system they reported that the wetland system under study occupied an area of 8400m^2, with a design flow of 3100 m^3/d. Parameters such as biological oxygen demand, chemical oxygen demand, suspended solids, total nitrogen, and total phosphorus in the influent and effluent of the wetland system were examined, and their removal rates were determined. It was found that the system was very effective in removing organic pollutants and suspended solids.

Drizo *et.al.* (1997) conducted a study to see the phosphate and ammonium removal by constructed wetlands with horizontal subsurface flow. The major objective of their experiment was to investigate the performance of horizontal subsurface flow constructed wetland using shale as substrata, in removal of phosphorous (P) and ammonia (N) from sewage. Both the planted and unplanted wetlands showed an extremely high P removal of 98-100 % over a period of 10 months of investigation. Ammonia N was also completely removed in the planted tanks, whereas in the unplanted ones the rates of removal varied between 40 and 75 %; removal of nitrate N varied between 85 and 95 % in planted and between 45 and 75 % in unplanted tanks. pH, Eh and temperature did not differ significantly amongst planted and unplanted tanks, but the inlet Eh was correlated with P removal. The presence of phragmites australis contributed significantly to P and N removal. In addition the plants showed excellent growth (up to 2 m in the first year), with good root and rhizome development, and showed potential for heavy metal removal.

Ulo Mander *et.al.* (1997) conducted an experiment for wastewater treatment in constructed wetlands. They reported that many natural/semi- natural wetlands have been used for municipal or agricultural wastewater treatment. Budgets of organic matter, total N and total P of three systems (a sand / plant filter with vertical flow, area 90 m^2, loading 3.8 g BOD_5 /m^{2}·d, a combined overland vertical flow root zone system on a phragmites, area 2400m^2, loading 1 g BOD_5/m^{2}·d, an aquatic macrophyte channel (bioditch), area 140 m^2, loading 40 g BOD_5/m^{2}·d) were analyzed. Except for nitrogen, the efficiency of the sand/plant filter was satisfactory: 82 % for BOD_5, 36 % for total N and 74 % total P respectively.

The poor performance with respect to nitrogen was due to weak vegetation. In the Phalaris-system, 65 % of organic matter, 67 % of nitrogen and 80 % of phosphorous was removed. The average output concentration of this system was always lower than the recommended limits (BOD_5 < 10mg/l, total N< 10 mg/l and total P < 2 mg/l). Due to the high input load, the BOD_5, total N and total P values in the outlet of the bioditch were high and extremely variable: 5 -100, 6 -16 and 1 - 4 mg/l respectively.

Jean *et.al.* (1999) conducted experiment on phosphorus removal in agricultural wastewater by a recently constructed wetland. A four-cell surface-flow wetland was constructed during the 1996 spring season and was used immediately the same summer and fall. While the general purpose of the project was to monitor the efficiency of the system under various operating conditions, the specific interest of the first year of operation was to study its efficiency in reducing phosphorus during the first weeks of use. With inflow concentrations around 20 mg/l, the removal of phosphorus was limited to 50 % for ortho-P and 63 % for total P during the first summer of use.

Kathleen (2000) has analyzed the residential subsurface flow constructed wetland performance in Northern Alabama. He reported sample collection study and statistical analysis of five such residential constructed wetlands over seasonal variations. Results of the data analysis show that constructed wetlands can reduce organic - content and coliform appreciably, by an average of 85 % and 90 % respectively.

Bista *et.al.* (2000) studied the performance of reed bed waste water treatment system in Nepal. He stated that the constructed wetland is simple in construction, maintenance and operation, and is a biological system, which applies the interaction between media, plants, wastewater and microorganisms during the degradation of the pollutants found in wastewater. This study was carried on existing operating treatment plants, which have operated for 1and 5 years. The organic matter removal varied from 86 to 93 %, and the effluent COD concentrations varied from 20 to 38 mg/l depending on organic loading rate and age of wetland. Also nutrient removal efficiency was satisfactory. The removal of fecal coliform was 98.3 %.

Srinivasan Neralla *et.al.* (2000) experimentally studied the improvement of domestic wastewater quality by subsurface flow constructed wetlands**.** He stated that the constructed wetlands from residences at eight locations in Texas have been used for 2–4 years to determine their effectiveness in improving the quality of septic effluent passing through them. Influent and effluent samples were collected and analyzed to determine the reduction in concentrations of BOD_5, TSS, VSS, ammonium-N (NH_4^+-N), phosphorus, total and fecal coliform bacteria. Results of these investigations indicate that the organic load, fecal coliform population, N and P concentrations of the septic water decreased considerably by passing through the wetlands. Constructed wetlands reduced BOD_5 of septic water by 80-90 % which provided for feasible disinfection by chlorination. Reduction in populations of fecal coliforms varied but generally, populations were reduced by 90 - 99 %. Chlorination further reduced populations of fecal coliforms to less than 2 cfu/100 ml.

Stecher *et.al.* (2001) studied the design of surface flow constructed wetland for onsite wastewater treatment. They constructed four wetland cells and the hydraulic and organic loads of domestic wastewater were varied. To investigate sizing, the wastewater depth in the cells were varied. Water quality parameters were measured for different depths. A comparison of planted verses unplanted wetland cells was also conducted. Results showed that increasing the depth in the wetland did not significantly increase reduction of BOD, even though detention time was increased. The BOD's for effluent wastewater were consistently 18 to 22 mg/l better than those predicted by the EPA design equation when hydraulic loads were greater than 1.0 m^3/d. Findings showed that under the same organic loads the cell containing plants reduced influent wastewater BOD values to 13 mg/l, while the cell without plants reduced influent wastewater BOD values to 21 mg/l. Planted cells also reduced influent ammonium (NH_4^{+}) values 35 % more and fecal coliform numbers by 30 % more than unplanted cells.

Selma *et.al.* (2001) studied the treatment of wastewater by natural systems. The study was conducted at two different systems: continuous and batch. In the continuous system, the treatment yields were monitored under different loading conditions for one year period. COD and SS removal efficiencies were obtained as 90 % and 95 %, respectively. The effluent COD concentration at an average loading of 122 g COD/m^2.d was satisfactory for the Turkish Water Pollution Control Regulation (TWPCR). This means that a 0.8 m^2 of garden area per person is required. Other removal values for the same conditions were as follows: TKN was 77 %, TN was 61 %, and PO_4^{-3} – P was 39 %.

David Steer *et.al.* (2002) studied the single family constructed wetland systems in Ohio, USA. They reported that twenty-one, three-cell systems (septic tank with two wetlands) were found to meet USEPA effluent load guidelines. These wetlands most frequently met the EPA standards for mitigation of BOD (89 %, below 30 mg/l); TSS (79 %, below 30 mg/l); and FC (74 %, below 1000 counts/100ml). Phosphorus and ammonia discharge met the guidelines less often (50 % at 1 mg/l and 16 % at 1.5 mg/l, respectively).These data also indicated that domestic treatment wetlands reduced the out put of fecal coliform 88 % to 27 %, total suspended solids 56 % to 53 %, biochemical oxygen demand 70 % to 48 %, ammonia 56 % to 31 % and phosphorus 80 % to 20 %. Analysis of variance for these systems indicated that biochemical oxygen demand reduction was 10 % less efficient during winter and ammonia was reduced 20 % more efficient in fall when compared with the other seasons. Phosphorus reductions display complex seasonal variations that imply that the least efficient phosphorus reduction occurs in winter and the most efficient reduction occurs in fall.

Dandigi *et.al.* (2002) used constructed wetland for treatment of municipal wastewater. For their study, a pilot free water surface flow wetland was designed and constructed near the Kakatiya Musical Garden of Warangal City, a historical place in the state of Andhra Pradesh. The detention period of wetland was seven days. The treatment plant with locally available emergent macrophyte as the wetland vegetation (i.e. typha latofolia) was taken up for the study. The studies were conducted during the period of April 2001 to March 2002, which included all the seasons and work continued for different depth of wastewater in the pilot wetland system. The investigation was conducted on weekly basis. The analysis for BOD, COD, TSS, TKN, TP, sulphates, hardness and chlorides were carried in the laboratory. The DO was nil in the inlet, except during rainy days.

The experimental results showed that, the efficiency of treatment wetland in removing BOD, COD, TKN and NH_4-N increased as the temperature increases. No significant changes were observed in the hardness and chlorides between inlet and outlet. It was observed that the DO level at the outlet was 3-4 mg/l for most of the time. The BOD and TSS removal in the wetland system between inlet and outlet was observed to be 85 to 90 %, while Kjeldahl Nitrogen, Phosphate and Sulphate removal were observed to be 70, 50 and 80 % respectively. From the studies carried out it was observed that, for summer and rainy seasons, the constructed wetland treatment for well settled municipal wastewater proved very efficient with a slight decrease in the performance during winter.

Hench *et.al.* (2003) studied the domestic waste water treatment by small constructed wetland. In order to evaluate efficiency of constructed wetlands for treatment of domestic wastewater for small communities located in rural areas, small scale wetland mesocosms (400 l each) containing two treatment designs (a mixture of Typha, Scirpus, and Juncus species, control without vegetation) were planted at two depths (45 or 60 cm) with pea gravel. Each mesocosm received 19 l/d of primary treated domestic sewage. Mesocosms were monitored (inflow and outflow samples) on a monthly basis over a two year period for pH, TSS, BOD_5, TKN, DO and conductivity. Microbiological analysis included enumeration of fecal coliforms, enterococci, Salmonella, Shigella and coliphage. Significant differences between influent and effluent water quality for the vegetated wetlands were observed in TSS, BOD_5 and TKN. Increased DO and reduction in fecal coliform, enterococci, Salmonella, Shigella, Yersinia and coliphage populations also were observed in vegetated wetlands. Greatest microbial reductions were observed in the planted mesocosms compared to those lacking vegetation.

Kuschk *et.al.* (2003) experimentally studied the annual cycle of nitrogen removal by a pilot scale subsurface horizontal flow constructed wetland under moderate climate. In spring and autumn removal efficiency were found to depend on the nitrogen load in a linear mode. The efficiencies in winter and summer differed extremely (mean removal rates of 0.15/0.7 $g/m^2.d$ (1%/13%) in January/August) and were independent of the nitrogen load (0.7 to 1.7 $g/m^2.d$). In principle oscillations of the removal rates in spring, forming several maxima, suggest seasonal specific effects caused by the dynamics of the plant physiology finally determining the nitrification efficiency, i.e. via O_2 supply. Nitrification is limited by temperature during all seasons and surprisingly in midsummer additionally restricted by other seasonal aspects forming a clear cut relative nitrification minimum (mean rate of 0.43 $g/m^2.d$ (32 %) in July. Denitrification was nearly complete in midsummer and was clearly restricted at seasonal temperature below 15^0C.

Diederik *et.al.* (2004) studied seven constructed wetlands in Belgium for their performance in removing pollutants. The main purpose of the wetlands was to treat domestic and dairy waste water. Average removal efficiencies were lowest with FWS reed beds (COD 61 %; SS 75 %; TN 31 % and TP 26 %). The best overall performance was obtained with VF wetlands (COD 94 %; SS 98 %; TN 52 %; TP 70 %), except for total nitrogen removal where one of the combined reed bed system did better (COD 91 %; SS 94 %; TN 65 %; TP 52 %). Despite this considerable achievement in pollutant removal, the effluent nutrient concentrations of many systems remain too high and involve substantial danger of eutrophication.

Belmont *et.al.* (2004) stated that constructed wetlands may be appropriate technologies for treating domestic waste water generated by small communities. To assess the removal of pollutants from waste water; they constructed a pilot-scale treatment wetland in the small community. The system, consisting of sedimentation terraces, stabilization pond, SSFW and VFW, removed more than 80 % of TSS, COD and nitrate from domestic sewage. Removal of ammonium was less efficient at about 50 %. This study also showed that ornamental flowers with high economic value planted in the SSFW performed as well as cattail (Typha angustifolia) in removing TSS and nitrogen. The treated water was suitable for irrigation, which could help to alleviate the scarcity of water in the Rio Texcoco watershed. Modelling exercises indicated that the pilot-scale wetland could be readily adapted to treat sewage from six families.

Shi *et.al.* (2004) studied the performance of a subsurface-flow constructed wetland in Southern China. The operational performance of a full-scale subsurface-flow constructed wetland, which treated the mixed industrial and domestic wastewater with BOD_5/COD mean ratio of 0.33 was analyzed. They reported that the constructed wetland system consists of screens, sump, pumping station, and primary settling basin, facultative pond, first stage wetland and secondary stage wetland. The designed treatment capacity is 5000 m^3/d, and the actual influent flow is in the range of less than 2000 to greater than 10000 m^3/d. The final effluent quality will meet the National Integrated Wastewater Discharge Standard; with the following parameters (mean values): COD 33.90 mg/l, BOD, 7.65 mg/l, TSS 7.92 mg/l, TN 9.11 mg/l and TP 0.56 mg/l.

Thammarat Koottatep *et.al.* (2004) studied the constructed wetland as option for septage treatment. They reported that the majority of urban dwellers in Africa depend on OSS systems for excreta disposal. The authors describe in detail pilot-scale investigations on using CW for the treatment of septage. The experiments are being conducted at AIT, Bangkok since1997. The plant 2 consists of three beds planted with cattail (Typha). A loading rate of 250 kg TS/m.yr was found optimum for the type of septage treated. Intermittent percolate impoundment is required to prevent cattail wilting during dry weather. 65 % of the septage liquid passes through the underdrain and 35 % is evapotranspirated. The beds have been operated for nearly four years with unimpaired bed permeability. Accumulated solids are low in viable helminth eggs and satisfy expedient sludge quality standards for agricultural use. Compared with conventional sludge drying beds, CW requires a much-reduced frequency at which dewatered biosolids need to be removed from the bed.

Peng Jian-feng *et.al.* (2005) studied the performance of multi-stage pond-wetlands ecosystem. Their study on the removal of different pollutants (BOD_5, COD, SS, TP, TN, NH_3-N etc.) in different seasons and different units for that system indicated that effluent BOD_5 and SS were constant to less than 11 mg/l and 14 mg/l throughout the experimental processes; but that the removal efficiencies of pollutants such as TP, TN, NH_3-N, COD varied greatly with season. The higher the temperature, higher was the observed removal in these systems. Additionally, each unit of the system functioned differently in removing pollutants. BOD_5 and SS were mainly removed in the first three units (hybrid facultative ponds, aeration ponds and aerated fish ponds), whereas nitrogen and phosphates were mainly removed in hydrophyte ponds and constructed reed wetlands. Finally they have concluded that the multi-stage pond-wetland ecosystem exhibits good potential for removing different pollutants, and the effluent quality meet several standards for wastewater reuse.

Jenseen *et.al.* (2003) studied the grey water treatment in combined bio-filter/ Constructed Wetlands in cold climates. In Norway a system consisting of an aerobic bio filter followed by a subsurface horizontal flow constructed wetland has been very successful in reducing organic matter, indicator bacteria, nitrogen and phosphorus in grey water. The average influent total phosphorus concentrations (measured as STE) are about 1 mg/l and the average influent total nitrogen concentrations are in the range 8 - 10 mg/l. The aerobic bio filter prior to the wetland is essential to remove BOD in a climate where the plants are dormant during the cold season. When combined with a horizontal flow constructed wetland the concentrations of indicator bacteria in the effluent meet European standards for swimming water quality. The effluent concentrations for phosphorus are generally less than 0.2 mg/l and for nitrogen less than 5 mg/l. The two combined bio filter /constructed wetland systems require 1 - $3m^2$ surface area per person.

SandeepTayade *et.al.* (2005) studied the feasibility of treatment of municipal wastewater with pilot scale constructed wetland. The study was conducted to examine the feasibility of constructed wetland system for treatment of sewage at NEERI, Mumbai. Treatment efficiency was evaluated for parameters such as BOD, N, P, TSS and Fecal Coliform. The results indicate high removal efficiencies particularly for BOD, TSS and FC. Wetland beds were prepared with locally available plants such as elephant grasses, cattails, etc and other similar species. Constructed wetland systems offer several potential advantages as a wastewater treatment process. These advantages include simple operation and maintenance, process stability under varying environmental conditions, lower construction and operating costs.

Valerijus Asiunas *et.al.* (2005) evaluated the performance of horizontal subsurface flow constructed wetlands for removal of pollutants. They ensure the efficient removal of nutrients and organic matter. They analyzed BOD_5, N and P removal efficiency with respect to filter loads. To achieve an expected wastewater treatment level according to BOD_5 (25 mg/l), loads of filters should not exceed 5.8 g/m.d that is, the treatment of wastewater produced by population equivalent requires a filter area of 10.5 m^2. After treatment in filters total N of wastewater contains 55-85 % of mineral N while nitrite-N and nitrate-N make up 0.1 % and 3.0 % on an average; the other part is composed of ammonia-N. Increasing total N concentrations contained in water outflow predetermine higher ammonia-N amounts. If water outflow contains 10 mg/l of total N, ammonia-N makes up 51.5 %; if it contains 40 mg/l, then ammonia-N makes up 81.0 %. The average total nitrogen removal efficiency is 37- 44 %. P removal is affected by the physico-chemical characteristics of sand and qualitative composition of phosphorus contained in wastewater. P removal up to 2 mg/l from domestic and other wastewater of similar composition requires no higher than 0.15 g/m^2.d load of filters.

Harikumar *et.al.* (2006) conducted a study on treatment of wastewater using artificial wetland. An artificial wetland was constructed in The Centre for Water Resource Development and Management (CWRDM), Calicut to treat wastewater from the canteen. The wastewater was allowed to pass through six different tanks viz, sedimentation tank, skimming tank, filtration tank, storage tank, constructed wetland and finally the treated water is collected in another storage tank. The analysis of treated samples indicated that BOD is reduced to 84%. The TKN values decreased to 90 % in the final out flowing water. The total coliform is reduced to 210 MPN/100 ml from a value of greater than 2400 MPN/100ml in the inflow water from the canteen. The oil and grease is reduced from a value of 144 mg/l to 1.6 mg/l. the COD value is decreased to 60 % in the out flow water.

Manios *et.al.* (2006) studied the qualitative monitoring of waste water reuse distribution system for COD, TSS, EC and pH. During a five month summer period of their study, samples of tertiary treated wastewater flowing in an extensive distribution system composed of storage tanks and pipes were collected at two week intervals from 21 different sampling points, including the exit from the Waste Water Treatment Plant (WWTP). The samples were analyzed for COD, TSS, EC and pH. The average COD and TSS in the WWTP exit were within the reuse limits for orchard irrigation, being 80 mg/l and 25 mg/l respectively. Both recorded higher value in the other sampling points, but still as an average below the above mentioned limits. COD values along the distribution system presented a strong correlation with the WWTPs effluent quality, affected mainly by the condition of the collector, whereas TSS presented a completely different behavior. EC and pH exceeded the optimum operation and reuse guidelines, mainly due to excessive septage in the WWTP. However both presented a stable and predictable behavior in correlation to the effluent quality, in terms of both distance and time, similar to that of COD.

2.4 Effect of hydraulic retention time on performance of constructed wetland

Wolverton (1994) studied the feasibility of marshes for wastewater treatment. He reported that this bio-technology involves the use of marsh plants, micro organisms and high surface area support media such as rocks. When plants such as reed, cattails, canna, arrow-arum, pickerelweed and green taro are planted in rock filers, artificial marshes are produced which are highly biologically active. These filters can reduce BOD_5 levels in septic tank and oxidation lagoon effluents from 110-50 mg/l to 10-2 mg/l in 12 to 24 h of hydraulic retention time. These marsh filters can also reduce toxic organic chemicals such as benzene from 9 mg/l to 0.05 mg/l in 24 h in addition to removing toxic heavy metals and radioactive elements from contaminated waters.

Green (1997) experimentally deliberated the efficiency of constructed wetlands for the removal of bacteria from wastewater. Removal of E. coli and total coliforms in the subsurface flow constructed wetland was investigated in field surveys and pilot experiments. Both systems use reed beds with 5-10 mm gravel medium receiving secondary effluents. A diurnal pattern of numbers was indicated in the survey of an operational tertiary reed bed. Removal of about 1.5 to 2.5 log was found in dry weather. Removal rates fell in wet weather although no change was detected in removal of $BOD_{5,}$ TSS and ammonia N. The effect of different flow rates was compared using a pilot reed bed. A trend of increasing removal was seen between retention times of 12, 24, 48 and 120 h but variation between samples implied caution. All effluent samples from the pilot plant had less than 1000 cfu E. coli/100 ml at retention times of 24 h or more.

Merlin *et.al.* (2002) studied the performance of constructed wetlands for municipal wastewater treatment in rural mountainous area. A global performance evaluation of an experimental Horizontal Sub-Surface Flow Constructed Wetlands (HSSF) was made after 6 years of functioning. The HSSF process treatment consists in a three-stage system dimensioned for 350 People Equivalent (PE). Different helophytes were planted such as Typha latifolia, Phragmites australis and Scirpus maritimus. The mean hydraulic residence time for sewage was closed to 4–5 days, but in summer the mean pollutant residence time increases to 6 days due to evapotranspiration. There is no clogging of the gravel matrix and the hydraulic conductivity was very good and stabilized.

There was a high removal of TSS all year around with an average of 95.6 % (± 3.6). More than 80 % of removal occurred in the first stage. Physical processes (decantation, filtration) associated with biological oxidation were the principle factors of this removal. For COD and BOD_5, removal efficiency in the first stage was close to 60 % on an average and more than 90 % at the outlet of the wetland. Influence of temperature seems very weak because there were no significant seasonal variations of the process efficiency. Minimum effluent quality standards (30 mg/l TSS; 120 mg/l COD; 40 mg/l BOD_5) were always respected. In cold periods, nutrient uptake was reduced but remained up to 60 % on an average. Mean bacterial removal efficiency was about two orders of magnitude (99 %) but can reach up to five orders of magnitude in summer.

Kaseva (2004) conducted the study for evaluating the performance of constructed wetlands in polishing pre-treated waste water. He evaluated the performance of three units of a sub-surface horizontal flow CW pilot plant in polishing effluent from the UASB reactor plant. Out of the three units, unit B was planted with Phragmites mauritianus, unit C with Typha latifolia and A was used as a control. The studied parameters were chemical oxygen demand (COD), nitrate (NO_3-N), nitrite (NO_2-N), ammonium (NH_4-N), fecal coliforms (FC), total coliforms (TC), pH, temperature and dissolved oxygen (DO). The study was carried out at an average hydraulic retention time of 1.93 days (1.85 in unit A, 1.96 in unit B and 1.99 in unit C) obtained as a ratio of the volume of wastewater in the wetland and the volumetric flow rate of wastewater through the wetland unit while taking into consideration the porosity of the media.

Better performance for the vegetated units B and C were obtained compared to the control unit A. Nutrients were least removed in all units (NH_4 - N 11.2 %, 25 % and 23 % in units A, B and C, respectively, NO_3 - N 32.2 %, 40.3 % and 44.3 % for units A, B and C, respectively, and NO_2 - N 23.9 %, 38.5 % and 23.1 % for units A, B and C, respectively). The COD removal rate was 33.6 %, 56.3 % and 60.7 % for units A, B and C, respectively. The study also indicated that pH increased from the influent to the effluent and that DO increase was related to the decrease of temperature. FC and TC removal ranged from 43 % to 72 %, with the least removal in unit A.

Sylvia Toet *et.al.* (2005) studied the effect of hydraulic retention time on the removal of pollutants from sewage treatment plant effluent, in a surface-flow wetland system. They evaluated the effect of four HRT, (0.3, 0.8, 2.3, and 9.3 days) on pollutant removal in a surface-flow wetland system for polishing tertiary effluent from a STP. The removal efficiency of pollutants at these HRT^s was based on mass budgets of the water inputs and outputs in parallel ditches, which together with a pre-settling basin, made up the wetland system. Fecal coliform and N-removal efficiencies in the ditches were enhanced by increasing the HRT, with only little removal of fecal coliform during spring-summer at a HRT of 0.3 days. An HRT of 4 days turned out to be required to meet the desired bathing water standard for fecal coliform (10^3 cfu 100 mg/l) and the future standard of ammonium (1 mg/l) all year. An annual N-removal efficiency of approximately 45 % can be accomplished in the ditches at this HRT, corresponding to an annual N mass loading rate of 150 g/m^2.yr.

Annual P removal was not improved by increasing the HRT even up to 9.3 days, largely because of the still high P mass loading rate (14 g/m^2.yr) in combination with relatively low P input concentrations. Substantial P removal can probably only be achieved at HRTs longer than 15 days, which will not be feasible for the situation investigated because of the large land area that would be required to reach such long HRTs. The future P standard (1 mg/l) can therefore only be met by additional chemical P removal. They have reported that in a densely populated country such as the Netherlands, adequate polishing of tertiary STP effluent in surface-flow wetlands with similar goals as for this wetland is restricted to small and medium-sized STPs. The simultaneous use of these treatment wetlands for other functions, such as nature conservation, recreation, and flood control, however, would permit the use of relatively larger land areas.

Akratos *et.al.* (2007) studied the effect of temperature, HRT, vegetation and porous media on removal efficiency of pilot-scale horizontal subsurface flow constructed wetlands. In order to investigate the effects of parameters on the performance of horizontal subsurface flow constructed wetlands treating wastewater, five pilot-scale units of dimensions 3 m in length and 0.75 m in width were operated continuously from January 2004 until January 2006 in parallel experiments. Three units contained medium gravel obtained from a mine. The other two containing fine gravel and pebble, both obtained from a river bed. The three units with medium gravel were planted one with common reeds and one with cattails, and one was kept unplanted. The other two units were planted with common reeds. Planting and porous media combinations were appropriate for comparison of the effect of vegetation and media type on the function of the system. Synthetic wastewater was introduced in the units.

During the operation period, four HRT^{s} (i.e., 6, 8, 14 and 20 days) were used, while wastewater temperatures varied from about 2 to 26^{0}C. The performance of the constructed wetland units was very good, since it reached on an average 89, 65 and 60% for BOD, TKN and orthophosphate (P-PO_4^{-3}), respectively. All pollutant removal efficiencies showed dependence on temperature. It seems that the 8-day HRT was adequate for acceptable removal of organic matter, TKN and P-PO_4^{-3} for temperatures above 15^{0}C. Furthermore, based on statistical testing, cattails, finer media and media obtained from a river showed higher removal efficiencies for TKN and P-PO_4^{-3}.

2.5. Selection of suitable filtering media in constructed wetlands.

Sapkota *et.al.* (1994) experimentally studied the gravel media filtration as a constructed wetland component for the reduction of suspended solids from maturation plant effluent. Experiments were carried out in a horizontal gravel media filter (GMF) with media size ranging from 5 to 40 mm. Such gravel based subsurface flow units have been used in both planted and unplanted formats in a range of constructed wetland systems. The GMF was subjected to various hydraulic application rates ranging from 1 to 30 m^3/m^2.d over a period of two years. The range of suspended solids concentration was 2 to 36 mg/l and that of turbidity was 3 to 44 NTU during the experimental period. The average removal of suspended solids varied from 30 to 86 %. It was observed that SS was reduced by a maximum of 86 % at an application rate of 13 m^3/m^2.d within the above noted SS range. Their study demonstrates that a constructed wetland format with a subsurface flow and horizontal gravel media component could be used as an alternative method for reducing SS from maturation pond effluent.

Brix *et.al.* (2001) conducted studies on the Media selection for sustainable phosphorus removal in subsurface flow constructed wetlands. They stated that the sorption of phosphorus (P) to the bed sand medium is a major removal mechanism for P in subsurface flow constructed wetlands. Selecting a sand medium with a high P-sorption capacity is therefore important to obtain a sustained P-removal. The P-removal properties of sand of different geographical origin varied considerably and the suitability of the sand for use as media in constructed reed beds thus differs. The P-sorption capacity of some sands would be used up after only a few months in full-scale systems, whereas that of others would subsist for a much longer time. The most important characteristic of the sands determining their P-sorption capacity was their Ca-content. Calcite and crushed marble were found to have high P-binding capacities. It is suggested that mixing one of these materials into the sand or gravel medium can significantly enhance the P-sorption capacity of the bed medium in a subsurface-flow constructed wetland system. It is also possible to construct a separate unit containing one of these artificial media. The media may then be replaced when the P-binding capacity is used up.

Bezbaruah *et.al.* (2003) studied the performance of a constructed wetland with a sulphur/limestone denitrification section for wastewater nitrogen removal. Effectiveness of a nonvegetated lab-scale subsurface flow constructed wetland for wastewater treatment had been evaluated with the feed ammonium concentration of approximately 20-40 mg /l and a hydraulic retention time of approximately 10 d. The present system had a nitrification zone plus a sulphur/limestone (S/L) autotrophic denitrification zone followed by an anaerobic polishing zone and was operated with and without aeration. The wetland had only 80% organics removal and no net nitrogen removal when there was no artificial aeration. However, almost 100% organics removal and approximately 81-90% total inorganic nitrogen removal were achieved when the oxic zone of the system was aerated with compressed air.

S/L autotrophic denitrification contributed 21 - 49 % of total NO_3-N removal across the whole wetland and 50 - 95 % across the S/L column. Total nitrogen and NH_4^+-N in the effluent were always less than 5.5 and less than 0.7 mg/l respectively, when the feed had NH_4^+-N of less than or equal to 35mg/l. Sulfate removal of approximately 53 - 69 % was achieved in the anaerobic polishing zone. The position of the S/L column was changed (1.78, 2.24, and 2.69 m from the inlet), and no remarkable difference in nitrogen removal was observed. However, without the S/L column, TN removal decreased to approximately 74 %, and the effluent NO_3-N increased about two times (9.13 mg/l).

Joan Garcia *et.al.* (2003) conducted a study with an objective to evaluate the role of HRT and granular medium in FC and somatic coliphage (SC) removal in tertiary reed beds. Experiments were carried out in a pilot plant with parallel reed beds (horizontal subsurface flow constructed wetlands), each one containing a different type of granular medium. The microbial inactivation ratios obtained in the different beds were compared as a function of three selected HRTs. The microbial inactivation ratio ranged between 0.1 and 2.7 log units for FC and from 0.5 to 1.7 log units for SC in beds with coarser granular material (5 - 25 mm), while it ranged between 0.7 to 3.4 log units of FC and from 0.9 to 2.6 log units of SC in the bed with finer material. (2-13 mm). HRT and granular medium are both key factors in microbial removal in the tertiary reed beds. The microbial inactivation ratio rises as the HRT increases until it reaches saturation value (in general at HRT of 3 days). The value of the microbial inactivation ratio at the saturation level and SC is approximately 3 m^2/person equivalent.

Korkusuz *et.al.* (2004) studied the treatment efficiencies of constructed wetlands for domestic waste water treatment. The main objective of their study was to quantify the effect of different substrates on the nutrient removal performance of constructed wetland. According to the study, concentration based average removal efficiencies of the slag and gravel reed bed were as follows: TSS (64 and 62 %), COD (49 and 40 %), NH_4^+ (88 and 58 %), TN (41 and 44 %), TP (63 and 9 %) and PO_4^{-3}-P (60 and 4 %). In general the performance of the slag system was better than that of gravel system.

2.6. Vegetation in the constructed wetlands.

Successful performance of constructed wetlands depends on ecological functions that are similar to those of natural wetlands, which are based largely on interactions within plant communities. Constructed wetlands have aerobic as well as anaerobic treatment zones. Probably the most common misconception concerns the ability of emergent wetland plants to transfer oxygen to their roots. Emergent aquatic plants are uniquely suited to the anaerobic environment of wetlands because they can move oxygen from the atmosphere to their roots. Research has shown that some oxygen “leaks” from the roots into the surrounding soil so the adjoining portion of the root is aerobic while other portion will be anaerobic.

Hans Brix (1994) reported the functions of macrophytes in constructed wetlands. He stated that the macrophytes have several intrinsic properties that make them an indispensable component of constructed wetlands. The most important function of macrophytes in relation to treatment of waste water is the physical effects brought about by the presence of the plants. The macrophytes stabilize the surface of the beds; provide good condition for physical filtration, prevent vertical flow systems from clogging, insulate against frost in winter, and provide a huge surface area for attached microbial growth. Contrary to earlier belief, the growth of macrophytes does not increase the hydraulic conductivity of substrate in soil based subsurface flow constructed wetland. The metabolism of the macrophytes affects the treatment processes to different extents depending on the design of the constructed wetland. Plant uptake of nutrient is only of quantities important in low loaded systems. Macrophytes mediated transfer of oxygen to rhizosphere by leakage from roots increases aerobic degradation of organic matter and nitrification. The macrophytes have additional site specific values by providing habitat for wildlife and making waste water treatment systems aesthetically pleasing.

Selma *et.al.* (2001) studied the treatment of wastewater by natural systems. In their studies the batch experimental systems consist of 12 pairs of serially connected tanks, with each pair having a surface area of 1 m^2. Each set was filled with sewage once a day, and the wastewater between the paired tanks was recycled periodically by the pump. Each pair of tanks was filled with materials such as gravel, peat, and perlite. Seven of them were vegetated with Phragmites, Cyperus, Rush, Iris, Lolium, Canna, and Paspalum, while the other five were not seeded. The best performances were obtained by Iris for COD (94 %), by Canna for ammonia nitrogen (98 %), and by Iris for total nitrogen (90 %) and phosphorus (55 %) removal.

Marco *et.al.* (2002) studied the feasibility of ornamental plants in constructed wetlands for treating domestic wastewater. Treatment of wastewater is not a priority in most developing countries unless communities can derive economic benefit from the water resources that are created by the treatment process. As part of their studies directed at improving the quality of water in the Rio Texcoco in central Mexico, they have determined the feasibility of using ornamental flowers for treatment of domestic wastewater. In a laboratory-scale study, they planted calla lilies. Subsurface flow wetlands planted with calla lilies could reduce levels of ammonia and nitrate in simulated domestic sewage. Floriculture activities in constructed wetlands could provide the economic benefits necessary to encourage communities in developing countries to maintain wastewater treatment systems.

There are different types of macrophytes for wetland systems like free floating aquatic, rooted floating aquatic, submerged aquatic, and emergent aquatic. The different type of vegetation and its parts have different functions regarding waste water in wetlands.

Kanabkaew *et.al.* (2004) studied the feasibility of aquatic plants in domestic waste water treatment. A pilot scale aquatic pond, with dimensions of 1.8 m in length, 0.6 m in width and 1.2 m in depth, was constructed at the Hat Yai Municipality Central Wastewater Treatment Plant, Thailand. Wastewater was introduced to the systems using peristaltic pumps to maintain a fixed flow rate at HRT of 5.4 and 10.5 days, respectively. Lotus (Nelumbo nucifera) and hydrilla (Hydrilla verticillata) were planted along with one control unit. Influent and effluent were analyzed for pH, SS, BOD_5, TKN, NH_3-N, NO_2-N, NO_3-N, TP and Coliform bacteria twice a week. The results showed that ponds with aquatic plants were superior to those without plants. The system with lotus showed the best removal efficiency for wastewater treatment. For the system with hydrilla, it was found that pH and SS of the effluent were high. It might not be suitable to use hydrilla for effluent polishing. This study could emphasize that lotus and hydrilla could provide an alternative aquatic plant system for wastewater treatment.

The following table describes the general types of plants and its importance in proper functioning of constructed wetlands.

Table 1 Characteristics of plants for constructed wetlands.

General classification	Role in the Treatment Process	Function
Free-Floating Aquatic e.g. Duckweed (Lemna),	Primary purposes are nutrient uptake and shading to retard algal growth. Dense floating mats limit oxygen diffusion from the atmosphere. Duckweed will be present as an invasive species.	Dense floating mats limit oxygen diffusion from the atmosphere and block sunlight from submerged plants.
Rooted Floating Aquatic e.g. Water lily (Nymphea), Pennywort (Hydrocotyle).	Primary purposes are providing structure for microbial attachment and releasing oxygen to the water column during daylight hours. Dense floating mats limit oxygen diffusion from the atmosphere.	Dense floating mats limit oxygen diffusion from the atmosphere and block sunlight from submerged plants.
Submerged Aquatic e.g. Pondweed (Potamogeton) Water weed (Elodea)	Primary purposes are providing oxygen to the water column during daylight hours.	Plants provide shelter and food for animals (especially fish).
Emergent Aquatic e.g. Canna (Cannaceae), Cattail (Typha)	Primary purpose is providing structure to induce enhanced flocculation and sedimentation. Secondary purposes are shading to retard algal growth and insulation during winter month.	Plants provide shelter and food for animals. Plants provide aesthetic beauty for human eyes.

Materials and Methods

CHAPTER III

MATERIALS AND METHODS

Constructed wetlands are attractive bio-remedial techniques for on-site domestic waste waters. They are also called artificial wetlands and are the cheapest option among the waste water treatment methods. It can be easily operated and maintained and have a strong potential for application in developing countries like India. Proper design and construction is necessary for better efficiency of the system. To study the feasibility of this environment friendly technology, a small, pilot scale SCW system was designed; developed and short term evaluation was carried out through the present study.

This chapter broadly encompasses the steps to be adopted to achieve the set of objectives in light of basic background data, location of experimental site and its characteristics features and climate.

3.1 General description of the study area

The experimental site was selected in the KCAET farm to which grey water from the selected source of Men's Hostel was diverted. The area is located at 10^0 52' 30" North Latitude and 76^0 East longitude. The average annual rainfall of about 2000 mm is received in this region from both south-west (SW) and north-east (NE) monsoon. The south-west (SW) monsoon occurs during June to September and north-east (NE) monsoon occurs during October to December. The minimum and maximum temperature prevails between 22^0C and 32.5^0C while average annual relative humidity is about 83 %. Meteorological data of the study area for the period of study is as appended in Appendix I.

The site was selected on the basis of easy availability and conveyance of grey water to the area. The selected site is at lower level than the source of grey water and hence desired water can easily be conveyed through pipes by using gravitational force thus avoiding the energy costs of pumping. The Men's Hostel bathrooms and washing area was selected as source of grey water. The waste water coming from these sources contain hair, soap and detergent contents (Na, Mg, B, phosphates, sulphates etc) and small quantity of oil, lint and dust particles along with bacteria.

3.2 Grey water Characterization for the design of SCW

To design any waste water treatment system, detailed analysis of quality of raw waste water is of prime importance. This investigation includes the analysis of waste water characteristics like pH, EC, TDS, salinity, TC and BOD_5.

To design the present SCW system, bathroom and washing area outlets of Men's Hostel were connected together to obtain mixed grey water from single point which will also help to convey it to the experimental site. Grey water samples were collected from the combined outlet at peak use periods (7 AM to 8 AM) of bathrooms for continuous three days. These samples were tested for pH, EC, TDS, salinity, TC and BOD_5 at the Central Water Analysis Laboratory (CWAL) located at the Centre for Water Resources Development and Management (CWRDM), Kozhikode using standard procedures. The SCW system was designed on the basis of influent BOD_5 of the grey water. The general procedure used for analysis of BOD_5 and DO is as follows:

3.2.1 Biological oxygen demand

Biological oxygen demand (BOD_5) is the measure of oxygen required by micro-organisms for the biological degradation of the organic matter present in the waste water. It is the most widely used parameter to check the organic pollution. The different apparatus and reagents used for the analysis and their preparation procedures are as given in the Appendix II.

Procedure

The dilution water was prepared at the rate of 1000 to 1200 ml per sample per dilution using the distilled water (DW). The dilution water was brought to the normal room temperature of 27 ^{o}C. The distilled water was saturated with air by shaking in a partially filled bottle, by bubbling with organic free filtered air or by storing in cotton plugged bottle for a day. Some water samples may not contain microbial population, for such wastes the dilution water can be seeded using effluent from a biological treatment system. Where this is not available, supernatant from domestic waste water after settling, at least for one hour but not more than 36 hours can be used. Enough seed volume can be added such that the DO uptake of the seeded dilution water is between 0.6 and 1.0 mg/l. For domestic waste water seed, usually 4 to 6 ml seed per litre of dilution water can be added. While the surface water sample usually do not require seeding.

Dilution of sample was done in such a way that the residual DO of at least 1 mg/l and a DO uptake of at least 2 mg/l can be obtained. For the grey water samples under consideration 50 times dilution was used. For preparing dilution a graduated cylinder of 1 litre capacity was used. The dilution water was siphoned in measuring cylinder to avoid presence of any air bubbles. The screw pin on the tube was used to regulate the flow. The cylinder was filled with DW to half the required volume i.e. up to 350 ml and then desired quantity of grey water sample (17 ml for the 50 times dilution) was added by another siphon tube followed by siphoning of DW to a level of 700 ml. Siphon mixed diluted grey water samples were filled in two BOD bottles and closed with stopper without entering any air bubble. The initial DO was determined as the procedure given in coming pages on one bottle while other two bottles were kept in the incubator at 20^{0}C for 5 days. The final DO was determined after 5 days of incubation.

Calculation

- When dilution water is not seeded BOD_5 (mg/l) =

$$\frac{(D_o - D_t)}{P}$$

- When dilution water is seeded BOD_5 (mg/l) =

$$\frac{[(D_o-D_t) - F \times (B_o-B_t)]}{P}$$

Where D_o = DO of diluted sample initially, mg/l

D_t = DO of diluted sample after 5 days of incubation at 20^oC, mg/l

P = decimal volumetric factor of sample used.

B_o = DO of seed control initially, mg/l

B_t = DO of seed control after incubation, mg/l

F = ratio of % seed in diluted sample to % seed in seed control

For the design purpose, three influent grey water samples were analyzed for BOD_5 but the system was designed for the badly polluted water i.e. for the maximum BOD_5.

3.2.2 Dissolved oxygen

Dissolved oxygen was analyzed by the Winkler's or Iodimetric method. The common principle in determination of DO, different apparatus and reagent used for analysis with their preparation procedure are as given in Appendix II.

Procedure

The diluted grey water sample was collected in BOD bottle with the help of DO sampler or siphon tubes. Later 2 ml manganese sulphate followed by 2 ml of alkali iodide azide reagent was added to BOD bottle with care that the tip of the pipette should be below the liquid level. The reagents and sample were mixed well by inverting the bottle 2 to 3 times and the precipitate was allowed to settle by leaving approximately 150 ml clear supernatant. At that stage, 2 ml of concentrated sulphuric acid was added and mixed well till precipitate goes in to solution. Then solution in BOD bottle was taken in a conical flask and titrated against sodium thiosulphate using starch as an indicator.

Calculations

1 ml of 0.025 N thiosulphate = 0.2 ml of oxygen

Dissolved oxygen (mg/l) =

$$\frac{(0.2 \times 1000) \text{ thiosulphate used for titration (ml).}}{200}$$

Dissolved oxygen was determined for all the collected samples as it is coupled with BOD_5 analysis.

3.3 Design of Subsurface flow constructed wetland

SCW is a natural waste water treatment system that combines biological treatment (consumption and conversion of organic matter to gases like CO_2, CH_4), chemical treatment (coagulation and settlement) and physical treatment (filtration). SCW is a properly designed impervious basin that contains water, filter substrata, vegetation and attached micro organisms.

3.3.1 Components of SCW

The details of main components of the SCW system namely basin, filter substrata and vegetation are briefly explained under this title.

Basin

SCW is generally constructed as an impervious basin, anywhere except existing natural wetlands by shaping the land surface to collect the surface waste water and by sealing the basin to retain the water for sufficient period of time without seepage and percolation. The basin usually consists of three compartments namely inlet section, filtering media and outlet section. In the inlet section the influent waste water was spread along the width of SCW system. From the inlet section it slowly entered in to filtering section and majority of suspended solids got either consumed by micro organisms or physically filtered in to the filtering section. The filtering section can have presence of phosphorous and other chemical arresting materials like calcium or aluminum salts. Also the filtering section had macrophytes which provided place for micro-organisms to grow on their roots and absorb many nutrients present in waste water for their physical growth. From the filtering section the waste water can move towards outlet section and finally to the effluent collection tank.

Filter substrata

The filter substrata in SCW can be locally available materials like soil, sand, crushed bricks, marble pieces, stones, gravel and pebbles. The bed material should have good adsorption and hence filtration quality. More surface area of filter material results in increase in the reaction constant of the material which is essential for chemical decay of pollutants. As stated earlier, in the present study, inlet section was filled with crushed bricks, filter section was filled with fine sand and lime mixture with soil layer at top and outlet section was filled with crushed stones (plate 3).

The filter media physically filters the waste water to remove any suspended solids present in it. It supports most of the organisms within the bed. The macrophytes which have the major role in water purification are supported by the same substrata. The filter material also supports the micro-organisms which play an important role in bio-degradation of waste material.

Vegetation

The emergent plants most frequently found in wetlands are Cannas, cattails, reeds, rushes, bulrushes, sedges etc. The macrophytes stabilize the surface of bed, provide good condition for physical filtration, prevent vertical flow system from clogging, insulate against frost in winter and provide huge surface area for attached microbial growth. Macrophyte roots transfer oxygen to the rhizosphere by leakage from roots which increase nitrification and aerobic degradation of organic matter. Also plants remove some of the pollutants like superfluous nitrogen and phosphorous from the waste water by absorbing the same for their vegetative growth.

In many parts of world, Canna is used as macrophyte due to its aesthetic appearance. In the present study Canna was used as the macrophyte in the SCW as it has attractive flowers and tall green foliage which is generally used in the gardens as floricultural crop (Plate 2 and 4).

3.3.2 Design elements of SCW

In this section of the chapter, major design elements of the SCW are discussed. The prime design elements considered are given below:

- Site selection for SCW
- Hydraulic design of SCW
- Area computation
- Retention time computation

Plate 3 shows the different materials used in the inlet, filter and outlet section of SCW while plate 4 shows the densely grown Canna macrophyte in the wetland.

Inlet **Filter** **Outlet**

Plate 3 Different materials used in the SCW system.

Plate 4 Densely grown Canna macrophyte in wetland

Site selection for SCW

For the present study, subsurface flow constructed wetland system was taken up to its merits over the other conventional costly and energy consuming engineered systems. Following points were considered for site selection of the SCW:

- Availability and easy conveyance of grey water
- Site topography

There was availability of massive amount of grey water from the Men's Hostel of KCAET. So it was decided to divert the randomly selected quantity of 110 l/d towards SCW for purification. The experimental site where SCW was installed is in the low lying area below the outlet of grey water source. Grey water from the source is conveyed through PVC pipes to the initial settling tank. The alignment of SCW was kept in such a way that it supports the gravity flow of grey water throughout the system. This in tern eliminated electricity charges for pumping and hence feeding the grey water to the system and also collection of effluent from the outlet section.

Hydraulic Design of SCW

Hydraulic Design of SCW is the determination of its total area, aspect ratio, bed slope and depth to achieve the expected performance level. Following data were required to design the SCW.

- Waste water inflow
- Influent BOD_5
- Required / expected effluent BOD_5
- Characteristics of filter media (porosity and reaction constant)
- Root depth of proposed macrophyte

For the design of SCW all the above mentioned data/parameters were collected by conducting laboratory experiment and direct analysis of grey water sample and from literature.

Inflow of influent

For the present study the inflow rate from the source was too large, which was difficult to handle in small experimental scaled SCW. So the arbitrarily selected quantity i.e. 110 l/d was diverted towards the SCW and remaining flow was bypassed using overflow pipe from the settling tank. The grey water from the source was first collected in the settling tank which was provided with three outlets. From the middle outlet flow was diverted to the SCW while top and bottom outlets were interconnected to bypass overflow and to flush the settling tank respectively.

Influent BOD_5

For design of any waste water treatment, BOD_5 of influent water is necessary. The waste water sample analysis showed that the maximum BOD_5 in the influent grey water was 85 mg/l at normal room temperature.

Effluent BOD_5

As per the EPA recommendations BOD_5 of the effluents directly released to the natural water streams should not exceed 20 mg/l. Efficient SCW can reduce BOD_5 even below this level. Properly designed and managed, subsurface flow constructed wetlands can reduce the BOD_5 of the effluent as low as below 5 mg/l. The macrophyte root in the wetland, itself is organic material which can decompose and add some BOD_5 to the effluent. Hence with reference to available literature, the effluent BOD_5 for this design of SCW was assumed as 5 mg/l.

Characteristics of filter media

Generally, it is advisable to use locally and cheaply available material as filter media. The media properties such as grain size, hydraulic conductivity, porosity and reaction constant should be considered for scientific design. Also the material should support the vegetation growth. For the present study, fine sand with soil layer at top was used in the filter section. The porosity of these materials was determined by means of laboratory experiment by using standard procedure as given below.

Determination of porosity of filter media

For the determination of porosity, known weight of filter material was taken in the standard measuring jar (1000 ml) to the fixed mark and initial weight and volume (W_1 and V_1) was taken. Then the jar was filled with normal water up to top surface of material such that there was no ponding of water above the sand surface in the jar. Subsequently the weight W_2 was taken. The difference in weight (W_2 -W_1) is the weight of water in the pores of filter material in the jar. From the relation of density and weight, volume to water present in voids (V_2) was found out and hence the porosity of the concerned material was calculated by the formula

$$n = \frac{V_2}{V_1} 100$$

Where n = Porosity of material, %

V_1= Total volume of material, cm^3

V_2 = Volume of voids, cm^3

Root depth of proposed macrophyte

Macrophyte is one of the major components of SCW which affect the treatment efficiency. “Canna” is universal in distribution, tough, capable of thriving under diverse environmental conditions, nutrient loving and easy to propagate. Also the rhizomes planted at wider distances can produce dense population in a short period of time. This study was undertaken to check the feasibility of SCW for on site grey water treatment. So it was desirable to use attractive ornamental vegetation in SCW. Considering all above points, Canna was selected as SCW vegetation. The roots of these plants generally penetrate up to a depth of 40 to 45 cm in its supporting media.

3.3.3 Hydraulic design.

When subsurface flow conditions are expected in the SCW bed it is common practice to use Darcy's law, which describes the flow regime in a porous media. Darcy's law is defined as follows.

$$Q=K_s\, i\, A \qquad (3.1)$$

Where,

Q = flow per unit time, m^3 /d

K_s = hydraulic conductivity of a unit area of the medium perpendicular to flow direction, $m^3/m^2/d$

A = total cross-sectional area, perpendicular to flow, m^2

i = hydraulic gradient of the water surface in the flow system, dh/dl, m/m

Darcy's law is not strictly applicable to subsurface flow wetlands because of physical limitations in the actual system. It assumes laminar flow conditions, which may not be the case when large rock or very coarse gravel is used as the media. Turbulent flow will occur in these coarse media when the hydraulic design is based on a high hydraulic gradient. Darcy's law also assumes that the flow (Q) in the system is constant and uniform, but in the actual case in a SCW the input versus output Q may vary due to precipitation, evaporation and seepage. Short circuiting of flow may occur due to unequal porosity or poor construction.

All of these factors limit the theoretical applicability of Darcy's law, but it remains as the only reasonably accessible model for design of these SCW systems. The Darcy's law can provide a reasonable approximation of the hydraulic conditions in this SCW beds if-

- Small to moderate sized gravel (< 4 cm) is used as the media
- The system is properly constructed to minimize short circuiting
- The system is designed to depend on a minimal hydraulic gradient
- The Q in equation (3.1) is considered to be the "average" flow [(Q_{in} +Q_{out})/2] in the system to account for any gains or losses due to precipitation, evaporation or seepage.

Aspect ratio and bed slope

The aspect ratio (L :W) of the wetland bed is a very important consideration in the hydraulic design of SCW wetland systems, since the maximum potential hydraulic gradient is related to the available depth of the bed divided by the length of the flow path. The hydraulic gradient (i factor in equation 3.1) defines the total head available-in the system to overcome the resistance to horizontal flow in the porous media. EPA has recommended the bed slope of SCW as 0.5 to 1 %. But practically it is very difficult and probably impossible with SCW systems to precisely design and construct the bed for a specific hydraulic gradient. This is due to variabilities in the media used and in construction techniques, and the potential for longer term partial clogging.

In addition, the construction of a bed with a sloping bottom provides no flexibility for future adjustments. Greater flexibility and control is possible with an adjustable outlet which permits control of the water level over the entire design depth of the bed. In this case, the bottom of the bed could be flat or with a very slight slope to ensure drainage, when required. However because of the hydraulic gradient requirements, aspect ratio (L: W) should be relatively low i.e. in the range of 0.4: 1 to 3:1 to provide the flexibility and the reserve capacity for future operational adjustments. For the present study the bed slope was kept nearly flat with an adjustable outlet to maintain the 45 cm depth of water in the filtering bed.

BOD removal

A first order plug flow model for BOD_5 removal has been used by a number of environmental and biological engineers for design of SCW systems. The general form of the model is as presented below:

$$\frac{C_e}{C_i} = e^{-K_T t} \qquad (3.2)$$

Where, C_e = effluent BOD_5, mg/l

C_i = influent BOD_5, mg/l

K_T = temperature dependent rate constant, d^{-1}

$= K_{20} (1.06)^{(T-20)}$

K_{20} = rate constant at 20 ^oC

T = temperature of liquid in the system, ^oC

t = hydraulic residence time, d

The rate constant K_{20} equal to 1.104 d^{-1} is suggested by EPA. This value is believed to be conservative and is associated with an apparent organic loading on the system of about 110 kg/ha/d. Also EPA has recommended that, as a safety factor, use a rate constant K_{20} = 0.828 $d^{-1,}$ which is 75 percent of the base value (1.104 d^{-1}). The effluent BOD_5 in equation 3.2 is, as previously discussed, influenced by the production of residual BOD within the wetland from decomposition of plant detritus and other naturally occurring organics. This residual BOD is typically in the range of 2 to 7 mg/l. As a result, equation (3.2) should not be used for designs for a final BOD less than 5 mg/l.

The "t", hydraulic resistance time (HRT) factor in equation (3.2) can be defined as follows:

$$\text{HRT, } t = \frac{L \text{ x } W \text{ x } n \text{ x } d}{Q}$$

$$= \frac{A_s \text{ x } n \text{ x } d}{Q} \qquad (3.3)$$

Where, L = Length of bed, m

W = Width of bed, m

n = porosity of the media, %

d = Average depth of liquid in the bed, m

Q = Average flow through the bed, m^3/d

A_s = Surface area of the SCW, m^2

The Q value in equation (3.3) is the average flow in the bed to account for precipitation, seepage, evapotranspiration and other gains and losses of water during transit of the bed. This is the same value used in Darcy's law for hydraulic design. The d value in equation (3.3) is the average depth of liquid $[(d_{inlet} + d_{outlet})/2]$ in the bed.

Putting Equation 3.3 in Equation 3.2,

$$\frac{C_e}{C_i} = e^{-K_T \frac{As x n x d}{Q}} \qquad (3.4)$$

Solving Equation 3.4 for A_s,

$$A_s = \frac{Q\,[\ln C_i - \ln C_e]}{K_T\,.\,d.\,n} \qquad (3.5)$$

In the present study the surface area of SCW was computed using equation 3.5.

Figure 3 depicts the schematic view of the SCW system.

Step by step procedure for design

The final design and sizing of the SCW bed for BOD removal is an iterative process, the general design steps for the design of SCW are as given below:

- Determine the media type, vegetation, and depth of bed to be used.
- Determine by field or laboratory testing the porosity (n) and hydraulic conductivity (K_s) of the media to be used.
- Determine the required surface area of the bed, for the desired level of BOD_5 removal, with equation (3.5).
- Depending on site topography, select a preliminary aspect ratio (L: W) in the range of 0.4: 1 up to 3: 1.
- Determine bed length (L) and width (W) from the previously assumed aspect ratio and results of step 2.
- Using Darcy's law (equation 3.1) with the recommended limits (K_s< 1/3 of effective value, hydraulic gradient S < 10 % of maximum potential) determine the flow (Q) which can pass through the bed in a subsurface mode. If this Q is less than the actual design flow, then surface flow will occur. In that case it is necessary to adjust the L and W values until the Darcy's Q is equal to the design flow.

- It is not valid to use equation 3.4 with effluent BOD (C_e) values below 5 mg/l. As previously discussed, these wetland systems export a BOD residual due to decomposition of the natural organic detritus in the system.

3.4 Fabrication of the subsurface flow constructed wetland

As stated earlier SCW system is an artificial marshland with impervious liner to avoid the water losses from the system. For the present experimental study the SCW system was made with 12 gauge MS sheet. The wetland tank was fabricated in the KCAET, workshop. The SCW system was designed as per procedure given in section 3.3 and for the required dimensions metal sheet was cut using mechanical metal sheet cutter. Afterwards, the tank was fabricated by joining different metal sheets by welding. The basin was made with MS sheet having three distinct sections. All three sections were separated by metal sheets in the form of baffles to make zigzag path of flow and to increase the length of travel of grey water in the wetland thus ensuring maximum microbial activity and absorption of nutrients by the plant roots.

In the inlet section influent grey water was spread along the width of treatment system. A PVC pipe with holes was used along the width of the inlet section to spread the waste water. The inlet section having two compartments was filled with crushed bricks of an average grain diameter 3 cm. The crushed brick was selected, as it has the property of adsorption of suspended solids present in waste water. Waste water from the inlet section slowly enters the filtering media and travels towards the outlet section. The filtering section consisted of two sections separated by metal sheet. The bottom 45 cm depth of filtering section was filled with sand mixed with lime above which 10 cm soil layer was placed for vegetation anchorage and root development.

With reference to available literature, calcium, aluminum or iron salts have phosphorous binding capacity and can be added in the filtering media, but the quantity to be added is not recommended by any author. For the present study as a trial, lime was mixed with sand, one percent by weight of sand. The lime is alkaline in nature and mixture of sand and lime can make effluent water alkaline as observed in the present study. Further detailed study is required to quantify the amount of lime in filtering media. Nearly all suspended solids get either consumed or converted to gases like CO_2 and CH_4 by the micro organisms attached to the filtering media and roots of vegetation.

The outlet section consists of PVC pipe, with holes at the bottom of the section and adjustable outlet to collect and convey water from outlet section to the collection tank. The outlet section was filled with crushed stones having average diameter of eight mm. The media in the outlet section was selected by considering the easy movement of effluent water from media to the outlet pipe and absence of suspended sand particles in effluent water to the collection pipe. The outlet section is provided with adjustable outlet to maintain the depth of water in SCW.

3.5 Field set-up of the subsurface flow constructed wetland

Based on previous design the wetland was designed, fabricated and was installed in the KCAET, instructional farm. All the three tanks namely settling tank, SCW system and effluent collection tank were arranged in such a way that the gravitational flow was followed throughout the system. The influent grey water from the combined outlet was collected in settling tank which was provided with three outlets. The top and bottom outlets of the settling tank were joined at bottom to facilitate the bypass of extra flow and flushing of tank whenever required. The middle outlet was diverted to the inlet section of SCW. In the inlet section initially settled influent grey water was spread over the width of system.

The SCW system tank was kept at an elevated position on an angle iron stand. The SCW tank was elevated to facilitate the easy collection of effluent from wetland and draining the whole system whenever required. The outlet section of

SCW system was provided with PVC pipe with holes at bottom, which was further attached to the adjustable outlet to maintain the desired water level in the system. The effluent water from SCW system was collected in another plastic tank. Effluent collection tank had outlet with valve at bottom to ease the drainage of extra water after irrigation from the collection tank.

3.6 Performance evaluation of the subsurface flow constructed wetland

In the present study, the performance of SCW system was evaluated by analyzing the influent samples collected before and after settling and effluent from the wetland. Two crops namely Amaranthus and Golden Duranta were also irrigated with raw and treated grey water. Biometric observations viz. height, number of leaves, stem thickness, canopy spread and yield of these plants were recorded and data collected were statistically analyzed.

3.6.1 Sample collection and analysis

The major objective of this study was to evaluate the performance of constructed wetland for the removal of pollutants, hence grey water samples were collected and analyzed before and after settling and also the effluent from the constructed wetland.

Plate 5 shows the complete field set-up of the SCW system consisting of the settling tank; SCW system and effluent collection tank with potted plants while plate 6 illustrate the dense and vigorously grown roots of Canna macrophyte in the SCW system in the present study.

Plate 5 Field set up of SCW system.

Plate 6 Dense and vigorously grown roots of Canna macrophyte in SCW system.

Three set of grey water samples were collected and analyzed at CWAL attached to the CWRDM, Kozhikode for its TSS, BOD_5, TC, sulphates, phosphates and TKN according to standard procedures as described. Each subset of sample consisted of three samples namely influent before and after settling and effluent from the SCW, i.e. the total number of samples analyzed for the performance evaluation of SCW system was 27. All the collected samples were immediately carried to the laboratory and kept under refrigeration to avoid the degradation of collected water quality. The BOD_5 and DO was analyzed with the procedure given in section 3.2 while the sulphates, phosphates and TKN were analyzed with the procedure given herewith.

3.6.1.1 Sulphate

The common principle, apparatus and different reagents used for determination of sulphate with their preparation procedure are given in Appendix II.

Procedure

The selected quantity (25 ml) of grey water sample was taken in a 100 ml conical flask. Then 1.25 ml conditioning reagent was added and mixed thoroughly by shaking. Afterwards a pinch of barium chloride crystals was added and stirred well for 1 min.

Immediately after the stirring period has ended, some of the solution was poured to the absorption cell of the photometer and turbidity was measured at 30 sec. intervals for 4 min.

The sulphate concentration was estimated by comparing the turbidity reading with a calibration curve prepared by carrying the sulphate standards.

For all the samples collected for performance evaluation of SCW system, the sulphate concentration was found with the said procedure and reduction to the initial values was checked on percentile basis.

3.6.1.2 Phosphates

The common principle in determination of phosphate and different reagents used for analysis with their preparation procedure are as given in Appendix II.

Procedure

The selected quantity i.e. 50 ml of sample was taken and 2 ml ammonium molybdate solution was added followed by 5 drops of stannous chloride solution. After 10 minutes but before 12 minutes, the colour of solution was measured using spectrophotometer at 690 nm. The standard graph was prepared by diluting appropriate volumes of phosphate working solution. From the graph slope of the line was found out. Then phosphate concentration was calculated by the following formula.

Calculations

$$\text{Phosphate concentration (mg/l)} = \frac{\text{Measured colour using spectrophotometer at 690 nm.}}{\text{Slope of the graph}}$$

For all the samples collected for performance evaluation of SCW system, the phosphate concentration was found with the said procedure and reduction to the initial values was checked on percentile basis.

3.6.1.3 Total Kjeldahl nitrogen

Total nitrogen also called as total Kjeldahl nitrogen (TKN) is the sum of ammonia nitrogen and organic nitrogen. This does not include nitrate and nitrite. The classical Kjeldahl method is used to determine the total nitrogen content. The general principle and different reagents used for determination of total nitrogen are as given in Appendix II.

Procedure

Digestion

An appropriate volume i.e. 100 ml of sample was taken in a Kjeldahl flask. It was diluted to about 200 ml with ammonia free distilled water. 10 ml concentrated H_2SO_4 and 1 ml copper sulphate was added to the solution. If organic matter is hard to destroy, 20 ml H_2SO_4 and 5 gm potassium sulphate also can be added. Few glass beads were added and boiled under hood until the solution becomes clear. Then the solution was digested for an additional 30 minutes and allowed to cool.

Distillation

The contents of digestion flask were transferred to a distillation flask and diluted to about 300 ml. The solution in the flask was made alkaline with sodium hydroxide using phenolphthalein indicator. The distillation was started after immersing the tip of condenser in 50 ml boric acid solution in a conical flask. About 200 ml of distillate was collected and used for further titration.

Titration

0.5 ml methyl red indicator solution was added to the distillate. Then the colour of the solution turned to yellow. This solution was titrated against 0.02 N sulphuric acid. The end point was the appearance of red colour. Same procedure was conducted for digestion and distillation for the blank also.

Calculation

Total Kjeldahl nitrogen (mg/l) =

$$\frac{1000 \times 0.28 \times 0.02 \text{ N } H_2SO_4 \text{ for (sample - blank) (ml)}}{\text{Sample taken for titration (ml)}}$$

The TKN was analyzed for all the samples collected for the performance evaluation of the SCW system except samples colleted for the design of the system. Finally the performance was evaluated on the basis of percentage reduction of the TKN to the initial concentration of influent grey water before settling.

3.6.1.4 Total coliform

The density of the total coliform was measured by the most probable number (MPN) technique.

Procedure

The Macconkey broth solution was prepared by dissolving the broth crystals to the warm distilled water. Two solutions was prepared for two strengths, namely single strength and double strength by dissolving 40 gm and 80 gm of broth crystals to 1 litre of warm distilled water respectively. Then the prepared double strength broth solution was filled in three test tubes and single strength broth solution was filled in six test tubes, 10 ml in each. Before putting the broth to the test tubes all the tubes were sterilized properly to avoid any residual bacteria in it. Furthermore the double strength tubes were inoculated with 10 ml of grey water samples. While the three single strength tubes were inoculated with 1 ml and rest three tubes with 0.1 ml of grey water samples.

The inoculation was carried out inside the sterilization cabin in the presence of ultra violet light. Later the small glass tube with one end closed (called Durams tube) was put with open end downward in each test tube and was inverted and shaked for some time to expel out all the air from Durams tube. Later test tubes were closed with cotton plug. Then all the test tubes were kept in incubator for 48 hours at 37.5^{0}C. After the incubation period test tubes were taken out and the Durams tubes were observed for the presence of air bubbles inside it. The number of tubes for the presence of air bubbles in each group of inoculated samples were observed and noted down. The bacterial density was read from the standard table recommended by APHA as given in Appendix V.

Plate 7 and 8 shows the two stage distillation unit used for getting distilled water and experimental set of distillation unit in determination of TKN. While plate 9 and 10 shows the filtration unit in determination of TSS and photoelectric colorimeter used in determination of phosphates.

3.6.2 HRT studies

To confirm the effect of HRT on performance of pollutant removal, three set of samples were collected. These samples were analyzed for TSS, BOD_5, TC, sulphates, phosphates and TKN for different HRT with the procedure described under section 3.2 and 3.6. Due to the financial limitations the number of samples in each set was restricted to five with HRT of 1, 2 3, 4 and 5 days. So the total number of samples analyzed for the HRT study was 15.

Before collection of these samples all the water from the wetland was drained through the PVC pipe provided at the bottom of the system. Then wetland was filled up to depth of 45 cm with the initially settled grey water. The grey water was stored in wetland for the required HRT, and whenever required collected from the outlet provided at the bottom of SCW system. All the samples collected for HRT study were carried to the laboratory and stored in the refrigerator to avoid the degradation of water quality.

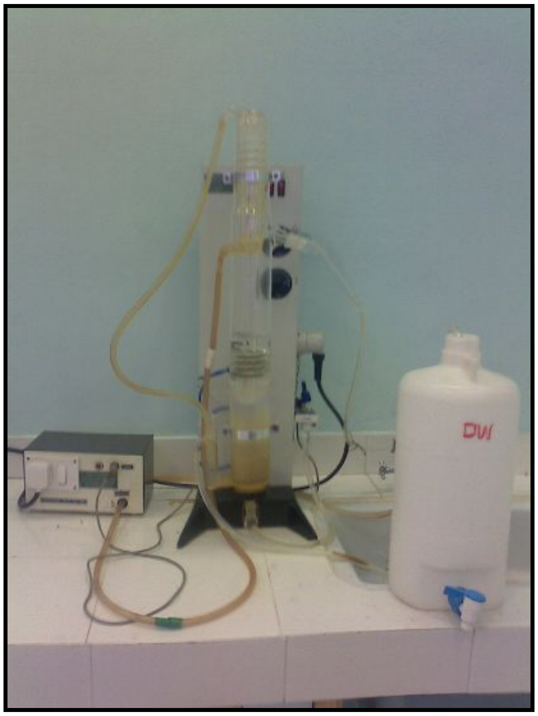

Plate 7 Two stage distillation Unit.

Plate 8 Experimental set up for distillation in determination of TKN.

Plate 9 Filtration unit for determination of TSS.

Plate 10 Photoelectric colorimeter used for determination of Phosphate.

3.7 Irrigation and biometric observations of irrigated plants

As stated earlier raw waste water handling and reuse is not safe for human, soil, crop and environmental health. Direct reuse of waste water for irrigation can cause many detrimental effects on the soil and crop quality. From the available literature it can be said that direct reuse of waste water is not safe even for pasture irrigation, as it can cause viral infection to direct (animal) and indirect (human being) consumers. Generally raw waste water consists of higher concentration of nitrates, nitrites, sulphates, phosphates along with certain heavy metals like Fe, Mn, Zn, Cu, B, Mo and Cd. Also commonly pH of domestic waste water is acidic; the direct reuse of this contaminated water for irrigation can reduce the nutrient uptake of plants resulting in reduced growth and yield.

Enough literature is available on raw waste water irrigation and its effects on soil and crop properties. But research on grey water treatment and its reuse for irrigation to study effects on soil and crop was not given enough importance at least in the developing countries like India. To pick out the effect of raw grey water irrigation on crop for its biometric parameters like height, weight, number of leaves and stem thickness, one vegetable crop (Amaranthus) and one ornamental crop (Golden Duranta) were irrigated in clay pots.

For this study Amaranthus and Golden Duranta plants were transplanted in clay pots filled with soil and decomposed cow dung manure. For the raw grey water irrigation three pots were planted with Amaranthus, where each pot had three plants. Similarly three pots were planted with Golden Duranta plants with one plant in each pot. The same set of plants was replicated for treated grey water irrigation. To demonstrate the effect of irrigation with same quantity of water, all the pots were irrigated with one litre of water per day. After planting, the plants were irrigated with fresh water for one week for the development of roots. The growth of Amaranthus and Golden Duranta plants were monitored by noting the biometric observations as explained below.

3.7.1 Plant height

The plant height of Amaranthus and Golden Duranta plants were measured from the soil surface in the pots to the top of foliage. The ordinary measuring scale was used to measure the height. For all the cases, the height was measured at the time of harvest of Amaranthus.

3.7.2 Vegetative growth

The number of leaves of Amaranthus plants was counted at the time of harvest of Amaranthus. As Golden Duranta plant is not an edible crop and also number of leaves doesn’t have significant effect on appearance, the leaves were not measured. For Golden Duranta instead of number of leaves the appearance was observed.

3.7.3 Stem thickness of plants

Stem thickness of the both the crops were measured at the time of harvesting of Amaranthus plants. The thickness of stem was measured just above the soil surface. A common scale was used to measure the same. For measurement the scale was held perpendicular to the eye sight and reading was read from the possible maximum distance from the plant to avoid bias in the actual size of stem.

3.7.4 Canopy spread

Canopy spread is the area covered by particular plant. It was measured by noting the distance of plant foliage at maximum length and perpendicular to it. Later canopy area was calculated by means of formula for area of circle by taking average value of two measured dimensions as diameter.

3.7.5 Yield

Yield of Amaranthus plants was noted at every harvest. Every time these plants were harvested before the emergence of flowers. While harvesting, the matured, edible portion of plant was picked out with the help of sharp knife. At the same time care was taken that some leaves were left back for photosynthesis and growth of remaining portion of plant. Finally the average yield at every harvest and total yield of plants irrigated with two different types of water was calculated.

3.8 Statistical analysis

For the performance evaluation study samples were collected at three stages at monthly interval. At each stage three set of samples were collected and analyzed, so at each stage number of replications was three. For HRT study also three sets were collected at monthly interval so number of replications was three. Whereas samples were collected at five different HRT so number of treatments was five.

In case of irrigation of Amaranthus and Golden Duranta plants, there were two treatments of irrigation with treated and untreated grey water. For the Amaranthus plants there were nine replications while for Golden Duranta plants number of replications was three.

3.8.1 ANOVA calculations

The analysis of variance (ANOVA) was used to demonstrate whether the means of several samples / populations i.e. the different parameters of water quality for influent and effluent from SCW system are significantly different or not. The fundamental technique of ANOVA is a partitioning of the total sum of squares into components related to the effects used in the treatments. Generally if there are three or more samples present then one way ANOVA test is used while for interactions between different treatments or nesting two treatments simultaneously, two way ANOVA or nested ANOVA test can also be used. For the present study one way ANOVA test was used as it doesn’t have any interactions. For the ANOVA the correction factor, degrees of freedom, total sum of squares, treatment sum of squares, replication sum of squares and error sum of squares were calculated as per standard statistical procedures. For the present study five treatments were used for the effluent with different HRT and due to financial limitations the numbers of replications were restricted to three.

3.8.2 Tukey's test

After ANOVA, the multiple comparison tests namely Tukey's test was used to determine which group means are significantly different. Tukey's Test is designed to perform a pair wise comparison of the means to see the significance in difference between different treatments. This test is usable only when the sample sizes are the same. Calculation procedure used for this test is as given below:

- First all sample means were arranged and numbered in order of increasing magnitude.
- Then pair-wise differences between sample means calculated as $\overline{X}_B - \overline{X}_A$ were determined, where B is the largest sample mean and A is the smallest sample mean.
- Afterwards the standard error (SE) was determined as,

$$SE = \sqrt{\frac{(Xi - X)2}{N}}$$

Where

Xi = i^{th} sample in population

X = sample mean

- Next to that the Tukey's value (q) was calculated as:

$$q = \frac{\text{Treatment mean sum of squares}}{\text{Error sum of squares}}$$

- The Critical value of $q_{\alpha, \nu, k}$ was read from the standard statistical table

Where,

α = significance level

ν = error degrees of freedom from the ANOVA

k = total number of means being tested.

- Result of null hypothesis (H_O): $\mu_B = \mu_A$ or all pair wise tests were determined.
- Finally pair wise comparisons of all events were done by

  - comparing first the largest mean to the smallest.
  - then the largest against the next smallest, and so on until largest is compared to the second largest.

- then the second largest to the smallest was compared followed by the next smallest, etc.
- It was continued until all possible comparisons have been made.

If no difference was found between means (i.e., cannot reject H_O), it was concluded that no difference exists between any means enclosed by these two.

3.8.3 'Student's t' test

To check the significance in difference of biometric parameters of plants irrigated with treated and untreated grey water, 'student's t' test was used. This test is one of the most commonly used techniques for testing a hypothesis on the basis of a difference between two sample means. The't' test determines a probability that two populations are the same or not with respect to the variable tested. The 't' test can be performed knowing just the means, standard deviation, and number of data points. To check the significance with't' test for the present study, the required initial parameters namely mean and standard deviation were calculated with usual statistical methods followed by the test statistics 't'. Before any calculations the null hypothesis was assumed that there was no significant difference between two treatments. The table value of 't' was read for the required degrees of freedom and at desired level of significance. If the calculated value of 't' is greater than the table value then reject the null hypothesis or otherwise accept.

Results and Discussion

CHAPTER IV

RESULTS AND DISCUSSION

Subsurface flow constructed wetland system is emerging as a low cost, efficient and easily operated alternative to conventional waste water treatment systems for treating almost all types of waste waters. This technology is capable of removing and / or transforming a variety of water pollutants by combination of physical, chemical and biological processes.

The present study was undertaken to design, construct, evaluate the performance and to check the effect of HRT on pollutant removal of this eco-friendly waste water treatment system to treat the grey water from Men's Hostel of KCAET. Analyses were carried out for determination of influent and effluent water characteristics to the SCW system and also the physical properties of the media. Moreover crop performance was compared with irrigation of raw and treated grey water irrigation in light of biometric observations viz. height, stem thickness, number of leaves, canopy spread, yield and appearance. The results obtained from different observations and analyses are discussed in this chapter.

4.1 Grey water Characterization

To design any waste water treatment system, detailed analysis of the water quality is of prime importance. This investigation includes the monitoring of data about waste water discharge, pH, EC, TDS, DO, and BOD_5.

To design a SCW for treatment of grey water in the present study, quality parameters of the grey water were monitored. All these parameters were found out using standard procedures as given earlier in section 3.2 and 3.6.

From the table 2 it is seen that there is no much variation in pH, salinity, TC and DO while there is great variation between EC, TDS, TSS and $BOD_{5.}$ Grey water from a community area may exhibit wide variability on a daily basis and long term monitoring can only give a reasonable approximation of average values. Due to the shortage of time and financial constraints, the samples were monitored only for three consecutive days. Also as the source was hostel, variation in use of detergents and soap by habitants can alone cause slight variation in water quality.

The characteristics of influent grey water were as given in Table 2.

Table 2 Characteristics of influent grey water

Parameter	Sample 1	Sample 2	Sample 3	Mean
pH	6.16	6.31	6.38	6.28
EC (µS)	284.69	259.78	139.50	227.99
TDS (mg/l)	182.20	166.26	89.28	145.91
Salinity (%)	0.10	0.10	0.10	0.10
TSS (mg/l)	140.00	100.00	260.00	166.67
TC (MPN/100 ml)	≥ 2400	≥ 2400	≥ 2400	≥ 2400
DO (mg/l)	220.00	280.00	263.33	254.44
BOD_5 (mg/l)	46.68	83.30	70.02	66.67

4.2 Hydraulic Design of SCW system

Using the design procedure given in section 3.3, the SCW system was designed, and fabrication of the metal tank with the designed dimensions was done in KCAET workshop. Preliminary information needed for the design of SCW was monitored using standard methods.

4.2.1 Influent inflow to the SCW

As explained earlier the inflow rate from the source was too large, which was difficult to handle in small experimental scaled SCW. So the randomly selected quantity i.e. 110 l/d was diverted towards the SCW system.

4.2.2 Influent grey water BOD_5

For the design purpose, three influent grey water samples were analysed. There was slight variation in BOD_5 of the influent water; hence the SCW system was designed for the severe water pollution i.e. for BOD_5 of 85 mg/l.

4.2.3 Desired level of effluent BOD_5

In wetland system vegetation itself is an organic material which can add some BOD_5 after decomposition of roots and dried stems. Properly designed and maintained wetland systems can reduce the BOD_5 concentration even below 5 mg/l, but as safety measure, effluent BOD_5 was assumed as 5 mg/l which will help to create conductive conditions for aquatic life.

4.2.4 Canna root depth

In the cited literature there was no reference available on the root depth of Canna macrophytes. Hence the root depth was obtained by making a trench near the Canna plant in the actual wetland from which the succours were obtained. The observed root depth of Canna plant was 40 - 45 cm.

4.2.5 Reaction constant

The EPA has recommended value of rate constant K_{20} equal to 1.104 d^{-1}. But as a safety factor for small scale, on-site wetland waste water treatment systems the rate constant K_{20} = 0.828 d^{-1} was used for the design, which is 75 percent of the base value (1.104 d^{-1}). This will increase the surface area of wetland and assures better effluent water quality.

4.2.6 Water losses in SCW

Losses in the SCW can take place due to evapotranspiration, horizontal and vertical seepage and deep percolation, but for the present study MS sheet was used for the fabrication of the tank, there were no losses due to seepage and deep percolation. In cited literature crop coefficient value for Canna was not available so for the design purpose, the losses due to evapotranspiration were taken as 1 cm/day. Hence total losses from wetland area were nearly 19 l/d which were rounded and taken as 20 l/d, so effluent discharge from wetland was 90 l/d and mean discharge from wetland was 100 l/d.

4.2.7 Average porosity of filter media

Sand and lime mixture was used as a filtering media in the SCW system. The porosity of the three samples was determined as per the procedure given in the section 3.2 and average value was used in the design. Table 3 depicts the total volume, volume of voids and porosity of the three samples.

Table 3 Porosity of the filtering media.

Sample No.	Total volume (cm^3)	Volume of voids (cm^3)	Porosity (%)
1	1000	479	47.9
2	1000	492	49.2
3	1000	484	48.4

The preliminary parameters for SCW system design are as given in Table 4.

Table 4 Preliminary data required for SCW design

Sl. No.	Parameter	Unit	Magnitude
1.	Influent inflow (diverted to SCW)	m^3/d	0.11
2.	Influent grey water BOD_5	mg/l	85
3.	Desired level of effluent BOD_5	mg/l	5
4.	Canna root depth	m	0.45
5.	Reaction constant (75 % of base value)	day^{-1}	0.828
6.	Average porosity of filter media	%	48.5

As per the results of design calculations shown in section 3.3, the final SCW system dimensions were obtained. The design calculations of the present SCW system are as given in Appendix IV. The dimensions of the SCW are as shown in table 5.

Table 5 Dimensions of SCW

Parameter	dimension
Length (m)	1.70
Width (m)	1.10
Aspect ratio (L:W)	1.5:1
Depth (m)	0.45
Inflow (lpd)	110.0
Outflow (lpd)	90.0
HRT (d)	3.7

4.3 Construction of SCW

Specific waste water characteristics (waste water quality and quantity), construction aspects (site topography, lining material, filter substrate, drainage system), system hydraulic parameters (hydraulic retention time and porosity) and vegetation features (vegetation selection and depth) were considered in the planning and design of a SCW. Based upon all the above aspects the SCW system was precisely fabricated and installed at the instructional farm of KCAET.

4.4 Performance evaluation of SCW system

After the installation and operation of SCW system, the pollutant removal capability of wetland was monitored by analyzing both influent and effluent water qualities at monthly interval. Each time, three set of samples were analyzed for influent grey water before and after settling and also effluent water sample from the SCW. The performance of SCW for the removal of the pollutants is discussed in this section.

4.4.1 Reduction of TSS

Most of the removal occurs within the inlet section due to the adsorption of suspended solids in crushed brick media and remaining is taken care by the initial portion of subsequent filter media.

Table 6 Reduction of TSS

Sl.No.	TSS concentration (mg/l)			% reduction
	Before settling	After settling	Eff. from SCW	
1	132	109	6	95.5
2	128	97	7	94.5
3	117	105	6	94.9
4	89	76	4	95.5
5	112	96	5	95.5
6	106	95	3	97.2
7	114	103	5	95.6
8	98	86	4	95.9
9	123	116	5	95.9

Table 6 shows the TSS concentration of the grey water samples before and after settling and also for the effluent from SCW system with the percentage reduction as compared to the initial values. In all the cases effective TSS removal was observed with a percentage reduction of nearly 95 %. So it is concluded that TSS removal is very effective in SCW.

This excellent removal of TSS may be observed due to the use of fine sand and crushed bricks as filtering media and use of baffles in wetland cross section to increase the length of flow of grey water in the SCW system.

Figure 4 presents the removal of TSS. For all the samples the final effluent TSS was observed well below the 7 mg/l regardless of the input level where the maximum TSS was seen as 132 mg/l. For some of the samples the higher TSS values were observed which may be due to the algal growth in to the settling tank and the conveying pipelines.

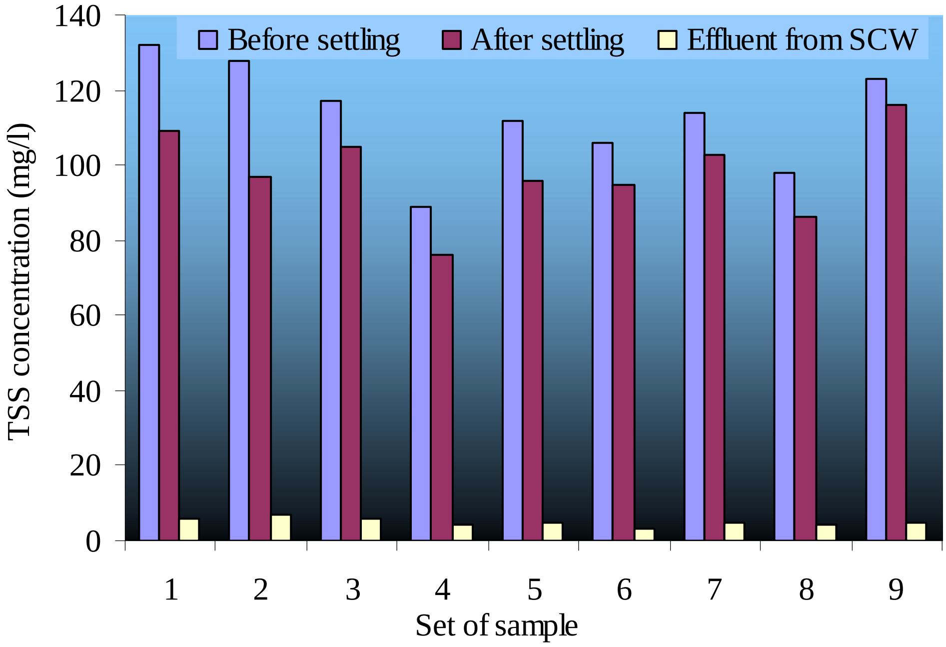

Fig. 4 TSS removal from the SCW

4.4.2 Reduction of BOD_5

The physical removal of BOD_5 is believed to occur rapidly through settling and entrapment of particulate matter in the void spaces in the sand and brick media. Soluble BOD_5 is removed by the microbial growth on the media surfaces and attached to the plant roots and rhizomes penetrating the bed.

Table 7 shows the BOD_5 concentration of the grey water samples before and after settling and also for the effluent from SCW system with the percentage reduction. For all samples the percentage BOD_5 removal was observed well above 90 %. Figure 5 shows the BOD_5 concentration before and after settling and from the SCW system. All effluent values are well below 5.5 mg/l regardless of influent values where the maximum and minimum influent BOD_5 concentration is 76.67 and 56.66 mg/l respectively.

Table 7 Reduction of BOD_5

Sl. No.	BOD_5 concentration (mg/l)			% reduction
	Before settling	After settling	Eff. from SCW	
1	66.63	53.33	4.73	92.9
2	56.66	23.33	3.99	93.0
3	73.33	50.00	3.33	95.45
4	72.91	64.37	4.62	93.66
5	76.62	72.45	5.49	92.83
6	63.91	58.25	3.96	93.80
7	76.67	73.33	3.87	94.96
8	63.33	60.00	3.87	93.89
9	76.67	66.67	4.13	94.61

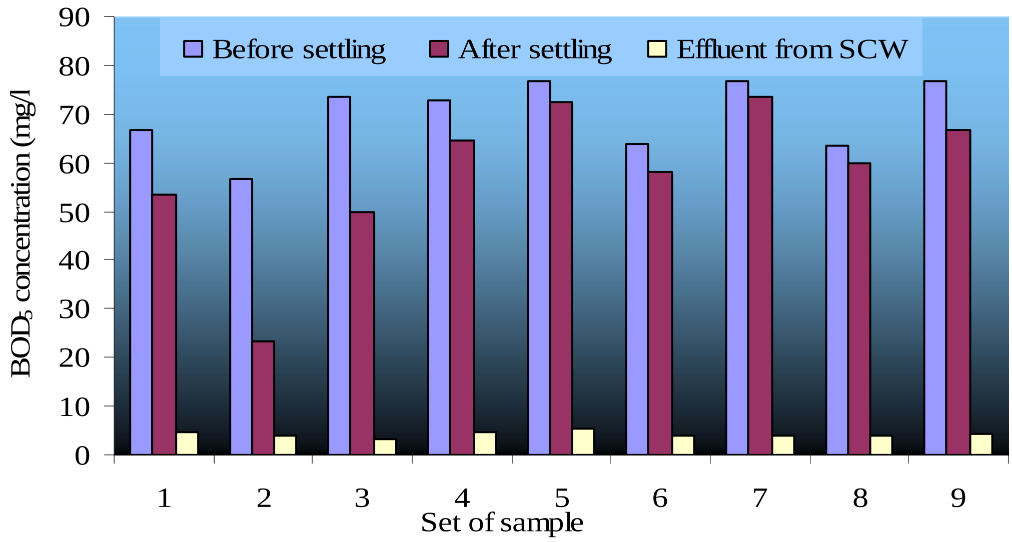

Fig. 5 BOD_5 removal in the SCW

Effluent BOD_5 values can not be expected below the 5 mg/l due to the decomposition of plant litter and other naturally occurring organic materials. But in the present study observation period was small, hence there was no death and decomposition of the macrophyte roots or other plant litter. So the observed effluent TSS concentration was even less than 5 mg/l.

4.4.3 Reduction of phosphates

The surplus concentration of phosphates in waste water can cause eutrophication in the natural water bodies. Eutrophication leads to the increasing domination of aquatic plants like water hyacinth, breeding of vectors such as mosquitoes and snails, generation of foul smell due to gases like hydrogen sulphide (H_2S), ammonia (NH_3), methyl alcohol (CH_3OH), fish killing and ground water pollution. So the maximum reduction in phosphate concentration is desirable to avoid the ill effects in natural water sources where waste water is released to these streams.

Table 8 presents the phosphates concentration of the grey water samples before and after settling and also for the effluent from SCW system with the percentage reduction.

Table 8 Reduction of phosphate.

Sl.No.	Phosphate concentration (mg/l)			% reduction
	Before settling	After settling	Eff. from SCW	
1	0.14	0.10	0.00	100.0
2	0.16	0.12	0.00	100.0
3	0.18	0.16	0.00	100.0
4	0.17	0.14	0.00	100.0
5	0.19	0.17	0.00	100.0
6	0.16	0.14	0.00	100.0
7	0.17	0.13	0.00	100.0
8	0.19	0.17	0.00	100.0
9	0.14	0.13	0.00	100.0

For all the samples the 100 % removal of phosphates was observed. This outstanding phosphate removal may be due to the use of fine river sand mixed with calcium carbonate (lime) as filter media in the wetland. Also the sand may have traces of oxides of iron and aluminium. All these chemicals have excellent phosphate binding capacity and hence were used in the wetlands. There is no much reduction after settling in the settling tank.

Figure 6 presents phosphate input before and after the settling of grey water. In all the cases 100 % phosphate reduction was achieved after passing through SCW system. Hence effluent phosphate concentration is not seen in the graph. For all the samples, the P concentration was in the range 0.14 - 0.19 mg/l before settling and in the range of 0.10 - 0.17 mg/l after settling.

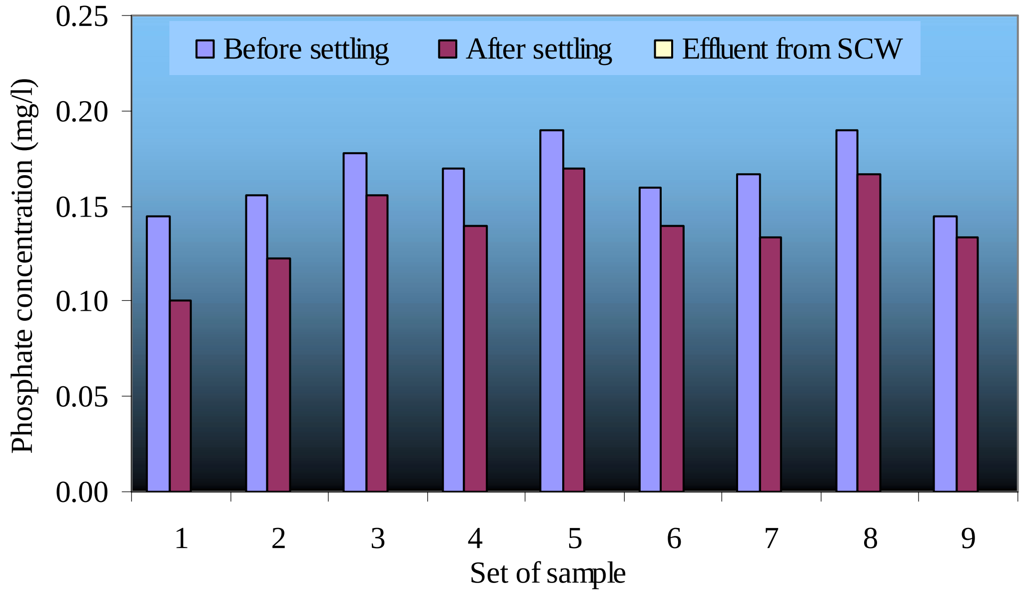

Fig. 6 Phosphate removal in the SCW

4.4.4 Reduction of sulphates

Sulphates may be present in the waste water from sources like washing soap and detergents. Superfluous presence of any constituent in water is not safe and sulphate is also not exception to it. Additional presence of sulphates in irrigation water can accumulate in the soil mass which can reduce the availability of water and other micro nutrients to the plant.

Table 9 depicts the sulphate concentration of influent before and after settling, effluent from SCW and percentage reduction compared to the initial values. In the influent water sulphate concentration was observed in the range

28.56 - 33.8 mg/l while it is in the range of 7.72 - 8.84 mg/l in the effluent water. In all the cases sulphate concentration was reduced to more than 72 % with maximum of 74.4 %.

Table 9 Reduction of sulphate.

Sl.No.	Sulphate concentration (mg/l)			% reduction
	Before settling	After settling	Eff. from SCW	
1	30.76	29.28	8.24	73.20
2	32.64	30.96	8.84	72.90
3	31.80	30.04	7.88	75.22
4	30.32	30.16	8.12	73.22
5	33.00	31.81	8.59	73.97
6	29.94	28.12	7.87	73.71
7	32.36	30.44	8.28	74.41
8	28.56	27.24	7.72	72.97
9	33.80	32.52	8.76	74.08

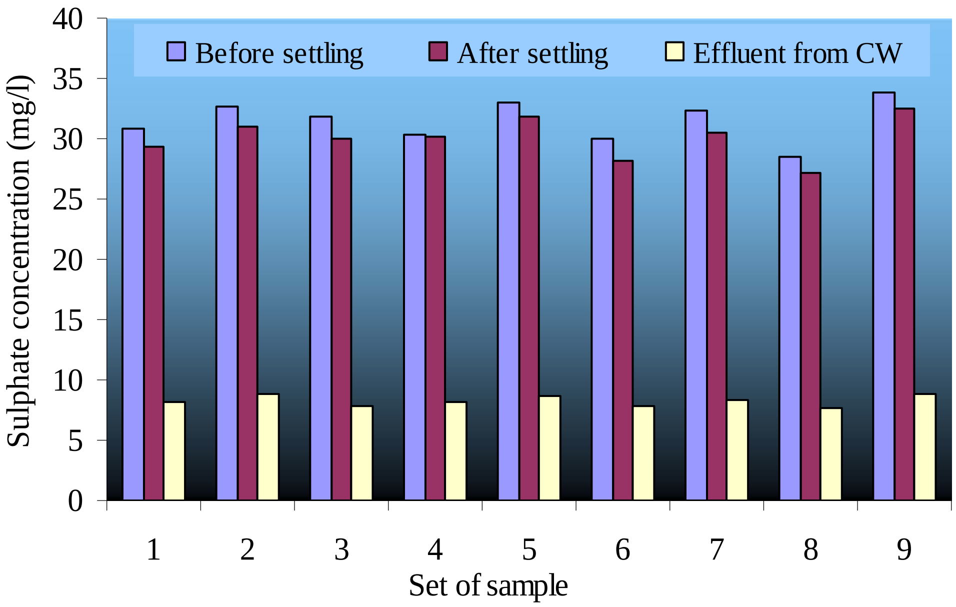

Fig. 7 Sulphate removal in the SCW

Figure 7 presents the sulphate removal before and after settling and effluent from the SCW system. In all the cases the sulphate concentration was observed well below the 9 mg/l which may be due to the fixation in the filtering media or absorbance by macrophytes for their growth. Higher R^2 value for the best fit curve indicates good correlation between input and output concentration of sulphate.

4.4.5 Reduction of TC

Table 10 shows the TC count of influent before and after settling, effluent from SCW and percentage reduction as compared to the initial values. In all the samples of inflow the TC counts were ≥ 2400 MPN/100ml both before and after settling, while the effluent water from SCW contains TC counts of ≤ 2 MPN/100ml i.e. in all the cases nearly 100 % reduction was obtained.

Table 10 Removal of TC

Sl.No.	TC density (MPN/100ml)			% reduction
	Before settling	After settling	Eff. from SCW	
1	≥2400	≥2400	≤2	≈100
2	≥2400	≥2400	≤2	≈100
3	≥2400	≥2400	≤2	≈100
4	≥2400	≥2400	≤2	≈100
5	≥2400	≥2400	≤2	≈100
6	≥2400	≥2400	≤2	≈100
7	≥2400	≥2400	≤2	≈100
8	≥2400	≥2400	≤2	≈100
9	≥2400	≥2400	≤2	≈100

Figure 8 shows the TC counts for the inflow and outflow from the SCW system. As in all cases, even for one day HRT nearly 100 % TC reduction was achieved so effluent TC is not seen in the figure.

Satisfactory removal of TC was achieved because of the use of fine river sand in the SCW as the filtering media with very low flow rates and the use of baffles to increase length of travel of water in the wetland. In some cases where higher discharge may occur due to intense rainfall or higher inflow of waste water, TC reducing efficiency can be affected. In such cases some form of final disinfection may be required for safe reuse of this waste water.

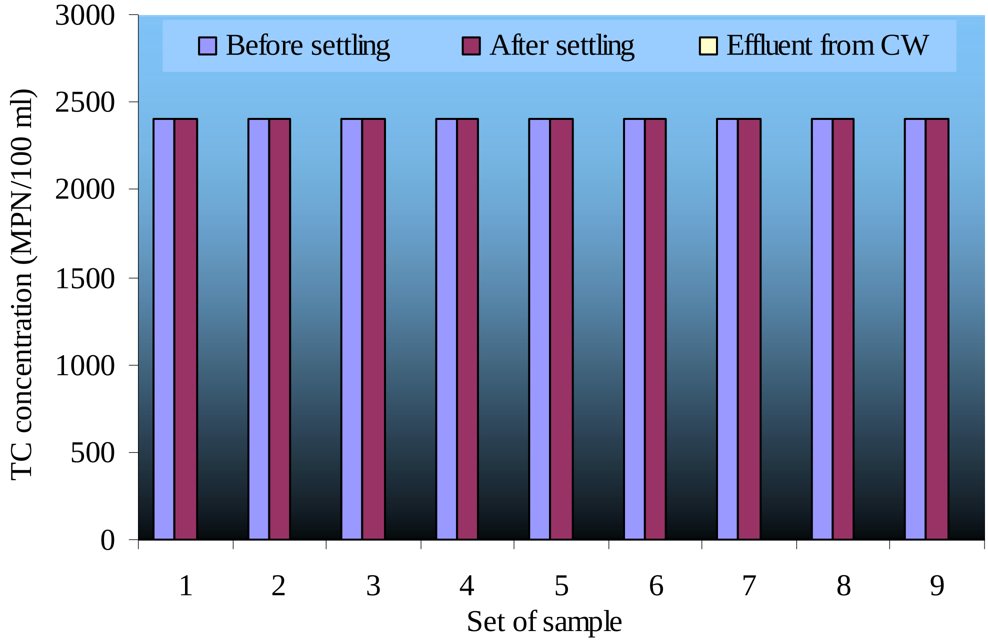

Fig. 8 TC removal in the SCW

4.4.6 Reduction of TKN

The wetlands presently in use for the removal of nitrogen operate on the principle of integrated biological processes, with internal and external sources of organic carbon. The plants using integrated processes with internal sources of carbon like dead plant roots and other organic materials have proved to be the most economical and reliable. Other processes use an intermittent reduction system achieving nitrification and denitrification simultaneously.

The removal of non- ionized ammonia is typically the major nitrogen parameter of concern due to its toxicity affecting fish and other aquatic animals, and its added oxygen demand on receiving streams. The nitrogen entering the wetland can be measured as organic nitrogen and ammonia which is together called as Total Kjeldahl Nitrogen (TKN). The organic nitrogen entering the SCW system is typically associated with particulate matter such as organic waste solids and/or algae along with plant detritus and other naturally occurring organic materials.

Biological nitrification followed by denitrification is the major pathway for ammonia removal in SCW. The general reactions that take place in nitrification and denitrification are as follows:

Nitrification-

$$NH_4^+ + O_2 \longrightarrow NO_3^-$$

Denitrification-

$$NO_3^- + BOD \longrightarrow N_2$$

Table 11 presents the TKN concentration of influent before and after settling, effluent from SCW and percentage reduction to the initial values. The influent concentration was in the range of 12.04 - 15.4 mg/l while effluent concentration was in range 0.56 - 2.24 mg/l. In all the cases the TKN reduction is more than 83 % with excellent value of 95.7 % when inflow concentration was comparatively lower.

Table 11 Reduction of total nitrogen

Sl.No.	TKN concentration (mg/l)			% reduction
	Before settling	After settling	Eff. from SCW	
1	13.72	12.60	2.24	83.70
2	12.04	10.92	1.12	90.70
3	13.16	10.64	1.40	89.36
4	14.28	14.00	0.84	94.12
5	12.88	12.32	0.56	95.65
6	13.16	12.04	0.84	93.62
7	14.84	13.72	1.40	90.57
8	15.40	14.28	0.84	94.55
9	14.28	13.16	1.12	92.16

Figure 9 presents the TKN removal in SCW. From the figure, it can be concluded that the SCW system is capable of removing the TKN well below the

2 mg/l except one exceptional case where concentration is 2.24 mg/l for an inflow concentration of 13.72 mg/l. For first three samples TKN removal was not as good as other samples, this may be due to the limited roots of macrophytes and its inadequate growth in the initial stage.

Also TKN removal efficiency can be increased by frequent harvest of the matured stems of the macrophytes as done in the present study but it can increase the labour cost for operating the SCW system.

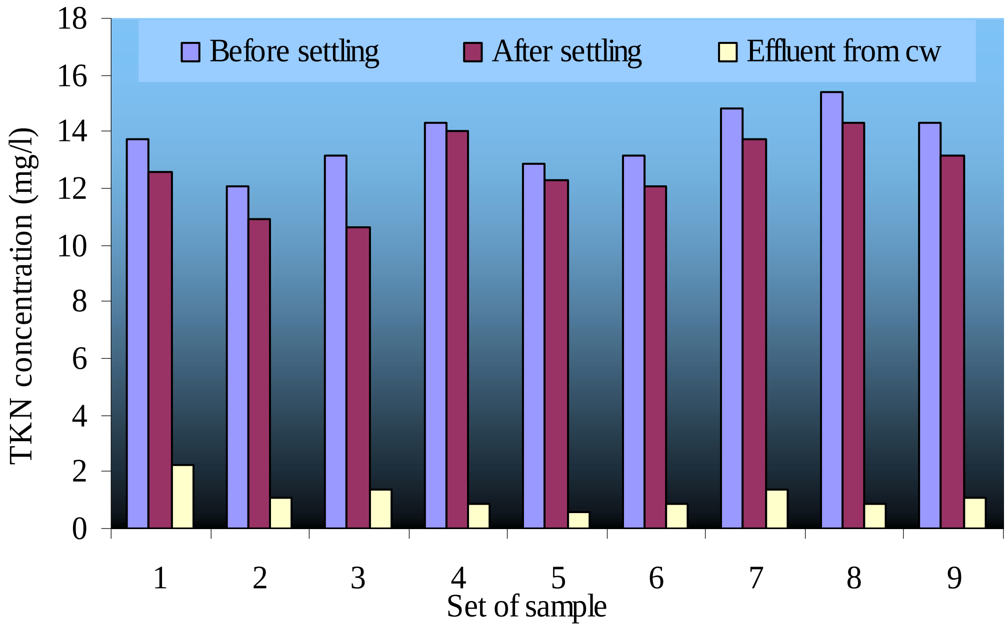

Fig. 9 TKN removal in the SCW

4.5 Hydraulic retention time (HRT) studies

Effect of HRT on pollutant removal was studied by collecting the effluent from the SCW at different residence times. For this study influent water was allowed to SCW up to a depth of 45 cm and then both inflow as well as outflow was stopped for required period of time by operating the valves provided to inlet and outlet pipes. The samples were collected at required times by opening the valve provided at the base of the system. Before supplying grey water in to SCW for HRT study, the system was drained thoroughly. The performance of SCW for the different HRT on removal of the pollutants is discussed in this section.

4.5.1 Effect of HRT on the reduction of TSS

The reduction in the TSS concentration of influent grey water in the wetland can be the due to the degradation of the organic matter by micro organisms and decomposition. And both these events are dependent on time of residence of waste water in the wetland.

Figure 10 compares the TSS removal rate to the HRT for the SCW system. From figure it is seen that the satisfactory TSS removal may be obtained for shorter retention time (1 day) with 95 % removal of TSS and it can not be increased more than 96.7 % even after 5 days of retention. The R^2 value for the best fit curve is 0.97, indicating an excellent correlation. So it can be concluded that majority of TSS reduction is the result of filtration in the fine media and desirable outcome can be expected even at lower HRT of one day or so.

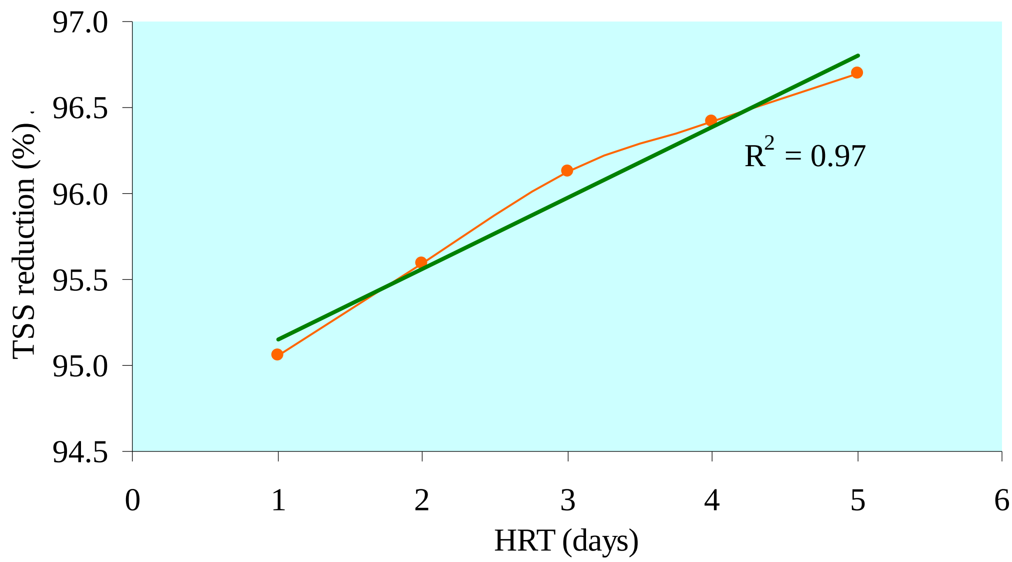

Fig. 10 Average TSS removal (%) versus HRT

Table 12 Results of ANOVA for TSS reduction.

Source of variation	DOF	Sum of squares	Mean sum of squares	F cal. value	F table value	LOS (%)
Treatment	4.00	5.22	1.31	8.01	7.01	1
Replication	2.00	3.22	1.61	9.87	8.65	1
Error	8.00	1.30	0.16			

Table 12 presents the results of statistical analysis. From the table it is clear that the calculated value of F for different treatments is higher than the tabulated value, showing that there is significant effect of HRT on removal of TSS.

Further the effect of HRT on performance of TSS removal was studied with Tukey's test, and it was concluded that to have significant difference in removal of TSS, the interval between two observations should be at least 2 days.

Also calculated value of F for different replications is higher than the table value which indicates that better TSS reduction can be achieved after longer period of time since the time of construction and operation. This may be due to the enlarged growth of macrophyte roots and attached bacterial composition after certain period of time since construction and operation started.

So it was concluded that the majority of TSS reduction was the result of filtration in the fine media and desirable outcome can be expected even at lower HRT of one day or so.

4.5.2 Effect of HRT on the reduction of BOD_5

Reduction in BOD_5 concentration is combined result of biological activities of micro organisms and physical filtration. Figure 11 presents BOD_5 removals versus the HRT for the grey water in the SCW.

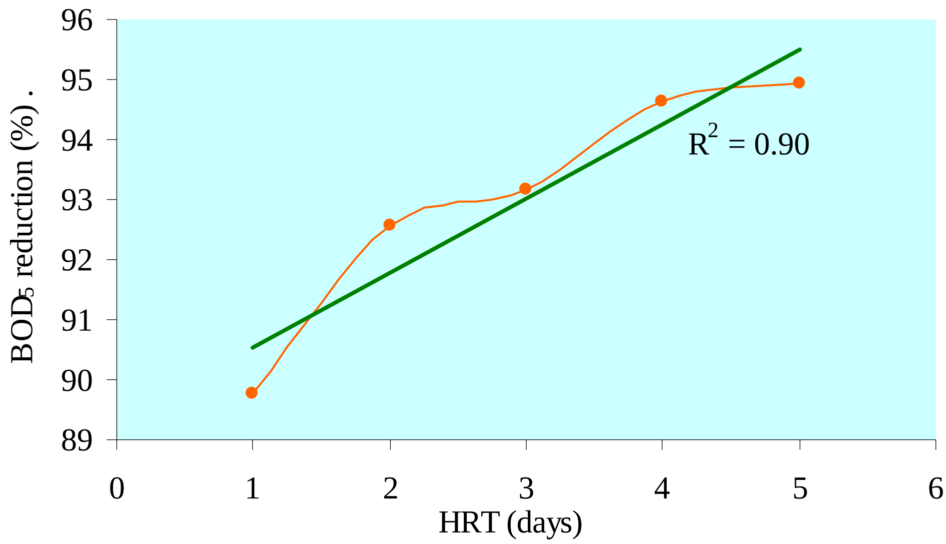

Fig. 11 Average BOD_5 removal (%) versus HRT

From the graph it is seen that the removal of BOD_5 is not so significantly dependent on residence time since BOD_5 removal improves only slightly thereafter, up to HRT of 5 days. The observed percentage reductions of concentration of BOD_5 were 89.8 % for 1 day and 94.9 % for 5 day HRT. The R^2 value for the best fit curve is 0.90.

Table 13 presents the results of ANOVA calculations for BOD_5. In the table calculated value of F for different treatments is higher than table value, which indicates that there is significant effect of HRT on performance of BOD_5 removal.

Table 13 Results for ANOVA for BOD_5 reduction.

Source of variation	DOF	Sum of squares	Mean sum of squares	F cal. value	F table value	LOS (%)
Treatment	4.00	51.25	12.81	101.46	7.01	1.00
Replication	2.00	0.53	0.27	2.10	8.65	1.00
Error	8.00	1.01	0.13			

Further effect of HRT on percentage reduction of BOD_5 was studied with Tukey's test. From the analysis with Tukey's test it was observed that there was significant difference between percentage reductions of BOD_5 for one and two day HRT but afterwards this difference was not significant. Also calculated value of F for different replications was not higher than table value which indicated that the acceptable BOD_5 reduction of above 90 % can be attained after one month of construction of wetland. So it was concluded that the adequate BOD_5 reduction can be attained after one month of construction and percentage removal of BOD_5 is strongly dependent on HRT while its effect is not significant for higher values of HRT.

4.5.3 Effect of HRT on the removal of phosphate

Phosphate removal in SCW systems is the effect of presence of phosphate binding material like aluminium or calcium salts in filtering media and uptake by macrophytes for their growth. Figure 12 presents the percentage phosphate reduction versus HRT. In the figure it is seen that for 1 day HRT the reduction in

P concentration is not so good, as only 74.3 % P removal achieved. For HRT of two days or more 100 % P reduction were observed.

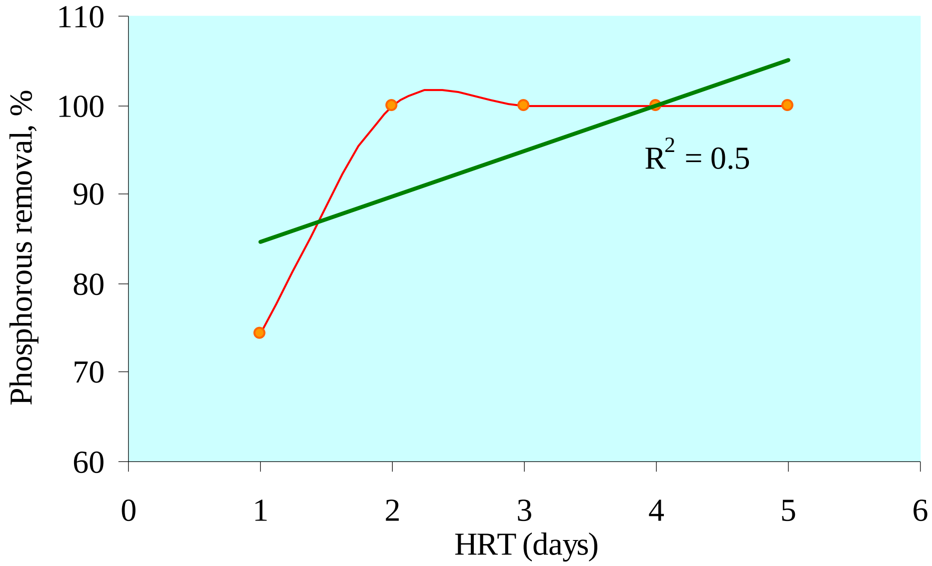

Fig. 12 Average phosphate removal (%) versus HRT

Table 14 presents the results of ANOVA calculations for average percentage reduction of phosphate concentration with respect to HRT. In the table, for different treatments the calculated value of F is well above the table value, which confirms that there is significant effect of HRT on phosphate removal. Further analysis with Tukey's test to check the extent of significance of HRT on percentage reduction of phosphate has shown good difference in phosphate concentration for 1 and 2 day HRT but furthermore it is not significant. This is due to the 100 % reduction of phosphate concentration for 2 day HRT or more.

Table 14 Results of ANOVA for phosphate reduction.

Source of variation	DOF	Sum of squares	Mean sum of squares	F cal. value	F table value	LOS (%)
Treatment	4.00	1580.89	395.22	47.17	7.01	1.00
Replication	2.00	16.76	8.38	1.00	8.65	1.00
Error	8.00	67.04	8.38			

Moreover the calculated value of F for different replications is lesser than table value which indicates that the superior phosphate reduction can be attained even after one month of construction. This will be due to the fact that, phosphate removal is not the result of only absorption by macrophytes for their growth but it equally depends on the presence of phosphate binding filtering media in wetland.

This brilliant phosphate reduction was observed due to the presence of P retentive media, but with time this P binding capacity can reduce and hence long term expectations cannot be defined.

4.5.4 Effect of HRT on the removal of the sulphate

Figure 13 compares the sulphate reduction (percentage) versus HRT. The relationship is similar to that shown in figure 11 for BOD_5. After an HRT of one day there is little improvement in the removal of sulphates. The R^2 value for the best fit curve is 0.90 which indicates the excellent correlation between sulphate removal and HRT.

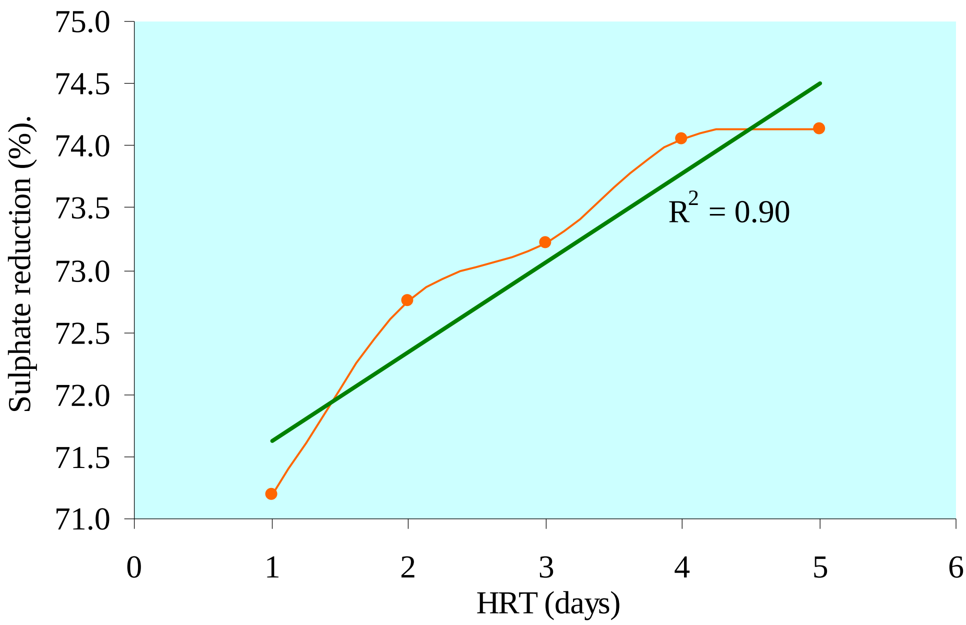

Fig. 13 Average sulphate removal (%) versus HRT

Table 15 presents the results of ANOVA calculations for sulphate removal. In the table, calculated value of F for different treatments is more than table value even at 5 % level of significance, which indicates that there is significant effect of HRT on removal of sulphates. Further analysis with Tukey's test resulted that, to have significant difference in the concentration of sulphates the interval between two observations should be at least 4 days. This may be due to very little improvement in reduction of sulphates concentration from HRT of one to five days. Also calculated value of F for different replications is less than table value which shows that sulphate reduction does not change with time.

Table 15 Results of ANOVA for sulphate reduction.

Source of variation	DOF	Sum of squares	Mean sum of squares	F cal. value	F table value	LOS (%)
Treatment	4.00	17.31	4.33	6.71	3.84	5.00
Replication	2.00	0.88	0.44	0.68	4.46	5.00
Error	8.00	5.16	0.64			

4.5.5 Effect of HRT on the removal of the TC

The reduction in density of TC bacteria from the waste water is the result of filtration in the fine media and attachment to the roots of macrophytes. The influent grey water after settling has faced none of these hence there was no reduction in density of TC. Also there was no effect of HRT on removal of TC. For all the time, the influent grey water had TC density of ≥ 2400 MPN/100ml while it was ≤ 2 MPN/100ml for effluent water from the SCW system. That is for all the cases nearly 100 % reduction in TC was observed even for shortest HRT of 1 day.

4.5.6 Effect of HRT on reduction of the TKN

Figure 14 compares the TKN reduction (percentage) versus HRT. The relationship between TKN removal (percentage) and HRT is very specific. For the HRT of 1 day, only 21 % TKN was removed, while removal efficiency increased to 56 %, 72 % and finally 100 % for HRT of 2, 3 and 4 days respectively. The R^2 value of the best fit curve is 0.93 which indicates the excellent correlation between TKN removal (percentage) and HRT.

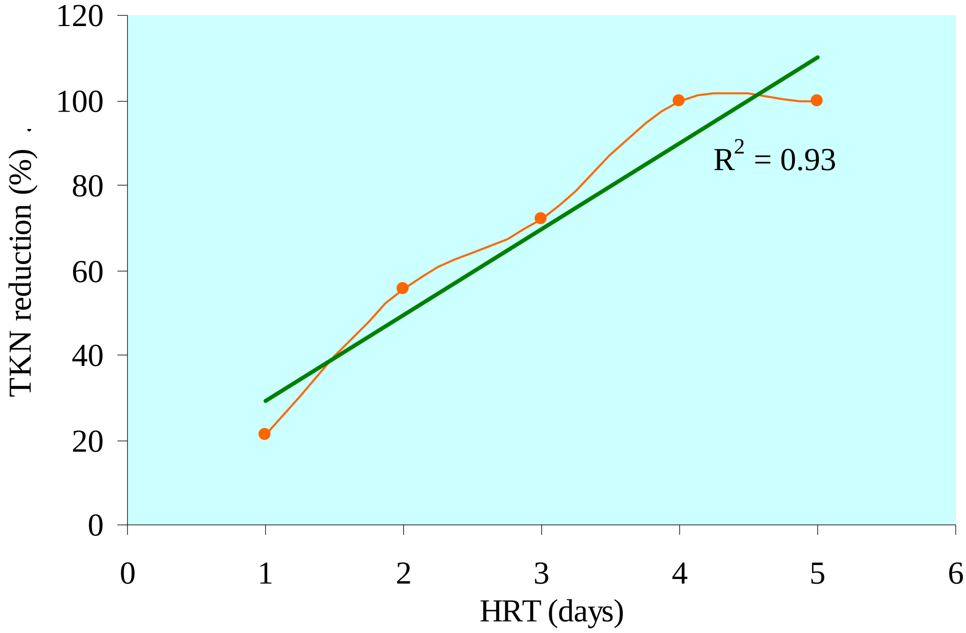

Fig. 14 Average TKN removal (%) versus HRT

Table 16 presents the results of ANOVA calculations for TKN. In the table, calculated value of F is well above the table value which indicates that there is significant effect of HRT on removal of TKN. Further analysis with Tukey's test shows that, to have significant difference in TKN concentration with respect to HRT, the observation interval should be at least 3 days. Also calculated value of F for different replications is less than table value, which indicates that there is no change in TKN removal after one month of operation.

Table 16 Results of ANOVA for TKN reduction.

Source of variation	DOF	Sum of squares	Mean sum of squares	F cal. value	F table value	LOS (%)
Treatment	4.00	13229.22	3307.31	12.29	7.01	1.00
Replication	2.00	1048.57	524.29	1.95	8.65	1.00
Error	8.00	2153.45	269.18			

Finally it can be concluded that the TKN removal efficiency is strongly dependent on the HRT but to have significant difference in TKN concentrations the interval between two observations should be sufficiently high depending on the conditions at site.

4.6 Effect of treated and untreated grey water on crop parameters

As waste water will have different chemical composition compared to natural water, it will have detrimental effects on soil and hence on crop health. Dissolved salts in waste water can accumulate in the root zone depth which can reduce the availability of water to crops. The presence of excessive concentration of specific ions like sodium, chloride or boron can lead to burning of leaves, leaf cupping, chlorosis and reduced growth and yield. Excessive nitrogen in irrigation water can lead to vigorous vegetative growth, delayed or uneven maturity and reduced crop quality. Excessive leaf growth leads to plant lodging or bending.

For the present study one food crop and one ornamental crop viz. Amaranthus and Golden Duranta respectively were irrigated by influent and effluent water. For the food crop, biometric observations like height, number of leaves, stem thickness; canopy spread and yield were monitored. For the Golden Duranta crop colour, appearance, height and canopy spread were observed.

4.6.1 Effect of influent and effluent water irrigation on Amaranthus

Nearly for all the observed parameters untreated grey water irrigated Amaranthus plants showed low response. This may be due to the disagreeable influent water quality. In the following paragraphs effect of treated and untreated grey water irrigation on crop response for height, number of leaves, stem thickness and yield are discussed.

4.6.1.1 Effect on crop height

Table 17 presents the height of Amaranthus crop irrigated with treated and untreated grey water at the time of different harvest. From the table it is clear that for all the cases effluent irrigated crop height is more than that irrigated with influent water except for some plants for first harvest. This may be due to the alkaline effluent water quality at the start of irrigation due to addition of lime in the filter media.

Figure 15 presents the comparison of average height of different plants at the time of harvest. From the figure it is seen that only for the first plant average height of effluent irrigated plant is less than others. This may be due to some inherent problem of that particular plant, as all other plants showed the reverse results.

Table 17 Amaranthus plant height (cm) for influent and effluent irrigation.

Sl. No.	First harvest		Second harvest		Third harvest		Average	
	Inf.	**Eff.**	**Inf.**	**Eff.**	**Inf.**	**Eff.**	**Inf.**	**Eff.**
1	35	20	39	43	42	46	38.67	36.33
2	38	35	44	68	43	73	41.67	58.67
3	34	57	48	65	53	63	45.00	61.67
4	29	36	49	43	50	48	42.67	42.33
5	23	45	35	75	39	73	32.33	64.33
6	29	46	48	43	47	42	41.33	43.67
7	17	26	29	50	31	53	25.67	43.00
8	24	28	31	61	39	67	31.33	52.00
9	30	49	56	54	51	55	45.67	52.67

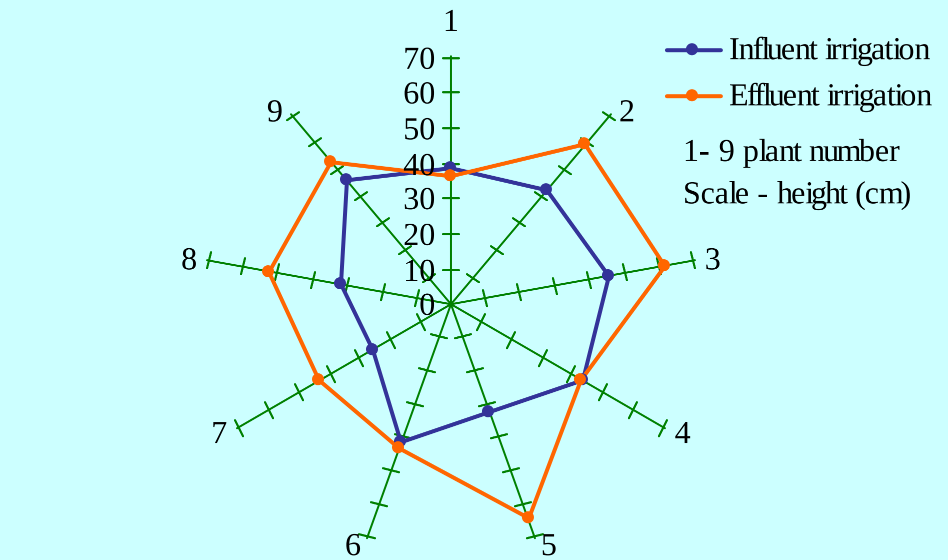

Fig. 15 Average height (cm) of Amaranthus plants for influent and effluent irrigation

In addition, the difference in height of Amaranthus plants irrigated with treated and untreated grey water was statistically compared with 'student's t' test. Result of 'student's t' test showed the significant difference in average height of plants irrigated with treated and untreated water for 1 % level of significance.

4.6.1.2 Effect on the number of leaves

Table 18 presents the height of Amaranthus crop irritated with treated and untreated grey water at the time of different harvests. In this case also results are similar to the height of plants. For most of the cases number of leaves of plants irrigated with effluent is more than influent irrigated plants.

Table 18 Number of leaves of Amaranthus plants for influent and effluent irrigation

Sl. No.	First harvest		Second harvest		Third harvest		Average	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1	42	20	78	76	86	82	68.67	59.33
2	47	26	59	89	55	94	53.67	69.67
3	46	59	80	103	81	95	69.00	85.67
4	27	41	72	73	68	81	55.67	65.00
5	24	37	43	98	48	89	38.33	74.67
6	23	40	52	82	49	85	41.33	69.00
7	35	26	39	98	38	110	37.33	78.00
8	38	33	42	85	46	98	42.00	72.00
9	42	56	45	73	68	79	51.67	69.33

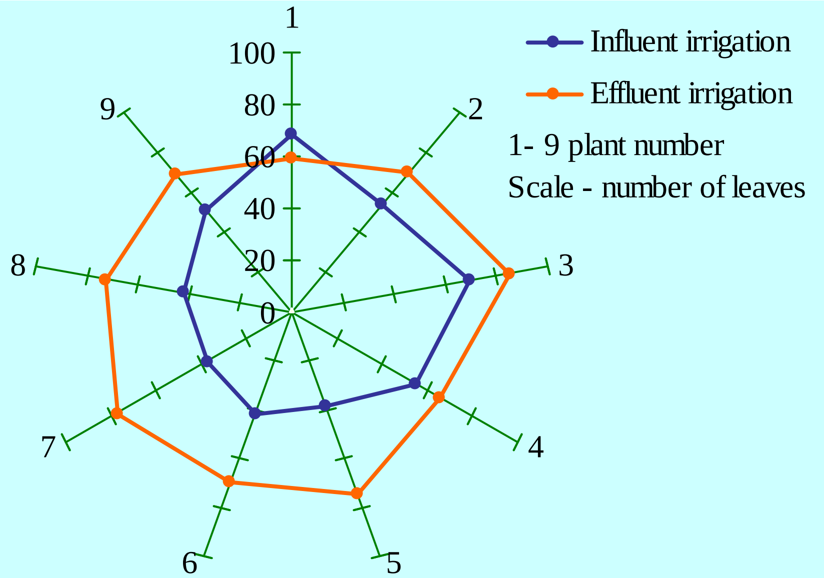

Fig. 16 Average number of leaves of Amaranthus plants for influent and effluent irrigation.

Figure 16 presents the comparison of average number of leaves of different plants at the time of harvest. From the figure, it is apparent that average number of leaves of plants irrigated with effluent is more than influent irrigated plants except for first plant and the cause for it may be the same as explained earlier. For influent irrigated plants average number of leaves is 45 while for plants irrigated with effluent water it is in the range of 70.

Additionally the variation in number of leaves of Amaranthus plants irrigated with treated and untreated grey water was statistically compared with ‘student’s t’test. Results of ‘student’s t’ test showed significant difference in average number of leaves at the time of harvest for 1 % level of significance.

4.6.1.3 Effect on crop stem thickness

Table 19 presents the stem thickness of Amaranthus crop irritated with influent and effluent grey water at the time of different harvests. In this case also the results are not so different from the earlier results.

Table 19 Stem thickness (mm) of Amaranthus plant for influent and effluent irrigation.

Sl. No.	First harvest		Second harvest		Third harvest		Average	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1	8	6	9	11	13	13	10.00	10.00
2	10	9	11	13	12	14	11.00	12.00
3	9	15	12	17	14	17	11.67	16.33
4	6	8	8	12	10	13	8.00	11.00
5	5	10	8	15	10	17	7.67	14.00
6	7	9	11	13	13	15	10.33	12.33
7	5	7	8	9	10	11	7.67	9.00
8	5	6	9	10	11	12	8.33	9.33
9	8	14	11	16	14	17	11.00	15.67

Before first harvest the results were quite unclear while for second and third harvest the effluent irrigated plants always showed bigger stem thickness than plants irrigated with influent water. For the plants irrigated with influent grey water the average stem thickness was 9.5 mm while for plants irrigated with effluent grey water average stem thickness observed was 12.2 mm.

Figure 17 presents the comparison of stem thickness of different plants at the time of harvest. From the figure, the average stem thickness of effluent irrigated plants can be easily differentiated from the stem thickness of plants irrigated with influent water. In all the cases the stem thickness of effluent irrigated plants was more than the stem thickness of influent irrigated plants.

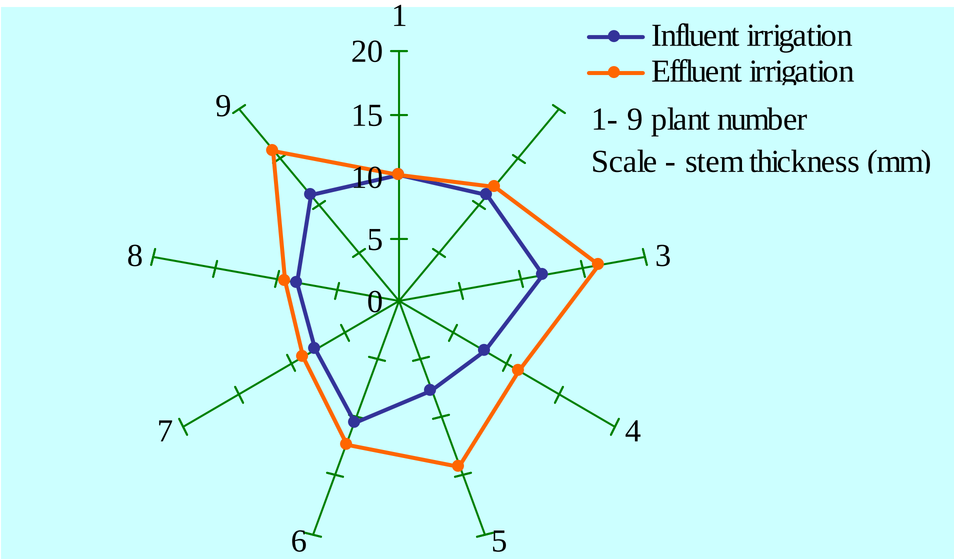

Fig. 17 Stem thickness (mm) of Amaranthus plants for influent and effluent irrigation

Additionally difference in the thickness of stem of Amaranthus plants irrigated with treated and untreated grey water was statistically compared with ‘student’s t’ test. Results of ‘student’s t’ test showed significant difference in the average stem thickness of plants irrigated with treated and untreated water for 5 % level of significance.

4.6.1.4 Effect on crop yield

Table 20 presents the yield of Amaranthus plants irritated with influent and effluent grey water at the time of different harvests. These results are not so different from the earlier results. Nearly in all cases the yield of plants irrigated with effluent grey water is more than yield of plants irrigated with influent water.

Table 20 Amaranthus yield (gm) for influent and effluent irrigation.

Sl. No.	First harvest		Second harvest		Third harvest		Average	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1	23.40	10.30	69.40	78.96	91.54	89.40	61.45	59.55
2	36.90	15.90	26.70	58.16	37.50	63.85	33.70	45.97
3	43.40	75.90	135.80	195.32	154.62	178.60	111.27	149.94
4	18.30	53.30	62.21	81.20	70.21	84.30	50.24	72.93
5	11.35	39.50	32.83	178.92	40.12	149.80	28.10	122.74
6	16.89	32.80	67.10	127.15	63.49	138.34	49.16	99.43
7	9.70	12.90	26.40	120.54	42.70	143.70	26.27	92.38
8	13.40	14.30	36.46	141.16	51.10	154.87	33.65	103.44
9	26.90	68.40	98.70	186.98	117.16	171.84	80.92	142.41

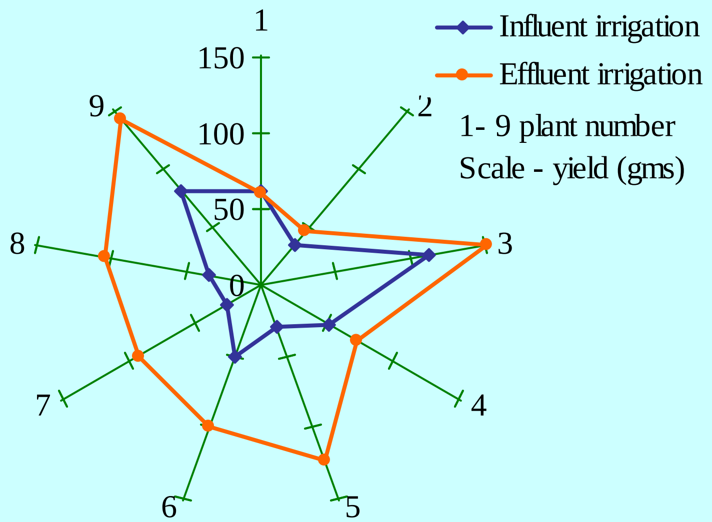

Fig. 18 Yield of Amaranthus (gm) for influent and effluet irrigation.

Figure 18 presents the comparison of yield of different plants at the time of harvest. From the figure it is seen that the yield of Amaranthus was more for crop irrigated with treated water than untreated water. The average yield per plant was 52.7 gm for the plants irrigated with influent grey water while the same was 96.4 gm for plants irrigated with effluent from constructed wetland. Moreover distinction in the yield of Amaranthus plants irrigated with treated and untreated grey water was statistically compared with ‘student’s t’ test. Results of this test showed significant difference in average yield of plants irrigated with treated and untreated water for 1 % level of significance.

4.6.1.5 Effect on crop canopy spread

Table 21 presents the canopy of Amaranthus plants irrigated with influent and effluent grey water at the time of different harvest. These results are not so different from the earlier results. Nearly in all cases the canopy spread of plants irrigated with effluent grey water is more than that of plants irrigated with influent water except for some plants and it may be due to inherent problem of particular plant.

Table 21 Amaranthus canopy spread (cm^2) for influent and effluent irrigation.

Sl. No.	First harvest		Second harvest		Third harvest		Average	
	Inf.	**Eff.**	**Inf.**	**Eff.**	**Inf.**	**Eff.**	**Inf.**	**Eff.**
1	511	314	1018	1699	1353	1386	961	1133
2	684	330	731	1627	684	1627	699	1194
3	805	963	1226	2782	1848	2598	1293	2114
4	491	552	1289	1105	1419	1487	1066	1048
5	416	731	573	2125	755	1925	581	1594
6	491	755	1195	2249	1135	1925	940	1643
7	227	491	255	1663	552	2125	344	1426
8	491	573	780	2876	935	3069	735	2173
9	616	990	594	2249	1226	2249	812	1829

Figure 19 presents the comparison of canopy spread (cm^2) of different plants at the time of harvest. From the figure it can be concluded that the canopy spread of Amaranthus irrigated with effluent water was more than that irrigated with raw grey water.

The average canopy spread per plant was about 826 cm^2 for the plants irrigated with influent grey water while the same was 1573 cm^2 for plants irrigated with effluent from constructed wetland. Moreover distinction in the canopy spread of Amaranthus plants irrigated with treated and untreated grey water was statistically compared with 'student's t' test. Results of 'student's t' test showed significant difference in average canopy spread of plants irrigated with treated and untreated water for 5 % level of significance.

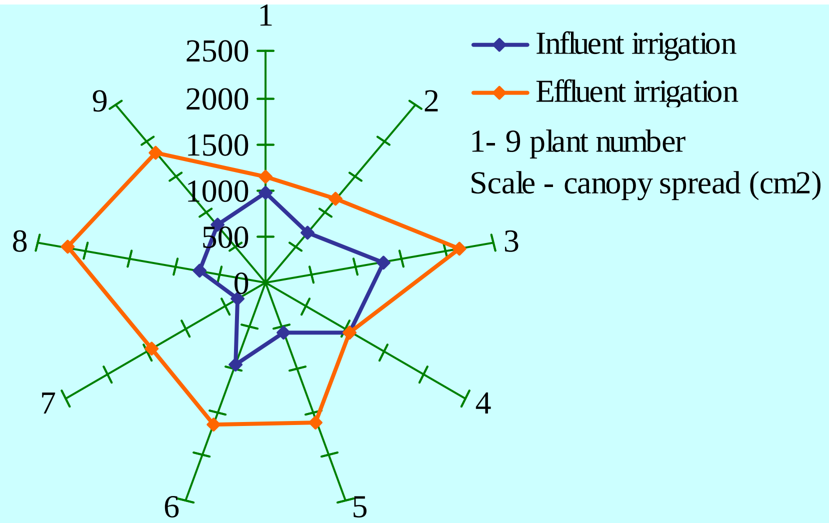

Fig. 19 Canopy spread of Amaranthus (cm^2) for influent and effluent irrigation

4.6.2 Effect of influent and effluent water irrigation on Golden Duranta

Golden Duranta is an ornamental plant with attractive yellow coloured foliage. Generally it is used as a vegetative fence, and can be widely seen in gardens. The raw grey water irrigation can have some detrimental effects on the colour of leaves and growth of plants. To demonstrate the effect of treated and untreated grey water irrigation on Golden Duranta plants in its growth and appearance, these plants were planted in clay pots and irrigated. After planting, to stabilize and to start growth of roots, the plants were irrigated with normal fresh water for a week. The effects of these treatments are discussed in the following headings.

4.6.2.1 Effect of raw and treated grey water irrigation on Golden Duranta height

All the plants irrigated with raw grey water had a lesser height than irrigated with effluent from SCW. The average height of plants irrigated with raw grey water was 27 cm while the same for plants irrigated with effluent from SCW was 31 cm. Table 22 presents the height (cm) of Golden Duranta plants irrigated with two types of water under study.

Table 22 Golden Duranta height (cm) for influent and effluent irrigation.

Sl. No.	First observation		Second observation		Third observation		Average	
	Inf.	**Eff.**	**Inf.**	**Eff.**	**Inf.**	**Eff.**	**Inf.**	**Eff.**
1	26	28	25	30	27	34	26.0	30.7
2	22	24	28	32	30	35	26.7	30.3
3	25	27	27	31	31	34	27.7	30.7

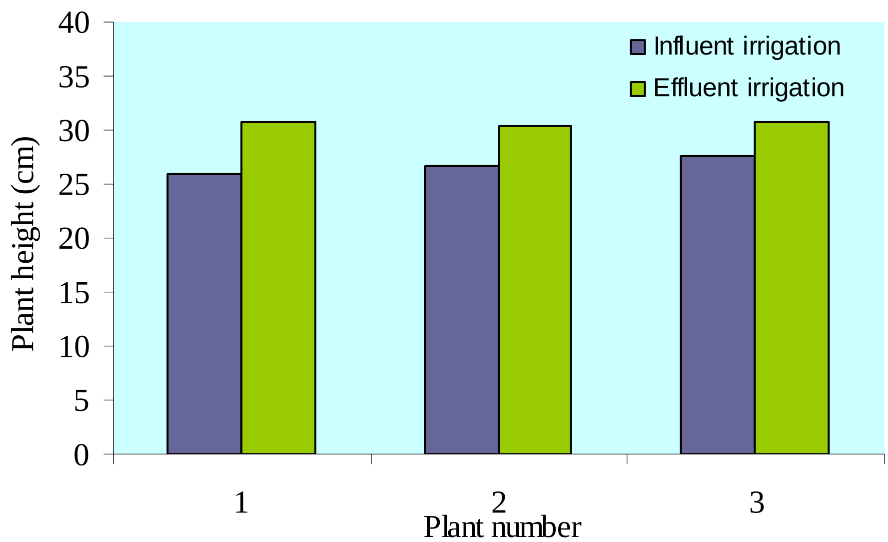

Fig. 20 Height of Golden Duranta (cm) plants irrigated with influent and effluent.

Figure 20 presents the height of Golden Duranta plants irrigated with two different types of water. From the figure it is clear that plants irrigated with effluent water are superior to that irrigated with influent water. The significance in the effect on height of plants irrigated by the two types of water was studied with 'student's t' test. The results of this test showed significant difference in height of these plants for 5 % level of significance. This difference in height may be due to salinity and other disagreeable quality parameters of grey water.

Plate 11 View of SCW system with potted plants and settling tank.

Effluent irrigation **Influent irrigation**

Plate 12 Comparison of appearance and growth of Golden Duranta plants irrigated with effluent and influent.

4.6.2.2 Effect of raw and treated grey water irrigation on Golden Duranta canopy spread and appearance.

The observations of canopy spread of plants irrigated with two different waters under consideration were not different from the results of the height of plants. For all the plants the canopy spread and vegetative growth of plants irrigated with raw grey water was not as good as plants irrigated with effluent from SCW. The average canopy spread of plants irrigated with raw grey water was 675.1 cm^2 while the same was 1123 cm^2 for plants irrigated with effluent from SCW system. Table 23 depicts the canopy spread of Golden Duranta plants irrigated with two types of water under study.

Table 23 Golden Duranta canopy spread (cm^2) for influent and effluent irrigation.

Sl. No.	First observation		Second observation		Third observation		Average	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1	531	733	661	914	780	1239	657	962
2	552	639	707	1472	908	2037	722	1383
3	472	709	661	1027	805	1337	646	1024

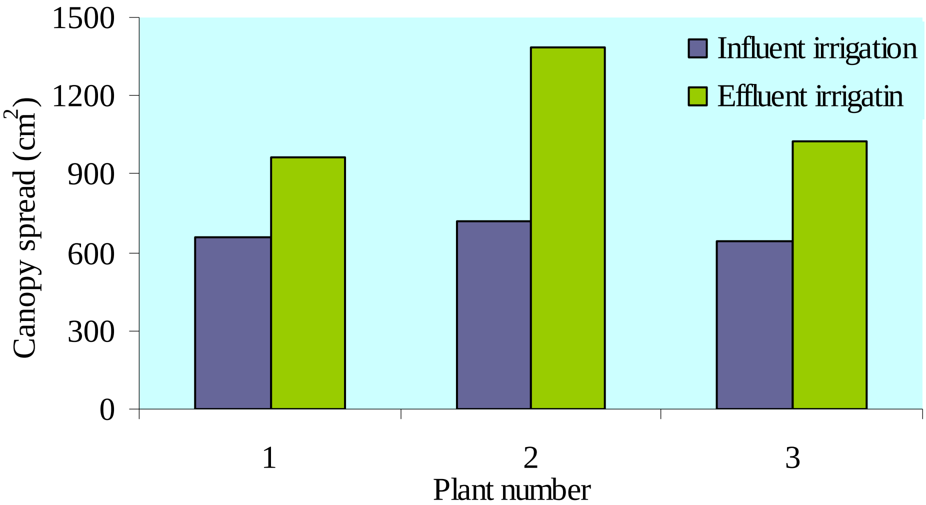

Fig. 21 Canopy spread (cm^2)of Golden Duranta plants irrigated with influetn and effluent

The figure 21 shows the canopy spread of Golden Duranta plants irrigated with two different quality waters. From the figure the difference between two treatments for growth can be easily distinguished.

The statistical analysis with 'student's t' test shows the significant difference between the heights of plants at 5 % level of significance. Also substantial difference was observed in appearance of plants irrigated with the two waters. All the time the plants irrigated with effluent from SCW were fresh while plants irrigated with raw grey water showed wilting symptoms. Though the other parameters namely environmental temperature, humidity, irrigation water quantity, soil type etc are same for two treatments this major difference in appearance and growth was due to the variation of water quality.

From all the above analyses the effectiveness of the SCW in improving grey water quality and its direct influence on crops could be substantiated. Residual analysis of crop and soil could not be performed due to time limitations and financial constraints.

Summary and Conclusion

CHAPTER V

SUMMARY AND CONCLUSION

Augmented population, increased industrialization and urbanization have led to enhanced fresh water demand and pollution problems, which have now become a global threat. In many parts of the world, increased fresh water demand can be met only by some sort of waste water treatment and reuse. In addition to pollution of natural water streams and ground water due to direct discharge of waste water from surroundings can result in environmental imbalance. Pollution of water bodies can result in the death of aquatic animals, enhanced growth of aquatic plants which causes meandering of flow and floods. Stagnation of waste water creates unsightly conditions and provides place for mosquito breeding and other insect vectors. Increased insects create discomfort to human life and can lead to dangerous life finale diseases like Dengue or Chikengunya as is happening for the past few years in some districts of Kerala.

Though demand of fresh water and pollution of the same cannot be totally avoided, it can be definitely managed to a great extent so that demand of potable water will reduce to a great extent along with reduction of water pollution. This can be achieved through waste water treatment and reuse. Worldwide since last many years, research on different methods of waste water treatment is going on. Presently engineers and water researchers have developed many efficient and attractive waste water treatment methods like microfiltration, ultrafiltration, nanofiltration and reverse osmosis etc. But for all these methods energy requirement is extremely high which is again scare due to fiery exploitation in industrialization and urbanization. Also to go for these methods preliminary waste water treatment is unavoidable as raw waste water will have high loads of organic volatile solids and indecomposable inorganic materials like plastic.

Use of constructed wetland is the best option for on-site waste water treatment, as it is the combination of physical, chemical and biological waste water treatment. The interest in the subject of water treatment or constructed wetland has been growing at a very rapid rate. It has been observed that wetland forms a cost effective, low energy and robust alternative to more conventional engineered systems to treat potential polluting substances. They also become part of the natural hydrologic cycle and provide a ready means of making treated water available for re-use. In the past few years the research works carried out in the developed and industrialized countries have resulted in information dissemination and still a lot is yet to be done, with reference to the developing countries like India.

Successful performance of constructed wetlands depends on ecological functions of wetland vegetation, climatic conditions and characteristics of waste water. Hence to check the performance of SCW in Kerala climatic conditions the present work was undertaken. The major focus was on the performance evaluation of constructed wetland for pollutant removal from the grey water and the effect of hydraulic retention time (HRT) on the same. For the design purpose three grey water samples were collected and analyzed at Central Water Analysis Laboratory (CWAL) at the Center for Water Resources Development and Management (CWRDM), Kozhikode. The samples were collected from combined outlet of bathroom and washing waste water and analyzed for BOD_5 which is the major design factor.

For the present study one small scale SCW system was fabricated with 12 gauge MS sheet in the workshop of KCAET, Tavanur. The length of tank was 1.7 m while width and depth were 1.1 m and 0.6 m respectively. The fabricated impervious MS metal sheet tank was installed in instructional farm. The SCW system had three distinct sections viz. inlet, filtration and outlet section separated by metal sheet in the form of baffles. These baffles were provided intentionally to increase the length of travel of grey water in wetland and hence to increase its efficiency.

The inlet section was filled with crushed bricks having average diameter of 3 cm. The selection was done on the basis of adsorptive property of bricks. The inlet section was provided with PVC pipe with holes to spread the grey water over the width of the section. The filtration section was filled with two layers. The bottom 45 cm depth was filled with fine river sand mixed with lime (1 % by weight of sand) while top 10 cm layer was soil for the better growth of macrophytes and anchorage in early days of operation. The fine sand and lime mixture was selected as filtering media due to the greater surface area available for growth and attachment of bacteria, better filtration and phosphorous binding capacity of lime. The outlet section was filled with crushed stones having average size of 8 mm. The material in the outlet section was selected after giving due consideration to easy movement of water towards the outlet pipe and the absence of sand particles in out-flowing water. The outlet section was provided with PVC pipe with holes at the bottom of section and adjustable outlet to maintain desired water level in the wetland.

The performance of SCW was monitored by analyzing the influent and effluent grey water samples from the wetland. The influent water samples were analyzed before and after settling. All the samples were analyzed for TSS, BOD_5, TKN, sulphates, phosphates and TC at CWAL, CWRDM, Kozhikode. The effect of HRT on performance of SCW was studied by maintaining the grey water in wetland for desired periods.

With reference to earlier works on waste water irrigation direct reuse of waste water is not safe and in some cases not possible. Hence to demonstrate the results of treated and untreated grey water irrigation on crop quality (height, stem thickness, number of leaves, yield, appearance and canopy spread) one vegetable crop and one ornamental plant viz. Amaranthus and golden duranta were irrigated in clay pots.

The statistical analysis was done for the data collected from the laboratory analyses and observations taken in the field which has evolved the following conclusions:

1. Grey water samples collected from the combined outlet of bathroom and washing waste had BOD_5 in the range of 47- 84 mg/l, acidic pH in the range of 6.0 - 6.3, TSS in the range of 100 - 260 mg/l while the TC density was ≥ 2400 MPN/100ml for all the samples.
2. The SCW system was designed and constructed with influent discharge of 110 l/d and in the light of results obtained from the analysis of grey water samples. The SCW was filled with suitable filtering media and planted with locally available ‘Canna’ macrophytes.
3. For all the cases the TSS concentration in influent water was well above 90 mg/l and the percentage reduction was higher than 94 % with effluent concentration in the range of 3 - 7 mg/l. The reduction in TSS concentration after settling was not good as it never exceeds 24 % while in majority cases it was less than 15 %. ANOVA calculations show the significant effect of HRT on percentage removal of TSS but further analysis with Tukey’s test resulted that to have significant difference in percentage removal the observation interval should be at least two days. This may be due to the higher rate of removal efficiency of 95 % or more at HRT of 1 day which never exceeds 97 % even after 5 day HRT. The higher R^2 value (0.97) shows the excellent correlation between HRT and percentage removal of TSS.

This excellent removal of TSS was achieved due to the use of fine river sand as filter media.

4. The BOD_5 concentration in influent water was always in the range of 56 - 77 mg/l while the percentage reduction was above 92 % with effluent concentration in range of 3.9 - 5.5 mg/l. In majority of cases the percentage reduction in BOD_5 concentration after settling was in range of 5 - 13 % with an exceptional case of 53 %. ANOVA calculations showed significant effect of HRT on percentage reduction of BOD_5. Further analysis with Tukey's test showed significant difference in BOD_5 concentration for 1 day and 2 day HRT which afterwards was not significant due to very small increase in efficiency with increase in HRT. The correlation coefficient R^2 = 0.9 shows the excellent correlation between HRT and BOD_5.
5. The phosphate concentration in influent grey water was in range of 0.14 - 0.19 mg/l while it was nill in effluent from the SCW. This 100 % reduction in phosphates was obtained due to use of fine river sand mixed with lime which has higher phosphorous binding capacity. The reduction in phosphate concentration after settling was in the range of 7 - 28 % which may have occurred due to settlement of phosphorous ions attached to heavy organic matter present in water. The ANOVA calculations showed significant effect of HRT on phosphate removal, while for HRT of two day or more it is not significant due to 100 % reduction in concentration.
6. The sulphate concentration for influent and effluent water was in the range of 28 - 33 mg/l and 7.5 - 8.5 mg/l respectively. The reduction in sulphate concentration after settling was as low as 0.5 - 6 % while for all the cases it was above 72 % for the effluent from SCW. ANOVA calculations have shown significant relationship between HRT and reduction in sulphate concentration. The higher R^2 value (0.9) shows

the excellent correlation between HRT and percentage reduction of sulphates but to have significant difference in concentrations the observation interval should be four days or more.

7. For all the cases the influent water had presence of TC with concentration of ≥ 2400 MPN/100ml which never changed after settling. While in effluent water TC concentration was ≤ 2 MPN/100ml. This excellent reduction in TC concentration was observed due to the use of fine river sand as filtering media, low flow rate and use of baffles to increase length of travel of water in SCW system. The HRT have not shown any impact on percentage TC reduction as nearly 100 % reduction was observed even for HRT of one day.
8. The TKN concentration in influent water was in the range of 12.04 - 15.40 mg/l while it was 10.64 - 14.28 mg/l after settling i.e. maximum reduction was only 19 %. The percentage reduction in effluent water from SCW was in the range of 84 - 96 % with TKN concentration of 0.56 - 2.24 mg/l. ANOVA calculations show the significant effect of HRT on TKN removal, while statistically to have significant difference in concentration the observation interval should be 3 days or more. The correlation coefficient R^2 = 0.93 shows the excellent correlation between HRT and reduction of TKN concentration.
9. The response of all the Amaranthus plants irrigated with raw grey water was notably weak than plants irrigated with effluent from SCW. Statistical analysis with ‘student’s t’ test showed the superiority for effluent irrigated plants over raw grey water irrigated plants. The average height, number of leaves, stem thickness, weight and canopy spread for the plants irrigated with raw grey water was 38.26 cm, 50.85, 9.52 mm, 52.75 gm and 826 cm^2 respectively while the same was 50.52 cm, 71.41, 12.19 mm, 98.76 gm and 1573 cm^2 for plants

irrigated with effluent from the SCW system. This notable difference in Amaranthus crop quality was observed due to the difference in quality of raw grey water and effluent from SCW.

10. For Golden Duranta plants also the results of raw and treated grey water irrigation were not different from that of Amaranthus plants. The statistical analysis with ‘student’s t’ test showed the significant difference in height and canopy spread of plants irrigated with two treatments at 5 % level of significance. In addition plants irrigated with raw grey water showed the leaf burning and discolouration.

Hence it can be concluded that the SCW system with Canna as macrophytes and fine river sand as filtering media is a good on-site grey water treatment method for rural communities which can reduce fresh water demand and make waste water available for secondary water uses. Also SCW systems have great potential to reduce the health risk by avoidance of breeding places of mosquito and other undesirable insects. Any locally available suitable macrophyte and filtering media can be used in small scale SCW system, and effective treatment of waste water from households can be performed. Thus this can be an efficient means of reusing the wasted precious resource of nature.

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Appendices

APPENDIX I

Meteorological data of study area for the period of study.

Meteorological data of study area for January 2007.

Date	Max. temp.(0C)	Min. temp.(0C)	Rainfall (mm)	Evaporation (mm)
1/1/2007	32.0	20.0	-	2.0
2/1/2007	33.0	19.0	-	2.0
3/1/2007	34.0	18.5	-	2.1
4/1/2007	33.5	19.0	-	2.0
5/1/2007	33.0	18.5	-	2.0
6/1/2007	33.0	19.0	-	2.0
7/1/2007	33.0	20.0	-	2.0
8/1/2007	33.5	21.0	-	2.2
9/1/2007	33.0	22.0	-	4.0
10/1/2007	34.0	23.0	-	4.0
11/1/2007	34.0	22.0	-	6.4
12/1/2007	34.5	22.5	-	2.0
13/1/2007	33.5	22.5	-	3.4
14/1/2007	34.5	20.5	-	2.6
15/1/2007	35.0	22.0	-	4.0
16/1/2007	34.0	21.0	-	2.3
17/1/2007	34.0	20.5	-	2.0
18/1/2007	34.0	19.5	-	2.2
19/1/2007	34.0	20.0	-	4.0
20/1/2007	34.0	19.0	-	1.8
21/1/2007	34.0	18.5	-	2.0
22/1/2007	35.0	19.5	-	4.0
23/1/2007	35.0	19.0	-	4.2
24/1/2007	35.0	19.0	-	4.2
25/1/2007	36.0	21.0	-	4.0
26/1/2007	33.5	21.0	-	4.0
27/1/2007	33.5	22.0	-	4.0
28/1/2007	34.0	23.0	-	4.0
29/1/2007	33.5	24.0	-	4.0
30/1/2007	34.4	23.0	-	3.6
31/1/2007	34.5	22.0	-	4.2

Meteorological data of study area for February 2007.

Date	Max. temp.(^{0}C)	Min. temp.(^{0}C)	Rainfall (mm)	Evaporation (mm)
1/2/2007	34.5	20.0	-	6.0
2/2/2007	35.0	19.5	-	4.4
3/2/2007	35.0	19.5	-	4.0
4/2/2007	33.0	22.0	-	6.0
5/2/2007	34.0	22.0	-	4.0
6/2/2007	33.0	22.0	-	4.0
7/2/2007	34.0	21.0	-	3.4
8/2/2007	34.5	21.0	-	4.0
9/2/2007	35.5	19.5	-	3.8
10/2/2007	35.0	21.0	-	4.0
11/2/2007	34.5	22.0	-	6.0
12/2/2007	34.0	22.0	-	4.2
13/2/2007	36.0	22.0	-	4.6
14/2/2007	33.0	20.0	-	4.2
15/2/2007	33.5	19.0	-	4.0
16/2/2007	31.5	18.5	-	3.6
17/2/2007	31.0	20.5	-	5.2
18/2/2007	32.0	22.0	-	4.0
19/2/2207	33.0	22.5	-	3.6
20/2/2007	35.5	24.0	-	7.0
21/2/2007	35.5	23.0	-	6.0
22/2/2007	35.5	22.0	-	6.2
23/2/2007	35.0	21.5	-	6.0
24/2/2007	35.0	21.0	-	6.4
25/2/2007	33.5	21.0	-	6.0
26/2/2007	34.0	22.0	-	6.0
27/2/2007	34.0	22.5	-	6.0
28/2/2007	34.0	23.5	-	4.6

Meteorological data of study area for March 2007.

Date	Max. temp.(^0C)	Min. temp.(^0C)	Rainfall (mm)	Evaporation (mm)
1/3/2007	35.0	23.0	-	6.0
2/3/2007	34.0	24.0	-	4.0
3/3/2007	33.0	22.5	-	4.6
4/3/2007	33.0	23.0	-	5.4
5/3/2007	36.0	23.0	-	6.0
6/3/2007	34.0	22.5	-	6.0
7/3/2007	34.0	23.0	-	6.4
8/3/2007	34.5	23.5	-	6.0
9/3/2007	34.0	22.5	-	5.4
10/3/2007	33.5	23.5	-	6.0
11/3/2007	33.5	23.5	-	3.0
12/3/2007	33.0	23.0	-	5.0
13/3/2007	34.0	22.5	-	6.0
14/3/2007	35.0	23.0	-	6.5
15/3/2007	35.0	24.5	-	6.0
16/3/2007	35.0	23.5	-	6.0
17/3/2007	37.0	24.5	-	6.0
18/3/2007	36.0	24.5	-	6.0
19/3/2007	35.5	24.0	-	7.0
20/3/2007	34.5	24.0	-	5.6
21/3/2007	35.0	24.5	-	6.0
22/3/2007	34.5	24.0	-	4.0
23/3/2007	35.0	25.0	-	5.2
24/3/2007	36.0	25.0	-	5.6
25/3/2007	34.5	24.0	-	6.0
26/3/2007	35.0	24.5	-	5.6
27/3/2007	35.5	24.5	-	6.0
28/3/2007	35.0	24.0	-	5.4
29/3/2007	35.5	24.0	-	5.0
30/3/2007	34.5	24.0	-	4.0
31/3/2007	35.0	24.5	-	2.2

Meteorological data of study area for April 2007.

Date	Max. temp.(^{0}C)	Min. temp.(^{0}C)	Rainfall (mm)	Evaporation (mm)
1/4/2007	35.0	23.5	-	2.2
2/4/2007	34.5	24.0	-	2.1
3/4/2007	35.0	22.6	-	2.2
4/4/2007	36.0	23.4	-	2.4
5/4/2007	35.5	22.0	-	3.0
6/4/2007	35.5	21.9	-	3.1
7/4/2007	35.0	22.8	-	3.4
8/4/2007	36.0	23.1	-	4.0
9/4/2007	35.5	23.6	-	3.1
10/4/2007	36.0	22.7	-	3.0
11/4/2007	37.0	22.5	30.0	3.6
12/4/2007	37.0	25.0	-	2.0
13/4/2007	33.5	23.0	-	6.0
14/4/2007	34.5	21.0	2.4	2.9
15/4/2007	36.0	20.0	15.2	7.2
16/4/2007	35.5	23.0	2.4	4.6
17/4/2007	34.5	22.0	9.0	5.0
18/4/2007	33.0	24.0	-	5.4
19/4/2007	34.0	24.5	-	4.0
20/4/2007	35.0	25.0	-	5.4
21/4/2007	34.0	23.5	-	4.5
22/4/2007	33.5	21.0	45.0	9.2
23/4/2007	33.0	23.5	-	4.0
24/4/2007	33.5	24.0	-	4.0
25/4/2007	34.0	23.5	-	4.0
26/4/2007	34.0	24.0	-	4.0
27/4/2007	34.0	24.5	-	6.0
28/4/2007	35.0	25.5	-	4.0
29/4/2007	34.5	25.0	-	4.8
30/4/2007	35.0	25.0	-	4.2

APPENDIX II

Different apparatus and reagents used for analysis.

Determination of BOD_5

Apparatus

- BOD bottles, 300 ml narrow mouth, flared lip, with tapered and pointed ground glass stoppers.
- Air incubator or water bath, thermostatically controlled at $27 \pm 1\ ^{o}C$. Entry of light must be prevented in order to avoid photosynthetic oxygen production.
- Accessories: plastic tube, screw- pin and 5 to 10 l water container.

Reagent

- Phosphate buffer solution was prepared by dissolving 8.5 gm KH_2PO_4, 21.75 gm K_2HPO_4, 33.4 gm $Na_2HPO_4.7H_2O$ and 1.7 gm NH_4Cl in 1litre distilled water.
- Magnesium sulphate solution was prepared by dissolving 22.5 gm $MgSO_4.7H_2O$ in 1 litre distilled water.
- Calcium chloride solution was prepared by dissolving 27.5 gm $CaCl_2$ in 1 litre distilled water.
- Ferric chloride solution was prepared by dissolving 0.25 gm $FeCl_3.6H_2O$ in 1 litre distilled water.
- Acid and alkali solution: 1N NaOH and 1 N H_2SO_4 were used for neutralizing the samples.
- Glucose glutamic acid solution was prepared by dissolving 150 mg dry reagent grade glucose and 15 mg dry reagent grade glutamic acid in 1 litre distilled water.

- Sample dilution water was prepared by adding 1 ml each of Phosphate buffer, $MgSO_4$, $CaCl_2$ and $FeCl_3$ solution per litre distilled water.

Determination of dissolved oxygen

Principle

Oxygen present in the sample rapidly oxidizes the divalent manganese hydroxide to its higher state of valency which precipitates as brown hydrated oxide after addition of NaOH and KI. Upon acidification, manganese reverts to divalent state and librates iodine from KI equivalent to the original DO content. The librated iodine is then titrated against hypo using starch as indicator.

Apparatus

- BOD bottles of capacity 300 ml.
- Sampling device for collection of samples.

Reagent

- Manganese sulphate was prepared by dissolving 480 gm manganese sulphate ($MnSO_4.2H_2O$) and diluted to 1000 ml. Filtration is done if necessary.
- Alkali iodide azide reagent was prepared by dissolving 500 gm NaOH or 700 gm KOH and 135 gm NaI or 150 gm KI in distilled water to make 1000 ml. To 40 ml of this solution 10 gm sodium azide is added. The resultant solution should not give colour with starch solution on acidification.
- Standard sodium thiosulphate was prepared by dissolving $Na_2S_2O_3.5H_2O$ (6.205 gm) in distilled water and diluted to 1000 ml.
- Starch indicator was prepared by dissolving soluble starch (2 gm) in 400 ml distilled water.

Determination of sulphate

Principle

Sulphate ion is precipitated in an acid medium with barium chloride in such a manner as to form barium sulphate crystals of uniform size. The absorbance of barium sulphate suspension is measured by turbidity meter and the sulphate ion concentration is determined by comparison of the reading with a standard curve.

Apparatus

Nephelometer

Reagent

- Conditioning reagent was prepared by mixing 50 ml glycerol with a solution containing 30 ml concentrated HCl, 300 ml distilled water, 100 ml 95 % ethyl or isopropyl alcohol and 75 gm NaCl.
- Barium chloride crystals.
- For preparing standard sulphate solution, 147.9 mg anhydrous sodium sulphate dissolved in distilled water and diluted to 1000 ml.

Determination of phosphate

Principle

Ammonium molybdate reacts with phosphate to form molybdophosphoric acid which is reduced to blue coloured complex 'molybdenum blue' by the addition of stannous chloride.

Reagents

- Ammonium molybdate solution:

  - 2.5 gm ammonium molybdate was dissolved in about 200 ml distilled water.
  - 280 ml concentrated H_2SO_4 was added carefully to 400 ml distilled water and allowed it cool. Then molybdate solution was added to the diluted acid and diluted to 1000 ml.

- Stannous chloride solution: 2.5 gm stannous chloride ($SnCl_2.2H_2O$) was dissolved in 100 ml glycerol and heated in a water bath. Mixed by stirring with a glass rod. This reagent is stable and required no special storage.
- Phosphate stock solution: 439 gm potassium dihydrogen phosphate (KH_2PO_4) was dissolved in distilled water and made up to 1000 ml in a volumetric flask.

Determination of total nitrogen

Principle

The nitrogen of organic matter is converted in to ammonium sulphate when treated with sulphuric acid in the presence of copper sulphate catalyst. An excess of alkali is then added (to liberate the ammonia from ammonium sulphate) and distilled. The distillate is either treated with Nessler reagent or standard sulphuric acid after absorption in boric acid solution.

$$2NH_3+2H_3BO_3 \longrightarrow 2NH_4^+ + 2H_2BO_3^-$$

$$H_2SO_4 \longrightarrow 2H^+ + SO_4^{2-}$$

$$2NH_4^+ + 2H_2BO_3^- + 2H^+ + SO_4^{2-} \longrightarrow (NH_4)_2SO_4 + 2H_3BO_3$$

Reagents

- Concentrated sulphuric acid
- 10 % copper sulphate solution was prepared by dissolving 10 gm copper sulphate, $CuSO4.5H_2O$ in 100 ml distilled water.
- Potassium sulphate.
- Phenolphthalein indicator solution.

- 50 % sodium hydroxide solution was prepared by dissolving 100 gm NaOH in 200ml distilled water. The prepared solution was placed in a rubber stoppered bottle.
- Mixed indicator solution was prepared by dissolving 200 mg methyl red indicator in 100 ml 95 % ethyl or isopropyl alcohol. Also the methylene blue was dissolved in 50 ml 95 % ethyl or isopropyl alcohol. The two solutions were combined. This mixed indicator was prepared monthly. End point with this indicator is the color change from pale green to lavender.

  Alternatively, methyl red indicator also can be used. It can be prepared by dissolving 50 mg methyl red in 100 ml ethyl alcohol. End point with this indicator is the appearance of red colour.
- 2 % boric acid solution was prepared by dissolving 10gm boric acid H_3BO_3 in ammonia free distilled water and diluted to 500 ml.
- 0.02 N standard sulphuric acid solution.

APPENDIX III

Results of grey water samples analyzed for the design of SCW system.

Dates of collection:

- Sample 1: 6th Oct. 2006
- Sample 2: 7th Oct. 2006
- Sample 3: 9th Oct. 2006

Parameter	Sample 1	Sample 2	Sample 3
pH	6.16	6.31	6.38
TSS (mg/l)	140.00	100.00	260.00
EC (μS)	284.69	259.78	139.5
TDS (mg/l)	182.20	166.26	89.28
Salinity (%)	0.10	0.10	0.10
TC (MPN/100ml)	≥2400	≥2400	≥2400
DO (mg/l)	220.00	280.00	263.33
BOD_5 (mg/l)	46.68	83.30	70.02

APPENDIX IV

The design calculations of the SCW system.

- Selected inflow – 100 l/d.
- Influent BOD_5 – 85 mg/l
- Expected effluent BOD_5 – 5 mg/l
- Porosity of filter media – 48.5 %
- Selected macrophyte – Canna
- Root depth of macrophyte – 45 cm
- Reaction constant, K_{20} = 0.828 day^{-1} (75 % of base value recommended by EPA)

Area of SCW (A_s) =

$$A_s = \frac{Q\,[\ln C_i - \ln C_e]}{K_T\,.\,d.\,n}$$

$$= \frac{0.11x[\ln 85 - \ln 5]}{0.739\ x0.45x0.48}$$

$$= 1.87\ m^2.$$

Assume aspect ration (L: W) = 1.5: 1

Hence length of SCW = 1.7 m

Width of SCW = 1.1 m

Hydraulic retention time (t)

$$HRT,\ t = \frac{L\ x\ W\ x\ n\ x\ d}{Q}$$

$$= \frac{1.7\ x1.1x0.48x0.45}{0.11}$$

$$= 3.7\ days$$

APPENDIX V

Various combinations of the results for the bacterial presence when three dilutions (10 ml, 1ml and 0.1 ml) and three tubes for each are used.

Number of tubes giving positive reactions out of three tubes			MPN index/100ml
0	0	0	≤2
0	0	1	3
0	1	0	3
1	0	0	4
1	0	1	7
1	1	0	7
1	1	1	11
1	2	0	11
2	0	0	9
2	0	1	14
2	1	0	15
2	1	1	20
2	2	0	21
2	2	1	28
3	0	0	23
3	0	1	39
3	0	2	64
3	1	0	43
3	1	1	75
3	1	2	120
3	2	0	93
3	2	1	150
3	2	2	210
3	3	0	240
3	3	1	460
3	3	2	1100
3	3	3	≥2400

APPENDIX VI

Observed concentration of different contaminants before and after settling and effluent from SCW for different set of samples.

- Date: 19th Feb. 2007

Sr.No.	Parameter	Before settling	After settling	Eff. from CW	% red.
1	TC (MPN/100ml)	≥2400	≥2400	≤2	≈100
2	TSS (mg/l)	132.00	109.00	14.00	89.39
3	Phosphates (mg/l)	0.14	0.10	0.00	100.00
4	BOD(mg/l)	66.63	53.33	4.73	92.90
5	sulphates	30.76	29.28	8.24	73.21
6	TKN	13.72	12.6	2.24	83.67

- Date: 20th Feb. 2007

Sr.No.	Parameter	Before settling	After settling	Eff. from CW	% red.
1	TC (MPN/100ml)	≥2400	≥2400	≤2	≈100
2	TSS (mg/l)	128.00	97.00	7.00	94.53
3	Phosphates (mg/l)	0.16	0.12	0.00	100.00
4	BOD(mg/l)	56.66	23.33	3.99	92.96
5	sulphates	32.64	30.96	8.84	72.92
6	TKN	12.04	10.92	1.12	90.70

- Date: 21st Feb. 2007

Sr.No.	Parameter	Before settling	After settling	Eff. from CW	% red.
1	TC (MPN/100ml)	≥2400	≥2400	≤2	≈100
2	TSS (mg/l)	117.00	105.00	6.00	94.87
3	Phosphates (mg/l)	0.18	0.16	0.00	100.00
4	BOD(mg/l)	73.33	50.00	3.33	95.45
5	sulphates	31.80	30.04	7.88	75.22
6	TKN	13.16	10.64	1.40	89.36

- Date: 26th Mar. 2007

Sr.No.	Parameter	Before settling	After settling	Eff. from CW	% red.
1	TC (MPN/100ml)	≥2400	≥2400	≤2	≈100
2	TSS (mg/l)	89.00	76.00	4.00	95.51
3	Phosphates (mg/l)	0.17	0.14	0.00	100.00
4	BOD(mg/l)	72.91	64.37	4.62	93.66
5	sulphates	30.32	30.16	8.12	73.22
6	TKN	14.28	14.00	0.84	94.12

➢ Date: 27th Mar. 2007

Sr.No.	Parameter	Before settling	After settling	Eff. from CW	% red.
1	TC (MPN/100ml)	≥2400	≥2400	≤2	≈100
2	TSS (mg/l)	112.00	96.00	5.00	95.54
3	Phosphates (mg/l)	0.19	0.17	0.00	100.00
4	BOD(mg/l)	76.62	72.45	5.49	92.83
5	sulphates	33.00	31.81	8.59	73.97
6	TKN	12.88	12.32	0.56	95.65

➢ Date: 28th Mar. 2007

Sr.No.	Parameter	Before settling	After settling	Eff. from CW	% red.
1	TC (MPN/100ml)	≥2400	≥2400	≤2	≈100
2	TSS (mg/l)	106.00	95.00	3.00	97.17
3	Phosphates (mg/l)	0.16	0.14	0.00	100.00
4	BOD(mg/l)	63.91	58.25	3.96	93.80
5	sulphates	29.94	28.12	7.87	73.71
6	TKN	13.16	12.04	0.84	93.62

➢ Date: 23rd Apr. 2007

Sr.No.	Parameter	Before settling	After settling	Eff. from CW	% red.
1	TC (MPN/100ml)	≥2400	≥2400	≤2	≈100
2	TSS (mg/l)	114.00	103.00	5.00	95.61
3	Phosphates (mg/l)	0.17	0.13	0.00	100.00
4	BOD(mg/l)	76.67	73.33	3.87	94.96
5	sulphates	32.36	30.44	8.28	74.41
6	TKN	14.84	13.72	1.40	90.57

➢ Date: 24th Apr. 2007

Sr.No.	Parameter	Before settling	After settling	Eff. from CW	% red.
1	TC (MPN/100ml)	≥2400	≥2400	≤2	≈100
2	TSS (mg/l)	98.00	86.00	4.00	95.92
3	Phosphates (mg/l)	0.19	0.17	0.00	100.00
4	BOD(mg/l)	63.33	60.00	3.87	93.89
5	sulphates	28.56	27.24	7.72	72.97
6	TKN	15.40	14.28	0.84	94.55

➢ Date: 25th Apr. 2007

Sr.No.	Parameter	Before settling	After settling	Eff. from CW	% red.
1	TC (MPN/100ml)	≥2400	≥2400	≤2	≈100
2	TSS (mg/l)	123.00	116.00	5.00	95.93
3	Phosphates (mg/l)	0.14	0.13	0.00	100.00
4	BOD(mg/l)	76.67	66.67	4.13	94.61
5	sulphates	33.80	32.52	8.76	74.08
6	TKN	14.28	13.16	1.12	92.16

APPENDIX VII

Concentration and percentage reduction of different contaminants in grey water for different HRT

- Set of observations after one month of construction and operation of SCW

Parameter	Inf.	1dHRT	% red.	2dHRT	% red.	3dHRT	% red.	4dHRT	% red.	5dHRT	% red.
TSS	116.0	5.0	95.7	5.0	95.7	5.0	95.7	4.0	96.6	4.0	96.6
Phos.	0.2	0.1	68.4	0.0	100.0	0.0	100.0	0.0	100.0	0.0	100.0
BOD	73.7	7.9	89.2	5.3	92.8	4.2	94.2	4.2	94.3	3.9	94.7
sulphates	31.2	9.3	70.3	8.2	73.7	8.1	73.9	8.0	74.3	7.9	74.7
TKN	12.6	9.2	26.7	5.3	57.8	0.0	100.0	0.0	100.0	0.0	100.0

- Set of observations after two months of construction and operation of SCW

Parameter	Inf.	1dHRT	% red.	2dHRT	% red.	3dHRT	% red.	4dHRT	% red.	5dHRT	% red.
TSS	132	6	95.5	5	96.2	4	97	4	97	4	97
Phos.	0.2	0	81.3	0	100	0	100	0	100	0	100
BOD	89.8	9.2	89.7	7.2	92	7.9	91.2	4.7	94.7	4.5	95
sulphates	30.3	8.8	70.8	8.6	71.8	8.2	73.1	7.8	74.4	7.9	73.9
TKN	16.5	12.9	22	6.4	61	2	88.1	0	100	0	100

- Set of observations after three months of construction and operation of SCW

Parameter	Inf.	1dHRT	% red.	2dHRT	% red.	3dHRT	% red.	4dHRT	% red.	5dHRT	% red.
TSS	117	7	94	6	94.9	5	95.7	5	95.7	4	96.6
Phos.	0.2	0	73.3	0	100	0	100	0	100	0	100
BOD	73.3	7.1	90.4	5.3	92.8	4.3	94.1	3.8	94.8	3.6	95.1
sulphates	30.7	8.5	72.4	8.4	72.8	8.4	72.7	8.2	73.4	8	73.8
TKN	15.7	13.4	14.3	8.1	48.2	11.4	27.4	0	100	0	100

- Average concentrations and percentage reduction of different contaminants in grey water for different HRT

Parameter	Inf.	1dHRT	% red.	2dHRT	% red.	3dHRT	% red.	4dHRT	% red.	5dHRT	% red.
TSS	121	6.0	95.1	5.3	95.6	4.7	96.2	4.3	96.4	4.0	96.7
Phos.	0.2	0.0	74.0	0.0	100.0	0.0	100.0	0.0	100.0	0.0	100.0
BOD	78.9	8.1	89.8	5.9	92.5	5.5	93.0	4.2	94.6	4.0	94.9
sulphates	30.7	8.9	71.2	8.4	72.8	8.2	73.2	8.0	74.0	8.0	74.1
TKN	14.9	11.9	20.6	6.6	55.6	4.4	70.2	0.0	100.0	0.0	100.0

Grey water treatment by Constructed Wetland

By

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ABSTRACT OF A THESIS

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ABSTRACT

Next to air, water is the most important requirement for human life to exist. With growing population and industrial development, demand of fresh water is increasing. Hence every community should take preventive measures to avoid careless pollution and contamination of the available water resources and reuse the waste water after treating it. For this, on-site grey water treatment with constructed wetland is the cheapest and practical option. To verify the performance of subsurface flow constructed wetland (SCW) for treatment of grey water in climatic conditions of Kerala, the present study was conducted at the instructional farm of KCAET, Tavanur. The experimental scale SCW system for discharge of 110 l/d was designed and constructed with MS sheet as per the USEPA procedure for influent BOD_5 of 85 mg/l and expected effluent BOD_5 of 5 mg/l. The SCW system was filled with crushed brick, fine river sand mixed with lime and crushed stones in the inlet, filtration and outlet section respectively. SCW system was planted with Canna macrophyte.

Raw grey water from the men's hostel of KCAET was diverted to low lying SCW system site with the use of gravitational force to avoid pumping and energy consumption for the same. The performance of SCW system for removal of TSS, $BOD_{5,}$ total nitrogen, sulphates and phosphates were studied by analysing the influent and effluent grey water samples from the SCW system. On an average the influent concentrations of these parameters were 132 mg/l, 70 mg/l, 14 mg/l, 32 mg/l and 0.17 mg/l respectively while the same for effluent was 5 mg/l, 4 mg/l, 1.2 mg/l, 8 mg/l and 0.00 mg/l respectively. In all the samples the TC counts in influent water were $\geq$2400 MPN/100ml while it was $\leq$2 MPN/100ml in the effluent from the SCW system. Excellent reduction of 90 % or above in TSS, $BOD_{5,}$ total nitrogen, phosphates and TC was observed and it may be due to use of fine river sand mixed with lime as filter media and Canna as a macrophite. The effect of HRT on the efficiency of removal of these parameters was studied by storing the raw grey water in SCW system for the required period of time. Statistical ANOVA calculations for

HRT study show the significant effect of same on % reduction of these elements. Furthermore the extent of significance was checked with Tukey's test and it was concluded that to have significant difference in observations the interval between successive observations should be 3 days or more. The effect of raw and treated grey water irrigation on Amaranthus and Golden Duranta plants was demonstrated by irrigating these plants in clay pots. For the Amaranthus plants irrigated with raw grey water, observed average height, number of leaves, stem thickness, canopy spread and yield were 38 cm, 51, 9 mm , 826 cm^2 and 158 gm while the same was 51 cm, 71, 12 mm, 1573 cm^2 and 296 gm respectively for the plants irrigated with effluent from the SCW. Statistical analysis with 'student's t' test showed significant difference for the height, number of leaves, and yield at 1 % level of significance and for stem thickness and canopy spread at 5 % level of significance. The Golden Duranta plants irrigated with raw and treated grey water shows significant difference in height and canopy spread at 5 % level of significance. Besides this raw grey water irrigated plants show discolouration and leaf burning. Hence it was concluded that the raw grey water irrigation is not effective for these plants. From the entire study it was concluded that the SCW system is the reliable option for on-site grey water treatment. This ecological treatment system can reduce many objectionable pollutants from waste water to great extent and make it available for secondary uses. Also it has potential to reduce the health risk due to avoidance of mosquitoes and other undesirable insects.