CHAPTER 1
INTRODUCTION

1.1 Background

Wastewater is the liquid waste of community. The components that make up the wastewater flow from a community include domestic wastewater, industrial wastewater, infiltration or inflow and storm water. The wastewater from community flows through natural drainage patterns or sewers and enters natural bodies of surface water such as river, lakes, ocean that have an inherent self-purification capacity. Water contains dissolved gases, such as oxygen and carbon dioxide and also important organic substances. But polluted water contains unbalanced amounts of oxygen, carbon dioxide and minerals, which become detrimental to fresh water life (Shrestha, 1990).

Dense human population, community living patterns and large scale agricultural and industrial activities typically produce liquid wastes on a scale that overwhelms the homeostasis of aquatic communities and causes unacceptable deterioration of water quality. Developing countries generally lack a policy for natural waters preservation, due probably to their successive financial crises leading to low levels of investments in sewage collection and proper treatment system and in some way, also due to their high human population density.

A common practice in Nepal is to discharge untreated wastewater and sewage directly into neighboring water bodies or onto land surfaces. Both domestic and industrial wastewater is discharged almost directly into the water body (river/lakes), and has caused significant environmental and public health damage. As a result the quality of some local streams and rivers has been degraded to the point where the water is probably not safe for human or livestock uses or for irrigation purposes. The present trend of pollution is so rapid and alarming that if serious attention and measures are not taken in time, most of the other rivers, streams, lakes and ponds in urban area could be changed into specific condition in near future.

Proper treatment of wastewater before disposal is utmost necessary to prevent the deterioration of surface and ground waters, to eliminate the waterborne disease epidemics and to reduce economic and social burden caused by the spreading of waterborne diseases.

Wastewater treatment is a multistage process to renovate the quality of wastewater before it re-enters in the body of water, is applied to the land or is reused. The treatment of wastewater is the necessity of human society to maintain a healthy life and pollution free environment.

Primarily there are three stages of wastewater treatment: Primary, secondary and tertiary treatment. Primary treatment removes coarser of the suspended solids and the floating matter. This removal is achieved in settling tanks or basins where the solids are drawn off from the bottom. Secondary treatment is biological treatment process to remove dissolved organic matter from wastewater. Secondary treatment can be aerobic or anaerobic. Secondary treatment generally contains one or more biological unit processes coupled with secondary sedimentation but for certain wastes a chemical unit process such as coagulation may also be involved. Tertiary treatment is defined as additional treatment system needed to remove suspended and dissolved substances remaining after conventional secondary treatment (Metcalf and Eddy, 1991).

Today, wide ranges of treatment technologies are available for use in our efforts to restore and maintain the chemical, physical and biological integrity of water. Many processes based on chemical and biological unit operations, have been developed and are applied for the treatment of wastewater.

The conventional wastewater treatment processes are costly and required skilled manpower and sophisticated technological inputs. The increasing capital and operational costs associated with conventional wastewater treatment plant, is of great concern to waste water authorities throughout the world.

In recent years, there has been increased interest on an alternative and innovative technology particularly in developing countries, with the aim of developing low-cost, low maintenance and environment friendly methods of treating wastewater. One of such method is the use of large aquatic plants in natural or artificial or constructed wetlands for wastewater treatment (Reed *et al.*, 1988). Constructed wetlands play an important role in water pollution control and wastewater management using natural processes. Due to simplicity of their design, operation and maintenance they seem nowadays to be the most promising technology to be applied in developing countries.

Constructed wetland is natural biological wastewater treatment technology. It is an alternative system. It is energetically sustainable because it uses only natural energy to reduce pollutants. This system utilizes wetland plants, soils and their associated microorganisms to remove contaminants from wastewater as well as other sources of contamination. They use the lands same processes as that occur in natural wetlands but have the flexibility of being constructed (Haberl *et al.*, 2003). Constructed wetlands are capable of removing a wide variety of contaminants, including bacterial pollution. Wetlands are known to act as bio-filters through a combination of physical, chemical and biological factors which all participants in the reduction of the number of bacteria (Green *et al.*, 1997).

Constructed wetland technology was first experimented in 1952 at Max Plank Institute, Germany to treat wastewater. After 20 years of research, the full-scaled CW was built in Othfresen, Germany. Since then, CWs have been widely used all over the world to treat various types of wastewater (Shrestha, 1999).

The first CW in Nepal was constructed at Dhulikhel Hospital in 1997, with technical collaboration of institute for Water Provision, University of Agriculture Sciences and Vienna, Austria. It was designed with an aim to treat 10 to 15 m^3 of wastewater per day within 30 beds. Now it has been expanded to 80 beds treating all its wastewater about 40 m^3 per day. Following the successful demonstration of CW technology in Dhulikhel Hospital, similar projects have been constructed at several other institutions. Sushma Koirala Memorial Hospital, Sankhu is second hospital in Nepal having CW. List of several CWs operating in Nepal is given in the Table 1 below:

Table 1: List of CW operating in Nepal

S.No	**Place**	**Date of operation**	**Type of wastewater**	**Treatment capacity**	**CW Configuration**
1	Dhulikhel Hospital, Dhulikhel	July, 1997	Wastewater from all units of the hospital	Designed for 10 m^3/day but treating 40 m^3 per day	HFB followed by VFB
2	Private house, KTM	April, 1998	Grey water	500L/day	VFB
3	Kathmandu Metropolitan City	August, 1998	Septage	40 m^3/day	Sludge drying beds followed by VFB
4	MIS.Panauti	August, 2000	All wastewater from school	25 m^3/day	HFB followed by VFB
5	Sushma Koirala Memorial Hospital	December, 2000	All wastewater from hospit6al	15 m^3/day	HFB followed by VFB
6	Kathmandu University	2001	All wastewater from university	>40 m^3/day	HFB followed by VFB
7	Staff Quarter of Middle Marsyandhi Hydro Electric Power Station	April, 2002	Wastewater from staffs.	26 m^3/day	HFB followed by VFB
8	ENPHO Laboratory	August, 2002	Wastewater from lab and staff toilet	1 m3/day	VFB
9	Tansen Municipality	Design stage	Sewer	30 m3/day	HFB followed by VFB
10	Pokhara Sub metropolis	Under construction	Septage and lechate	115 m^3/day	HFB followed by VFB
11	Kapan Monastry	Under construction	Wastewater from units of monastery	17 m^3/day	HFB followed by VFB

Source:ENPHO (2003).

1.2 Justification

The river water particularly along the religious sites should be of high quality. This is especially important if these rivers are used for sacred bathing. The high quality river water can be ensured if the upstream wastewater are collected, transferred and treated in the wastewater treatment system before discharging into the river. Wastewater can be treated by various techniques such as oxidation pond, stabilization pond, activated sludge process, oxidation ditch and trickling filter etc. The effluent treatment system such as iodations ditch may not be of high quality so that it can be discharged just upstream of the religious sites. For instance, this is why the effluent from the Guheswori treatment plant has been discharge downstream of Pashupatinath Temple at near Til Ganga. Therefore there is a need of study to evaluate the use of cost effective natural system such as constructed as a polishing unit to upgrade the quality of treated effluent before discharging upstream of the religious sites.

Besides, very little research work about CW is carried out in Nepal. Performance study of CW with different media and different influent wastewater quality particularly in our climatic condition may be essential. It may also be essential to know the effectiveness of different available local media. The water is mainly used for domestic purpose, religious purification and countless human activities. People are made aware by numerous bodies of the importance to maintain the water quality. This has been inspired me for detail study and conservation of environment of this area. The present work on the pollutants removal efficiency of reeds from the domestic wastewater discharging in Bagmati River was conducted in order to notice the possibilities of the use of reeds for domestic wastewater treatment.

1.3 Objectives

Main objective of this research is to reduce the level of pollutants by treating sewage properly before being discharged into river. The specific objectives of the study are:

- To analyze various physico-chemical parameters of wastewater.
- To determine removal efficiency of reed beds under different flow rates.
- To compare removal efficiency of planted and unplanted reed beds.

CHAPTER 2

LITERATURE REVIEW

2.1 Types of Constructed Wetlands

Two types of constructed wetlands are currently used for remediation applications: surface flow system and subsurface flow system.

2.1.1 Surface flow system

The surface flow system wetland typically consists of a basin or channels 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 (Brix, 1994).

2.1.2 Sub-surface flow system

Subsurface flow system is filled with a treatment media, such as rock or gravel, which is placed on top of the soil or lining on the cell bottom. The depth of the media layer is usually about one to two feet. The wastewater flows just below the media surface and remains unexposed to the atmosphere while it saturates the layers below. The saturated media and soil, together with the wetland plants roots, create conditions below the surface of the system that are conductive to treatment (Brix, 1994).

Treatment in the subsurface flow system is more efficient than in the surface flow wetland because the media provides a greater number of small surfaces, pores and crevices where treatment can occur. Waste-consuming bacterial attach themselves to the various surfaces, and waste materials in the water become trapped on the pores and crevices on the media and in the spaces between media (Brix, 1994).

Depending upon the flow path there are two types of subsurface flow constructed wetland. They are horizontal flow system and vertical flow system. In horizontal flow system, wastewater is fed in at the inlet and flow slowly through the porous medium under the surface of the bed in more or less horizontal path until it reaches in outlet zone. In vertical flow system, wastewater is fed vertically through perforated pipes laid above the bed surface. The beds are fed intermittently. The liquid is passed onto the bed in a large batch thus flooding the surface (Brix, 1994).

2.2 Components of Constructed wetland

2.2.1 Substratum

The substratum in constructed wetlands is composed of soils or gravel, a mixture of both organic and inorganic matter in various stages of decomposition and may also contain large number of microorganisms. Substratum plays important role in treatment processes because it forms integral link. The first role of media is physical treatment of the wastewater (Wood, 1990). Filtration and sedimentation of suspended solids and pathogens occurs along with the sorption of phosphorous and dissolved organics (Lance, *et al.,* 1976). Second role is that it provides a stable surface area for the attachment of microbial biofilms. Small media, such as sand, are more effective in sorption and filtration than gravel or rocks because the smaller media contain smaller pore sizes and larger surface areas. Thirdly, it gives the solid support for wetland plant growth (Wood, 1990).

2.2.2 Microorganisms

Wetlands and aquatic habitats provide suitable environmental condition for the growth and reproduction of microscopic organisms. The microorganisms are typically responsible for degradation of organic content in the wastewater. Some microbes species e.g. *Nitrosomonas, Nitrobactor* and denitrifiers, prevailing in the wetlands are capable of removing nitrogen from the wastewater through a sequential nitrification or denitrification reaction which is major pathway for ammonia removal in both free and subsurface flow system (Reed *et al*., 1995).

2.2.3 Macrophytes

The larger aquatic plants growing in wetlands are usually called macrophytes. The major portion of these plants (leaves and flowers) emerges above the media surface and is exposed to the air, while their roots and rhizomes are submerged beneath the water and media (Kadlec *et al.*, 1996).

Not all wetland species are suitable for wastewater treatment since plants for treatment wetlands must be able to tolerate the combination of continuous flooding and exposure to wastewater or storm water containing relatively high and often variable concentration of pollutants. Three of the most commonly used plants species in subsurface wetland are bulrush (*Scirpus sps*), reeds (*Phragmites sps*), and cattails (*Typha sps).* The extensive rooting structures of these species make viable options for wastewater treatment.

Brix, 1997 categorized the most important functions of macrophytes in the treatment of wastewater as physical and metabolic. Physical effects include filtration of particles, reduction in turbulence, stabilization of sediments, providing an increased surface area for biofilm growth on stems, leaves, roots and rhizomes. Metabolic effects include nutrient uptake and oxygen release from the roots.

2.3 Removal mechanism of CW

2.3.1 Organic Matter Removal Mechanisms

Pollutant removal mechanism in wetlands depends on system of wastewater supplied through the bed, quantity of oxygen supplied for microbes and the characteristics of the wastewater. Organic matter is removed in CW by biological process, which is mainly depended on activity of microorganisms.

The organic matter present in the wastewater is removed due to the aerobic and anaerobic microbial degradation. The development of microbial population in Constructed Wetlands is similar to the conventional activated sludge or trickling filter plants as microbial growth is dependent on physical and chemical environment rather to be more rapid and complete than anaerobic decomposition.

The rate of oxygen release from the roots of the wetland plants was found generally highest in the subtropical region of the young roots and insignificant with old roots and rhizomes (Brix, 1993). Gradients of DO concentrations in horizontal direction also exist particularly due to root release, atmospheric diffusion and microbial respiration. This results in spatial variability of the DO profiles both in water column and bed depth of operating Constructed Wetlands.

2.3.2 Nitrogen Removal Mechanism

Nitrogen is essential building block in the synthesis of protein. Nitrogen data will be required to evaluate the treatability of wastewater by biological process. Total nitrogen is comprised of organic nitrogen, ammonia, nitrite and nitrate. The removal mechanisms for nitrogen in Constructed Wetlands include volatization, ammonification, nitrification or denitrification, plant uptake and matrix adsorption. However, the major removal mechanism in most Constructed Wetlands is microbial nitrification and denitrification (Copper *et al.,* 1996; Hammer, 1998). Although plant uptake of nitrogen occurs, plants uptake can remove only a minor fraction. Reports have indicated that under optimum conditions the amount of nitrogen removal through harvesting the plant biomass accounted for only 10-16% of total removed nitrogen. Nitrogen removal mechanisms in surface and subsurface Constructed Wetlands system are similar (Hammer, 1998).

2.3.3 Phosphorous Removal Mechanisms

The phosphorous are usually found in the form of orthophosphate, polyphosphate and organic phosphate. The orthophosphates for example PO_4^{+}, PO_4^{-2} and H_3PO_4 are available for biological metabolism without further breakdown. Polyphosphates are converted to the orthophosphate forms by the hydrolysis process. But the hydrolysis process is quite slow. The organically bound phosphorous is usually of minor in most domestic wastewater.

The phosphorous removal mechanisms in wetland systems include vegetation uptake, microbial assimilation, adsorption onto soil (mainly clay) and organic matter and precipitation with calcium, magnesium, iron and manganese. Adsorption and precipitation reaction are the major removal pathways when the hydraulic retention time is longer and fine texture soils are being used, since this allows greatest opportunity for phosphorous sorption and soil reaction to occur (Reed *et al*., 1988).

2.3.4 Total Suspended Solids Removal Mechanism

Settable solids are removed easily via gravity sedimentation as wetland systems generally have long hydraulic retention time. Non-settling colloidal solids are removed via mechanisms, which include straining (if sand media is used); sedimentation and biodegradation (as result of bacterial growth) and adsorption of other solids (plants, soil, sand and gravel media etc.) (USEPA, 1993).

2.3.5 Pathogen Removal Mechanism

Constructed wetlands are known to offer a suitable combination of physical, chemical and biological factors for removal of pathogenic organisms. (Cooper *et al.,* 1998) Wastewater is a hostile environment for pathogenic organisms and factors such as natural die-off, temperature, UV radiation; unfavorable water chemistry, predation and sedimentation cause pathogen population to be reduced. Natural wastewater treatment systems like Constructed Wetlands reduce pathogens more successfully due to longer residence time and land intensive treatment (Kadlec *et al.*, 1996).

2.4 Summary of Research Works on Constructed Wetland

Wittgren and Tobiason (1995) studied in the wastewater treatment plant in the town of Oxelosund, Sweden, having mechanical and chemical treatment for removal of BOD and phosphorous. During 1993 subsurface flow wetland system of 21 ha was created with an aim to achieve 50% N-removal. In May 1994 it was concluded that neither wastewater toxicity nor oxygen deficiency but sub-optimal hydraulic loading conditions, a lack of suitable surfaces for ion exchange of NH_4^+ as well as for attachment of nitrifiers and Phosphorous deficiency were considered potentially important factors in limiting nitrification.

Yang *et al*. (1995) studied on constructed wetland wastewater treatment system at Bainkeng, Shenzhen for 3 years. Study was conducted to understand removal efficiencies of constructed wetland systems for municipal wastewaters from small or medium scale towns in the sub-tropics. BOD, COD, SS, TN and TP were the parameters examined and their removal rates were determined. It was found that system was very effective in removing organic pollutants and SS.

Bulc *et al*. (1997) studied on use of Constructed Wetlands for landfill leachate treatment. The system consists of two interconnected beds with a horizontal surface flow. Reduction efficiency percentage was achieved 68%, 46%, 81%, and 85% for COD, BOD_5, NH_4-N, and bacteria respectively.

Green *et al.* (1997) investigated removal of *E.coli* and total coliforms in subsurface flow constructed wetlands in field surveys and pilot experiments. Removals of *E.coli* and total *coliforms* were compared in dry and wet periods in surveys on two successive years. Removal fell in wet weather than in dry weather. No change was detected in removal of TSS, BOD_5 and ammonia-N. The effect of different flow rates was compared using a pilot reed bed. Increasing removal efficiency was found with increase in retention time.

Ottova *et al*. (1997) studied on five constructed wetlands in the Czech Republic during 1994 and 1995 in order to determine removal of total *Fecal coliform* bacteria and *Enterobacteriaceae* along with total count of aerobic and anaerobic bacteria in water. The result revealed that the relation of *coliform* bacteria is very high and exceeds common retention values for conventional systems.

Okurut *et al.* (1999) investigated the viability of the use of constructed wetlands planted with indigenous *Cyperus papyrus* and *Phragmites mauritianus* plants for the purification of pre-settled municipal wastewater in tropical environments, in concrete lined constructed wetlands for 11 months. BOD and TSS concentration in the effluent from both systems were below 20 mg/l and 25 mg/l respectively. The removal rates for COD, NH_4^+ and phosphate in *C.papyrus* system were 3.75,1.01 and 0.05(g/m^2,day) and in *P.mauritianus* were 1.52, 0.97 and 0.068 (g/m^2,day) respectively. In both systems a high degree of *Fecal coliform* removal was attained at longer retention times.

Vymazal (1999) studied on the removal of BOD_5 on constructed wetland with horizontal subsurface flow. The result from the Czech horizontal subsurface flow constructed wetlands showed an average treatment efficiency of 86.6%.

Shrestha *et al.* (2001) in their paper "Constructed Wetland technology transfer to Nepal", describes an approach carried out in Nepal to transfer Constructed Water technology of wastewater treatment. According to them three constructed wetlands (hospital wastewater treatment, greywater treatment of a single household, septage treatment) were built and two have been so far investigated and their treatment efficiencies turned out to be very high. They have pointed out several recommendations to promote the technology in developing countries.

Kucuk *et al.* (2003), studied on the removal performance of ammonium nitrogen and COD from tannery effluents by horizontal subsurface flow reed bed consisting *Phragmites australis* for one year at five different hydraulic retention time. The results indicated that NH_4-N removal is significantly affected by hydraulic retention time while COD is not.

CHAPTER 3

METHODS AND METHODOLOGY

3.1 Description of Experimental Setup

The experiment was carried out in the premises of Guheswori Treatment Plant owned by Bagmati Area Sewerage Project (BASP) which is located near the Pashupati temple at the bank of Bagmati River on the northern eastern part of the Kathmandu city.

The experimental setup consists of three units of Horizontal Flow Bed of size 6m X 2m X 0.6m (Length X Breadth X Height). Two units are planted with *Phragmitis karka* (local reed) and one is unplanted. Beds are filled with gravel media supported below on a layer of puddle local clay and overlaid by a thin polythene liner. Bed 3 was not working properly so study was carried out only on Bed 1 and 2. The unplanted bed was used as blank control to study the effect of plants in treatment process.

Media composition of the beds:

Bed 1 consists of gravel media of 2-10 mm (diameter) collected from the river. The pore volume of the gravel media is 35%.

Bed 2 consists of same gravel media as in Bed 1.

The system was fed with wastewater drawn from grit chamber of oxidation ditch system, which is allowed to settle in two settling tanks. From the settling tanks water flow into V-notch which allow the equal distribution of water into three beds. The systems were fed at desired hydraulic loadings.

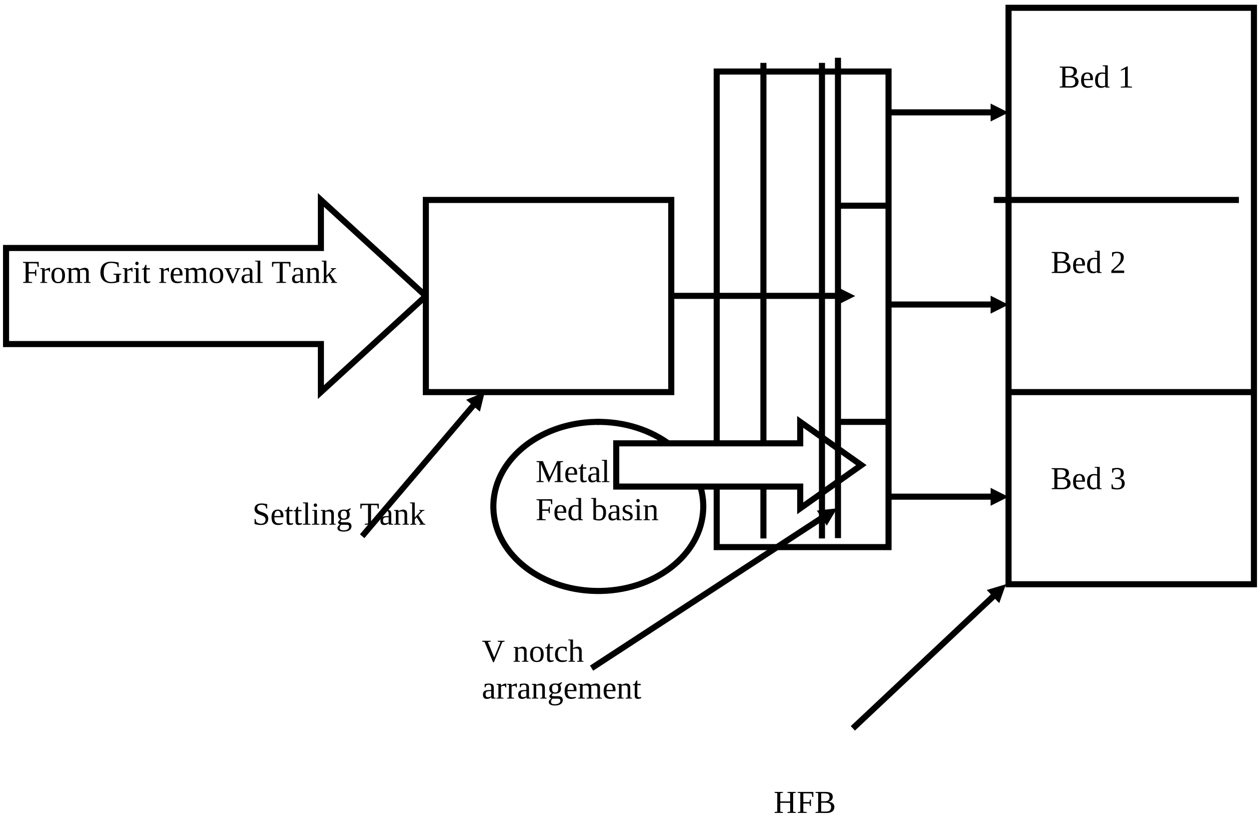

Fig. A

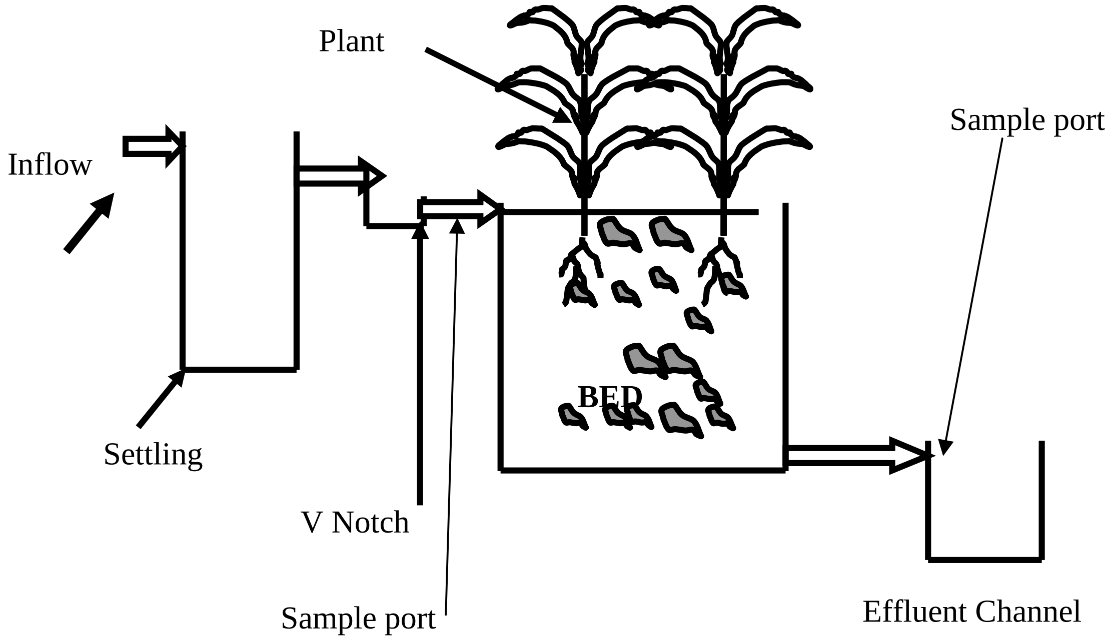

Fig. B

Fig 1: (A, B) Layout of Experimental Setup.

3.2 Sampling

The sampling techniques used on Constructed Wetland must assure that representative samples are collected because samples will ultimately serve as the basis for evaluating the efficiency of the system.

3.2.1 Sampling points

There were three sampling points S_1, S_2 and S_3. First sampling point was the outlet of the settling tank i.e. S_1.Other two sampling points were outlet of planted HFB and blank HFB i.e. S_2 and S_3 respectively.

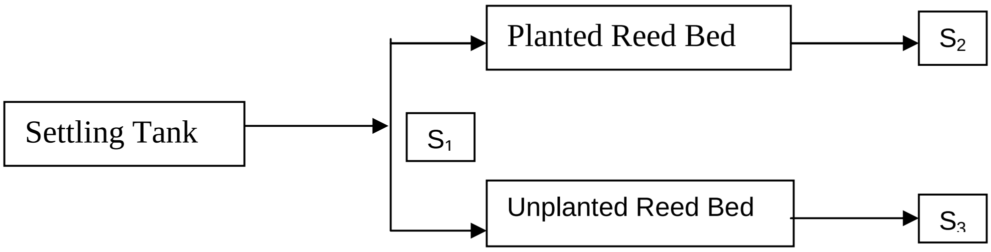

Fig 2: Diagram showing sampling points.

3.2.2 Sampling frequency

All the parameter tested during the experiment was conducted from the composite samples. The composite samples were collected drop wise for 24 hrs and mixed in proportion to the wastewater flow. Sampling was done once a week.

3.2.3 Sample preservation

Samples were collected in the sterile sampling bottles made of polyethylene. They were transported to the BASP laboratory and where analysis for ammonium was always done immediately. Samples not examined on same day were preserved one by adding sulfuric acid and another without adding sulfuric acid inside refrigerator at 4^{o}C.

3.3 Laboratory Analysis

Physical, chemical and bacteriological examinations of wastewater samples were performed on the laboratory in accordance with Standard methods (APHA, 1998) except TKN which was measured as accordance to Tare (2001). For each sample five readings were taken and their mean values were noted as an average.

3.3.1 pH

pH was measured using pH meter. Each sample was poured in three different beakers and pH meter was dipped into it. Reading was taken for 5 times and mean value was noted.

3.3.2 Temperature

Temperature was measured using mercury thermometer graduated up to 50^oC. It was measured for five times for each samples and mean value was noted.

3.3.3 Dissolved Oxygen (DO)

Samples from various sampling ports were collected in three different beakers. DO was measured using DO meter. For each sample five readings were taken and mean of five readings were noted as average reading.

3.3.4 Biological Oxygen Demand (BOD)

Dilution was prepared by mixing 2000ml of distilled water and 2000ml of tap water. Dilution water was poured in a jar and saturated with oxygen by bubbling air through air compressor. About 400ml of dilution water was taken in a 1 L measuring cylinder and to it was added required volume of sample (7ml for influent and 70ml for effluent) and diluted up to 700ml.It was mixed carefully using air compressor. Completely mixed dilution was marked in two BOD bottles ensuring that no bubbles were entrapped. The initial DO in one of bottles was determined and another bottle was tightly closed by stopper and incubated for 5 days at 20^{o}C.Initial and final DO was determined by Wrinkler method. For that 1ml of manganese sulfate solution followed by 1ml of alkali iodide-azide solution was added to the sample. Bottle was inverted several times after applying stopper to mix the sample reagents. Brown precipitate observed was allowed to settle for 15 minutes.1ml concentrated sulfuric acid was added and again shaked after applying stopper till precipitate dissolved. Volume corresponding to 200ml was poured into Erlenmeyer flask and titrated against 0.025M sodiumthiosulfate solution to pale yellow color Two drops of starch indicator was added to same solution and again titrated until the solution changed from dark blue to colorless.

Calculations:

$$DO\ (mg/l) = \frac{Volume\ of\ sodium\ thiosulfate\ consumed \times 200 \times f}{Volume\ of\ BOD\ bottle}$$

$$BOD_5\ ,(mg/l) = (Initial\ DO - Final\ DO) \times Dilution\ Factor$$

$$Dilution\ factor = \frac{Total\ volume\ after\ dilution}{Volume\ of\ undiluted\ sample}$$

3.3.5 Chemical Oxygen Demand (COD)

For determination of COD, (10ml sample and 10ml distilled water) for influent, (20 ml sample) for effluent and (20ml distilled water) for blank was taken in 250ml round bottom flask containing 0.4gm of mercuric sulfate (II) and several glass beads.30ml of sulfuric acid reagent was added slowly and then was added 10ml of potassium dichromate (0.25N) solution. Solution was mixed and cooled thoroughly. The flask was then placed to condenser and refluxed for 2 hours. The condenser was rinsed with about 10 ml distilled water before disconnecting from flask. The content was poured in flat bottom flask.70ml distilled water was added and allowed to cool up to room temperature. The solution was titrated against FAS after adding 2-3 drops of Ferroin indicator until the color changed from blue green to violet red.

Calculation:

$$COD\ (mg\ O_2\ L^{Z1})\ \mathrm{X}\ \frac{8000\ |\ M\ \ |\ (V_1 Z V_2)}{V_s}$$

V_1= Volume of FAS titrant used to titrate Blank (ml)

V_2 = Volume of FAS titrant used to titrate Sample (ml)

V_s = Volume of sample

M= Molarity of FAS (mol/l)

3.3.6 Total Kjeldahl Nitrogen (TKN)

50ml sample was taken in a Kjeldahl flask and 10ml digestion solution was added. Some glass beads were added to flask and put in dissector and temperature was set at 50oC.Solution was boiled briskly till large amount of white fumes came out. When solution turned transparent it was allowed to cool up to room temperature. The content was rinse into the 50ml volumetric flask and marked up to 50ml.Sample was diluted 10 times by taking 5ml sample from volumetric flask and diluting up to 50ml in 50ml volumetric flask.10ml diluted sample was taken in a test tube. One drop ETDA and 1ml Nessler reagent was added and shaked properly. Four standard solutions were made by taking 2ml, 6ml, 8ml and 10ml working ammonia solution and making volume of 50ml. Absorbance and concentration were determined from spectrophotometer adjusted at 420nm.

3.3.7 Ammonia Nitrogen (NH_4-N)

About 20 ml sample was filtered and from that only 10 ml was taken in a test tube. One drop of EDTA was added and mixed well and then was added 1ml Nessler reagent. Color changed to yellow. Five standards of various concentrations were also prepared along with blank. Concentrations were determined from spectrophotometer adjusted at 420nm.

3.3.8 Total Phosphate (TP)

35ml of sample was taken in a 100ml conical flask.1ml concentrated sulfuric acid and 5ml concentrated nitric acid was added and digested to a volume of 1-2ml in a hot plate. The content was cooled and poured in the 50 ml volumetric flask by rinsing slowly.1 drop of phenolphthalein indicator was added and 1 N NaOH was added drop wisely until pink tinge was seen. The final volume of 35ml was made and allowed to stand for sometime for precipitate to settle. Then, 10ml of molybdate reagent was added and brought up to the volume to 50ml.For the preparation of blank, 35ml distilled water was taken in a 50ml volumetric flask and 10ml molybdate reagent was added and volume of 50ml was made adding further distilled water. Standards of various concentrations were prepared and concentration was calculated from spectrophotometer adjusted at 470nm.

3.3.9 Total Suspended Solids (TSS)

Filter paper was washed with laboratory water in the filter holder under suction and removed into the aluminium foil. Filter paper was dried in oven at 105°C for one hour and placed inside desiccators for cooling. Paper was weighed and then put in the filtration assembly and measured volume of sample was filtered under slight suction. Filter was removed into the watch glass and dried in oven at 105°C for one hour. Filter was cooled in desiccators and again weighed.

Calculation:

$$SS\,(mg\,L^{-1}) = \frac{1000 \times (Weight\ after\ filtration - Weight\ Prior\ to\ filteration)}{Volume\ of\ the\ sample\,(ml)}$$

3.3.10 Pathogen

Multiple tube fermentation test also called as MPN method is a measure of the most probable number (statistically) of organisms that are present in the water sample.

One liter distilled water and 36.5gm of broth was mixed properly and put in pressure cooker. It was boiled over a heater for 15 minutes. After cooling it for sometime, 9ml of broth thus prepared was taken in test tubes (15 tubes for 1 sample). Durham tube was inverted in a test tube without any air bubble to enter. The tube was capped with cotton plug and put for autoclaving for 15 minutes for sterilization.

Often the bacterial contamination of wastewater is high enough to require dilution before enumeration by standard techniques. Thus samples were diluted through serial dilution technique. Three dilutions for each sample were prepared and 1ml of each diluted wastewater was added in the 5 tubes with broth. Tube were resealed through same cotton plug and incubated at 45^{o}C for 24 hours. Similarly 1ml of sterilized blank solution was added to one tube and it was also incubated. Tubes exhibiting gas production were assumed to have given positive results indicating the presence of *Coliform* organisms.

Calculation:

$$MPN\ per\ 100\ ml\ \text{X}\ \frac{Value\ \ from\ table\ |10}{l\,\text{arg}\,est\ volume\ tested\ in\ dilution\ series\ used\ \ for\ MPN\ \text{det}\,er\,\text{min}\,ation}$$

Statistical analysis

3.4.1 Correlation Analysis

Correlation coefficient has been calculated to obtain the inter relationship between flow rate and various parameter removal efficiencies (Bajracharya, B.C., 1999).

$$\text{r} = \frac{\text{¡¥ Z} \quad \text{¡} \quad {}^{\text{¥}}\!\big/_{n}}{\sqrt{\text{¡}^{2}\ \text{Z}^{ƒ}\ \ \text{¡Å}^{2}\!\big/_{n} \qquad \text{¥}^{2}\ \text{Z}^{ƒ}\ \ \text{¥Å}^{2}\!\big/_{n}}}$$

Where, ¡ &¥ are two variables.

CHAPTER 4

RESULTS

4.1 pH and Temperature Readings

The temperature and pH variation in the beds are shown in (Annex I, Table 1). Temperature of sample throughout study period ranges from 23 to 27.5 ^{o}C. Inlet pH value ranges from 6.5 to 7.9. In planted bed it ranges from 5.9 to 7.4 while in case of unplanted bed it ranges from 6.1 to 7.6.

4.2 Dissolve Oxygen Variation

Variation of DO concentration throughout the study period (Annex I, Table 2(a and b)) showed that DO concentration in the influents ranged from 0.15 mg/l to 0.27 mg/l. DO along the bed in HF planted bed increased from 0.27 mg/l to 1.30 mg/l (Fig. 3) where as in the unplanted bed DO increased from 0.27 to 0.86 mg/l at minimum flow rate of 0.464 m^3/d (Fig. 4). At maximum flow rate of 3.05 m^3/d DO increased from 0.08 to 0.43 mg/l in planted bed and in unplanted bed DO increased from 0.01 to 0.11 mg/l. In planted bed, DO concentration increased by 40.74% in 1st sampling port, 348.14% in 2nd sampling port and 381.48% in effluent from influent in low flow rate 0.464 m^3/d. While in other three flows, there was decrease in DO in 1st sampling port and increased by 289.47%, 148%, 160% in 2nd sampling port at flow rates 1.56 m^3/d, 2.26 m^3/d, 3.05 m^3/d respectively. Effluent DO concentration increased up to 321.05%, 176% and 186.66% in flow rates 1.56 m^3/d, 2.26 m^3/d and 3.05 m^3/d respectively (Table 2). In unplanted bed, DO concentration increased by 3.7% in 1st sampling port, 203.7% in 2nd sampling port and 68.6% in effluent from influent. In case of flow rates, 1.56 m^3/d, 2.26 m^3/d, DO concentration decreased in 1st sampling port and increased by 100%, 56% in 2nd sampling port and 115.7%, 68% in effluent respectively. In case of high flow rate 3.05 m^3/d, DO concentration decreased along the bed from influent (Table 3).

Table 2: Average percentage increase of DO along planted bed.

Flow m^3/d	% Increased in 1st sampling port	% Increased in 2nd sampling port	% Increased in effluent
0.046	40.74	348.14	381.48
1.56	-5.26	289.47	321.05
2.26	-16	148	176
3.05	-46.66	160	186.66

Table 3: Average percentage increase of DO along unplanted bed.

Flow m^3/d	% Increased in 1st sampling port	% Increased in 2nd sampling port	% Increased in effluent
0.046	3.7	203.7	218.51
1.56	-57.89	100	115.78
2.26	-52	56	68
3.05	-93.33	-33.33	-26.66

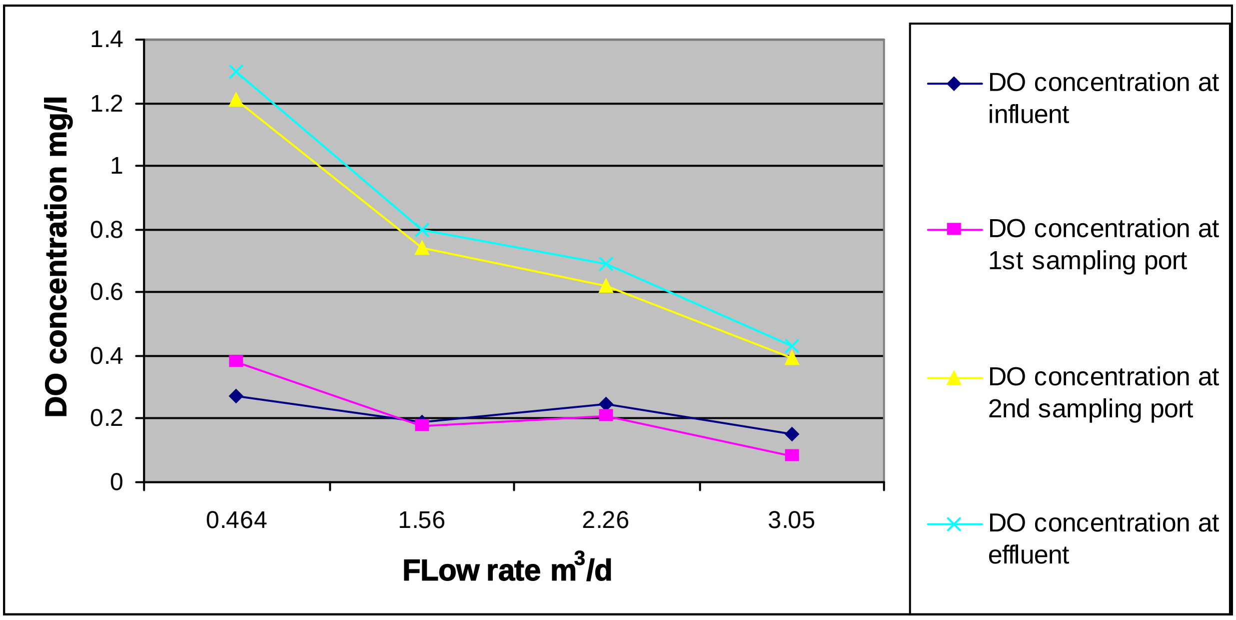

Fig 3: Increased in DO concentration along the planted bed over various flow rates.

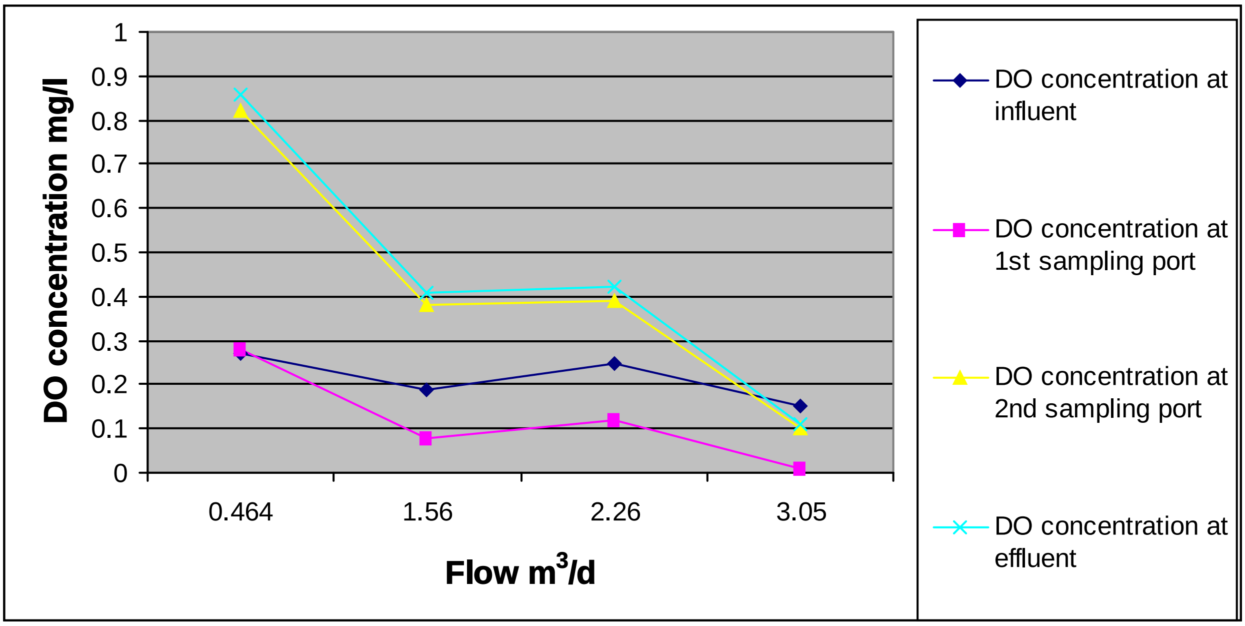

Fig 4: Increased in DO concentration along the unplanted bed over various flow rates.

4.3 Organic Matter Removal Efficiency

Biological Oxygen Demand Removal Efficiency

The average influent and effluent Biological Oxygen Demand concentration and the average removal efficiency observed at various flow rates are presented in Table 4. The average influent BOD concentration ranges from 104 to 187 mg/l and effluent BOD concentrations ranges from 24.43 to 82.46 mg/l in planted bed and 40.81 to 107.69 mg/l in unplanted bed (Table 5 and Figure 5). Average removal efficiency ranges from 43.75 to 79.38% and 31.006 to 66% in planted and unplanted bed respectively.

Both, the correlation analysis (Annex II, Table 1and 2) and the regression analysis were carried out to establish the relationship between BOD removal efficiency and flow rates (Figure 6). The correlation analysis showed negative correlation between flow rate and percentage removal of BOD in both planted and unplanted beds. The regression analysis showed the following relationships:

For planted bed:

$$y_{BOD} = -13.721x_1 + 86.368 \ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

For unplanted bed:

$$y_{BOD} = -13.489x_1 + 73.067 \ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

Where,

y_{BOD}= BOD_5 removal efficiency in %

x_1= Flow rate in m^3/d

Results showed that linear relationship exists between BOD removal efficiency and flow rate for both planted and unplanted reed beds.

Table 4: Average Influent and effluent concentration and BOD removal efficiency in planted and unplanted bed

Flow m^3/d	Inlet Mg/l	HFPB Mg/l	% Removal	HFUB Mg/l	% Removal
0.464	118.87	24.43	79.38	40.81	66
1.56	128.89	44.45	65.69	60.56	53.06
2.26	187.96	82.46	56.02	107.69	43.27
3.05	104.42	58.78	43.75	72.1	31.006

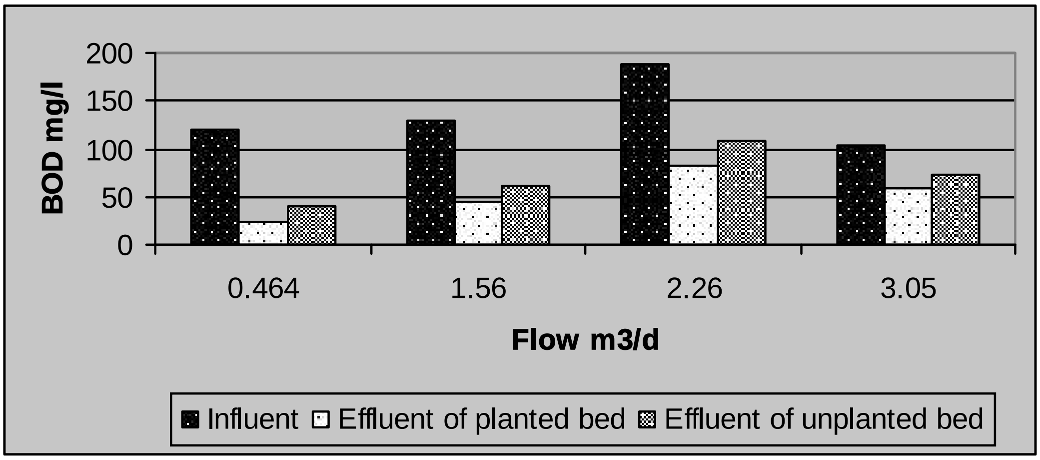

Fig. 5: Influent and effluent BOD concentration.

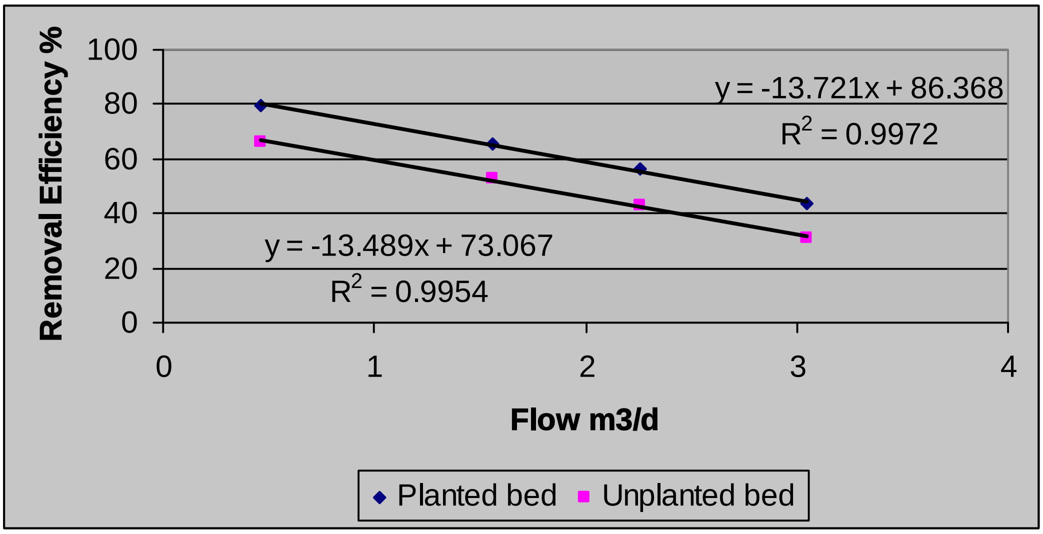

Fig. 6: Regression equations established between flow and BOD removal efficiency

Chemical Oxygen Demand Removal Efficiency

The average influent, effluent concentrations as well as removal efficiency of both planted and unplanted beds are presented in Table 5.The average influent Chemical Oxygen Demand (COD) concentration ranges from 186.16 to 393.83 mg/l and effluent COD concentrations ranges from 34.1 to 178.18 mg/l in planted bed and 58.13 to 209.96 mg/l in unplanted bed (Fig 7). Average removal efficiency ranges from 43.92 to 81.85% and 39.88 to 68.78% in planted and unplanted respectively (Fig. 8).

Both, the correlation analysis (Annex II, Table 3 and 4) and the regression analysis were carried out to establish the relationship between COD removal efficiency and flow rates (Fig. 8). The correlation analysis showed negative correlation between flow rate and percentage removal of COD in both planted and unplanted beds. The regression analysis showed the following relationships:

For planted bed:

$$y_{COD} = -14.594x_2 + 87.891 \ldots\ldots\ldots\ldots 3$$

For unplanted bed:

$$y_{COD} = -11.399x_2 + 73.668 \ldots\ldots\ldots\ldots 4$$

Where,

y_{COD} = COD removal efficiency in %

x_2= Flow rate in m^3/d

Results showed that linear relationship exists between COD removal efficiency and flow rate for both planted and unplanted reed beds.

Table 5: Average Influent and Effluent concentration and COD removal efficiency of planted and unplanted bed

Flow m^3/d	Inlet Mg/l	HFPB Mg/l	% Removal	HFUB Mg/l	% Removal
0.464	186.16	34.1	81.85	58.13	68.78
1.56	254.4	90.42	63.86	110.84	55.96
2.26	393.83	178.18	54.9	209.96	46.45
3.05	247	138.517	43.92	148.882	39.88

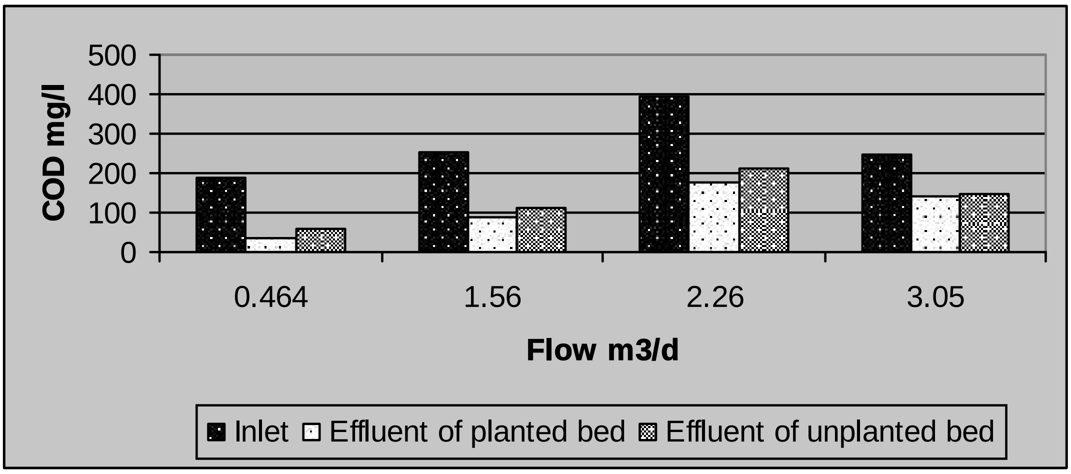

Fig.7: Influent and effluent COD concentration

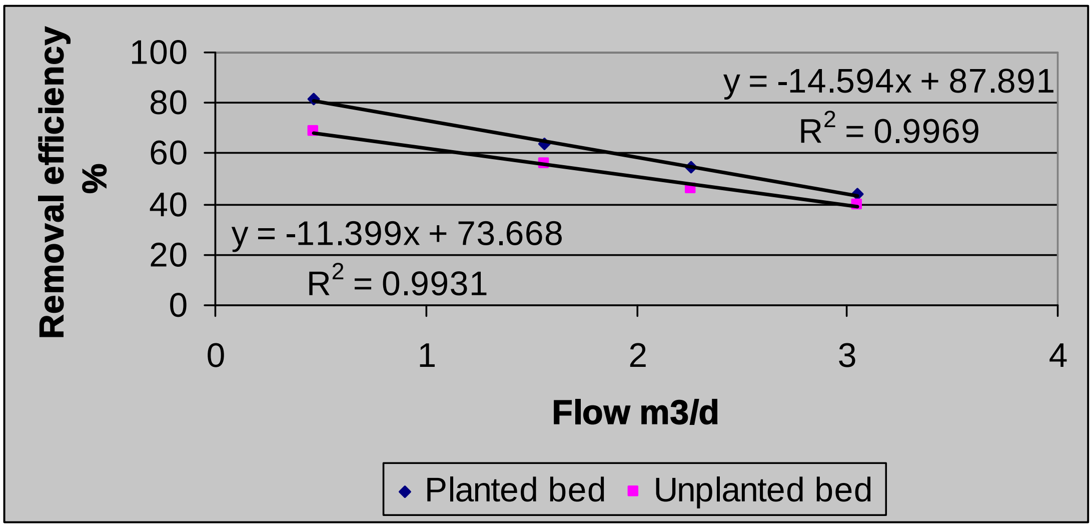

Fig. 8: Regression equations established between flow and COD Removal Efficiency

4.4 Nitrogen Removal Efficiency

The average removal efficiencies and influent and effluent Total Kjeldahl Nitrogen (TKN) concentration of both planted and unplanted bed are shown in Table 6. The average influent TKN concentration ranges from 37.72 to 52.38 mg/l and effluent TKN concentrations ranges from 24.06 to 32.32 mg/l in planted and 32.8 to 43.65 mg/l in unplanted bed (Table 6 and Figure 9). Average removal efficiency ranges from 26.11 to 44.16 % and 13.11 to 23.72 % in planted and unplanted beds respectively.

Similarly, the average removal efficiencies and influent and effluent ammonia concentration of both planted and unplanted bed are shown in Table 7. The average influent NH4-N concentration ranges from 27.86 to 38 mg/l and effluent NH4-N concentrations ranges from 14.16 to 23.44 mg/l in planted bed and 20.53 to 27.62 mg/l in unplanted bed (Fig. 10). Average removal efficiency ranging from 27.56 to 58.91% and 23.17 to 35.41% in planted and unplanted bed respectively.

Both, the correlation analysis (Annex II, Table 5and 6 for TKN, 7and8 for NH_4-N) and the regression analysis were carried out to establish the relationship between TKN, and Ammonia removal efficiency and flow rates (Figure 11 and Figure 12). The correlation analysis showed negative correlation between flow rate and percentage removal of TKN and NH_4-N in both planted and unplanted beds. The regression analysis showed the following relationships:

For planted bed:

$y_{TKN} = -6.7332x_3 + 48.17$……………………………5

$y_{Ammonia} = -110732x_4 + 65.654$…………………….…6

For unplanted bed:

$y_{TKN} = -4.1369x_3 + 25.7$……………………………7

$y_{Ammonia} = -4.55x_4 + 36.45$…………………………..8

Where,

y_{TKN} and $y_{Ammonia}$ = TKN/Ammonia removal efficiency in %

x_3 and x_4= Flow rates in m^3/d

Results showed that linear relationship exists between both TKN and Ammonia removal efficiency and flow rate for both planted and unplanted reed beds.

Table 6: Average Influent and Effluent concentration and TKN removal efficiency of planted and unplanted bed

Flow m^3/d	Inlet Mg/l	HFPB Mg/l	% Removal	HFUB Mg/l	% Removal
0.464	43	24.06	44.16	32.8	23.72
1.56	52.38	32.32	38.22	42.06	19.64
2.26	37.72	24.62	34.81	31.56	16.33
3.05	40.38	29.78	26.11	35.04	13.11

Table 7: Average Influent and Effluent concentration and NH_4-N removal efficiency of planted and unplanted bed

Flow m^3/d	Inlet Mg/l	HFPB Mg/l	% Removal	HFUB Mg/l	% Removal
0.464	34.58	14.16	58.91	22.26	35.41
1.56	38	19.8	48.08	27.62	27.29
2.26	27.86	16.13	42.02	20.53	26.58
3.05	32.34	23.44	27.56	24.74	23.17

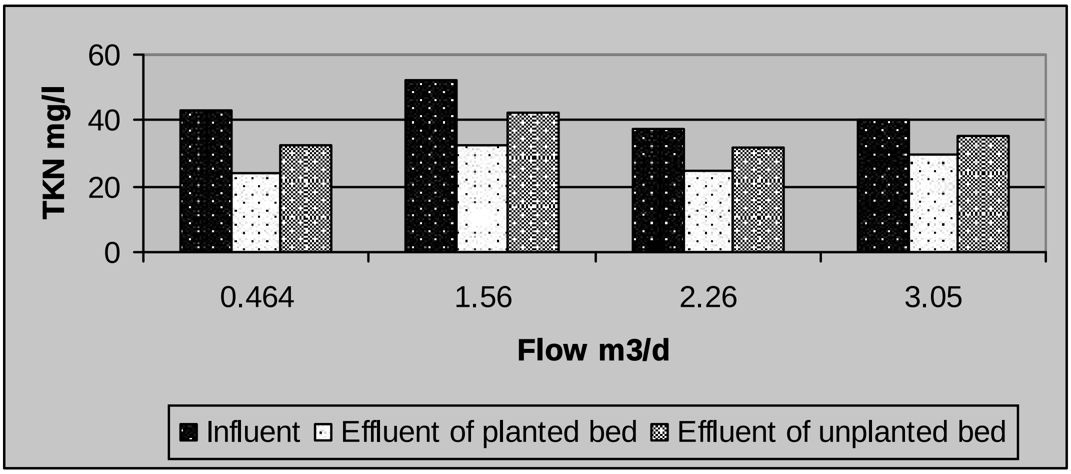

Fig.9: Influent and effluent TKN concentration

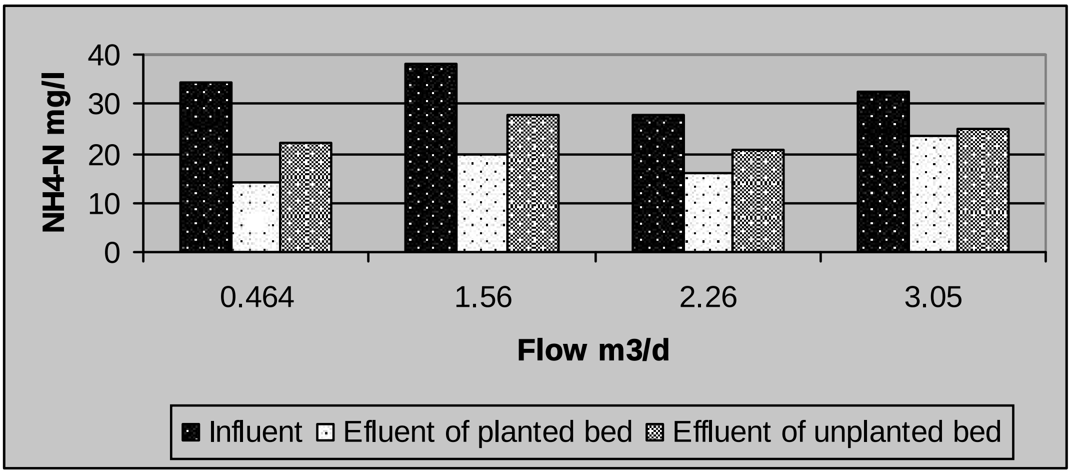

Fig. 10: Influent and effluent NH4-N concentration

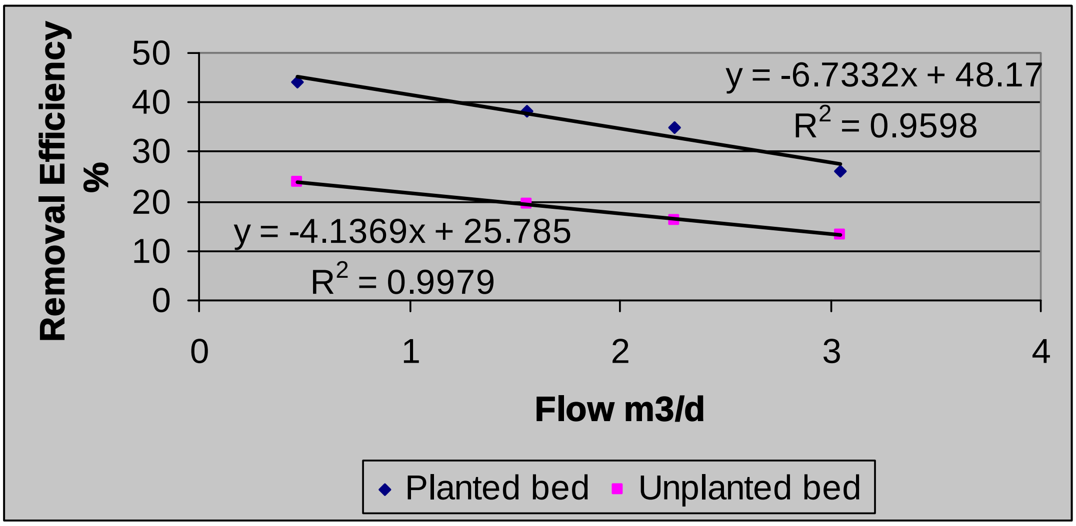

Fig. 11: Regression equations established between flow and TKN Removal Efficiency

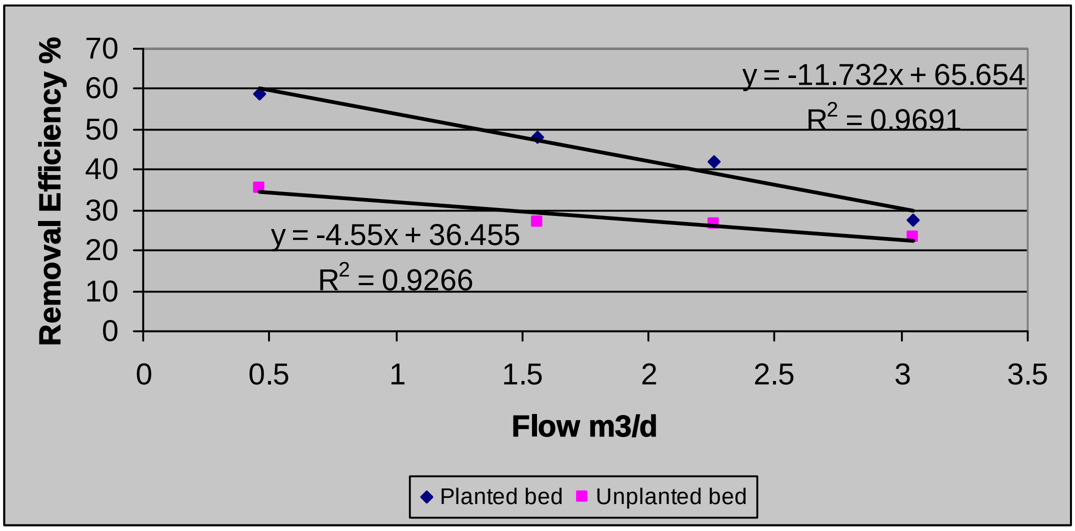

Fig. 12: Regression equations established between flow and NH_4-N Removal Efficiency

4.5 Total Phosphate Removal Efficiency

The average removal efficiency of both planted and unplanted bed is shown in Table 8 below. The average influent TP concentration ranges from 1.275 to 1.46 mg/l and effluent TP concentrations ranges from 0.756 to 1.142 mg/l in planted bed and 1.161 to 1.352 mg/l in unplanted (Fig. 13). Average removal efficiency ranges from 13.09 to 34.27% and 6.99 to 12.11% in planted and unplanted respectively.

Both, the correlation analysis (Annex II, Table 9 and 10) and the regression analysis were carried out to establish the relationship between TP removal efficiency and flow rates (Fig. 14) below. The correlation analysis showed negative correlation between flow rate and percentage removal of TP in both planted and unplanted beds. The regression analysis showed the following relationships:

For planted bed:

$$y_{TP}= -7.865x_5+ 39.437 \ldots\ldots\ldots\ldots 9$$

For unplanted bed:

$$y_{TP} = -1.747x_5 + 12.03 \ldots\ldots\ldots\ldots 10$$

Where,

y_{TP} = TP removal efficiency in %

x_5= Flow rate in m^3/d

Results showed that linear relationship exists between TP removal efficiency and flow rate for both planted and unplanted reed beds.

Table 8: Average Influent and Effluent concentration and TP removal efficiency of planted and unplanted bed

Flow m^3/d	Inlet Mg/l	HFPB Mg/l	% Removal	HFUB Mg/l	% Removal
0.464	13.7	9	34.27	12.04	12.11
1.56	14.6	10.46	28.4	13.52	7.35
2.26	12.75	9.65	24.3	11.61	8.86
3.05	13.14	11.42	13.09	12.22	6.99

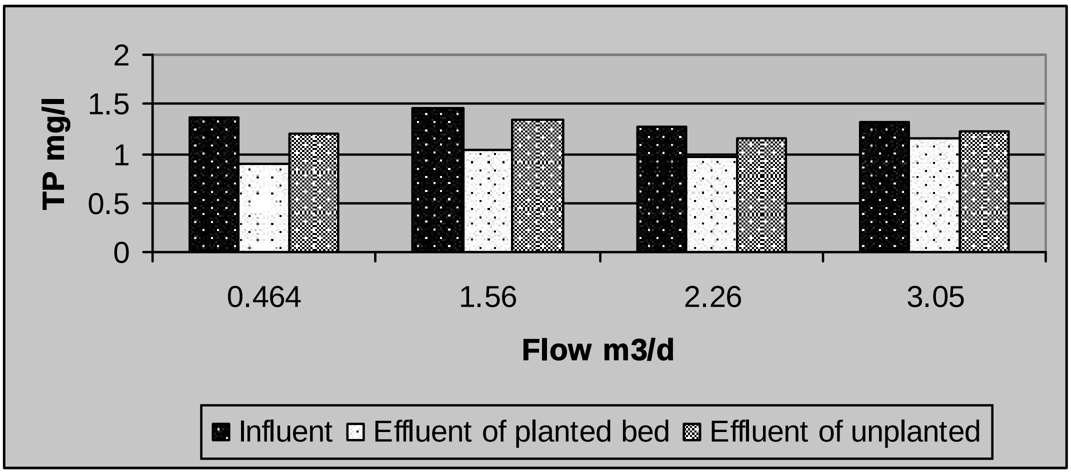

Fig. 13: Influent and effluent TP concentration

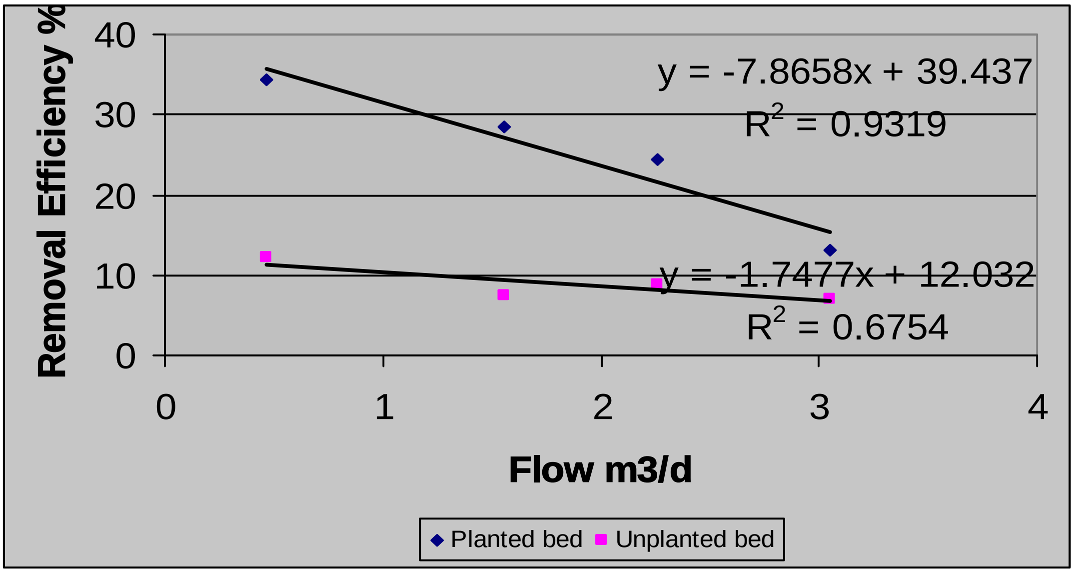

Fig. 14: Regression equations established between flow and TP Removal Efficiency

4.6 Total Suspended Solids Removal Efficiency

(Table 9) below shows the average removal efficiency along with influent and effluent concentration along both planted and unplanted beds. The average influent TSS concentration ranges from 143.16 to 166.2 mg/l and effluent TSS concentrations ranges from 22.22 to 81.41mg/l in planted bed and 32.05 to 90.43 mg/l in unplanted bed (Fig. 15). Average removal efficiency ranges from 50.98 to 84.41 % and 45.58 to 77.55 % in planted and unplanted beds respectively.

Both, the correlation analysis (Annex II, Table 11 and 12) and the regression analysis were carried out to establish the relationship between TSS removal efficiency and flow rates (Fig. 16) below. The correlation analysis showed negative correlation between flow rate and percentage removal of TSS in both planted and unplanted beds. The regression analysis showed the following relationships:

For planted bed:

$$y_{TSS}= -13.824x_6 + 92.591 \qquad \ldots\ldots\ldots 11$$

For unplanted bed:

$$y_{TSS} = -13.39x_6 + 04.00 \qquad \ldots\ldots\ldots 12$$

Where,

y_{TSS} =TSS removal efficiency in %

x_6= Flow rate in m^3/d

Results showed that linear relationship exists between TSS removal efficiency and flow rate for both planted and unplanted reed beds.

Table 9: Average Influent and Effluent concentration and TSS removal efficiency of planted and unplanted bed

Flow m^3/d	Inlet Mg/l	HFPB Mg/l	% Removal	HFUB Mg/l	% Removal
0.464	143.16	22.22	84.41	32.05	77.55
1.56	148	35.02	76.18	46.79	68.42
2.26	152	64.58	57.41	76.75	49.48
3.05	166.2	81.41	50.98	90.43	45.58

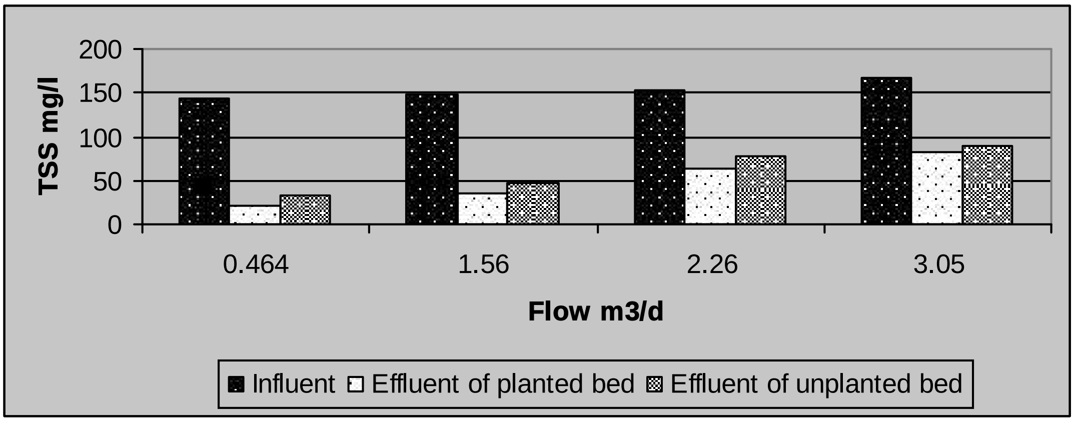

Fig. 15: Influent and effluent TSS concentration

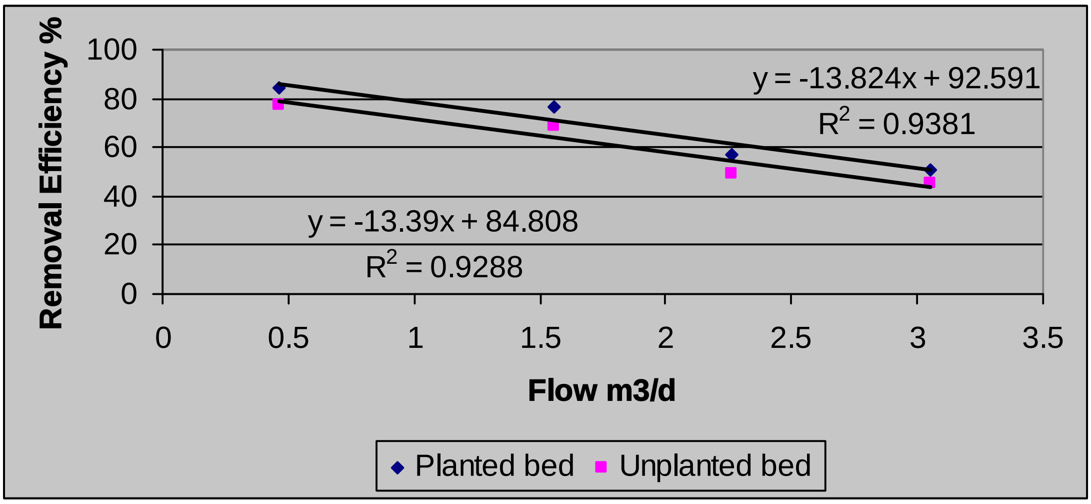

Fig. 16: Regression equations established between flow and TSS Removal Efficiency

4.7 Pathogen Removal Efficiency

The influent *Fecal coliforms* concentrations were found to vary from 5 x 10^5 MPN/100 ml and 2.4 x 10^6 MPN/100. *Fecal coliform* removal efficiency of HFPB was observed 89.8% and 82% at flow rate 0.464 m^3/d and 2.26 m^3/d respectively (Table 10). The *Fecal coliform* removal efficiency of HFPB is 89.8% and removal efficiency of HFUB is 72% at flow rate 0.464 m^3/d. The *Fecal coliform* removal efficiency of HFPB and HFUB is 82% and 62.5% respectively at flow rate 2.26 m^3/day. The *Fecal coliform* test could not be done for flow rate 1.56 and 3.05 due to difficulties in lab operations.

Table 10: FC removal efficiency of planted and unplanted bed

Flow m^3/d	**Inlet mg/l**	**HFPB mg/l**	**% Removal**	**HFUB mg/l**	**% Removal**
0.464	5 x 10^5	5.1 x 10^4	89.8	1.4 x 10^5	72
2.26	2.4 x 10^6	4.3 x 10^5	82	9 x 10^4	62.5

CHAPTER 5
DISCUSSION

Result showed that pH value was less in effluent of planted bed than influent whereas incase of unplanted bed pH value sometime decreases slightly but remain same for most of the time. The decrease in pH in the effluent confirmed the decay of organic materials. This has also been observed by Kao, *et al*. (2001). Reason for decrease in planted bed might be due to decaying of plant matters whereas in case of unplanted bed pH value were almost same through out the study period because there were no decaying matter present as in case of planted bed.

At all flow rates, the DO increased along the bed after first sampling ports. At higher flow rates, DO change along the bed was less than that in lower flow rate. DO at 1st sampling port dropped at flow 3.05, 2.26 and 1.56 m^3/d. The lowering of DO in the first port indicates that the first part of the bed experiences high microbial activity. The deposition of the incoming suspended organic matter near the inlet zone might have caused high microbial activity. However, DO at flow rate 0.464 m^3/d in planted bed has increased near the inlet. It might be due to low organic deposition in the inlet zone in comparison to high flow rates resulting in sufficient aeration from plant root zone. In both planted and unplanted beds, DO increase after 1st sampling port. This might be because of decrease in organic load along the bed and also due to oxygen recovery from atmospheric input and plant root zone. DO in the effluent showed 381.48%, 321.05%, 176% and 186.66% increase in flow rates 0.464m^3/d, 1.56m^3/d, 2.26m^3/d and 3.05m^3/d respectively which show that constructed wetland is an aerobic and more effective in transferring through the root zone system, porous gravel bed and sometime intermittent flow of the influent sewage.

Result showed that organic matter removal efficiency of planted bed is more than that of unplanted bed. This might be because wetland plants have unique characteristics of adaptation to anaerobic soil conditions such as developing internal air spaces (aerenchyma) for transporting oxygen into the root. Reddy (1990) also explained that oxygen transport into the root zone plays an important role in BOD_5 removal by promoting oxidation-reduction reaction in the rhizosphere. Comparison of removal rate of BOD and COD among planted and unplanted bed showed only little differences which showed that plant had only little contribution in organic matter removal. Similar result has been obtained from Tanner (2001). The average removal efficiency for BOD_5 in planted bed at flow rate 0.464 m^3/d is 79.38% which is similar to results reported in Vymazal (1999) in Czech Republic. The final effluent concentration of BOD in planted bed at low flow rate was 24.43 mg/l, which is within the National Bureau Standard of Nepal. The COD removal efficiency of 81.8% was obtained in planted bed at low flow rate, which is within the range reported in CW at temperate locations. Removal efficiency of organic matter was high in low flow rate, due to more availability of time of contact of wastewater with bio-film. The ratio of BOD to COD is indicator of biodegradability of wastewater. The ratio of BOD_5 to COD is greater than 0.3 (i.e. 0.4 to 0.7) for the influent obtained in the bed, which indicates that wastewater obtained is bio-chemically degradable. Yang (1995) reported the same finding for the wastewater of Bainkeng, Shenzhen.

Planted bed is more effective in removing ammonia nitrogen than unplanted bed. This is because oxygen is essential for the oxidation of ammonia to nitrate. The plant roots are the primary source of oxygen needed for nitrification of ammonia in subsurface flow wetlands. Similar concept has been also described by USEPA (1993) that wastewater contact with the root zone is essential for effective treatment. Limited nitrogen removal that is about 44.16%, in planted bed with flow rate 0.464 m^3/d, in comparison to organic matter removal is because of insufficient oxygenation for nutrient removal. This has also been explained by field measurement done by Vymazal (1999), which showed that the oxygenation of the rhizosphere of Horizontal Subsurface Flow Constructed Wetlands is insufficient and therefore, the incomplete nitrification is the major cause of limited nitrogen removal. Result indicated that planted bed is more efficient than unplanted bed on total nitrogen removal, which is in agreement with result obtained by Marques (2001). Comparison of TN removal performance for planted and unplanted system, done by Tanner (2001) also showed a clear trend of improved TN removal by the most of planted wetlands except wetlands receiving highly nitrified, low BOD wastewater, wastewater containing high levels of COD and sulphur.

Result showed very low removal of total phosphate in comparison to other parameters. This might be because of the type of media used, as sorption to the media is a major removal mechanism for phosphate in subsurface flow constructed wetlands. Gravel used in the bed might have low phosphate sorption capacity. Brix (2001) also explained that phosphorous bound in the media of reed bed mainly as a consequence of adsorption and precipitation reaction with calcium, aluminium and iron in the sand or gravel substrate. The capacity of a reed bed to remove P may therefore be dependent on the contents of these minerals in the substrate. (Table 9) showed that planted bed is more efficient in phosphate removal in comparison to unplanted bed. This might be due to availability of oxygen in planted bed through root zone that led to a rapid degradation of organic matter, which enhanced the release, and subsequent substrate sorption of formerly incorporated phosphate. Gruneberg *et al.* (2001) also found that the system with aeration showed higher removal performance. Similar result was also observed by DeBusk *et al.* (1990) and Tanner (1995). Another reason for planted bed showing enhanced phosphate removal compared to unplanted bed might be due to plant uptake and subsequent harvesting. This was also been mentioned by Lantzke (1998). However, according to Brix (1997) the amount of phosphorous that can be removed by harvesting the plant biomass usually constitutes only an insignificant fraction of the amount of phosphorous loaded into the system with sewage. Regression equation (Fig 14) showed linear relationship between flow rate and phosphate removal. Phosphate removal was high in low flow rate. Mann *et al*. (1993) also found that increasing the retention time via reduced flow rate, may result in increased phosphate removal.

Result showed that, horizontal flow constructed wetlands are best on total suspended solid removal (Table 10). It might be because the gravel used as substrate is best on removing suspended solids. This was also explained by Yang (1995), who found that among various kinds of media used, removal of suspended solids mainly occurred in gravel bed. Manios (2003) also found that best performance for total suspended solid removal was obtained by gravel bed. Regression equation established between TSS removal and flow rate (Fig 16) showed linear relationship for both planted and unplanted beds. Removal was high in low flow rate, which might be because of more time availability for gravity sedimentation, which is main mechanism for removal of TSS from the system. This was also explained by USEPA (1993). There was no significant difference in the performance of planted and unplanted bed in TSS removal but still planted bed is slightly efficient than that of unplanted bed because of more trapping and degradation of suspended particles in planted bed than in unplanted bed. USEPA (1993) also explained that planted beds are relatively effective in TSS removal because of the relatively low velocity and high surface area in planted bed than in unplanted bed. It has also been explained that planted beds act like horizontal gravel filters and there by provide opportunities for TSS separations by gravity sedimentation, straining and physical capture, and adsorption on biomass film attached to gravel and root system.

Fecal coliform reduction was found to be dependent on flow rate (Table 11). Lower flow rate provides an opportunity for chemical and biological *Fecal coliforml* removal processes such as oxidation and predation by protozoa, to get established and augment the reduced physical processes that are lowered at longer detention time. This result is in agreement with Okurut (1999). Marques (2001) also found that *Fecal coliform* depend on hydraulic loading or flow rate not on factor species. Result also showed that removal of *Fecal coliform* was high in planted bed than in unplanted bed, which might be because of low concentration of oxygen in unplanted bed than in planted bed where root of macrophytes provide oxygen. Gray (1989) and Ottova (1997) had also explained that free open zones within the CW for oxygenation are essential in enhancing the reduction of pathogens. According to Tanner (2001), mechanism including settling, adsorption, and protozoan grazing and possibly release of anti-microbial compounds are believed to account for the pathogen attenuation observed in SSF treatment wetlands.

CHAPTER 6

CONCLUSION AND RECOMMENDATION

Conclusion:

There is a great lack of proper wastewater treatment in developing countries like Nepal. With respect to the environment this situation should be changed as far as possible. One of the most promising technologies for application in developing countries seems to be Constructed Wetlands due to their characteristic properties like utilization of natural processes, simple construction, simple operation and maintenance, cost effectiveness, etc.

The present study reveals that Horizontal Subsurface Flow Constructed Wetland is best on removing pollution from wastewater. The existing CW provided a very cost effective treatment system for the wide scope. This is in contrast to the expensive conventional techniques that are unaffordable in a developing country like Nepal. Removal efficiency of Horizontal Subsurface Flow Constructed Wetland depends upon the flow rate. Removal efficiency is high during low flow rate. Planted bed is more efficient in pollutant removal than unplanted bed. The system showed high efficiency for organic matter and TSS removal. They even meet the effluent requirement recommended by National Bureau of Standard and Measurement, Government of Nepal for BOD_5. Total Phosphate removal was very low compared to other mechanism. They showed moderate removal efficiency for Nitrogen. Constructed Wetland has the advantages of low requirement for area, high tolerance to loading rates and easy operation. These sorts of treatment technology can be made available to small towns to tackle problems of water pollution.

Recommendation:

1. It is essential to increase public awareness about the importance and use of reeds on constructed wetland for treatment of wastewater before discharging it to water.

2. Further research has to be made on increasing phosphorous removal efficiency from reed beds.
3. Researches on use of plants other than *Phragmities* on wastewater treatment should be done. Plants other than *Phragmities* could be used on constructed wetland such as sugarcane, which is beneficial as cash crop as well as wastewater treatment.
4. The experiment had revealed that it is very important to understand conditions, which favor nitrification and denitrification with in an integrated system in situ of CWs.

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ANNEX I

Table 1: Temperature and pH reading during study period

Dates	Temperature ^{o}C	pH readings		
		Inlet	Planted bed	Unplanted bed
02/05/2006	26.5	7.5	7.2	7.2
14/05/2006	24	7.5	7.4	7.5
21/05/2006	25.5	7.9	7.3	7.4
28/05/2006	24	7.4	7.2	7.4
04/06/2006	24.5	7.3	7.1	7.3
11/06/2006	24.5	7.3	7.1	7.3
18/06/2006	23	7.6	7.4	7.6
29/06/2006	24.5	7.5	7.3	7.3
09/07/2006	27	6.5	6.4	6.3
17/07/2006	27	6.5	6.4	6.3
24/07/2006	26.5	6.6	5.9	6.3
31/07/2006	27	6.8	6.4	6.7
06/08/2006	27	6.7	6.1	6.1
13/08/2006	28	7	6.3	6.9
20/08/2006	26.5	6.7	64	6.7
27/08/2006	24.5	6.5	6.3	6.5
03/09/2006	25.5	6.7	6.2	6.7
10/09/2006	26.5	6.8	6.1	6.5
17/09/2006	26	6.8	6.1	6.7
10/10/2006	27.5	7	6.5	6.9
17/10/2006	26.5	6.7	6.2	6.6

Flow	Date	Influent	1st sampling port	% increased	2nd sampling port	% increased	Effluent	%increased
	18/06/2006	0.12	0.12	0	0.56	366.6666667	0.63	425
	29/06/2006	0.13	0.13	0	0.73	461.5384615	0.78	500
1.56	09/06/2006	0.23	0.22	-4.3478261	0.84	265.2173913	0.92	300
	17/07/2006	0.26	0.26	0	0.81	211.5384615	0.87	234.61538
	Average	0.19	0.18	-5.2631579	0.74	289.4736842	0.8	321.05263
	31/07/2006	0.18	0.09	-50	0.43	138.8888889	0.45	150
	06/08/2006	0.05	0	-100	0.29	480	0.3	500
3.05	13/08/2006	0.11	0.07	-36.363636	0.47	327.2727273	0.5	354.54545
	20/08/2006	0.17	0.1	-41.176471	0.5	194.1176471	0.55	223.52941
	27/08/2006	0.24	0.15	-37.5	0.28	16.66666667	0.35	45.833333
	Average	0.15	0.08	-46.666667	0.39	160	0.43	186.66667
	03/09/2006	0.22	0.32	45.4545455	1	354.5454545	1.1	400
	10/09/2006	0.32	0.44	37.5	1.35	321.875	1.47	359.375
0.464	17/09/2006	0.26	0.36	38.4615385	1.27	388.4615385	1.35	419.23077
	10/10/2006	0.29	0.39	34.4827586	1.21	317.2413793	1.28	341.37931
	17/10/2006	0.26	0.4	53.8461538	1.23	373.0769231	1.3	400
	Average	0.27	0.38	40.7407407	1.21	348.1481481	1.3	381.48148

Table 2: a. DO reading throughout the study period in planted bed.

	02/05/2006	0.24	0.15	-37.5	0.35	45.83333333	0.4	66.666667
2.26	14/05/2006	0.27	0.16	-40.740741	0.36	33.33333333	0.43	59.259259
	21/05/2006	0.23	0.33	43.4782609	1.15	400	1.25	443.47826
	Average	0.25	0.21	-16	0.62	148	0.69	176

Table 2: b. DO reading throughout the study period in unplanted bed.

Flow	Date	Influent	1st sampling port	% increased	2nd sampling port	% increased	Effluent	%increased
	18/06/2006	0.12	0.02	-83.333333	0.19	58.33333333	0.2	66.666667
	29/06/2006	0.13	0.04	-69.230769	0.41	215.3846154	0.46	253.84615
1.56	09/06/2006	0.23	0.1	-56.521739	0.49	113.0434783	0.51	121.73913
	17/07/2006	0.26	0.15	-42.307692	0.41	57.69230769	0.45	73.076923
	Average	0.19	0.08	-57.894737	0.38	100	0.41	115.78947
	31/07/2006	0.18	0	-100	0.13	-27.7777778	0.14	-22.22222
	06/08/2006	0.05	0	-100	0.03	-40	0.04	-20
3.05	13/08/2006	0.11	0	-100	0.12	9.090909091	0.12	9.0909091
	20/08/2006	0.17	0	-100	0.13	-23.5294118	0.15	-11.76471
	27/08/2006	0.24	0.03	-87.5	0.08	-66.6666667	0.09	-62.5
	Average	0.15	0.01	-93.333333	0.1	-33.3333333	0.11	-26.66667

	03/09/2006	0.22	0.24	9.09090909	0.71	222.7272727	0.75	240.90909
	10/09/2006	0.32	0.28	-12.5	0.93	190.625	0.97	203.125
0.464	17/09/2006	0.26	0.29	11.5384615	0.83	219.2307692	0.86	230.76923
	10/10/2006	0.29	0.32	10.3448276	0.82	182.7586207	0.87	200
	17/10/2006	0.26	0.27	3.84615385	0.82	215.3846154	0.85	226.92308
	Average	0.27	0.28	3.7037037	0.82	203.7037037	0.86	218.51852
	02/05/2006	0.24	0.04	-83.333333	0.22	-8.33333333	0.25	4.1666667
2.26	14/05/2006	0.27	0.07	-74.074074	0.17	-37.037037	0.19	-29.62963
	21/05/2006	0.23	0.24	4.34782609	0.79	243.4782609	0.81	252.17391
	Average	0.25	0.12	-52	0.39	56	0.42	68

Table 3: BOD reading and removal efficiency of beds through out the study period

Date	**Flow m^3/d**	**Inlet mg/l**	**HFPB mg/l**	**% removal**	**HFUB mg/l**	**% removal**
02/05/2006	2.26	220.69	98.692568	55.28	121.60019	44.9
14/05/2006	2.26	125.52	53.546832	57.34	68.65944	45.3
21/05/2006	2.26	235.04	98.881328	57.93	140.976992	40.02
28/05/2006	2.26	267.15	117.38571	56.06	161.09145	39.7
04/06/2006	2.26	143.34	63.943974	55.39	74.25012	48.2
11/06/2006	2.26	136.07	62.360881	54.17	79.60095	41.5
Average	2.26	187.9683	82.468549	**56.02833**	107.696524	**43.27**
18/06/2006	1.56	103.7	32.26107	68.89	49.3612	52.4
29/06/2006	1.56	176.01	63.152388	64.12	83.25273	52.7
09/07/2006	1.56	120.37	46.571153	61.31	51.51836	57.2
17/07/2006	1.56	117	40.8447	65.09	54.873	53.1
24/07/2006	1.56	127.39	39.427205	69.05	63.82239	49.9
Average	1.56	128.894	44.451303	**65.692**	60.565536	**53.06**
31/07/2006	3.05	105.69	60.444111	42.81	73.56024	30.4
06/08/2006	3.05	106.31	62.82921	40.9	77.28737	27.3
13/08/2006	3.05	98.05	51.642935	47.33	66.370045	32.31
20/08/2006	3.05	103.07	58.224243	43.51	66.78936	35.2
27/08/2006	3.05	109	60.7893	44.23	76.4962	29.82
Average	3.05	104.424	58.78596	**43.756**	72.100643	**31.006**
03/09/2006	0.464	116.79	19.807584	83.04	39.7086	66
10/09/2006	0.464	147.79	36.134655	75.55	56.60357	61.7
17/09/2006	0.464	134.31	20.025621	85.09	49.15746	63.4
10/10/2006	0.464	111.01	24.033665	78.35	33.85805	69.5
17/10/2006	0.464	103.59	26.850528	74.08	30.86982	70.2
29/10/2006	0.464	99.75	19.780425	80.17	34.713	65.2
Average	0.464	118.8733	24.438746	**79.38**	40.8184167	**66**

Table 4: COD reading and removal efficiency of beds through out the study period

Date	Flow m^3/d	Inlet mg/l	HFPB mg/l	% removal	HFUB mg/l	% removal
02/05/2006	2.26	450	203.85	54.7	231.75	48.5
14/05/2006	2.26	395	183.28	53.6	208.56	47.2
21/05/2006	2.26	421	198.712	52.8	223.551	46.9
28/05/2006	2.26	435	198.36	54.4	224.46	48.4
04/06/2006	2.26	350	149.8	57.2	194.25	44.5
11/06/2006	2.26	312	135.096	56.7	177.216	43.2
Average		393.8333	178.183	**54.9**	209.9645	**46.45**
18/06/2006	1.56	295	101.775	65.5	131.865	55.3
29/06/2006	1.56	335	119.595	64.3	133.665	60.1
09/07/2006	1.56	320	105.92	66.9	139.84	56.3
17/07/2006	1.56	182	71.344	60.8	87.542	51.9
24/07/2006	1.56	140	53.48	61.8	61.32	56.2
Average	1.56	254.4	90.4228	**63.86**	110.8464	**55.96**
31/07/2006	3.05	210	119.91	42.9	122.43	41.7
06/08/2006	3.05	160	87.2	45.5	94.88	40.7
13/08/2006	3.05	240	135.12	43.7	145.44	39.4
20/08/2006	3.05	330	174.24	47.2	194.04	41.2
27/08/2006	3.05	295	176.115	40.3	187.62	36.4
Average	3.05	247	138.517	**43.92**	148.882	**39.88**
03/09/2006	0.464	201	29.547	85.3	69.948	65.2
10/09/2006	0.464	195	26.91	86.2	62.01	68.2
17/09/2006	0.464	230	44.62	80.6	61.87	73.1
10/10/2006	0.464	200	55.8	72.1	67.6	66.2
17/10/2006	0.464	154	22.022	85.7	46.97	69.5
29/10/2006	0.464	137	25.756	81.2	40.415	70.5
Average	0.464	186.1667	34.109167	**81.85**	58.1355	**68.78333**

Table 5: TKN reading and removal efficiency of beds through out the study period

Date	Flow m^3/d	Inlet mg/l	HFPB mg/l	% removal	HFUB mg/l	% removal
02/05/2006	2.26	34.7	21.2	38.9049	29	16.42651
14/05/2006	2.26	37.6	24.5	34.84043	31.2	17.02128
21/05/2006	2.26	35.9	24.3	32.31198	29.5	17.8273
28/05/2006	2.26	41.4	28	32.36715	34.8	15.94203
04/06/2006	2.26	39	25.1	35.64103	32.7	16.15385
11/06/2006	2.26	37.72	24.62	34.8131	32.2	14.63415
Average	2.26	37.72	24.62	**34.8131**	31.5666667	**16.33418**
18/06/2006	1.56	58.3	35.3	39.45111	45.9	21.2693
29/06/2006	1.56	51.5	33.7	34.56311	41.3	19.80583
09/07/2006	1.56	53	30.2	43.01887	42.8	19.24528
17/07/2006	1.56	49.4	31	37.24696	40.02	18.98785
24/07/2006	1.56	49.7	31.4	36.82093	40.3	18.91348
Average	1.56	52.38	32.32	**38.2202**	42.064	**19.64435**
31/07/2006	3.05	39.5	30.4	23.03797	34.7	12.1519
06/08/2006	3.05	41.3	29.3	29.05569	36.4	11.86441
13/08/2006	3.05	44.5	31.5	29.21348	36.9	17.07865
20/08/2006	3.05	37.2	28.6	23.11828	33.2	10.75269
27/08/2006	3.05	39.4	29.1	26.14213	34	13.70558
Average	3.05	40.38	29.78	26.11351	35.04	**13.11065**
03/09/2006	0.464	47.8	28.4	40.58577	37.5	21.54812
10/09/2006	0.464	44.6	26.3	41.03139	33.2	25.56054
17/09/2006	0.464	43.6	23.4	46.33028	32.1	26.37615
10/10/2006	0.464	39.7	21.1	46.85139	30.3	23.67758
17/10/2006	0.464	40.8	22.2	45.58824	31.2	23.52941
29/10/2006	0.464	41.5	23	44.57831	32.5	21.68675
Average	0.464	43	24.066667	**44.1609**	32.8	**23.72976**

Table 6: Ammonia Nitrogen reading and removal efficiency of beds through out the study period

Date	Flow m^3/d	Inlet mg/l	HFPB mg/l	%removal	HFUB mg/l	%removal
02/05/2006	2.26	26.7	16.4	38.57678	19.6	26.59176
14/05/2006	2.26	27	15.7	41.85185	19.8	26.66667
21/05/2006	2.26	25.9	15.2	41.31274	19.1	26.25483
28/05/2006	2.26	32.3	18.3	43.34365	26.4	18.26625
04/06/2006	2.26	29.7	16.6	44.10774	21	29.29293
11/06/2006	2.26	25.6	14.6	42.96875	17.3	32.42188
Average	2.26	27.86667	16.133333	**42.02692**	20.5333333	**26.58239**
18/06/2006	1.56	42.4	24.1	43.16038	31.2	26.41509
29/06/2006	1.56	38.3	20.1	47.51958	27.8	27.41514
09/07/2006	1.56	39.7	20.4	48.61461	28.1	29.21914
17/07/2006	1.56	34.6	17.1	50.57803	25.3	26.87861
24/07/2006	1.56	35	17.3	50.57143	25.7	26.57143
Average	1.56	38	19.8	**48.08881**	27.62	**27.29988**
31/07/2006	3.05	31.2	25.1	19.55128	25.1	19.55128
06/08/2006	3.05	33.7	25.6	24.03561	25.7	23.73887
13/08/2006	3.05	38.6	26.9	30.31088	27.3	29.27461
20/08/2006	3.05	28.7	19.6	31.70732	22.2	22.64808
27/08/2006	3.05	29.5	20	32.20339	23.4	20.67797
Average	3.05	32.34	23.44	**27.5617**	24.74	**23.17816**
03/09/2006	0.464	38.7	15.1	60.98191	23.4	39.53488
10/09/2006	0.464	36.4	14.3	60.71429	23.1	36.53846
17/09/2006	0.464	36.7	14.9	59.40054	23.7	35.42234
10/10/2006	0.464	30.5	13.1	57.04918	21.1	30.81967
17/10/2006	0.464	32.2	13.5	58.07453	21.6	32.91925
29/10/2006	0.464	33	14.1	57.27273	20.7	37.27273
Average	0.464	34.58333	14.166667	**58.91553**	22.2666667	**35.41789**

Table 7: TP reading and removal efficiency of beds through out the study period

Date	Flow	Inlet	HFPB	% removal	HFUB	% removal
02/05/2006	2.26	12.22	9.4	23.07692	11.5	5.89198
14/05/2006	2.26	12.9	9.6	25.5814	11.7	9.302326
21/05/2006	2.26	13	9.8	24.61538	11.7	10
28/05/2006	2.26	12.5	9.9	20.8	11.9	4.8
04/06/2006	2.26	13.1	9.7	25.9542	11.6	11.45038
11/06/2006	2.26	12.8	9.5	25.78125	11.3	11.71875
Average	2.26	12.75333	9.65	24.30153	11.6166667	8.860573
18/06/2006	1.56	15.2	11.5	24.34211	14.1	7.236842
29/06/2006	1.56	14.9	10.7	28.18792	13.4	10.06711
09/07/2006	1.56	14.3	10.2	28.67133	13.6	4.895105
17/07/2006	1.56	14.1	9.9	29.78723	13.5	4.255319
24/07/2006	1.56	14.5	10	31.03448	13	10.34483
Average	1.56	14.6	10.46	**28.40461**	13.52	**7.359842**
31/07/2006	3.05	13.2	11.7	11.36364	12.4	6.060606
06/08/2006	3.05	13.5	11.3	16.2963	12.7	5.925926
13/08/2006	3.05	12.8	10.6	17.1875	11.9	7.03125
20/08/2006	3.05	13.3	11.9	10.52632	12	9.774436
27/08/2006	3.05	12.9	11.6	10.07752	12.1	6.20155
Average	3.05	13.14	11.42	**13.09025**	12.22	**6.998754**
03/09/2006	0.464	13.7	8.8	35.76642	12	12.40876
10/09/2006	0.464	14.1	9.1	35.46099	12.4	12.05674
17/09/2006	0.464	13.9	9	35.2518	12.2	12.23022
10/10/2006	0.464	13.3	9.1	31.57895	11.6	12.78195
17/10/2006	0.464	13.5	9	33.33333	12	11.11111
Average	0.464	13.7	9	**34.2783**	12.04	**12.11776**

Table 8: TSS reading and removal efficiency of beds through out the study period

Date	**Flow**	**Inlet**	**HFPB**	**% removal**	**HFUB**	**% removal**
02/05/2006	2.26	180	81	55	86.94	51.7
14/05/2006	2.26	107	48.471	54.7	52.965	50.5
21/05/2006	2.26	174	68.73	60.5	89.958	48.3
28/05/2006	2.26	157	67.196	57.2	82.111	47.7
04/06/2006	2.26	168	70.728	57.9	83.664	50.2
11/06/2006	2.26	126	51.408	59.2	64.89	48.5
Average	2.26	152	64.588833	**57.41667**	76.7546667	**49.48333**
18/06/2006	1.56	150	34.95	76.7	40.95	72.7
29/06/2006	1.56	130	33.02	74.6	39	70
09/07/2006	1.56	157	31.243	80.1	47.885	69.5
17/07/2006	1.56	164	37.392	77.2	57.072	65.2
24/07/2006	1.56	139	38.503	72.3	49.067	64.7
Average	1.56	148	35.0216	**76.18**	46.7948	**68.42**
31/07/2006	3.05	155	75.64	51.2	82.925	46.5
06/08/2006	3.05	179	85.204	52.4	98.092	45.2
13/08/2006	3.05	164	83.148	49.3	89.052	45.7
20/08/2006	3.05	161	80.017	50.3	91.448	43.2
27/08/2006	3.05	172	83.076	51.7	90.644	47.3
Average	3.05	166.2	81.417	**50.98**	90.4322	**45.58**
03/09/2006	0.464	165	24.585	85.1	32.67	80.2
10/09/2006	0.464	121	21.296	82.4	26.378	78.2
17/09/2006	0.464	142	24.566	82.7	34.932	75.4
10/10/2006	0.464	152	23.864	84.3	31.768	79.1
17/10/2006	0.464	147	20.139	86.3	36.456	75.2
29/10/2006	0.464	132	18.876	85.7	30.096	77.2
Average	0.464	143.1667	22.221	**84.41667**	32.05	**77.55**

ANNEX II

Table 1: Correlation Analysis of flow rate and % removal of BOD in Planted Bed.

FLOW m^3/d	BOD removal%	x	y	x2	y2	xy	r
2.26	56.02	0.4265	-5.19	0.181902	26.9361	-2.21354	
1.56	65.69	-0.2735	4.48	0.074802	20.0704	-1.22528	-0.99
3.05	43.75	1.2165	-17.46	1.479872	304.8516	-21.2401	
0.464	79.38	-1.3695	18.17	1.87553	330.1489	-24.8838	

Table 2: Correlation Analysis of flow rate and % removal of BOD in Unplanted Bed.

FLOW m^3/d	BOD removal%	x	y	x2	y2	xy	r
2.26	56.02	0.4265	-5.19	0.181902	26.9361	-2.21354	
1.56	65.69	-0.2735	4.48	0.074802	20.0704	-1.22528	-0.99
3.05	43.75	1.2165	-17.46	1.479872	304.8516	-21.2401	
0.464	79.38	-1.3695	18.17	1.87553	330.1489	-24.8838	

Table 3: Correlation Analysis of flow rate and % removal of COD in Planted Bed.

FLOW m^3/d	COD removal%	x	y	x2	y2	xy	r
2.26	54.9	0.4265	-6.2325	0.181902	38.84406	-2.65816	
1.56	63.86	-0.2735	2.7275	0.074802	7.439256	-0.74597	
3.05	43.92	1.2165	-17.2125	1.479872	296.2702	-20.939	-0.99
0.464	81.85	-1.3695	20.7175	1.87553	429.2148	-28.3726	

Table 4: Correlation Analysis of flow rate and % removal of COD in Unplanted Bed.

FLOW m^3/d	COD removal%	x	y	x2	y2	xy	r
2.26	46.45	0.4265	-6.3175	0.181902	39.91081	-2.69441	
1.56	55.96	-0.2735	3.1925	0.074802	10.19206	-0.87315	
3.05	39.88	1.2165	-12.8875	1.479872	166.0877	-15.6776	-0.997
0.464	68.78	-1.3695	16.0125	1.87553	256.4002	-21.9291	

Table 5: Correlation Analysis of flow rate and % removal of TKN in Planted Bed.

FLOW m^3/d	TKN removal%	x	y	x2	y2	xy	r
2.26	34.81	0.4265	-1.015	0.181902	1.030225	-0.4329	
1.56	38.22	-0.2735	2.395	0.074802	5.736025	-0.65503	
3.05	26.11	1.2165	-9.715	1.479872	94.38123	-11.8183	-0.98
0.464	44.16	-1.3695	8.335	1.87553	69.47222	-11.4148	

Table 6: Correlation Analysis of flow rate and % removal of TKN in Unplanted Bed.

FLOW m^3/d	TKN removal%	x	y	x2	y2	xy	r
2.26	16.33	0.4265	-1.87	0.181902	3.4969	-0.79756	
1.56	19.64	-0.2735	1.44	0.074802	2.0736	-0.39384	
3.05	13.11	1.2165	-5.09	1.479872	25.9081	-6.19199	-1.006
0.464	23.72	-1.3695	5.52	1.87553	30.4704	-7.55964	

Table 7: Correlation Analysis of flow rate and % removal of NH_4-N in planted Bed.

FLOW m^3/d	NH4 removal%	x	y	x2	y2	xy	r
2.26	42.02	0.4265	-2.1225	0.181902	4.505006	-0.90525	
1.56	48.08	-0.2735	3.9375	0.074802	15.50391	-1.07691	
3.05	27.56	1.2165	-16.5825	1.479872	274.9793	-20.1726	-0.98
0.464	58.91	-1.3695	14.7675	1.87553	218.0791	-20.2241	

Table 8: Correlation Analysis of flow rate and % removal of NH_4-N in Unplanted Bed.

FLOW m^3/d	NH4 removal%	x	y	x2	y2	xy	r
2.26	26.58	0.4265	-1.5325	0.181902	2.348556	-0.65361	
1.56	27.29	-0.2735	-0.8225	0.074802	0.676506	0.224954	
3.05	23.17	1.2165	-4.9425	1.479872	24.42831	-6.01255	-0.971
0.464	35.41	-1.3695	7.2975	1.87553	53.25351	-9.99393	

Table 9: Correlation Analysis of flow rate and % removal of TP in Planted Bed.

FLOW m^3/d	TP removal%	x	y	x2	y2	xy	r
2.26	24.3	0.4265	-0.715	0.181902	0.511225	-0.30495	
1.56	28.4	-0.2735	3.385	0.074802	11.45823	-0.9258	
3.05	13.09	1.2165	-11.925	1.479872	142.2056	-14.5068	-0.965
0.464	34.27	-1.3695	9.255	1.87553	85.65503	-12.6747	

Table 10: Correlation Analysis of flow rate and % removal of TP in Unplanted Bed.

FLOW m^3/d	TP removal%	x	y	x2	y2	xy	r
2.26	8.86	0.4265	0.0325	0.181902	0.001056	0.013861	
1.56	7.35	-0.2735	-1.4775	0.074802	2.183006	0.404096	
3.05	6.99	1.2165	-1.8375	1.479872	3.376406	-2.23532	-0.822
0.464	12.11	-1.3695	3.2825	1.87553	10.77481	-4.49538	

Table 11: Correlation Analysis of flow rate and % removal of TSS in Planted Bed.

FLOW m^3/d	TSS removal%	x	y	x2	y2	xy	r
2.26	57.41	0.4265	-9.835	0.181902	96.72723	-4.19463	
1.56	76.18	-0.2735	8.935	0.074802	79.83423	-2.44372	
3.05	50.98	1.2165	-16.265	1.479872	264.5502	-19.7864	-0.96
0.464	84.41	-1.3695	17.165	1.87553	294.6372	-23.5075	

Table 12: Correlation Analysis of flow rate and % removal of TSS in Unplanted Bed.

FLOW m^3/d	TSS removal%	x	y	x2	y2	xy	r
2.26	49.48	0.4265	-10.7775	0.181902	116.1545	-4.5966	
1.56	68.42	-0.2735	8.1625	0.074802	66.62641	-2.23244	
3.05	45.58	1.2165	-14.6775	1.479872	215.429	-17.8552	-0.964
0.464	77.55	-1.3695	17.2925	1.87553	299.0306	-23.6821	

ANNEX III

Photo 1: Overall view of Horizontal Flow Constructed Wetland.

Photo 2: Settling tanks for pre-treatment.