PERFORMANCE EVALUATION OF PILOT SCALE VERTICAL FLOW SUBSURFACE CONSTRUCTED WETLAND TREATING MUNICIPAL WASTEWATER

A DISSERTATION PAPER

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LETTER OF ACCEPTANCE

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ABSTRACT

Constructed Wetland is being used as a low cost treatment system by most of the developing countries to treat wastewater. A pilot scale vertical sub surface flow Constructed Wetland was constructed in the premises of BASP, Kathmandu for the treatment of wastewater. The pilot scale constructed wetland consists of two units/beds of equal size i.e., 6m x 2m x .7m. One of the beds was planted with locally available reeds, *Phragmites karka* and another was left unplanted and treated as blank. Gravel and sand was used as the media in the bed. To evaluate the pollutants removal efficiency of the treatment beds in four different flow rates, composite wastewater samples were collected and analyzed from April 2006 to Oct 2006. The two treatment beds show excellent removal percentage of pollutants, however planted bed was found to be more effective than unplanted bed. Removal efficiency were reduced from 95.75 % to 76.7% for BOD, 94.07% to 77.7% for COD, 95.58% to 72.76% for TSS, 61.16% to 39.97% for TKN, 72.87% to 24.78% to 48.11% for NH_4-N, 52.46% to 24.78% for TP, when the flow rate was increased from 0.464 m^3/d to 3.05m^3/d. Dissolved Oxygen (DO) found to be increased in the effluents. *Fecal coliform* removal efficiency was above 90%. Biomass percentage of reeds was found 57.07 %, which indicates high productivity and can be used in making fertilizer, mulch and handicrafts.

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ABBREVIATIONS

BASP	Bagmati Area Sewerage Project
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
CW	Constructed Wetland
DO	Dissolve Oxygen
FC	*Fecal Coliform*
MPN	Most Probable Number
NH4-N	Ammonia Nitrogen
SSF	Sub-Surface Flow
TKN	Total Kjeldahl Nitrogen
TP	Total Phosphate
TSS	Total Suspended Solid
UV	Ultra Violet
VFPB	Vertical Flow Planted Bed
VFUB	Vertical Flow Unplanted Bed

CHAPTER-I
INTRODUCTION

1.1 Background

Environmental pollution has progressively come into sharp focus all over the world. Now a day the problem of environmental pollution is a burning concern for society everywhere. At present time environmental pollution is increasing day by day in every corner of the world especially in industrial and urban areas.

Life on earth is inextricably linked with water. It is the primary components of living organism. Water is one of the most important renewable natural resource and is essential for nearly every human endeavor.

Water is regarded as polluted when it is changed in its quality or composition, directly or indirectly as a result of human activities so that it becomes less suitable for drinking, domestic, and agricultural and other purposes for which it would otherwise be quite suitable in its natural (unpolluted) state. Some waste entering into water bodies as industrial effluent cannot be degraded or processed by nature within a reasonable period of time and such waste begin to accumulate and pollute the environment.

Most of the rivers in Nepal such as Bagmati, Bishnumati of Kathmandu, Singhia of Biratnagar, Sirsia of Birgunj, which are running through the urban areas, are highly polluted. The destructive effects of sewage can be clearly seen on the bank of these rivers. If the waste is allowed to accumulate, it will give offensive odour to water. In addition untreated wastewater usually contains disease-causing microorganisms and can produce toxic compounds. For this reason, the immediate and nuisance free removal of wastewater from its source of generation followed by treatment and disposal is not only desirable but also necessary.

The Bagmati River originates upstream from Kathmandu and flows as the largest and most culturally significant river through the valley. Upstream from

Kathmandu Valley, the overall water quality is very good, but this deteriorates as the river reaches the urban areas within the valley. Table 1 presents typical water quality data of the Bagmati River at Sundarighat, heavily populated section of Kathmandu.

Table 1: Water Quality Parameter of the Bagmati River at Sundarighat

	May, 2002	Aug., 2002	Oct., 2002	Dec., 2002
pH	7.0	7.3	6.7	6.5
TSS(mg/L)	166	304	92	144
BOD (mg/L)	240	54	50	109
COD (mg/L)	317	110	181	255
DO (mg/L)	0.7	6.4	0.4	1.9
NH_4-N (mg/L)	18	4	18	20
PO_4-P (mg/L)	1.7	0.3	1.3	1.0
Faecal coliform (per 100mL)	$230x10^{4}$	$2x10^{4}$	$5.6x10^{4}$	$1.8x10^{4}$

Source: ENPHO, 2003)

The main cause of degrading water quality of Bagmati River is the discharge of untreated sewage and dumping of solid waste into river water and on the riverbank (HMG/MOHPP, 1994). Open drains, sewer pipes connected to the water courses, discharge of faeces, burning of dead bodies, sand mining and livestock rearing were visible at several places on the banks and in the water courses of Bagmati River. As a result, the river is shrinking with germs and human waste. At times, the adverse effects of the direct discharge of sewage and untreated industrial effluents could be seen up to 10km downstream of Kathmandu valley (NPC/IUCN, 1991).

The liquid waste collected from houses of municipality, communities and industrial discharge is collectively known as wastewater. It consists of 99% water, 0.02-0.03% suspended solid, organic inorganic substances together with microorganisms like Bacteria, Fungi, protozoa and viruses. If the wastewater is not treated before discharging it into the water bodies, the organic and inorganic matter in the waste will decompose producing harmful chemicals and gases. Further the microorganism present will create several health hazards (Rajbanshi, 2004). So the wastewater must be treated for a hygienic life.

Wastewater treatment is a multi-stage process to renovate the quality of wastewater before it re-enters a body of water (Manel, 1996). Depending upon the size of the treatment system, broadly there are two types of wastewater treatment system, they are- Centralized and Decentralized type. The centralised wastewater management using conventional wastewater treatment system is an expensive and unsustainable system difficult to manage and operate by developing countries like Nepal. The alternate to this is decentralised wastewater management using natural treatment system. Among the natural treatment systems, constructed wetland appears to be an appropriate alternative. In recent years, constructed wetland system has emerged as an attractive low-cost decentralized wastewater treatment alternative. Constructed wetlands have a uniform water level and a different root substrate support where bio-film formation occurs, besides a restricted biodiversity (Gopal, 1999). Plants are important for a good wetlands performance they absorb nutrients, their roots offer mechanical resistance to water flow, increase the Hydraulic Retention Time (HRT), provide a large surface area for microbial growth, and transport oxygen to anaerobic layers. Plants biomass production could also be of economical importance.

There is a growing interest also in Nepal to develop and adopt the technology for water pollution control to suit the local condition. This study focuses on the decentralized wastewater treatment using vertical flow subsurface constructed wetland.

1.2 Objectives of the Study

The overall objective of the study is to evaluate the performance of the Vertical Subsurface flow Constructed wetland in treating the wastewater. Other objectives are:

- To analyze the physico-chemical parameters of the wastewater.

- To analyze the physico-chemical parameters of wastewater after treated by reed bed.
- To compare the removal efficiency of planted and non-planted reed bed system.
- To determine the biomass of reeds (*Phragmites karka*).

1.3 Justification of the Study

In our country most of the municipalities don't have proper wastewater treatment and disposal facilities. Most of the rivers in Kathmandu Valley are sacred and people take religious bath in these rivers. So it is necessary to maintain and improve the quality of these rivers to make it pollution free. In view of improving the quality of Bagmati River, Bagmati Area Sewerage construction and Rehabilitation Project (BASP) was formed by Government of Nepal in 2052. This plant has been constructed in order to treat the domestic and industrial waste generated in the area upstream of Guheshwari Temple and Mitra park area to prevent pollution of sacred river Bagmati. The treatment system of Bagmati Sewage Project need huge amount of investment skill and maintenance cost and consumes more amount of energy (Sarah, 2001), which is difficult to handle for a developing country like Nepal. This has inspired me for detailed study on low cost treatment systems; amongst which constructed wetland appears to be low cost as well as a natural biological wastewater treatment system. The present work on the pollutants removal efficiency of reeds from domestic wastewater discharging into the Bagmati River was conducted in order to notice the possibilities of the use of reeds for domestic wastewater treatment.

Beside very little research work has been carried out on constructed wetlands in Nepal. Performance study of constructed wetland and different influent wastewater quality particularly in our climatic condition is essential.

HAPTER-II

LITERATURE REVIEW

2.1 Centralized Waste Water Treatment System

The centralized wastewater management system consisting of large intercepting sewerage system leading to central treatment plant has been successfully applied over many decades in densely populated urban areas of developed and developing countries and contributed to a great extent to the improvement of hygienic conditions in these areas. The central treatment plants are treatment units, involving biophysical reactors. Because of the large amount of flow, the only option to treat sewage collected in the centralised system is by conventional type of mechanized system. The most common centralized treatment plants are activated sludge system, oxidation ditch, trickling filter or stabilization pond (non aerated lagoon) (Sarah, 2001).

There are five centralized wastewater treatment plant existing in the Kathmandu valley. These are an activated sludge plant at Guheshwari, non-aerated lagoons at Khodku and Dhobighat and aerated lagoons at Sallaghari and Hanumanghat. Of the five treatment plants, the only wastewater treatment plant in operation as on December 2006 is the activated sludge system at Guheshwari.

The large centralized treatment system involves huge capital cost. For instance the construction cost of sewerage treatment facility at Guheshwari is 600 million rupees. The cost includes the construction of 14 km of sewer line and the oxidation ditch (Shah, 2003). The cost of decentralised system, whereas, is one half to one third of conventional sewerage system (Sarah, 2001).

The cost of operation and maintenance of the centralised system is also huge. For instance annual operating cost of Guheshwari treatment plant is 8 million rupees (Shah, 2003). The annual operating cost of the decentralised system is only 5 to 10% of the operating cost of centralised system (Sarah, 2001).

The use of activated conventional sludge in developing nations has come under much criticism in recent years (Harleman, 2001). The major disadvantages of activated sludge systems are high operating cost associated with high-energy needs. Nepal has few exploitable fossil fuel sources, so electricity production efforts have been primarily focused on hydroelectric plants. Even this source is largely untapped, so electricity remains very expensive.

2.2 Decentralized Waste Water Treatment System

Decentralized Waste Water Treatment Systems are small-scale based treatment system, which are managed and monitored by the community itself with comparatively low energy needs. In contrast to centralized system in decentralized system wastewater is managed for a few wards of a town, suburb, cluster of homes, industrial estate, factory, commercial premises or urban high rise building that is located within or adjacent to the premise(s). It is also sometime called as on-site community wastewater management. The sewage generated from a community are managed within the community and as close as possible to the source of waste generation. In general the decentralised wastewater management concept:

- Broadens the technology options and permits tailoring the solutions to the prevailing conditions;
- Minimises the freshwater requirements for waste transportation;
- Reduces the risks associated with system failure;
- Increases wastewater reuse opportunities; and
- Permits incremental development and investment in the community wastewater system (Shah, 2003).

Due to high operating cost and huge energy needs of large/centralized treatment plants, small and decentralized treatment systems are in high demand. There are vast wealth of small scale or decentralised sewerage technologies specially designed to service small communities of which Constructed wetlands are gaining popularity in the developed and developing countries like Nepal. These are design to mimic the natural removal processes of natural wetlands.

2.3 Constructed Wetland

Constructed wetlands are natural wastewater treatment systems consisting of shallow (usually less than 1 m deep) ponds or channels which have been planted with aquatic plants, and which rely upon natural microbial, biological, physical and chemical processes to treat wastewater. They typically have impervious clay or synthetic liners, and engineered structures to control the flow direction, liquid detention time and water level. Depending on the type of system, they may or may not contain an inert porous media such as rock, gravel or sand. The reuse or reclamation of wastewater using constructed wetland technology also provides an opportunity to create or restore valuable wetland habitats for wildlife and environmental enhancement (Hammer, 1990).

The basic features of constructed wetlands are that they are uniformly graded, have flat vegetative soil surfaces, and have a device for uniform wastewater distribution at the inlet side of the system and collection device at the end. Plants are important for a good wetland performance because they absorb nutrients, their roots offer mechanical resistance to water flows, increases the Hydraulic Retention Time (HRT), provides a large surface area for microbial growth and transport oxygen to anaerobic layers. Plants biomass could also be of economical importance. The plants mostly used in constructed wetlands are reeds, cattails, sedges, pennywort etc. (Reed *et al.*, 1988).

2.3.1 Classification of constructed wetland system

There are two types of constructed wetlands treatment system depending upon the flow pattern as

- **Free water surface flow system (FWS):** FWS wetland contains appropriate emergent aquatic vegetation in a relatively shallow bed or channel. In this case, the surface or water is exposed to the atmosphere as it flows through the bed.
- **Subsurface Flow System (SSF):** Constructed wetlands with SSF contain a foot or more of permeable media (rock, gravel, sand and soil have been all used). This media supports the root system of the vegetation, but the water flow is maintained below the top of the media (Reed, 1991).

SSF wetland can be further categorized according to the direction of flow into horizontal and vertical.

- **Horizontal sub-surface flow constructed wetland:** In horizontal flow constructed wetland the wastewater is fed at the inlet and flow slowly through the porous medium under the surface of the bed in a more or less horizontal path until it reaches the outlet zone.

- **Vertical sub-surface flow constructed wetland:** Vertical flow constructed wetland system comprise a flat bed of gravel topped with sand planted with macrophytes. These beds are fed intermittently in a large batch thus flooding the surface. Wastewater then gradually percolates down through the bed and is collected by a drainage network at the base. The bed drains completely free and it allows air to refill the bed. This kind of feeding leads to good oxygen transfer and hence the ability to nitrify (Cooper *et al.,* 1996). The oxygen diffusion from the air contributes much more to the filtration bed oxygenation as compared to oxygen transfer through plant parenchyma system. The major propose of macrophyte presence in vertical flow system is to help maintain the hydraulic conductivity of the bed.

2.3.2 Removal mechanism of pollutants in constructed wetland

The main components of Constructed wetland (CW) are substratum, microorganism and macrophytes. Macrophytes pose several functions in relation to the water treatment. The presence of vegetation in wetlands distributes and reduces the current velocities of the water. These create better condition for sedimentation of suspended solid, reduces the risk of erosion and resuspension and increase the contact time between the water and the plants surface areas (Vymazal *et al.,* 1998). Wetland plant requires nutrients for growth and reproduction, which they take up primarily through their root systems. Besides, oxygen is passed through the rhizosphere via the leaves and the stems of the macrophytes through the hollow rhizomes and out into the soil and gravel (Cooper *et al*., 1996). The oxygen leakage at the root tips serves to oxidize and detoxify potential harmful reducing substances in rhizosphere (Vymazal *et al.,* 1998). Wetland provide suitable environment for growth and reproduction of microscopic organism. Bacteria and fungi are much important in wetland treatment system because of their role in the assimilation, transformation and recycling of chemical constituents present in various wastewater. The substratum in CW is composed of soils and gravel. Biofilm formation in the substrate accounts for most off the organic matter decomposition in the wetland. Media also acts as active sites for adsorption of constituents like Phosphorus and metals (USEPA, 1999).

Wetland systems reduce many contaminants including organic matter, suspended solid, nitrogen, phosphorus, trace metals, pathogens by a complex variety of physical, chemical and biological processes (Vymazal *et al.,* 1998).

- **Organic matter removal:** Setttleable organic matter removed in wetland system under quiescent condition by sedimentation and filtration. Attached and suspended microorganism decomposes soluble organic compounds.

Organic compounds are degraded aerobically as well as anaerobically. The oxygen require for aerobic decomposition is supplied directly from the atmosphere through diffusion and/or by oxygen leakage from macrophyte roots (Moshiri, 1993). Anaerobic degradation will occur during periods with oxygen depletion. Anaerobic degradation of organic matter is much slower than aerobic degradation. However when oxygen is limiting at high organic loading, anaerobic degradation will predominate (Vymazal *et al.*, 1998). Uptake of organic matter by the macrophytes is negligible compared to biological degradation (Cooper *et al.*, 1996). According to data compiled by Moshiri (1993), constructed wetland systems may be expected to remove 50 to 90% of BOD_5.

- **Total suspended solid Removal:** All settleable and floatable solids are removed in wetland system due to long hydraulic residence time. The major removal mechanisms are sedimentation and filtration. Non-settleable and colloidal solids are removed by bacterial growth and collision with other solids such as plants, suspended solid etc. in all constructed wetland systems, most of the solids are removed within the first few meters beyond the inlet zone because of filtration and sedimentation (Hammer, 1990). Moshiri (1993) has compiled the removal efficiency for TSS as 40-94%.

- **Nitrogen removal:** The removal mechanism for nitrogen in constructed wetland includes volatilization, ammonification, nitrification or denitrification, plant uptake and matrix adsorption (Vymazal *et al.*, 1998). However the major removal mechanism in most constructed wetlands is microbial nitrification and denitrification (Cooper *et al*, 1996). Although plant uptake of nitrogen occurs, plants can remove only a minor fraction. Moshiri (1993) has compiled the removal rate for nitrogen as 30-98%.

- **Phosphorus removal:** Phosphorus removal in constructed wetlands occurs through adsorption, absorption, complexation and precipitation. A significant clay content and Iron, Aluminum and Calcium will enhance phosphorus removal. Phosphorus is removed by precipitation by Iron and Aluminum in acidic conditions (pH<6), and by Calcium and Magnesium in alkaline conditions (pH above 8) (Polprasert and Veenstra, 2000). Moshiri (1993) has compiled the removal rates for phosphorus as 20-90%. Wetland system either natural or constructed, have not typically been very effective in reducing inorganic phosphorus. The wetland provides a temporary sink for organic phosphorus removal, however, chemical and biological equilibrium of the soil strata and wetland plants are generally not sufficient for extensive inorganic phosphorus removal (Geohring *et al.*, 1995).

- **Pathogen removal:** Constructed wetlands are known to offer a suitable combination of physical, chemical and biological factors for the removal of pathogenic organisms (Vymazal *et al.*, 1998). Wastewater is a hostile environment for pathogenic organism, and factors such as natural die off, temperature and ultraviolet radiation, unfavorable water chemistry, predation and sedimentation cause pathogen populations to be reduced. Natural wastewater treatment system like constructed wetland reduces pathogen more successfully due to longer residence time and land intensive treatment (Kadlec and Knight, 1996).

2.4 History of Constructed Wetland for Waste Water Treatment

With advent of large industries and high population density also increased the amount of waste and at the same time disposal of waste had become a major concern. Failing to deal with these wastes in the past led to contaminated surface and sub-surface waters. Several treatment technologies were developed to treat the waste and eco-friendly appropriate technologies were also under investigation since several decades.

The first research work utilizing artificial wetlands for the treatment of wastewater began at Max Planck Institute in Germany during 1953 by Kathe Seidel. She tried to alleviate problems of over fertilization, pollution and siltation using wetland vegetation, which was thought to be primarily responsible for the treatment of wastewater (Seidel, 1976). In the majority of cases, the flow path was vertical and each cell is planted with Common bulrushes (*Schoenoplectus lacustris)* within the gravel media. Excellent performance for removal of BOD_5 TSS, nitrogen, phosphorus, and more complex organics was claimed (Seidel, 1976). But Seidel's experiments were heavily criticized because the investigations and calculations were mostly aimed only at the use of plants for nutrient removal by plant uptake not on media characteristic.

It took more than twenty years of research before the first operational full scale constructed wetland for municipal sewage was built in Othfresen in Germany (Kickuth, 1977). Till 1990 about 500 of these reed beds or "root zone" systems had been constructed in Germany, Denmark, Austria, and Switzerland and the technology is still spreading at a fast rate. Most of the systems are planted with the Common Reed (*Phragmites australis),* but some systems include other species of wetland plants (Brix, 1994). Since then constructed wetlands have been used around the world to treat various types of wastewater. Constructed wetland with vertical flow system has been in operation for decades in different places in Europe. Several papers presented in international conferences have highlighted the promising performance of vertical flow system. The removal processes can be significantly intensified in vertical flow system with less area requirement. A constructed wetland consisting of several beds laid parallel with percolation flow and intermittent loading will increase soil oxygenation several fold, stimulating sequential nitrification and denitrification and Phosphorus adsorption (Brix and Schierup, 1990).

The knowledge gained in wetland functioning and the experiences in constructed wetland based wastewater treatment during the past three decades or so have been discussed in many workshop, symposia and conferences.

Kantawanichkul *et al.,* (1999) studied on the efficiencies of vertical flow constructed wetland for wastewater treatment. Pollutants were reduced effectively in the treatment system when effluent water was analyzed. They reported that removal efficiency of pollutants was reduced when HLR was doubled.

Obaraska-Pempkowiat *et al.,* (2000) studied on the efficiency of constructed wetland for wastewater treatment. They reported a substantial amount of organic matter removal in the treatment system while the Total Nitrogen (TN) and Total Phosphorus (TP) were removed moderately.

Gervin and Brix (2001) studied on the removal of nutrients from combined sewer outflow in a vertical flow constructed wetland system. A higher removal of TN and TP were reported.

Marques *et al.,* (2001) studied on two macrophytes *Zizaniopsis bonariensis* and *Typha sobulata* in a subsurface flow constructed wetland and a sand based wetland receiving anaerobically tr'eated municipal wastewater. All parameters were monitored in two hydraulic loading rates (HLR). The main effect of HLR with decreased removal for increased load were reported for *Fecal coliform*, ammonia nitrogen, total nitrogen and total suspended solid. In higher loading treatment, Chemical Oxygen Demand (COD), Total Phosphorus (TP) was removed more efficiently by planted bed than unplanted sand bed as reported.

Arias *et al.,* (2003) studied on the removal of indicator bacteria in an experimental constructed wetland system consisting of sedimentation tank, two vertical flow beds and a filter unit with calcite aimed at removing phosphorus. They reported a reduction of 1.7 log units of *Fecal coliform* bacteria and suggested filtration as the major removal mechanism.

Cui li-hua, *et al.,* (2003) studied on the treatment of septic tanks effluent using vertical flow constructed wetlands. They found that when septic tank effluent was treated by vertical flow filter, the removal rates for BOD, COD, SS, TN and TP were high. The removal rate for total coliform index was extremely high as compared to other parameter.

Weedon (2003) studied on the effectiveness of removing pollutants in compact vertical flow constructed wetland with a pond serving eight residents. More than 90% removal of pollutants was achieved with the system. Average phosphorus removal was decreased during the study period suggesting saturation of sand gravel media as the main reason behind. An almost 4 log unit of fecal reduction was reported.

Browne and Jenssen (2005) treated sewage from a community consisting of 160 people, at Vidarasen in Norway using a pond reed bed system. The treatment performance during the first five years showed a high degree of removal efficiency and is unaffected by harsh winter condition.

Koottatep, *et al.*, (2005) experimented on the treatment of septage in CW in tropical climate for seven years. The experiment has been conducted by using three constructed wetlands units operating in a vertical flow model, planted with narrow leaf cattails (*Typha augustifolia*). The results show a high degree of removal efficiency of pollutants in CW in treating septage.

Paing and Voisin (2005) experimented on the purification performance of twenty wastewater treatment plants with vertical reed bed filters, built from 1998 to 2003. The first stage vertical reed bed directly fed with raw wastewater by intermittent feeding achieved a high removal of TSS, BOD_5 and COD. They reported that to obtain optimal performance from reed bed, rigorous operation and maintenance were required.

Zhi-wen, *et al.*, (2005) studied on the seasonal and annual variations of wastewater purification efficiency of Rongcheg constructed wetlands in Shandong Province. The treatment performance of first five years showed that the constructed wetland could effectively reduce concentration of TSS, BOD_5 and COD, and *Fecal coliform*. The nitrogen and phosphorus removal efficiencies were found least during the study.

2.5 History of Constructed wetland in Nepal

Environment and Public Health Organization (ENPHO) introduced the use of constructed wetlands for wastewater treatment as an alternative to conventional wastewater treatment technologies. The first ENPHO designed constructed wetland system with a two staged sub-surface flow was for Dhulikhel hospital, in the leadership of Dr. Roshan R. Shrestha in 1997. Due to the Success of Dhulikhel Hospital system, four more sub-surface constructed wetland systems have been built in and around Kathmandu in the past few years (Shrestha, 2001). The Kathmandu Metropolitan city (KMC) established its own septage treatment plant based on this technology. The Malpi International School, located near Panauti, has adopted a similar system to treat household wastewater before discharging the water in The Rosie River. The Sushma Koirala Hospital at Sankhu and Kathmandu University at Banepa also has their own constructed wetland to treat their domestic wastewater.

There are several-constructed wetland systems that are in design phase in Nepal. The Pokhara sub-Metropolitan City's system that is under construction will be the largest constructed wetland system in Asia. The technology is getting popular and gradually becoming adapted within Nepal.

Results from numerous research reports and paper have shown that the technology of wetland system treatment has great potential in controlling water pollution from domestic, industrial and non point source contaminants. It has been widely recognized as a simple effective, reliable and economical technology as compared to several types of conventional system. On the other hand very little research has been done in developing countries like Nepal where the technology may be most effective.

CHAPTER-III
METHODS AND METHODOLOGY

3.1 Study Area

This study was carried out at a pilot scale Constructed Wetland (CW) system located in the premises of Guheshwari Treatment Plant owned by Bagmati Area Sewerage Project (BASP) which is located near the Pashupati Temple at the bank of Bagmati River on the North-eastern part of Kathmandu city.

3.2 Experimental setup

The experimental setup consists of three settling tanks, one feeding tank and two vertical flow bed with subsurface flow system. The settling tanks are of 1000 L capacity with three chambers for primary treatment. The two units of vertical flow beds are of size 6m x 2m x 0.7m with an area of $12m^2$. Of these two vertical flow units, one is planted with *Phragmitis karka*, a locally available reed plant and the other unit is left unplanted and is treated as blank bed. The schematic diagram of the set up is shown in the Fig.1 (A, B). Rhizomes of reeds are used for plantation in the bed. Plantation was done on February 2006. At the time of plantation, 9 Rhizomes were planted in per meter of the bed.

Each of the bed was sealed with an impermeable plastic liner at the bottom and on the sides. Course sand is used as a supporting media for aquatic plants at the top layer and the bottom layer of the bed consisted of gravel, as a drainage layer. The bottom layer consists of 20-30 mm uniformly graded gravel and on the top lies sand of 0.98 mm effective size.

The system is fed with wastewater drawn from grit chamber of oxidation ditch system of BASP and is collected on settling tanks. From settling tanks the wastewater is pumped into a tank of 500 L and flows into the treatment beds. A timer is fitted, which helps in intermittent feeding of wastewater in the treatment beds. The wastewater distribution system in the bed consists of four perforated polyethylene pipes in each bed that lies across the bed surface. Wastewater is distributed into the beds three or four times per day through perforated pipes. Separate drainage pipes have been provided to collect treated water from two beds and is connected into small drainage line.

All the construction works were done in the supervision of environmental engineers from Pulchowk Campus.

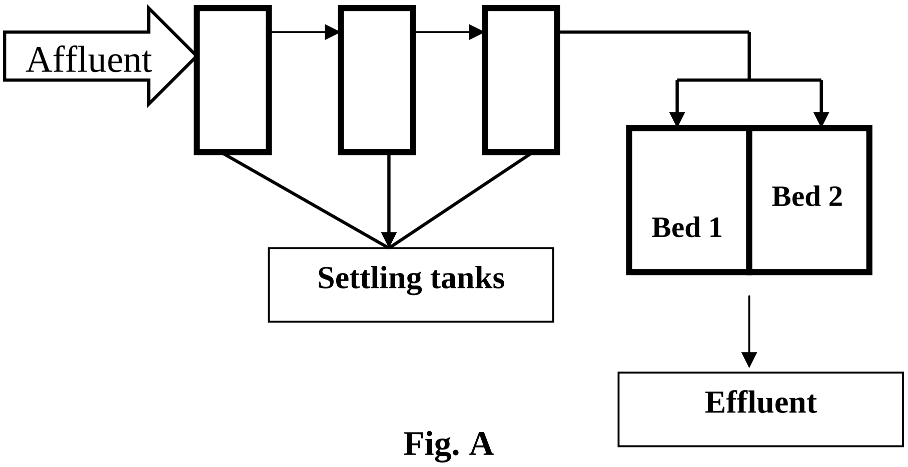

Fig. A

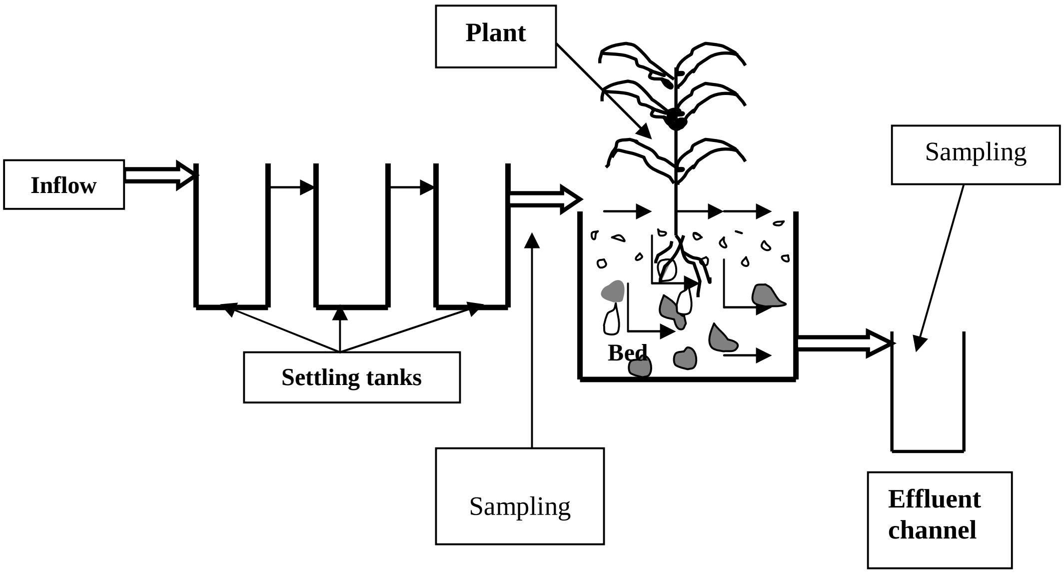

Fig. B

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

3.3 Experimental analysis

The experiment was carried out from May 2006 to October 2006. The performance of two treatment beds are carried out at four different flow rates, viz. 0.464,1.56, 2.26, 3.05 m^3/d. Five samples were taken for each flow rate at an interval of one week.

3.3.1 Sampling process

The two units of vertical flow beds are set at specific flow rate. The flow was measured by using plastic buckets of 10 liters divided by the time taken it to fill. Then the beds are allowed to stabilize in the required flow rates and thereafter, composite wastewater samples of 24 hours are collected form the inlet and two outlet chambers of the bed, once a week. The samples are collected in the glass bottles of 1000 liter and taken to the laboratory for analytical test.

3.3.2 Methods for analyzing wastewater samples

To fulfill the objectives of the study, physical, chemical and bacteriological examinations of wastewater were performed in the laboratory. Various physico-chemical parameters viz. Temperature, pH and Dissolved Oxygen (DO) Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solid (TSS), Total Kjeldahl Nitrogen (TKN), Ammonia Nitrogen (NH_4-N), Total Phosphate (TP), *Fecal coliform* (FC) are selected for wastewater study. All the experiments were performed in the laboratory of BASP. Procedures for the determination of each parameter were adopted from Standard Methods of APHA (1995) except TKN, which was done in accordance with the Manual of IIT Kanpur (2001). In every sampling five readings were taken for each parameter and the mean value was noted.

3.4 Physico chemical parameters

- **Temperature**

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

- **PH**

For measuring pH, beakers were filled with influent and effluent samples and then a battery operated pH meter was dipped in the beaker up to the level marked in the pH meter and the pH was recorded.

- **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 1L-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's 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 shake 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:

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

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

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

- **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 10ml-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 Ferrous Ammonium Sulphate (FAS) after adding 2-3 drops of Ferroin indicator until the color changed from blue green to violet red.

Calculation:

$$COD\ (mg\ O_2\ L^{-1}) = \frac{8000 \times M \times (V_1 - V_2)}{V_s}$$

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)

- **Total Suspended Solid (TSS)**

Filter paper was washed with laboratory water in the filter holder under suction and removed into the Aluminum foil. Filter paper was dried in oven at 105^{o}C for one hour and placed inside desiccator for cooling. Paper was weighted 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^{o}C for one hour. Filter was cooled in desiccators and again weighted.

Calculation:

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

- **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 50^{o}C.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 EDTA and 1ml Nessler's 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.

- **Ammonia Nitrogen (NH_4-N)**

About 20 ml samples were 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's reagent. Color changed to yellow. Five standards of various concentrations were also prepared along with blank. Concentrations were determined from spectrophotometer adjusted at 420nm.

- **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. One drop of phenolphthalein indicator was added and 1N NaOH was added drop wise 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.

- **Biological examination: *Fecal coliform* (FC)**

Multiple tube fermentation test is a measure of the Most Probable Number (MPN) 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:

$$MPN\ per\ 100\ ml\ \mathrm{X}\ \frac{Value\ from\ table\ |\ 10}{largest\ volume\ tested\ in\ dilution\ series\ used\ for\ MPN\ determination}$$

3.5 Biomass determination of reeds

Biomass is the standing crop expressed in terms of weight of the living matter present. For the sampling of reeds, a quadrate size of 25cm x 25cm was used and ten samples were taken. A harvest method was adapted to estimate the biomass of reeds. Reeds in the quadrate were cut and kept in an oven for 24 hours at 70^{0}C, after then dry weight of reeds was taken. Percentage of biomass was determined by using following formula.

Biomass of reed (%)= $\frac{DryWeight}{WetWeight}$ X100

3.6 Statistical analysis

Carl Pearson's correlation coefficient was used as statistical analysis using the following formula

$$r = \frac{\sum xy - \frac{\sum x \sum y}{n}}{\sqrt{\left(\sum x^2 - \frac{(\sum x)^2}{n}\right)\left(\sum y^2 - \frac{(\sum y)^2}{n}\right)}}$$

Where, x & y are two variables.

CHAPTER-IV
RESULTS

4.1 Temperature and pH

The temperature and pH recorded during the study period are presented in Table a (Annex I). The temperature of wastewater varies from 23-28^{o}C. The influent pH ranges from 6.5 to 7.9 while the pH of effluent ranges from 5.9 to 7.4 and 6.1 to 7.6 for planted bed and unplanted bed respectively.

4.2 Removal of Biological Oxygen Demand (BOD)

The average influent and effluent BOD concentration and the removal efficiencies for vertical flow planted bed (PB) and unplanted bed (UB), at different flow rates during the study period are presented in Table 2 (Annex I-Table b). The average BOD concentration entering into the system was found 104.42mg/l to 187.97mg/l. The final average effluent BOD concentration ranges from 5.05mg/l to 33.12mg/l for PB and 17.92mg/l to 56.65mg/l for UB. The average BOD removed from both PB and UB at four flow rates is shown in the Fig.2. At a flow rate of 0.464m^3/d, average BOD removal efficiency was found to 95.75 % for PB and 84.6% for UB. When flow rate was increased to 3.05m^3/d, efficiency decreased to 76.7% for PB and 64.7% for UB.

Table 2: Average BOD Removal Performance at Different Flow Rates

Flow (m^3/d)	Influent (mg/l)	Effluent (Planted bed) (mg/l)	%Removal	Effluent (Unplanted Bed) (mg/l)	%Removal
0.464	118.87	5.05	95.75	17.92	84.6
1.56	128.89	11.97	90.88	29.26	60.0
2.26	187.97	33.12	82.08	56.65	69.67
3.05	104.42	24.29	76.7	36.74	45.4

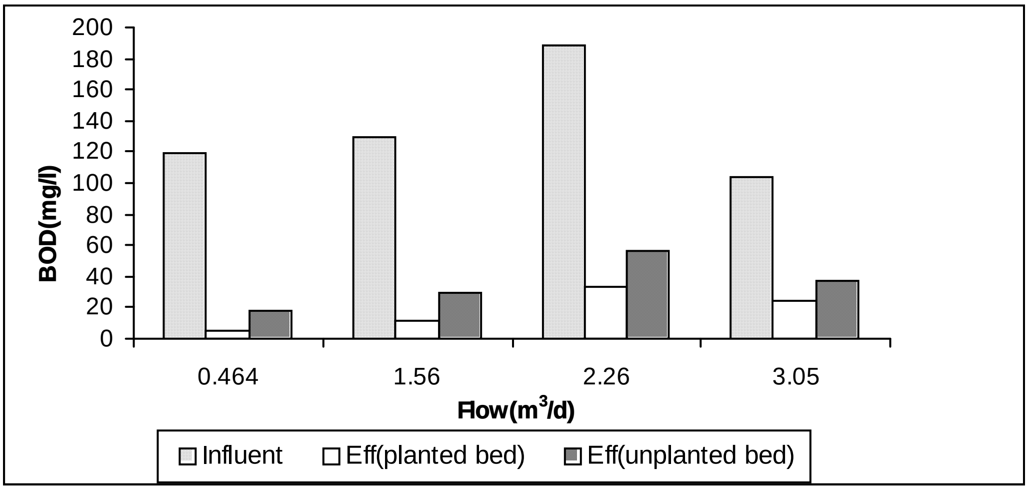

Fig.2 BOD removal in vertical flow planted and unplanted reed bed

Correlation (Annex II, Table 1 and 2) and Regression analysis were carried out to establish the relationship between BOD removal efficiency and flow rates (Fig.3). The correlation analysis shows that BOD removal efficiency and flow rates are negatively correlated. The regression analysis showed the following relationship:

For Planted Bed $y_{BOD} = -7.6607x_1+100.4$

For Unplanted Bed $y_{BOD}= -13.103x_1+88.94$

Where y_{BOD}=BOD removal efficiency in %, and

x_1=flow rate in m^3/d

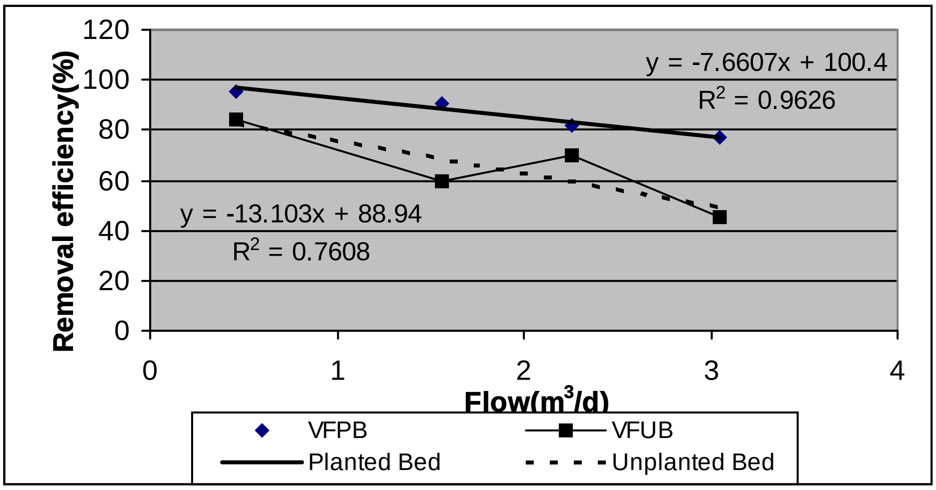

Fig.3 Regression equations established between flow rate and BOD Removal Efficiency

Results showed that linear relationship existed between BOD removal efficiency and flow rate for both planted reed bed and unplanted reed bed. Results also indicated that planted bed is more effective in removing BOD than unplanted bed.

4.3 Removal of Chemical Oxygen Demand (COD)

Table 3 (Annex I-Table c) consists of the average influent and effluent COD concentration and the removal efficiencies for vertical flow planted bed (PB) and unplanted bed (UB), at different flow rates during the study period. The average COD concentration entering into the system was found 186.17mg/l to 393.83mg/l. The final average effluent COD concentration ranges from 11.09mg/l to 81.32mg/l for PB and 29.4mg/l to 100mg/l for UB. The average COD removed from both PB and UB at four flow rates are shown in the Fig.4. At a flow rate of 0.464m^3/d, average COD removal efficiency was found to 94.07% for PB and 83.97% for UB. When flow rate was increased to 3.05m^3/d, efficiency decreased to 77.7% for PB and 70.64% for UB.

Table 3: Average COD Removal Performance at Different flow rates

Flow (m^3/d)	Influent (mg/l)	Effluent (Planted Bed) (mg/l)	%Removal	Effluent (Unplanted Bed) (mg/l	%Removal
0.464	186.17	11.09	94.07	29.48	83.97
1.56	254.40	31.13	87.70	41.18	83.86
2.26	393.83	81.32	79.50	100.11	74.60
3.05	247.00	54.72	77.70	71.83	70.64

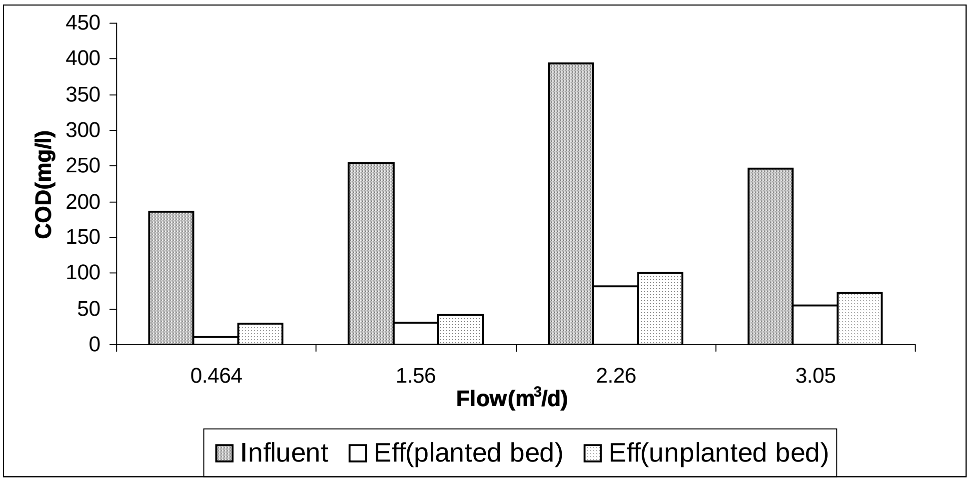

Fig.4. COD removal in vertical flow planted and unplanted reed bed

Regression analysis (Fig.5) and correlation analysis (Annex II, Table 3 and 4) was carried out to establish the relationship between COD removal efficiency and flow rate. A negative correlation was found to exist between COD removal efficiency and flow rate. The regression analysis showed the following relationship:

For Planted Bed y_{COD}= -6.7499x_2 +97.118

For Unplanted Bed y_{COD}= -5.5861x_2 +88.509

Where y_{COD}=COD removal efficiency in %, and

x_2=flow rate in m^3/d

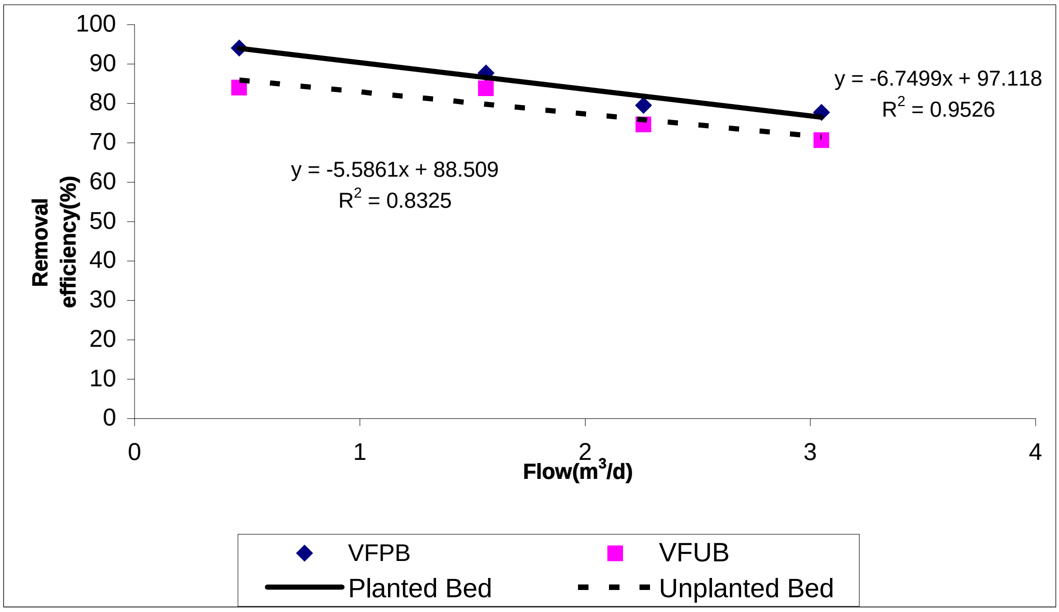

Fig.5 Regression equations established between flow rate and COD Removal Efficiency

Results showed that linear relationship existed between COD removal efficiency and flow rate for both planted reed bed and unplanted reed bed. Results also indicated that planted bed is more effective in removing COD than unplanted bed.

4.4 Removal of Total Suspended Solid (TSS)

The detail of average influent and effluent TSS concentration from vertical flow planted bed (PB) and unplanted bed (UB), at different flow rates during the study period are presented in Table 4 (Annex I, Table d). The average influent TSS concentration found to vary from 143.17mg/l to 166.2mg/l while the average effluent TSS concentration varied from 6.4mg/l to 45.3mg/l for PB and 16.3mg/l to 53.7mg/l for UB. The average TSS removed from both PB and UB, at four flow rates is shown in the Fig.6. At a flow rate of 0.464m^3/d, average TSS removal efficiency was found to 95.58% for PB and 88.62% for UB. When flow rate was increased to 3.05m^3/d, efficiency decreased to 72.76% for PB and 67.78% for UB.

Table 4: Average TSS Removal Performance at Different Flow Rates

Flow (m^3/d)	Influent (mg/l)	Effluent (planted Bed) (mg/l)	%Removal	Effluent (unplanted Bed) (mg/l	%Removal
0.464	143.17	6.36	95.58	16.27	88.62
1.56	148.00	21.46	85.44	29.69	79.96
2.26	152.00	29.18	80.83	35.89	76.40
3.05	166.20	45.30	72.76	53.65	67.78

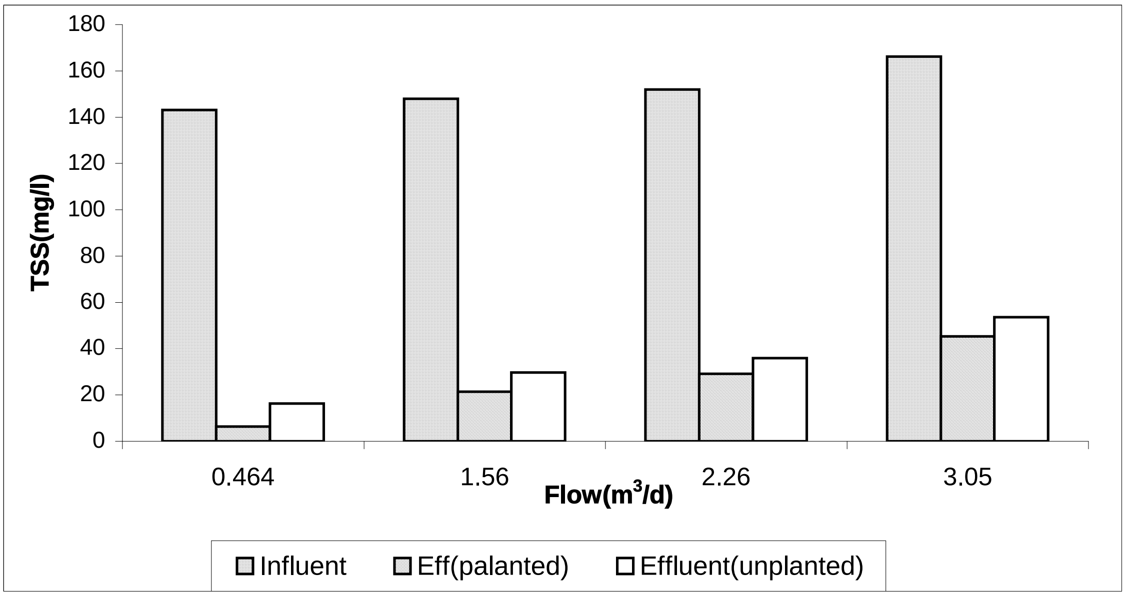

Fig.6. TSS removal in vertical flow planted and unplanted reed bed

Both, correlation (Annex II, Table 5 and 6) and regression analysis (Fig.7) were carried out to establish the relationship between TSS removal efficiency and flow rate. Flow rate and TSS removal efficiency were found negatively correlated with each other. The regression analysis showed the following relationship:

For Planted Bed $y_{TSS} = -8.6601x_3 + 99.532$

For Unplanted Bed $y_{TSS} = -7.8045x_3 + 92.499$

Where y_{TSS} =TSS removal efficiency in %, and

x_3=flow rate in m^3/d

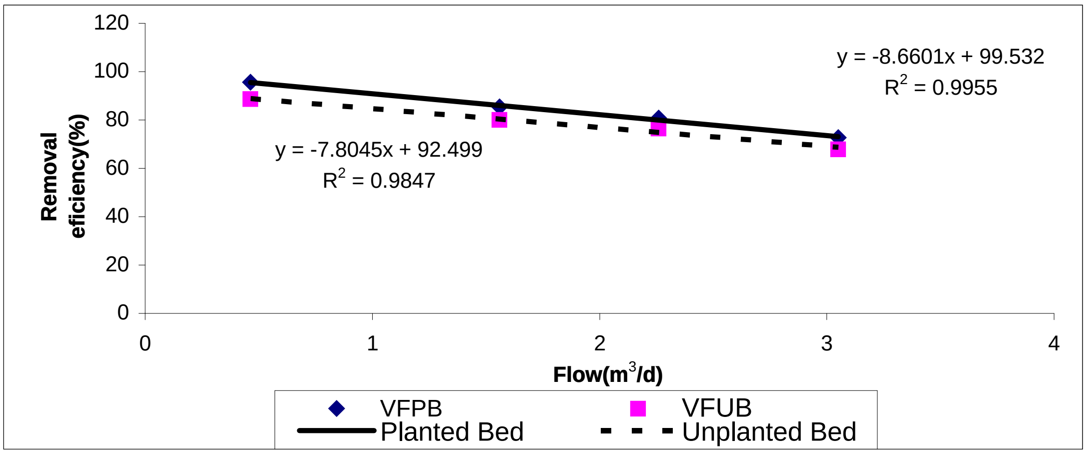

Fig. 7 Regression equations established between flow rate and TSS Removal Efficiency

Results showed that linear relationship existed between TSS removal efficiency and flow rate for both planted reed bed and unplanted reed bed. Results also indicated that planted bed and unplanted reed bed are almost equally effective in removing TSS than unplanted bed.

4.5 Removal of Total Kjeldahl Nitrogen (TKN)

The average influent and effluent TKN concentration from vertical flow planted bed (PB) and unplanted bed (UB), at different flow rates during the study period are presented in Table 5 (Annex I, Table e). The average influent TKN concentration found to vary from 37.72mg/l to 52.38mg/l while the average effluent TKN concentration varied from 16.7mg/l to 24.24mg/l for PB and 27.52mg/l to 36.06mg/l for UB. The total TKN removed from both PB and UB at four flow rates are shown in the Fig.8. At a flow rate of 0.464m^3/d, average TKN removal efficiency was found to 61.16% for PB and 37.01% for UB. When flow rate was increased to 3.05m^3/d, efficiency decreased to 39.97% for PB and 25.16% for UB.

Table 5: Average TKN Removal Performance at Different flow rates

Flow (m^3/d)	Influent (mg/l)	Effluent (planted Bed) (mg/l)	%Removal	Effluent (unplanted Bed) (mg/l	%Removal
0.464	43.00	16.70	61.16	27.08	37.01
1.56	52.38	24.02	54.14	36.06	31.16
2.26	37.72	20.13	46.62	27.52	27.05
3.05	40.38	24.24	39.97	30.22	25.16

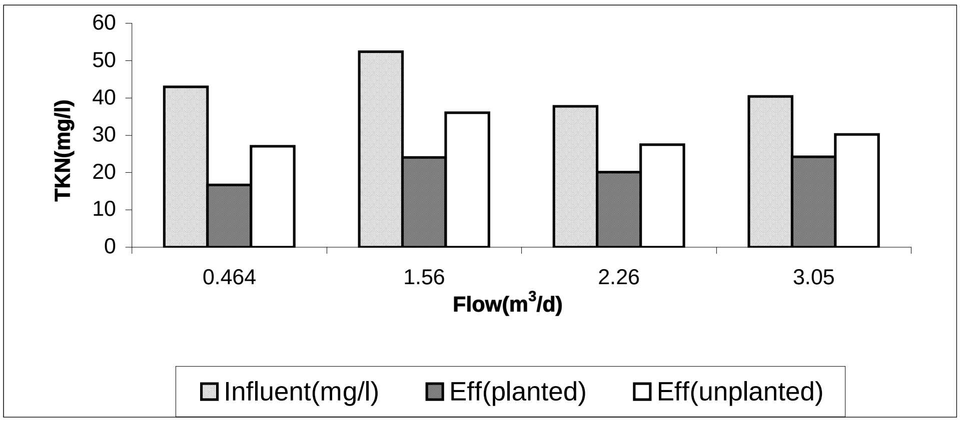

Fig.8. TKN removal in vertical flow planted and unplanted reed bed

Regression analysis (Fig.9) and correlation analysis (Annex II, Table 7 and 8) were carried out to establish the relationship between TKN removal efficiency and flow rate. The correlation analysis shows that TKN removal efficiency and flow rates are negatively correlated. The regression analysis showed the following relationship:

For Planted Bed $y_{TKN} = -8.322x_4 + 65.734$

For Unplanted Bed $y_{TKN} = -4.7255x_4 + 38.76$

Where y_{TKN} =TKN removal efficiency in %, and

x_4=flow rate in m^3/d

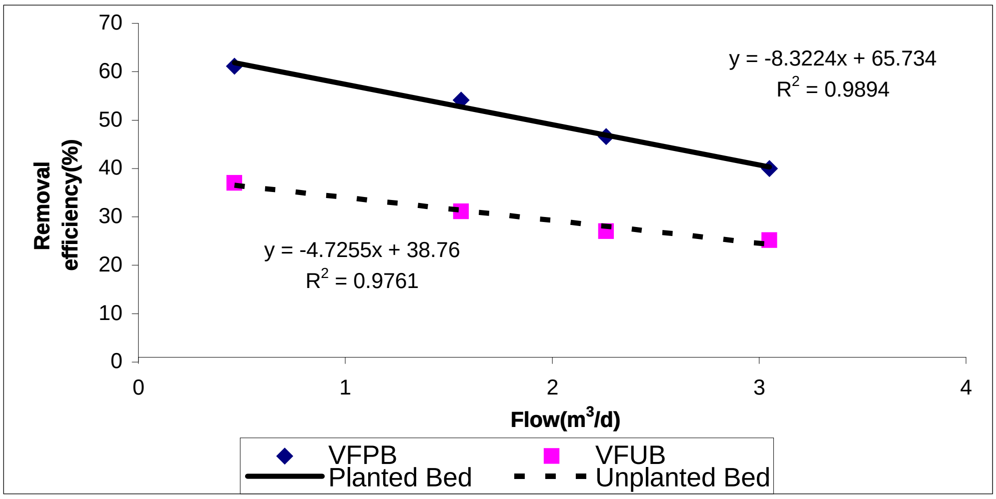

Fig.9. Regression equations established between flow rate and TKN Removal Efficiency

Results showed that linear relationship existed between TKN removal efficiency and flow rate for both planted reed bed and unplanted reed bed. Results also indicated that planted bed is more effective in removing TKN than unplanted bed.

4.6 Removal of Ammonia Nitrogen (NH_4-N)

Table 6 (Annex I, Table f) shows the average influent and effluent NH_4-N concentration from vertical flow planted bed (PB) and unplanted bed (UB), at different flow rates during the study period. The average influent NH_4-N concentration found to vary from 27.87mg/l to 38mg/l while the average effluent NH_4-N concentration varied from 9.38 mg/l to 16.78 mg/l for PB and 18.97mg/l to 24.04mg/l for UB. The NH_4-N removed from both PB and UB at four flow rates are shown in the Fig.10. At a flow rate of 0.464m^3/d, average NH_4-N removal efficiency was found to 72.87% for PB and 45.16% and UB respectively. When flow rate was increased to 3.05m^3/d, the efficiency of removal decreased to 48.11% and 28.45% for PB and UB respectively.

Table 6: Average NH_4-N Removal Performance at Different Flow Rates

Flow (m^3/d)	Influent (mg/l)	Effluent (planted Bed) (mg/l)	%Removal	Effluent (unplaned) (mg/l)	%Removal
0.464	34.58	9.38	72.87	18.97	45.15
1.56	38.00	12.88	66.11	24.04	36.73
2.26	27.87	12.67	54.34	19.17	31.22
3.05	32.34	16.78	48.11	23.14	28.45

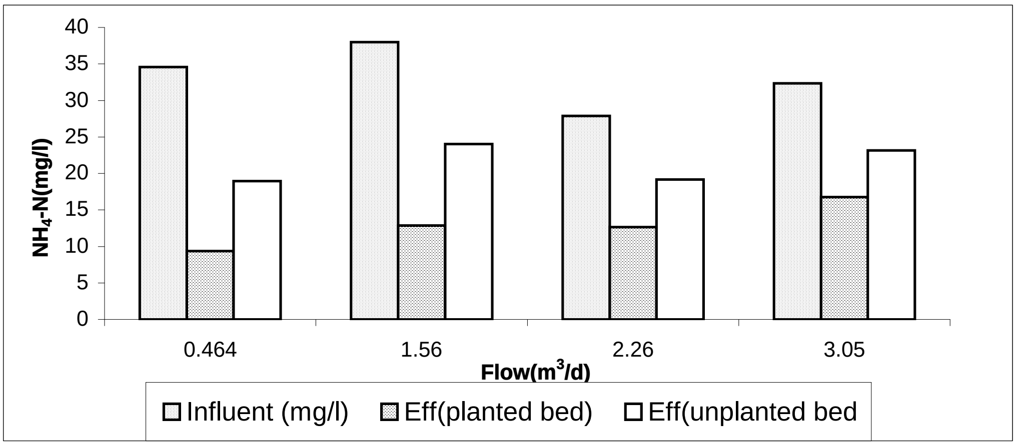

Fig.10. NH_4-N removal in vertical flow planted and unplanted reed bed

Correlation (Annex II, Table 9 and 10) and regression analysis (Fig.11) were carried out to establish the relationship between NH_4-N removal efficiency and flow rate. NH_4-N removal efficiency and flow rate were found to be negatively correlated. The regression analysis showed the following relationship:

For Planted Bed $y_{NH4\text{-}N} = -10.012x_5 + 78.714$

For Unplanted Bed $y_{NH4\text{-}N} = -6.6353x_5 + 47.556$

Where $y_{NH4\text{-}N}$ =NH_4-N removal efficiency in %, and

x_5=flow rate in m^3/d

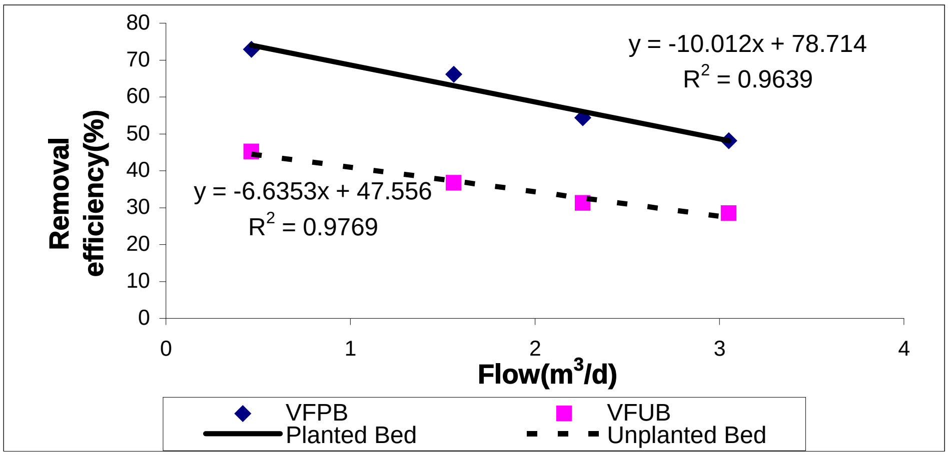

Fig.11 Regression equations established between flow rate and NH_4-N Removal Efficiency

Results showed that linear relationship existed between NH_4-N removal efficiency and flow rate for both planted reed bed and unplanted reed bed. Results also indicated that planted bed is more effective in removing NH_4-N than unplanted bed.

4.7 Removal of Total Phosphorous (TP)

The average influent and effluent TP concentration from vertical flow planted bed (PB) and unplanted bed (UB), at different flow rates during the study period are presented in Table 7 (Annex I, Table g). The average influent TP concentration found to vary from 12.7mg/l to 14.6mg/l, similarly the effluent TP concentration varied from 6.52mg/l to 9.88mg/l for PB and 7.38mg/l to 9.45mg/l for UB. The TP removed from both PB and UB, at four flow rates are shown in the Fig.12. At a flow rate of 0.464m^3/d, average TP removal efficiency was found to 55.46% for PB and 46.11% for UB. When flow rate was increased to 3.05m^3/d, efficiency decreased to 24.78% for PB and 22.91% for UB.

Table 7: Average TP Removal Performance at Different Flow Rates

Flow (m^3/d)	Influent (mg/l)	Effluent (planted Bed) (mg/l)	%Removal	Effluent (unplanted Bed) (mg/l)	%Removal
0.464	13.7	6.52	52.46	7.38	46.11
1.56	14.6	7.5	48.52	8.6	41.08
2.26	12.75	8.93	30.06	9.45	26.01
3.05	13.14	9.88	24.78	10.14	22.91

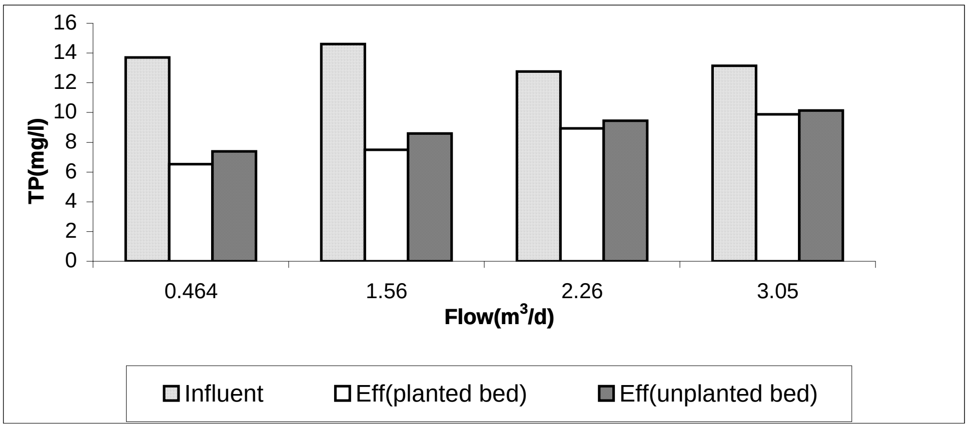

Fig.12. TP removal in vertical flow planted and unplanted reed bed

Regression analysis (Fig.13) as well as correlation analysis (Annex II, Table 11 and 12) was carried out to establish relationship between TP removal efficiency and flow rate. A negative correlation found to exist between flow rates and TP removal efficiency. The regression analysis showed the following relationship:

For Planted Bed $y_{TP} = -11.669x_6 + 60.352$

For Unplanted Bed $y_{TP} = -9.8057x_6 + 52.01$

Where y_{TP}=TP removal efficiency in %, and

x_6=flow rate in m^3/d

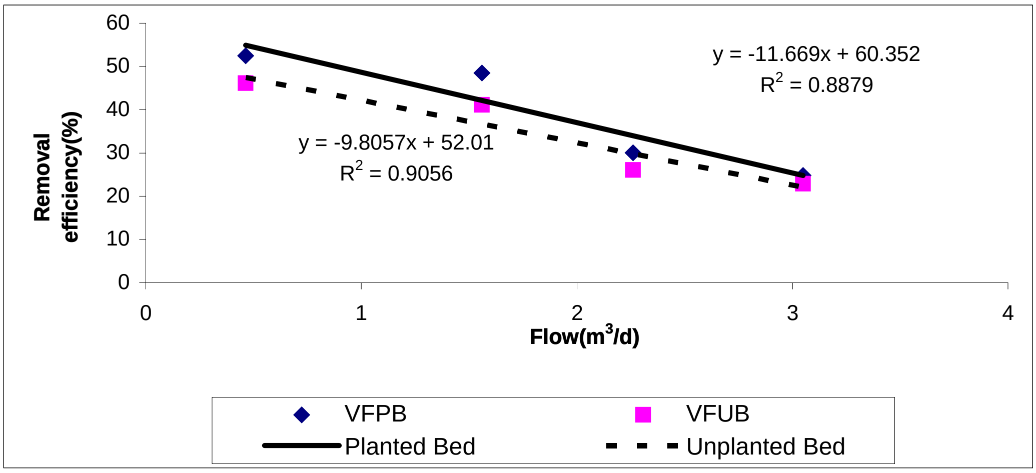

Fig.13. Regression equations established between flow rate and TP Removal efficiency

Results showed that linear relationship existed between TP removal efficiency and flow rate for both planted reed bed and unplanted reed bed. Results also indicated that planted bed is slightly more effective in removing TP than unplanted bed.

4.8 Dissolved Oxygen (DO)

Average Dissolved Oxygen (DO) concentrations recorded during the study period in the treatment beds are presented in Table 8 (Annex I, Table h). Influent DO concentration ranged from 0.05mg/l to 0.32mg/l. The average effluent DO value in the vertical flow planted bed (PB) was 2.42mg/l at flow rate 0.464m^3/d, whereas for unplanted bed (UB), DO value was 1.98mg/l at the same flow rate. The DO concentrations in both PB and UB, at four flow rates are shown in the Fig.14.

Table 8: DO data sheet of treatment beds during the study period

Flow (m^3/d)	Influent DO (mg/l)	Vertical flow bed DO (mg/l)	
		Effluent (Planted)	Effluent (Unplanted)
0.464	0.27	2.42	1.98
1.56	0.19	1.89	1.46
2.26	0.25	1.67	1.35
3.05	0.15	1.38	1.09

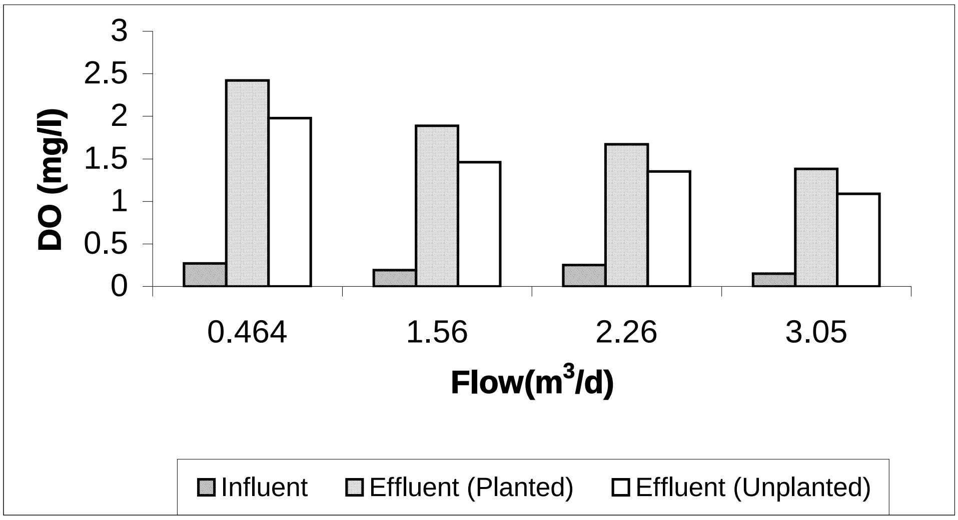

Fig.14. DO concentration in vertical flow planted and unplanted reed bed

4.9 Removal of *Fecal coliform* (FC)

The influent and effluent *Fecal coliform* (FC) concentrations in vertical flow planted bed (PB) and unplanted bed (UB), at different flow rates during the study period are presented in Table 10. The influent fecal coliforms found are $5*10^5$ MPN/100ml and $2.4*10^6$ MPN/100ml in flow rates $0.464m^3/d$ and $2.26m^3/d$ respectively. The removal efficiency of Planted bed was higher (97.2%) than unplanted bed (74%) in $0.464m^3/d$ flow rate. We cannot record FC data at flow rate 1.56 m^3/d and 3.05 m^3/d due to some laboratory failure.

Table 9: FC Removal efficiency in Different Flow Rates

Flow m^3/d	Influent MPN/100ml	Vertical flow bed MPN/100ml		Removal Efficiency(%) (Planted)	Removal Efficiency(%) Unplanted
		Effluent (Planted)	Effluent Unplanted		
0.464	$5*10^5$	$1.4*10^4$	$1.3*10^5$	97.2	74.0
2.26	$2.4*10^6$	$1.2*10^5$	$8*10^5$	95.0	66.67

4.10 Biomass of Reeds

At the time of plantation 9 rhizomes/m^2 of the reed were planted in the bed. At the time of harvesting, the density of the reeds was found 50 plants/m^2. The average biomass percentage of reeds was found to be 57.07%.

Table10: Biomass (%) of reeds in Vertical Flow Constructed Wetland

Quadrat	Q_1	Q_2	Q_3	Q_4	Q_5	Q_6	Q_7	Q_8	Q_9	Q_{10}
Fresh wt. (gm)	628.0	509.1	569.8	601.9	772.9	1057.1	725.6	878.9	644.3	637.0
Dry wt. (gm)	401.0	298.0	307.2	344.6	529.8	637.5	356.0	495.7	305.1	351.7
Biomass (%)	63.9	58.6	53.9	57.3	68.6	60.3	49.1	56.4	47.4	55.2

CHAPTER-V
DISCUSSION

Organic matters in the wastewater are characterized by Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) concentration. The organic matter removal in Constructed Wetland (CW) depends on the influent characteristic of wastewater, quantity of wastewater supplied and retention time of wastewater.

During this study period, organic matters (BOD/COD) removal efficiency was higher in planted bed than unplanted reed bed. Higher removal efficiency could be explained by the higher oxygen concentration in the planted reed bed. The organic matter removal is mainly through physical and biological process within the CW. Physical removal occurs rapidly through settling and entrapment of particulate matter in the void spaces of the sand-gravel media. Soluble organic matter is removed by the microbial growth on the media surfaces which accounts same for both planted and unplanted bed feeding with same influent organic matter. But some organic matter is attached to the plant root and rhizomes in the planted bed. The oxygen released from the roots and rhizomes of reeds oxidizes the organic matter attached to it, which result in higher removal percentage of organic matter in the planted bed. Tanner *et al.,* (1999) also emphasized on the plant root zone oxygen release in enhancing microbial oxidation of COD in gravel bed CW.

On the other hand, removal of organic matter (BOD/COD) is influenced by the flow rates of the wastewater feeding the two treatment beds. We observed higher removal of organic matter (BOD_5 95.8%, COD 94.1%) in lowest flow rate ($0.464 m^3/d$) in planted bed. This could be due to Hydraulic Retention Time (HRT), which is the ratio between flow rate and surface area of the treatment beds. As flow rate decreases, retention time of wastewater increases within the two treatment beds, which helps in longer physical and biological removal processes within the system, thus increasing the removal efficiency. Further low flow rates increase contact time of wastewater within the system components (media, vegetation), thus increasing the oxidation of organic matter in the root zone of the planted bed, thus reducing higher concentration of organic matter. Similar results were observed by Marques *et al.,* (2001), who reported low Hydraulic Loading Rate (HRT= flow rate divided by surface area) has main effect in increasing performance of vertical flow CW. They also reported planted reed bed is more efficient in removing organic matter than unplanted bed. It shows that reeds have better performance than blank sand-gravel bed. Kantawanichkul *et al.,* (1999) also observed 10% decrease in COD removal efficiency when hydraulic load was doubled in vertical flow wetland. He reported that longer HRT enhances biodegradation and physical removal mechanism of organic matter in CW.

Through out the study, I found a very high removal of total suspended solid (TSS) in the two treatment beds. But higher removal was observed in planted reed bed (95.6%) than unplanted bed (88.6%). This difference shows that reeds have little influence in removing total suspended solid. The difference in removal efficiency could be due to plant root zone resistance upon the wastewater flow which increases the retention time of wastewater in the planted bed, thus increasing the time for removal processes like gravity sedimentation and filtration. Further reed plants also extend some resistance to wastewater flowing through the bed. Similar results were obtained by Tanner (2001) who observed small difference in TSS removal efficiency in planted and unplanted reed bed and describes settling and retention time as the primary process undergoing removal of TSS.

Removal efficiency of TSS was also influenced by flow rate as in the case of BOD and COD. We found highest TSS removal (95.6%) in lowest flow rate ($0.464m^3/d$). I found negative correlation between flow rate and TSS removal. This might be because when the flow rates are increased, the beds get little time for the solids in the wastewater to be settled by sedimentation and filtration, which are the main processes involved in removing TSS in CW.

Short retention time due to high flow rate is insufficient for settling small particles. Similar explanation has been given by Marques *et al.*, (2001), during their study, they found TSS removal efficiency decreases from 86.1% to 46.1%, when HLR were increased.

Total Kjeldahl Nitrogen (TKN) and Ammonia Nitrogen (NH_4-N), both of the removal efficiencies were affected by wetland vegetation (*Phragmitis karka*) and flow rate. For these variables an increase in flow rates affected both the planted and unplanted in the same way that is decreasing the performance. The influent ammonia concentration (average 27.8mg/l to 38mg/l) might have been partly oxidized to nitrate, partly absorbed by the plants and partly reduced to nitrogen gas in the denitrification process. Ceballos *et al.,* (2001) has also explained the similar process for reduced NH_4-N in the effluent of CW.

Removal efficiency was higher in planted than unplanted bed, which might be due to release of oxygen by plant root zone and is improved the nitrification process in the planted reed bed. Similar results were also reported by Marques *et al.,* (2001) who reported TKN and NH_4-N removal was more efficient in planted (*Typha sobulata*) than unplanted sand bed. They explained possibility of root zone oxygen release in stimulating nitrification with further denitrification in anaerobic sites for most of the TKN removal in planted wetlands. High removal of nitrogen in planted reed bed than unplanted gravel bed might be because of higher density and activity of nitrifying bacteria in the biofilm associated with reed plant's roots and rhizomes than gravel media. Similar explanation has been given by Williams *et al.,* (1994) for the high removal of nitrogen in the planted bed.

Besides, TKN and NH_4-N removal efficiencies decrease with increased flow rates in both treatment beds. This decrease with increased flow rate can be explained by short retention time of influent wastewater. Short retention time does not allow sufficient contact of wastewater in the treatment beds, for good nitrification, thus decreasing nitrification process. Similar explanation has been given by Marques *et al.,* (2001) and reported insufficient oxygenation of wastewater in high HLR, which is the main reason for decreased removal efficiencies of nitrogen. Similar explanation has also given by Kantawanichkul *et al.,* (1999), he observed removal efficiency of TKN decreased from 88% to 55% when HLR was doubled. Vertical flow system secures a good contact between the wastewater and bed medium, and the intermittent loading created alternating wet and dry periods, which increases nitrification in the treatment beds. Similarly, increased nitrification also reported by Gervin and Brix (2001).

Total phosphorous removal efficiency for both treatment beds are low as compared to BOD and COD removal efficiencies. It might be because reeds can uptake little phosphorous for their metabolism or the adsorption capacity of gravel is low in case of phosphorous. Debusk *et al.,* (1990) in Florida observed similar low phosphorous removal in CW. Another reason for lower TP (Total Phosphorus) removal efficiency might be due to the anaerobic condition causing denitrification, which is unfavorable for adsorption and precipitation of phosphorous in CW. Gopal (1999) has also reported similar type of mechanism for low phosphorous removal in CW.

Highest total phosphorous (TP) removal efficiency (52.5%) was observed in planted reed bed. This can be explained by three removal processes in the CW. They are sedimentation of phosphorous deep in the bed due to media characteristics, some phosphorous is absorbed by the reeds and some phosphorous is adsorbed by the media. Muetia (2001) has given similar explanation for phosphorous removal in CW.

Gervin and Brix (2001) found 90% TP removal in vertical flow constructed wetland and explained that use of crushed marvel, which has a higher binding capacity, as media is the main reason behind the higher removal of TP. Luederitz *et al.,* (2001) reported lower TP removal in Einsdorf while higher TP removal in Wolfsberg vertical flow CW. They explained that a part of the Phosphorus is bound to Calcium (Ca) rich sand that was used in the construction of Wolfsberg CW, while no such efforts were made in Einsdorf CW.

Further phosphorous removal efficiency shows negative correlation with flow rates in both treatment beds. TP removal efficiency decreases from 52.5% to 24.8% in planted bed and 46.1% to 22.9% in unplanted bed when flow rate increases from 0.464m^3/d to 3.05 m^3/d. This decrease is due to short retention time of wastewater in the treatment beds and also due to high flow rate. The longer the retention time, the more time will be available for physical and biological removal processes. Marques *et al.,* (2001), observed similar decrease TP removal in high HLR, decrease occur more in unplanted sand bed than in planted (*Typha sobulata*) bed. Ceballos *et al.,* (2001) also found higher removal of TP in longer Hydraulic Retention Time (HRT), but the overall removal efficiency was low in CW planted with *Typha spp.*

Influent DO concentration indicates anoxic condition in the wastewater, which might be due to oxygen consumption by microbes for their growth in the wastewater. We observed higher effluent DO values in planted bed than unplanted bed in all flow rates which indicates oxic condition in the effluent. This difference could be explained by atmospheric reaeration, diffusion, convection and plant root zone oxygen release. Despite these processes DO concentration in the effluent is low, which might be because of respiration by microorganism, organic matter degradation and nitrification. However, lower DO concentration is important in CW, which enhances denitrification process, thus removing organic nitrogen. Wastewater reaeration when flowing vertically in the system and the plant releasing oxygen through their roots, which might be the main reason behind the increased concentration of effluent DO in the planted bed. Since DO is negligible in wastewater, influent DO profile shows minute fluctuation with organic load. But in case of effluent characteristics, DO fluctuated more.

Fecal coliform removal was higher in planted than unplanted bed, which shows the role of reeds in removing fecal bacteria from the polluted wastewater in the CW. Antibiotics released by the reed roots and predation by the protozoa might be the probable reason behind the better removal of *Fecal coliform* in planted bed. High anaerobic condition in the unplanted bed, due to absence of root zone oxygen release, might prolong *Fecal coliform* survival in the bed. Arias *et al.,* (2003) showed that vertical flow CW system has the capacity to remove indicator bacteria from the wastewater. Kantawanichkul *et al.,* (1999) reported 99% of FC removal efficiency in CW. Further, flow rate of wastewater in the bed has influenced the fecal removal mechanism. As flow rate increased *Fecal coliform* removal efficiency in the two treatment beds was decreased. Marques *et al.,* (2001) also reported a decrease in FC removal efficiency from 100% to 89% when the HLR was doubled.

Biomass production shows that the reeds have high productivity in the Constructed Wetland, which could be very important economically. They could be used to make fertilizer, stems could be used for making small decorative furniture etc.

CHAPTER-VI
CONCLUSION

Constructed wetlands are increasingly used to treat domestic sewage, industrial wastewater and agricultural runoff in recent years. The wetland treatment process is gaining international interest and application due to its low maintenance and operational cost and high removal capacity. The present study was conducted in vertical flow constructed wetland in four different flow rates and removal efficiencies of various parameters were recorded. Through out the study period, the influent wastewater characteristic reflected a strong concentration. However this kind of influent wastewater is common in urban areas like Kathmandu due to overpopulation and industrial units. The results obtained in this study indicates that vertical flow constructed wetland system is capable of treating sewage wastewater. Both the treatment beds could treat the sewage wastewater effectively, however the planted bed was found to be more suitable for removing organic matter, suspended solids and nitrogen compounds from wastewater. Further, removal efficiencies of all parameters were found affected by flow rates of the wastewater flowing through the system. Removal was obtained with high efficiency level at lower flow rates. Hydraulic retention time was found to be very important for removal processes in constructed wetland. The effluent quality meets the requirement recommended by Nepal Bureau of Standard and Measurement (NBSM) for industrial waste water for $BOD_{5,}$ COD, TSS, and NH_4. *Phragmitis karka* has important role in treatment, and its biomass value indicates that it could be of economical importance. It can be used as raw materials for producing fertilizer, mulch, and handicrafts.

CHAPTER-VII
RECOMMENDATIONS

Following recommendation were put forwarded

- The system has limited capacity for removal of Phosphorus, as presently conceived, so supplemental treatment may be necessary to enhance efficiency.
- Use of constructed wetland for wastewater treatment in locations with sufficient land base available must be encouraged to reduce pollutants input to receiving water.
- Public awareness programme on significance of Constructed Wetland using reeds or any other plant species must be encouraged at the community level.
- Further research in the field is required to establish Constructed Wetland system as a low cost treatment system in Nepal.

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ANNEX I

Table a: Temperature and pH readings during study period

Dates	Temperature (^oC)	pH readings		
		Influent	Effluent (Planted bed)	Effluent (Unplanted bed)
02/05/2006	26.5	7.5	7.1	7.3
14/05/2006	24	7.5	7.3	7.5
21/05/2006	25.5	7.9	7.4	7.5
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	7.2	7.3
18/06/2006	23	7.6	7.3	7.5
29/06/2006	24.5	7.5	7.3	7.3
09/07/2006	27	6.5	6.3	6.4
17/07/2006	27	6.5	6.3	6.4
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	7.0	6.3	6.9
20/08/2006	26.5	6.7	6.4	6.5
27/08/2006	24.5	6.5	6.3	6.5
03/09/2006	25.5	6.7	6.3	6.6
10/09/2006	26.5	6.8	6.1	6.4
17/09/2006	26	6.8	6.2	6.7
10/10/2006	27.5	7.0	6.5	6.9
17/10/2006	26.5	6.7	6.4	6.7

Table b: BOD Data Sheet of Treatment Beds during the Study Period

Date	Flow (m^3/d)	Influent (mg/l)	VFPB (mg/l)	%Removal	VFUB (mg/l)	%Removal
5/2/2006	2.26	220.69	41.93	81	64.66	70.7
5/14/2006	2.26	125.52	22.84	81.8	42.04	66.5
5/21/2006	2.26	235.04	38.31	83.7	74.74	68.2
5/28/2006	2.26	267.15	42.21	84.2	76.13	71.5
6/4/2006	2.26	143.34	28.23	80.3	43.14	69.9
6/11/2006	2.26	136.07	25.17	81.5	39.18	71.2
Average	2.26	187.96	33.11	82.08	56.65	69.67
6/18/2006	1.56	103.7	8.81	91.5	19.49	81.2
6/29/2006	1.56	176.01	19.01	89.2	48.05	72.7
7/9/2006	1.56	120.37	8.91	92.6	29.73	75.3
7/17/2006	1.56	117.0	10.64	90.9	20.59	82.4
7/24/2006	1.56	127.39	12.48	90.2	28.41	77.7
Average	1.56	128.89	11.97	90.88	29.25	77.86
7/31/2006	3.05	105.69	19.23	81.8	32.34	69.4
8/6/2006	3.05	106.31	29.44	72.3	40.07	62.3
8/13/2006	3.05	98.05	22.15	77.4	38.72	60.5
8/20/2006	3.05	103.07	29.27	71.6	36.69	64.4
8/27/2006	3.05	109.0	21.36	80.4	35.86	67.1
Average	3.05	104.42	24.29	76.7	36.74	64.74
9/3/2006	0.464	116.79	3.85	96.7	15.53	86.7
9/10/2006	0.464	147.79	8.86	94	17.43	88.2
9/17/2006	0.464	134.31	2.82	97.9	19.74	85.3
10/10/2006	0.464	111.01	5.21	95.3	15.65	85.9
10/17/2006	0.464	103.59	4.24	95.9	20.51	80.2
10/29/2006	0.464	99.75	5.28	94.7	18.65	81.3
Average	0.464	118.87	5.04	95.75	17.92	84.6

Table c: COD Data Sheet of Treatment Beds during the Study Period

Date	Flow (m^3/d)	Inlet (mg/l)	VFPB (mg/l)	%Removal	VFUB (mg/l)	%Removal
5/2/2006	2.26	450	111.15	75.3	122.85	72.7
5/14/2006	2.26	395	74.26	81.2	103.09	73.9
5/21/2006	2.26	421	85.46	79.7	102.72	75.6
5/28/2006	2.26	435	86.13	80.2	102.66	76.4
6/4/2006	2.26	350	73.85	78.9	93.80	73.2
6/11/2006	2.26	312	57.09	81.7	75.50	75.8
Average		393.83	81.32	79.5	100.11	74.6
6/18/2006	1.56	295	38.64	86.9	48.08	83.7
6/29/2006	1.56	335	38.19	88.6	52.59	84.3
7/9/2006	1.56	320	40.0	87.5	54.72	82.9
7/17/2006	1.56	182	19.47	89.3	27.11	85.1
7/24/2006	1.56	140	19.32	86.2	23.38	83.3
Average	1.56	254.4	31.12	87.7	41.17	83.86
7/31/2006	3.05	210	47.88	77.2	65.31	68.9
8/6/2006	3.05	160	37.12	76.8	48.96	69.4
8/13/2006	3.05	240	50.88	78.8	69.12	71.2
8/20/2006	3.05	330	66.33	79.9	91.41	72.3
8/27/2006	3.05	295	71.39	75.8	84.37	71.4
Average	3.05	247	54.72	77.7	71.83	70.64
9/3/2006	0.464	201	14.87	92.6	37.989	81.1
9/10/2006	0.464	195	11.11	94.3	34.71	82.2
9/17/2006	0.464	230	10.12	95.6	29.67	87.1
10/10/2006	0.464	200	16.0	92	23.4	88.3
10/17/2006	0.464	154	5.85	96.2	29.722	80.7
10/29/2006	0.464	137	8.63	93.7	21.372	84.4
Average	0.464	186.17	11.09	94.07	29.47	83.97

Table d: TSS Data Sheet of Treatment Beds during the Study Period

Date	Flow (m^3/d)	Inlet (mg/l)	VFPB (mg/l)	%Removal	VFUB (mg/l)	%removal
5/2/2006	2.26	180	32.94	81.7	39.06	78.3
5/14/2006	2.26	107	20.01	81.3	23.96	77.6
5/21/2006	2.26	174	30.97	82.2	41.06	76.4
5/28/2006	2.26	157	31.55	79.9	37.21	76.3
6/4/2006	2.26	168	34.10	79.7	43.34	74.2
6/11/2006	2.26	126	24.94	80.2	30.74	75.6
Average	2.26	152	29.08	80.83	35.89	76.4
6/18/2006	1.56	150	22.95	84.7	28.05	81.3
6/29/2006	1.56	130	21.06	83.8	24.96	80.8
7/9/2006	1.56	157	20.09	87.2	31.87	79.7
7/17/2006	1.56	164	23.61	85.6	34.27	79.1
7/24/2006	1.56	139	19.59	85.9	29.32	78.9
Average	1.56	148	21.46	85.44	29.69	79.96
7/31/2006	3.05	155	36.11	76.7	38.90	74.9
8/6/2006	3.05	179	46.01	74.3	54.95	69.3
8/13/2006	3.05	164	49.03	70.1	58.71	64.2
8/20/2006	3.05	161	46.36	71.2	55.86	65.3
8/27/2006	3.05	172	49.02	71.5	59.85	65.2
Average	3.05	166.2	45.30	72.76	53.65	67.78
9/3/2006	0.464	165	7.26	95.6	17.65	89.3
9/10/2006	0.464	121	5.80	95.2	14.27	88.2
9/17/2006	0.464	142	4.68	96.7	14.34	89.9
10/10/2006	0.464	152	8.66	94.3	18.69	87.7
10/17/2006	0.464	147	7.79	94.7	17.34	88.2
10/29/2006	0.464	132	3.96	97.0	15.31	88.4
Average	0.464	143.17	6.36	95.58	16.27	88.67

Table e: TKN Data Sheet of Treatment Beds during the Study Period

Date	Flow (m^3/d)	Inlet (mg/l)	VFPB (mg/l)	%Removal	VFUB (mg/l)	%Removal
5/2/2006	2.26	34.7	19.6	43.51	27.3	21.32
5/14/2006	2.26	37.6	18.2	51.59	25.4	32.44
5/21/2006	2.26	35.9	18.2	49.30	26.2	27.01
5/28/2006	2.26	41.4	21.1	49.03	29.6	28.50
6/4/2006	2.26	39	22.5	42.30	27.5	29.48
6/11/2006	2.26	37.72	21.2	43.79	29.1	22.85
Average	2.26	37.72	20.13	46.62	27.51	27.05
6/18/2006	1.56	58.3	24.1	58.66	39.4	32.41
6/29/2006	1.56	51.5	23.7	53.98	34.5	33.01
7/9/2006	1.56	53	24.3	54.15	38.9	26.60
7/17/2006	1.56	49.4	24.6	50.20	34.2	30.76
7/24/2006	1.56	49.7	23.4	52.91	33.3	32.99
Average	1.56	52.38	24.02	54.14	36.06	31.15
7/31/2006	3.05	39.5	23.9	39.49	29.9	24.30
8/6/2006	3.05	41.3	26.3	36.31	32.1	22.27
8/13/2006	3.05	44.5	25.3	43.14	31.3	29.66
8/20/2006	3.05	37.2	22.6	39.24	28.5	23.38
8/27/2006	3.05	39.4	23.1	41.37	29.3	25.63
Average	3.05	40.38	24.24	39.97	30.22	25.16
9/3/2006	0.464	47.8	18.1	62.13	30.1	37.02
9/10/2006	0.464	44.6	16.7	62.55	29.1	34.75
9/17/2006	0.464	43.6	16.2	62.84	27.2	37.61
10/10/2006	0.464	39.7	16.5	58.43	25.6	35.51
10/17/2006	0.464	40.8	16.3	60.04	25.1	38.48

Table f: NH_4-N data sheet of treatment beds during the study period

Date	Flow (m^3/d)	Inlet (mg/l)	VFPB (mg/l)	%Removal	VFUB (mg/l)	%Removal
5/2/2006	2.26	26.7	12.1	54.68	19.4	27.34
5/14/2006	2.26	27	14.3	47.03	18.2	32.59
5/21/2006	2.26	25.9	12.4	52.12	19.3	25.48
5/28/2006	2.26	32.3	13.3	58.82	20.1	37.77
6/4/2006	2.26	29.7	12.5	57.91	18.9	36.36
6/11/2006	2.26	25.6	11.4	55.46	19.1	25.39
Average	2.26	27.87	12.67	54.34	19.17	31.22
6/18/2006	1.56	42.4	15.2	64.15	25.9	38.91
6/29/2006	1.56	38.3	12.1	68.40	24.5	36.03
7/9/2006	1.56	39.7	13.3	66.49	25.1	36.77
7/17/2006	1.56	34.6	12.3	64.45	23.4	32.36
7/24/2006	1.56	35	11.5	67.14	21.3	39.14
Average	1.56	38	12.88	66.10	24.04	36.73
7/31/2006	3.05	31.2	17.9	42.62	21.2	32.05
8/6/2006	3.05	33.7	16.5	51.03	24.4	27.59
8/13/2006	3.05	38.6	16.8	56.47	26.7	30.82
8/20/2006	3.05	28.7	17.1	40.41	20.9	27.17
8/27/2006	3.05	29.5	15.6	47.11	22.5	23.72
Average	3.05	32.34	16.78	48.11	23.14	28.44
9/3/2006	0.464	38.7	10.2	73.64	21.5	44.44
9/10/2006	0.464	36.4	8.2	77.47	19.7	45.87
9/17/2006	0.464	36.7	9.7	73.56	20.5	44.14
10/10/2006	0.464	30.5	10.1	66.88	16.9	44.59
10/17/2006	0.464	32.2	9.9	69.25	17.1	46.89
10/29/2006	0.464	33	8.2	75.15	18.1	45.15
Average	0.464	34.58	9.38	72.86	18.97	45.15

Table g: TP Data Sheet of Treatment Beds during the Study Period

Date	Flow (m^3/d)	Inlet (mg/l)	VFPB (mg/l)	%Removal	VFUB (mg/l)	%Removal
5/2/2006	2.26	12.22	6.1	50.08	7.3	40.26
5/14/2006	2.26	12.9	7.3	43.41	7.8	39.53
5/21/2006	2.26	13	6.9	46.92	8.2	36.92
5/28/2006	2.26	12.5	12.7	-1.6	11.2	10.4
6/4/2006	2.26	13.1	13.9	-6.10	13.5	-3.05
6/11/2006	2.26	12.8	6.7	47.65	8.7	32.03
Average	2.26	12.75	8.93	30.06	9.45	26.01
6/18/2006	1.56	15.2	6.9	54.60	9.2	39.47
6/29/2006	1.56	14.9	7.3	51.01	8.3	44.29
7/9/2006	1.56	14.3	7.5	47.55	9.1	36.33
7/17/2006	1.56	14.1	8.1	42.55	8.4	40.42
7/24/2006	1.56	14.5	7.7	46.89	8	44.82
Average	1.56	14.6	7.5	48.52	8.6	41.07
7/31/2006	3.05	13.2	7.1	46.21	7.9	40.15
8/6/2006	3.05	13.5	14.3	-5.92	14.5	-7.40
8/13/2006	3.05	12.8	14.8	-15.62	12.4	3.12
8/20/2006	3.05	13.3	6.7	49.62	8.4	36.84
8/27/2006	3.05	12.9	6.5	49.61	7.5	41.86
Average	3.05	13.14	9.88	24.77	10.14	22.91
9/3/2006	0.464	13.7	6.7	51.09	7.3	46.71
9/10/2006	0.464	14.1	7.1	49.64	7.5	46.80
9/17/2006	0.464	13.9	6.9	50.35	7.8	43.88
10/10/2006	0.464	13.3	5.8	56.39	8.1	39.09
10/17/2006	0.464	13.5	6.1	54.81	6.2	54.07
Average	0.464	13.7	6.52	52.46	7.38	46.11

Table h: DO data sheet of treatment beds during the study period

Dates	Flow (m^3/d)	Influent DO (mg/l)	Vertical flow bed DO (mg/l)	
			Effluent (Planted)	Effluent (Unplanted)
5/2/2006	2.26	0.24	1.24	1.07
5/14/2006		0.27	1.46	1.13
5/21/2006		0.23	2.31	1.86
5/28/2006		0.26	1.96	1.02
6/4/2006		0.28	2.03	1.12
Average		0.25	1.67	1.35
6/18/2006	1.56	0.12	2.0	1.47
6/29/2006		0.13	2.0	1.49
7/9/2006		0.23	1.73	1.33
7/17/2006		0.26	1.82	1.54
7/24/2006		0.18	1.98	1.41
Average		0.19	1.89	1.46
7/31/2006	3.05	0.18	1.45	1.2
8/6/2006		0.05	1.35	0.99
8/13/2006		0.11	1.3	1.05
8/20/2006		0.17	1.56	1.3
8/27/2006		0.24	1.24	0.92
Average		0.15	1.38	1.09
9/3/2006	0.464	0.22	2.16	1.81
9/10/2006		0.32	2.43	2.01
9/17/2006		0.26	2.5	1.98
10/10/2006		0.29	2.5	2.0
10/17/2006		0.26	2.5	2.11
Average		0.27	2.42	1.98

ANNEX II

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

FLOW	BOD removal	x	y	x2	y2	xy	r
2.26	82.08	0.43	-4.25	0.18	18.04	-1.81	0.98
1.56	90.88	-0.27	4.55	0.08	20.73	-1.25	
3.05	76.6	1.22	-9.73	1.48	94.62	-11.83	
0.464	95.75	-1.37	9.42	1.88	88.78	-12.90	

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

FLOW	BOD removal	x	y	x2	y2	xy	r
2.26	69.67	0.4265	4.7525	0.181902	22.58626	2.026941	0.87
1.56	60	-0.2735	-4.9175	0.074802	24.18181	1.344936	
3.05	45.4	1.2165	-19.5175	1.479872	380.9328	-23.743	
0.464	84.6	-1.3695	19.6825	1.87553	387.4008	-26.9552	

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

FLOW	COD removal%	x	y	x2	y2	xy	r
2.26	79.5	0.4265	-5.2425	0.181902	27.48381	-2.23593	0.97
1.56	87.7	-0.2735	2.9575	0.074802	8.746806	-0.80888	
3.05	77.7	1.2165	-7.0425	1.479872	49.59681	-8.5672	
0.464	94.07	-1.3695	9.3275	1.87553	87.00226	-12.774	

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

FLOW	COD removal%	x	y	x2	y2	xy	r
2.26	74.6	0.4265	-3.665	0.181902	13.43222	-1.56312	0.91
1.56	83.86	-0.2735	5.595	0.074802	31.30403	-1.53023	
3.05	70.64	1.2165	-7.625	1.479872	58.14062	-9.27581	
0.464	83.96	-1.3695	5.695	1.87553	32.43303	-7.7993	

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

FLOW	TSS removal%	x	y	x2	y2	xy	r
2.26	80.83	0.4265	-2.8225	0.181902	7.966506	-1.2038	0.99
1.56	85.44	-0.2735	1.7875	0.074802	3.195156	-0.48888	
3.05	72.76	1.2165	-10.8925	1.479872	118.6466	-13.2507	
0.464	95.58	-1.3695	11.9275	1.87553	142.2653	-16.3347	

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

FLOW	**TSS removal%**	**x**	**y**	**x2**	**y2**	**xy**	**r**
2.26	76.4	0.4265	-1.79	0.181902	3.2041	-0.76343	
1.56	79.96	-0.2735	1.77	0.074802	3.1329	-0.48409	
3.05	67.78	1.2165	-10.41	1.479872	108.3681	-12.6638	0.99
0.464	88.62	-1.3695	10.43	1.87553	108.7849	-14.2839	

Table 7: Correlation Analysis of flow rate and % removal of TKN in Planted Bed

FLOW	**TKN removal%**	**x**	**y**	**x2**	**y2**	**xy**	**r**
2.26	46.62	0.4265	-3.8525	0.181902	14.84176	-1.64309	0.99
1.56	54.14	-0.2735	3.6675	0.074802	13.45056	-1.00306	
3.05	39.97	1.2165	-10.5025	1.479872	110.3025	-12.7763	
0.464	61.16	-1.3695	10.6875	1.87553	114.2227	-14.6365	

Table 8: Correlation Analysis of flow rate and % removal of TKN in Unplanted Bed

FLOW	**TKN removal%**	**x**	**y**	**x2**	**y2**	**xy**	**r**
2.26	27.05	0.4265	-3.0475	0.181902	9.287256	-1.29976	0.98
1.56	31.16	-0.2735	1.0625	0.074802	1.128906	-0.29059	
3.05	25.16	1.2165	-4.9375	1.479872	24.37891	-6.00647	
0.464	37.02	-1.3695	6.9225	1.87553	47.92101	-9.48036	

Table 9: Correlation Analysis of flow rate and % removal of NH4-N in Planted Bed

FLOW	**NH_4 -N removal%**	**x**	**y**	**x2**	**y2**	**xy**	**r**
2.26	54.34	0.4265	-6.02	0.181902	36.2404	-2.56753	0.98
1.56	66.11	-0.2735	5.75	0.074802	33.0625	-1.57263	
3.05	48.11	1.2165	-12.25	1.479872	150.0625	-14.9021	
0.464	72.88	-1.3695	12.52	1.87553	156.7504	-17.1461	

Table 10: Correlation Analysis of flow rate and % removal of NH4-N in Unplanted Bed

FLOW	**NH_4-N removal%**	**x**	**y**	**x2**	**y2**	**xy**	**r**
2.26	32.22	0.4265	-3.4225	0.181902	11.71351	-1.4597	0.99
1.56	36.74	-0.2735	1.0975	0.074802	1.204506	-0.30017	
3.05	28.45	1.2165	-7.1925	1.479872	51.73206	-8.74968	
0.464	45.16	-1.3695	9.5175	1.87553	90.58281	-13.0342	

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

FLOW	TP removal%	x	y	x2	y2	xy	r
2.26	30.06	0.4265	-8.8925	0.181902	79.07656	-3.79265	0.94
1.56	48.52	-0.2735	9.5675	0.074802	91.53706	-2.61671	
3.05	24.77	1.2165	-14.1825	1.479872	201.1433	-17.253	
0.464	52.46	-1.3695	13.5075	1.87553	182.4526	-18.4985	

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

FLOW	TP removal%	x	y	x2	y2	xy	r
2.26	26.02	0.4265	-8.01	0.181902	64.1601	-3.41627	0.95
1.56	41.08	-0.2735	7.05	0.074802	49.7025	-1.92818	
3.05	22.9	1.2165	-11.13	1.479872	123.8769	-13.5396	
0.464	46.12	-1.3695	12.09	1.87553	146.1681	-16.5573	

The Nepal Bureau of Standards and Measurements (NBSM) has issued a standard covering the discharge of industrial wastewater to surface waters (NS 229-2046) and is presented below in Table 13 :

Table 13: NBSM effluent criteria

Parameter	Unit	Values
BOD_5	mg/l	30-100
COD	mg/l	250
Ammonia Nitrogen, , mg/l	mg /l	50
Suspended solids	mg/l	30-200
Oil and Grease	mg/l	10

However, there are no national standard for the discharge of the effluent from the wastewater treatment plant.

ANNEX III

VF planted and unplanted beds before plantation

VF planted and unplanted beds after plantation

Outlet of VF bed

Showing Rhizomes of Reeds