A COMPARATIVE STUDY OF THE POTENTIALS OF HYDROPONIC, SOIL BASED AND HYBRID VETIVER PHYTOREMEDIATION SYSTEMS TO TREAT WASTEWATER

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for a Master of Science Degree in Agricultural Engineering of Egerton University

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DECLARATION AND RECOMMENDATION

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I, Imanya Wycliffe Lishenga, declare that this thesis is my original work and that to the best of my knowledge it has not, wholly or in part, been presented for the award of any degree or diploma in any other university known to me.

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Recommendation:

This thesis is the candidate's original work, having been prepared with our guidance and assistance. It is submitted for examination with our approval as the official university supervisors.

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DEDICATION

This thesis is dedicated to my daughter; Shelsmith Ilusa, parents; Peter and Jesca Lishenga, nephew; Allan N'ganga, niece; Sheila, and siblings; Betty, Phylis and Tony Lishenga, for their support, encouragement and inspiration, especially during the most difficult of times in the course of my studies.

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Imanya Wycliffe Lishenga.

ABSTRACT

Wastewater treatment is extremely important and mandatory in the modern world. For many developing countries, conventional wastewater treatment technologies urban centers are increasingly becoming impractical or expensive, being dependent on land availability, electrical energy and skilled personnel. They are also being seen as wasteful, since their designs are based on aspects of disposal. Phyto-remediation, which involves the use of aquatic plants to absorb pollutants from wastewater, has the potential to improve on these technologies. Vetiver grass is one of the most promising plants for use in these aspects. This particular study was aimed at comparing the performance of vetiver grass in the reduction of the levels of BOD, COD, total nitrogen (TN), total phosphorous (TP) and total suspended solids (TSS) from wastewater when the vetiver is established using three different techniques: in a soil medium (soil-based system), with roots suspended in water (hydroponic system) and finally, a hybrid of these two. It comprised of three distinct experimental units made using metal boxes of dimensions 1.0 x 0.6 x 0.4m (length x width x depth), established with 120 vetiver plants using the three techniques. The treatments, together with a control were replicated thrice. They were administered with 40 litres of post-septic tank wastewater and their pollutant reduction abilities determined over three, five and seven day contact periods. The data was analyzed by the Statistical Analysis Software (SAS 2008) at α=5%, revealing significant differences between them. For instance, over the 5-day contact time, the soil-based, the hybrid and the hydroponic systems achieved TN reduction rates of 57.1, 49.8 and 49.4% respectively against the control with 26.14%. For BOD, the systems achieved rates of 75.1, 68.4, and 65.4% against the control's 37.7%. When their abilities were evaluated over different contact times, all the three treatments including the control achieved significantly different reduction rates. For TN the soil-based system achieved the rates of 33.6, 56.1 and 67.4% compared with the control's 16.5, 25.6 and 31.1% for the 3, 5 and 7- day contact periods respectively. For BOD, these rates were 49.8, 75.5 and 80.8 against 14.9, 38.7 and 43.4% respectively. For the duration of the experiment, plant age had a significant effect on the vetiver systems' performance after the sixth week. It was concluded that wastewater treatment systems that contain vetiver grass perform best if the plants are established in a soil medium than hydroponically or by the hybrid technique, and are therefore recommended.

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LIST OF ACRONYMS AND ABBREVIATIONS

AN	Amoniacal Nitrogen
ANOVA	Analysis of Variance
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
CRD	Completely Randomized Design
CWSB	Coast Water Services Board
DO	Dissolved Oxygen
EMCA	Environmental Management and Co-ordination Act
GSADH	Government of South Australia Department of Health
H	Hydroponic Unit
HLR	Hydraulic Loading Rate
HRT	Hydraulic Retention Time
HS	Hybrid (Hydroponic and Soil-based) Unit
LSD	Least Significance Difference
MEDLI	Model for Effluent Disposal Using Land Irrigation
MoPND	Ministry of Planning and National Development
NWMPAS	National Water Master Plan Aftercare Study
NEMA	National Environment Management Authority
OLR	Organic Loading Rate
PBPS	Plant-Based Pond Systems
PPM	Parts per million
QLDNR	Queensland Department of Natural Resources
S	Soil-based Unit
SAS	Statistical Analysis System
SSF	Sub-surface Flow
ThOD	Theoretical Oxygen Demand
TKN	Total Kjeldhal Nitrogen
TN	Total Nitrogen

TOC	Total Organic Carbon
TON	Threshold Odour Number
TP	Total Phosphorus
TSS	Total Suspended Solids
TDS	Total Dissolved Solids
USEPA	United States Environmental Protection Agency
UV	Ultra-Violet
VCW	Vetiver Constructed Wetland
VS	Vetiver Systems
WSP	Wastewater Stabilization Ponds

CHAPTER ONE: INTRODUCTION

1.1 Background

Wastewater treatment is virtually compulsory in the modern world to address the twin critical problems of water scarcity and environmental degradation. This is reflected in the changing of pertinent laws of many countries, many awareness movements, creation of many international protocols and conventions and in the constant search for new environment friendly and sustainable treatment technologies. In Kenya, wastewater issues are high on the agenda of a broad spectrum of entities, from industrial managers through municipal authorities to the individual home owners. Evidence of this concern can be seen in the large number of newspaper articles in the print media, and the many workshops and seminars that have been held at local and national levels regarding the problem in different parts of the country. The National Environmental Management Authority (NEMA) is in charge of environmental regulation in Kenya and requires that water discharged into the environment must be of an acceptable quality (appendix Table A3).

The current approaches to wastewater treatment for urban areas in developing countries are increasingly being viewed as costly, unsustainable, inadequate and wasteful (Nhapi, 2004; King, 2000; Oron, 1994). In Kenya, the problem of inadequate and inefficient sewerage system is vast, extending to virtually all the major towns. Only 14% of the population living in 215 urban areas is reported to be covered by sewerage systems (NWMPAS, 2008). Mombasa city has only 30% of its population covered with the local sewer system (CWSB, 2008), while Kilifi town has no centralized sewer system. It is estimated that Mombasa town alone needs Ksh. 20 billion to handle its daily sewage output of 160,000 cubic meters (CWSB, 2008). Consequently many towns and establishments along the Kenyan coastline are actively contributing to the problem of marine pollution, hence threatening marine ecosystems and resources such as coral reefs, fisheries, among others. Worldwidely there is a wide range of wastewater treatment systems that are currently in use. These include the highly sophisticated and efficient containerized "package plant" systems, which are however expensive, power dependent and requiring expert maintenance (Nhapi, 2004; de Mowbray, 2009). To manage their wastewater, many urbanizing

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areas in Kenya mainly rely on septic tanks which have limited capacities to contain increasing sewage. This type of system is no longer sufficient and acceptable, hence tertiary treatment must be done. Since other current and traditional wastewater treatment options are considered expensive and in most cases insufficient (Nhapi, 2004; Truong and Hart, 2003), new alternatives or improvements on existing ones need to be sought.

The use of aquatic plants in the treatment of wastewater is a potential alternative for incorporation of measures that enhance efficiency and sustainability in addressing the problem. The plants have the potential to play a major role in the reduction of pollutant levels in wastewater while providing nutrient reclamation options (Nhapi, 2004; Oron, 1994; Hart *et al.,* 2003). As noted by de Mowbray (2009), both natural and constructed wetlands have been used extensively throughout the world for over 30 years and found to be a particularly appropriate technology for the developing world, producing effluents that meet required standards. Opportunities exist in the betterment of such technologies through research in the enhancement of treatment efficiencies, cost reduction and times taken to achieve the desired treatment standards. Different plants have been used in these systems including typha grass (*typha latifolia*), nile cabbage (*pistia stratiote*), papyrus (*cyperus papyrus*), duckweed (*lemna species*) vetiver grass (*vetiveria zizanioides*) among others. Of the many plant species that have been studied, vetiver grass has consistently performed exceptionally well in various studies aimed at evaluating their abilities to treat wastewater (Njau and Mlay, 2003; Liao *et al.,* 2003). In various studies, it has been revealed that vetiver plants perform better than many other plants in wastewater treatment and works well both when established hydroponically or in a soil medium as in the case of the horizontal subsurface-flow systems (Hart *et al.,* 2003, Njau and Mlay, 2003; Liao *et al.,* 2003). This research evaluated and compared the performance of vetiver grass in wastewater treatment across three distinct systems; a hydroponic system, soil-based system and a hybrid of the two. It sought to yield important preliminary information related to the abilities of vetiver plants to treat wastewater when established using the three techniques. Such information is useful in the constant search of more effective, affordable and sustainable technologies for wastewater treatment.

1.2 Statement of the problem

The current approaches to wastewater treatment in developing countries' urban centers are increasingly becoming expensive, unsustainable and insufficient. This has prompted intensive research in phytoremediation, the use of aquatic plants such as vetiver and others to treat wastewater. Many studies regarding the performance of vetiver plants in the treatment of wastewater have been carried out, with the plants being independently established either hydroponically or in a soil medium, and usually in different settings. Attempts have been made to compare the outputs from such studies. But more conclusive comparative inferences regarding the potentials of soil-based versus hydroponic vetiver systems can only be drawn if the two systems were to be tested concurrently under similar settings. Information from such researches, if any is available, is quite scanty.

1.3 Objectives of the Study

The broad objective of this study was to evaluate and compare the potentials of the hydroponic, the soil-based and the hybrid vetiver systems in the treatment of wastewater.

The specific objectives were;

i. To determine the effects of the hydroponic, the soil-based and the hybrid vetiver systems on the levels of Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Nitrogen (TN), Total Phosphorus (TP) and Total Suspended Solids (TSS) in domestic wastewater.

ii. To establish the effects of contact period on the performance of the vetiver systems in the reduction of the levels of these pollutants in domestic wastewater.

iii. To determine the effects of the age of the vetiver plants on the percentage reduction in the levels of these pollutants in domestic wastewater.

1.4 Hypotheses

This research was guided by the following null hypotheses;

a. There are no significant differences between the effects of the hydroponic, the soil-based and the hybrid vetiver wastewater treatment systems on the levels of BOD, COD, TN, TP, and TSS in domestic wastewater.

b. There are no significant differences between the effects of contact period on the levels of these parameters in domestic wastewater.

c. There are no significant differences between the effects of the age of the vetiver plants on the percentage reduction in the levels of these parameters in domestic wastewater.

1.5 Justification

The use of vetiver plants in wastewater treatment has not been exhaustively studied and documented in Kenya. Worldwide, little research work, if any, has so far been done to compare the performance of vetiver systems established using the three different techniques in the treatment of domestic wastewater. In order to improve on the performance of vetiver plants in wastewater treatment, one requires selecting not only the most suitable method of plant establishment but also the optimal contact time. Additionally, one would require estimating the efficiencies of the systems as the plants attain different ages and stages to be able to infer the most suitable wastewater loading rates corresponding to a particular age. Such information which is vital for the design and management of small, sustainable, efficient and decentralized wastewater treatment systems can be obtained from such research studies. Therefore research in phytoremediation is quite important, particularly using vetiver systems. They have the potential to solve ecological and economic problems simultaneously; checking environmental pollution while enabling water and nutrient recycling, besides other uses (Smeal, *et al.,* 2003).

1.6 Scope of the Study

There are several kinds of wastewaters such as domestic, industrial, agricultural and many others. This study only considered domestic wastewater sourced from the septic tanks serving Pwani University's Resource Centre. Furthermore the only parameters considered were TN, TP,TSS, BOD and COD, from a long list of parameters involved in the treatment of wastewater.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

Wastewater emanates from four primary sources; municipal sewage, industrial runoff, agricultural runoff, storm water and urban runoff. It is a complex mixture of natural and manmade organic and inorganic substances. In its broadest sense wastewaters can be split into domestic (sanitary) wastewater also known as sewage, industrial (trade) wastewaters and finally, municipal wastewater which is a mixture of the two. As the wastewaters receive treatment, increasing emphasis is being placed on their pollution effects and the economics of mitigation against these effects.

Local and national authorities demand that wastewaters be treated by the polluter to a certain standard before discharge to the local authority sewer or water bodies (Appendix Table 3). For some towns, the approach has been to have a large centralized wastewater treatment system run by local authorities. This has involved the use of a combination of highly technological and high energy consuming treatment techniques. The conventional biological treatment systems in developing countries include activated sludge, oxidation ditches, septic tanks, trickling filters and waste stabilization ponds. Since these approaches have some shortcomings, increasing attention has been devoted to their improvement and development of alternative systems. Various types of approaches have been proposed, including those that use aquatic plants. Aquatic plants systems apart from the treatment function also provide an opportunity for nutrient recovery and sometimes, use as animal feed besides other potential uses. Some researchers believe that this approach is the best solution particularly for household-centered sanitation (King, 2000). Amongst a host of plants that have been used for this function, is the vetiver grass, whose performance has proved to be promising. Further research in the use of vetiver grass in wastewater treatment is therefore a worthy venture. To date, it is not very clear which of the two treatment systems, the hydroponic vetiver systems and those established in a soil medium, performs better than the other in the treatment of wastewater.

2.2 Composition of Domestic Wastewater

Domestic sewage is mainly composed of human black and grey water. Black water is the water from the toilets, while grey water refers to the waters from kitchen and bathroom. These waters are principally organic although traces of inorganic substances cannot be ruled out. Raw wastewater additionally contain nutrients, nitrogen and phosphorous. All these impurities degrade the quality of water in the water bodies into which they are disposed. By volume, sewage is 99.9% water with the material that require to be removed amounting to just 0.1% (Gray, 2009). Figure 2.1 illustrates the general composition of raw wastewater.

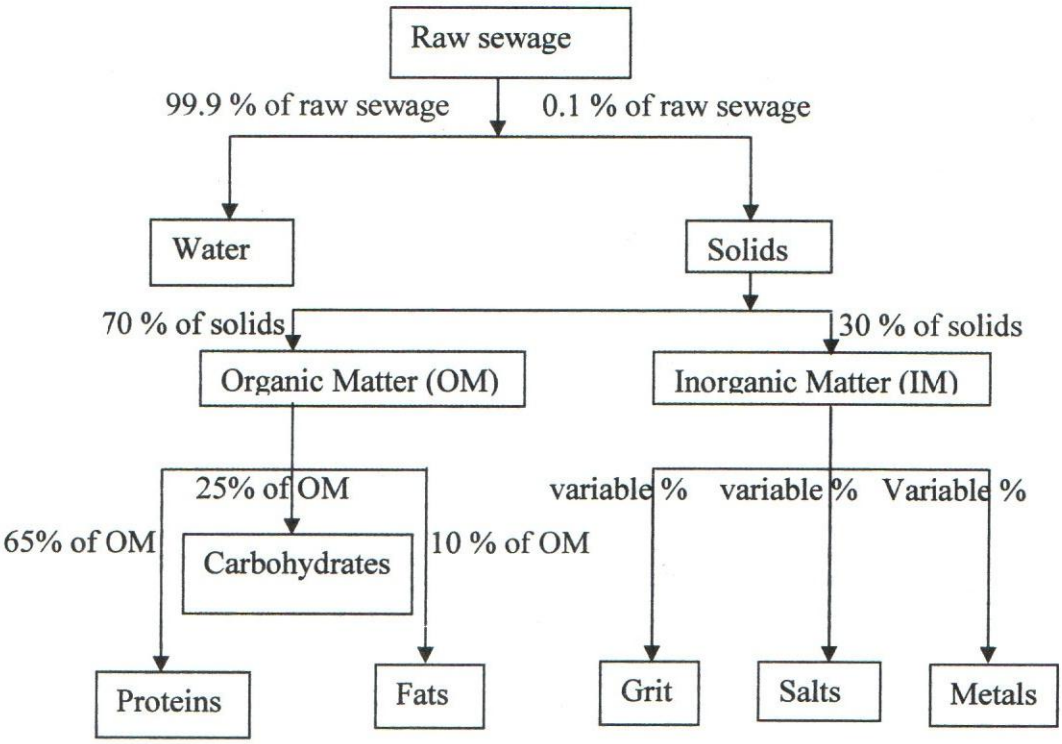


Figure 2.1: General composition of raw wastewater by volume (Gray, 2009).

The specific pollutant composition of domestic wastewater varies greatly both in the constituents and their individual concentration. Table 2.1 shows the typical concentration of raw domestic waste water for selected contaminants. Appendix Table A1 presents a more detailed guide.

Table 2.1: Typical concentration of raw domestic wastewater for selected constituents (Ogombe, 2001,

Contaminant	Units	Weak conc.	Medium conc.	Strong conc.
Suspended solids(SS)	mg/l	100	220	350
B.O.D_5, 20°C	mg/l	110	220	400
C.O.D.	mg/l	250	500	1000
Total N	mg/l	20	40	85
Total Phosphorous	mg/l	4	8	15
Total coli form	No./100 ml	10^6-10^7	10^7-10^8	10^7-10^9

For purposes of designing a treatment system of domestic wastewater it is imperative to quantify the amounts of these waters. The volume of domestic wastewater that can be handled by a treatment system is dependent on number of households contributing factors. These factors include the habitation factor and the mean flow per capita per day (Gray, 2009). This contribution may be calculated using the equation:

$$Q_d = H * F\ m^3 house - day^{-1}; \quad (2.1)$$

where :

H is the habitation factor per house; and

F is the mean flow per capita per day.

If the number of households in the community is known, then volume of domestic wastewater to be handled daily can be determined.

2.2.1 Nitrogen and Phosphorous in Wastewater

Nitrogen exists in wastewater in various forms such as organic nitrogen, ammonia, nitrites and nitrates. It is removed through the processes of volatilization, ammonification, nitrification,

denitrification, and plant uptake and matrix adsorption. Research has shown that the main removal mechanism in most wetlands is nitrification/denitrification, but volatilisation predominates in case of floating plants (Ogombe, 2001). Nitrogen is usually measured as Kjeldhal nitrogen, which is the sum of the organic nitrogen and ammonia nitrogen present. Total nitrogen is the sum of Kjeldhal nitrogen and the oxidized nitrogen. In raw wastewater and settled wastewater, there is no oxidized nitrogen present and hence the total nitrogen is equal to the Kjeldhal nitrogen (Gray, 2009).

Phosphorous exists in wastewater in the form of organic phosphate, orthophosphate, and polyphosphate. The average phosphorous concentration in sewage is between 5 and 20 mg/l as total phosphorous. The organic phosphate is usually of minor importance in most domestic wastes, while the polyphosphates undergo hydrolysis in aqueous solutions and revert to orthophosphate forms. Orthophosphates can be determined directly by adding a substance such as ammonium molybdate which will form a coloured complex with the phosphate. The polyphosphates and organic phosphates must be converted to orthophosphates using an acid digestion step before they can be determined in a similar manner (Tchobanoglous *et al.*, 2003). It can be removed from wastewater by three processes of adsorption, plant absorption, complexation and precipitation. Both nutrients can be removed using algal ponds. Plants however have higher affinities for nitrogen than for phosphorous (Ogombe, 2001).

In terms of water quality, nutrients can be considered as pollutants when their concentrations are sufficient to allow excessive growth of aquatic plants, particularly algae. This lowers the attractiveness of the receiving water bodies for recreational use, as drinking water supply and as a viable habitat for other living things. The process of nutrient enrichment of water bodies, referred to as eutrophication, is a threat to water bodies. It can lead to algal blooms, which eventually die and decompose and consequently lower the levels of dissolved oxygen (DO) of water bodies. The DO can reach levels too low to sustain normal life forms. The algae and decomposing organic matter add colour, turbidity, odour and objectionable tastes to the water. The nitrogen in the form of nitrate in water is convertible into highly toxic nitrites in infant's

intestinal tracts when ingested. This can cause the potentially fatal 'blue baby' disease (Masters, 1991).

2.2.2 Organic Matter in Wastewater

Many organic materials are soluble in water. Organics in natural water systems may come from natural sources or may result from human activities. Most natural organics consist of the decay products of organic solids, while synthetic organics are usually the result of wastewater discharges or agricultural practices. Dissolved organics in water are usually divided into two broad categories: biodegradable and non-biodegradable (refractory) organics.

Biodegradable material consists of organics that can be utilized for food by naturally occurring micro-organisms within a reasonable length of time. In dissolved form, these materials usually consist of starches, fats, proteins, alcohols, acids, aldehydes, and esters. They may be the end-product of the initial microbial decomposition of plant or animal tissue, or they may result from domestic or industrial wastewater discharges. Although some of these materials can cause colour, taste, and odour problems, the principal problem associated with biodegradable organics is a secondary effect resulting from the action of microorganisms on these substances.

Microbial utilization of dissolved organics can be accompanied by oxidation (addition of oxygen to, or the deletion of hydrogen from, elements of the organic molecule) or by reduction (addition of hydrogen to, or deletion of oxygen from, elements of the organic molecule). The oxidation process is by far more efficient and is predominant when oxygen is available. The amount of oxygen consumed during microbial utilization of organics is called the biochemical oxygen demand (BOD).

The concentration of organic matter in water is expressed by means of oxygen consumption during its decomposition. The principle measures, often called parameters, used to characterize the organic matter in wastewater include the Biochemical Oxygen Demand (BOD), the Chemical Oxygen Demand (COD), the Total Organic Carbon (TOC) and the Theoritical Oxygen demand

(ThOD). The daily per capita output of organic waste is some 30-50 grams as BOD, about half of this being associated with black water, and half with grey water (Pickford, 1986). Actually, it is BOD_5, which is the oxygen consumption measured over 5 days that is used to characterize the organic matter in wastewater. The oxygen consumption after 5 days is not included as all easily decomposed matter is broken down within 5 days. Values of the 20° C BOD_5 of municipal waters varies from about 100 to 500 mg/l (Linsley and Franzini, 1979; Jorgensen and Johnsen, 1989). In its simplest version, the 5-day test begins by placing water or effluent samples into two standard bottles of 60 or 300mL. One sample is analyzed immediately to measure the initial dissolved oxygen concentration in the effluent, often using a winkler titration (Weiner and Mathews, 2007). The second BOD bottle is sealed and stored at 20°C in the dark, to avoid photosynthetic oxygen generation. The amount of dissolved oxygen remaining in the sample after 5-days is then measured. The difference between the initial and final oxygen concentration is the BOD_5. An effluent with a high BOD may be harmful to a stream if the oxygen consumption is great enough to cause anaerobic conditions which can lead to depletion of dissolved oxygen in the receiving water bodies (Weiner and Mathews, 2007).

The other common parameter used to characterize wastewater, the COD, refers to the oxygen equivalent of the organic matter in wastewater that can be oxidized chemically using potassium dichromate in an acid solution, usually sulphuric acid. However, COD is less specific, since it measures everything that can be chemically oxidized, rather than just levels of biologically active organic matter. It is faster to determine it, about ten minutes in duration, than the BOD_5, which takes about 2.5 hrs (Linsley and Franzini, 1979). Often, a statistical relationship is worked up for the particular wastewater to translate COD to the time consuming BOD_5 (Jorgensen and Johnsen, 1989). The ThOD and TOC respectively are calculated from the chemical formula of the organic waste. Since the ultimate oxidation of organic carbon is to carbon dioxide (CO_2), the total combustion of a sample yields some information about the potential effluent demand for an effluent sample. Sometimes the ratios of BOD_5 to TOC and BOD_5 to COD are used to characterize wastewater as in Table 2.2.

Table 2.2 Comparison of ratios of various parameters used to characterize municipal wastewater (Linsley and Franzini, 1979)

Type of wastewater	BOD_5/TOC ratio	BOD_5/COD ratio
Untreated	1.2-1.5	0.50-0.65
After primary settling	0.90-1.10	0.40-0.55
Final effluent	0.25-0.50	0.10 -0.25

2.2.3 Physical Pollutants in Wastewater

The principle physical characteristics of wastewater are its solids content, colour, odour, and temperature. Colour is a qualitative characteristic used to assess the general condition of wastewater. The colour of domestic wastewater is normally grey to yellow-brown according to the time of the day (Gray, 2009). The temperatures of wastewater vary greatly with the source and season. They remain several degrees warmer than the air temperature except during the warmest months, because the specific heat of water is much greater than that of air.

Raw sewage is a turbid liquid with small but visible particles of organic material that readily settle out of suspension. The total solids include any material left in a container after water is removed by evaporation, usually at 103-105°C (Weiner and Mathews, 2007). They consist of the insoluble and suspended solids and the soluble compounds dissolved in water. The suspended solids' content is found by drying, weighing and filtering, while the volatile ones are found by igniting the residue. About 40% of the solids in wastewater are suspended (Linsley and Franzini, 1979). Smell is another quality used to characterize wastewater. Direct measurements of smell can be made if causative agents are known, for instance by gas or liquid chromatography. Domestic wastewater has a musty odour which is generally non offensive unless the waters become anaerobic, in which case they release a pungent smell (Gray, 2009).

2.2.4 Pathogens in Domestic Wastewater

Pathogens are disease-causing organisms in wastewater. Their general concentration and presence in wastewater is evidenced indirectly through biological indicators referred to as 'indicator organisms'. The coliform groups of bacteria, Escherichia coli, which originate from the intestinal tract of warm-blooded animals, are used as the biological indicators of the presence of pathogens in wastewater. In the US, a generalized standard of expediency of one coliform in 100 ml of water has been used as a threshold for safe water (Gray, 2009, Maskew *et al.*, 1968). In Kenya, authorities stipulate a maximum of 30 coliforms in 100 ml of water for wastewater discharges into natural water bodies (NEMA, 2006). The presence of coliforms does not prove that there are pathogenic organisms in the water, but indicates that such pathogens might be present (Weiner and Mathews, 2007). The removal of pathogenic microorganisms is brought about by a combination of physical, chemical and biological processes. Physically pathogens are removed by adsorption and settlement, while overall concentration is reduced by dilution. Biologically, pathogens are killed by predation by other microorganisms and grazing by macro-invertebrates. Chemically they are reduced by such chemicals like chlorine. UV radiation and short wave visible light are lethal to bacteria.

2.3 Wastewater Treatment

Wastewater treatment involves the modification of the characteristics of the water such that they are at a level, which poses no threat to the environment. It has three basic aims:

a. To destroy the causative agents of those water related diseases which are associated with domestic wastes;
b. To convert the wastes into a readily re-usable resource and to conserve and recycle the water, nutrients and energy; and
c. To prevent the pollution of any water bodies on or below the ground into which it is discharged with or without reuse.

To achieve its aims, the wastewater treatment process must produce an effluent of a quality within the standards set by an established authority. In Kenya, this is the mandate of local authorities, as guided by the National Environmental Management Authority (NEMA). The generalized effluent standards for discharge into water bodies in Kenya are given in Table 2.3 below.

Table 2.3: Generalized Effluent standards for discharge into water bodies for Kenya (NEMA, 2006)

Systems Parameter	Unit of measurement	Effluent concentration
BOD_5	mg/l	30
COD	mg/l	50
Total Suspended solids	mg/l	30
Hydrogen ion Conc.	pH units	6.5-8.5
TSS	mg/l	2
Total Nitrogen	mg/l	2

Detailed standards are given in the Appendix Table A3.

2.3.1 Wastewater Treatment Approaches

The earliest form of wastewater treatment is an on-site approach using the pit privy system. This consists of a pit over 2m deep into which human waste was deposited. This system is still commonly used in camps and third world countries. The composting toilet, which accepts both human excrement and food remains to produce useful compost, is an extension of the pit privy. However, the commonest form of on-site wastewater treatment currently employed is the septic tank and tile-field/soak-pit system. A septic tank consists of a concrete box that removes the solids in the waste and promotes partial decomposition. The solid particles settle out and eventually fill the tank. They are periodically removed. The water overflows into a tile-drain or soak-pit that facilitates its seepage in to the ground. A tile field consists of a perforated plastic

pipe laid in a one meter deep trench, while a soak-pit typically consists of pits whose bases contain gravel and sand to facilitate effluent seepage into the ground (Bengtsson and Whitaker, 1986). The prime consideration in designing a septic tank and tile-field/soak-pit system is the ability of the ground to absorb the effluent.

Land availability constraints in urbanized areas have necessitated the shift from household based on-site to centralized communal wastewater treatment approaches using water as a carrier. This has led to the development of complex wastewater treatment plants that provide an engineering solution to the problem. A wastewater treatment plant is a combination of separate treatment processes designed to produce effluents of a desired composition and flow rate. The various wastewater treatment processes can be classified as physical, chemical or biological. The physical processes include screening, sedimentation, aeration, filtration, grit removal and centrifugation. These are the dominant processes in the primary treatment of wastewater. The chemical ones include disinfection, ion exchange, coagulation, precipitation and neutralization. The biological ones include activated sludge, oxidation ditches, trickling filters and waste stabilization ponds. These remove most of the biochemical demand for oxygen. Normally, a treatment system may consist of two or more of these processes (Weiner and Matthews, 2007). Wastewater is treated at three distinct levels; primary, secondary and tertiary.

Primary treatment predominantly utilizes the physical treatment processes that are designed to remove the non-homogenizable solids. A variety of screens consisting of a set of steel bars spaced about 2.5 cm apart remove materials that might damage equipment or hinder further treatment (Tchobanogous *et al.*, 2003). When sufficiently clogged, they are cleaned either by hand or mechanically. The second treatment step is the comminutor, a circular grinder designed to grind the solids coming through the screens to about 0.3 cm or less in diameter (Weiner and Mathews, 2007). The third step is the removal of grit from the wastewater as these have a potential to damage equipment upfront. Grit is removed in the grit chamber, a widened part of the flow channel where the flow is slowed to promote grit settlement. Most wastewater treatment systems have a settling tank where as much of the solids as possible are settled. These are also

referred to as sedimentation tanks or clarifiers. They are usually designed for a specific retention time. The solids settle to the bottom of the clarifiers and are removed as sludge.

The primary objective of secondary treatment is to reduce the BOD level and this is achieved by employing predominantly biological processes. These remove most of the biochemical demand for oxygen. Biological treatment involves the conversion of the dissolved and colloidal organic matter in the wastewater to biological cell tissue, and to end products such as CO_2, H_2O and NH_3 (equations 2.2, 2.3 and 2.4), and subsequent removal of the cell tissue, normally by settling (Linsley and Franzini, 1979).

Oxidation

$$COHN_5 + O_2 + \text{Bacteria} \longrightarrow CO_2 + H_2O + NH_3 + \text{Other end products} + \text{Energy} \qquad (2.2)$$

Synthesis

$$COHN_5 + O_2 + \text{Bacteria} + \text{Energy} \longrightarrow \underset{\text{New cell tissue}}{C_5H_7NO_2} \qquad (2.3)$$

Endogenous respiration

$$C_5H_7NO_2 + 5O_2 \longrightarrow 5CO_2 + 2H_2O + NH_3 \qquad (2.4)$$

The major concerns in biological treatment are with the creation of optimum environmental and physical conditions to maximize new cell tissue formation rates and their removal. The biological conversion can be accomplished aerobically and anaerobically, the earlier being faster and hence preferred (Linsley and Franzini, 1979). The commonest biological treatment systems are the trickling filters and the activated sludge. The trickling filter consists of a filter bed of rocks over which liquid waste is trickled. An active biological growth that forms on the rocks obtains food from the wastewater dripping through the rock bed. Air is circulated through the rocks to promote the aerobic process. Often the flow is re-circulated and higher treatment efficiency attained. The activated sludge system differs from the trickling filter in that it re-circulates and re-uses microorganisms that are suspended in the liquid. It consists of a tank full of wastewater from the primary clarifier and a mass of microorganisms. Air is bubbled through this aeration tank to facilitate aerobic processes in which the microorganisms decompose the

organic material to carbon dioxide, water and some stable compounds. The production of new organisms is relatively low and they are separated from the liquid in a settling tank sometimes referred to as the secondary or final clarifier. The microorganisms remaining in the tank having no food available are said to be activated hence the name activated sludge (Weiner and Mathews, 2007).

Figure 2.2 below is a schematic representation of the biological conversion of organic matter in wastewater to stable end-products.

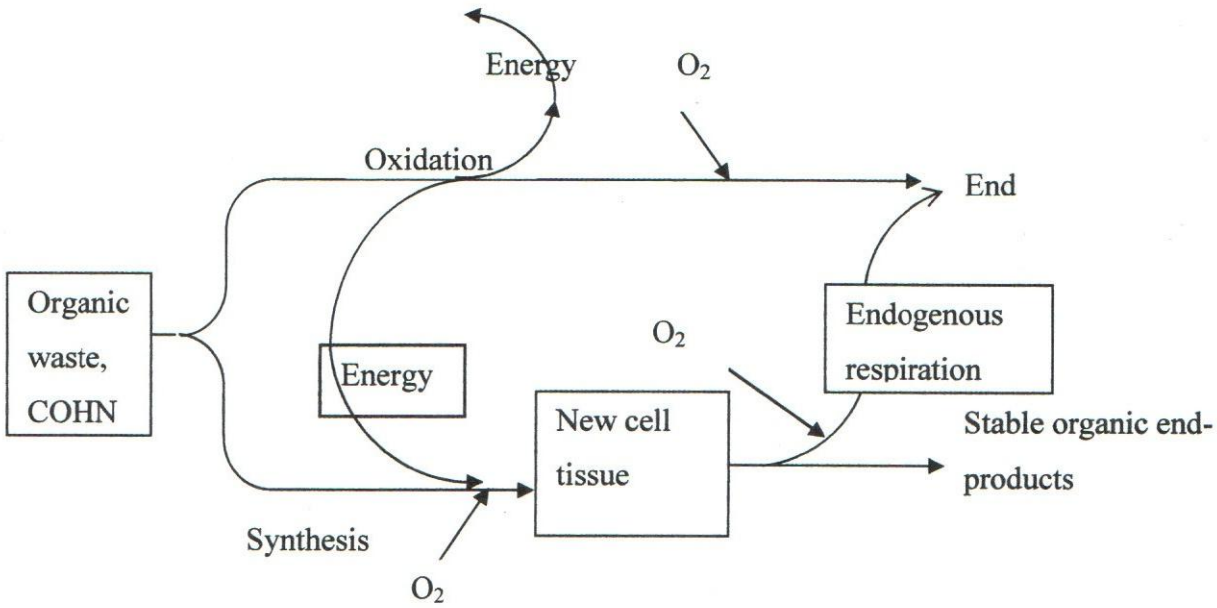


Figure 2.2: The aerobic biological conversion of organic matter in wastewater to stable organic other end products. (Linsley and Franzini, 1979)

The effluents from secondary treatment are often not sufficiently clean, with some BOD and suspended solids remaining. Neither primary nor secondary treatments are effective in removing phosphorous and other nutrients or toxic substances. These are removed at the tertiary treatment stage that uses a combination of biological and chemical processes. A popular tertiary treatment system is the polishing or oxidation pond, which if aerated is referred to as an aerated lagoon. Other tertiary treatment options are chemical such as carbon adsorption, reverse osmosis, flocculation among others, which serve to further remove BOD, nutrients and suspended solids. The effluents may then be discharged into water bodies or applied as land treatment. The

nutrients nitrogen and phosphorous that remain in wastewater are usually beneficial to crops. A typical wastewater treatment plant is shown schematically in Figure 2.3 below.

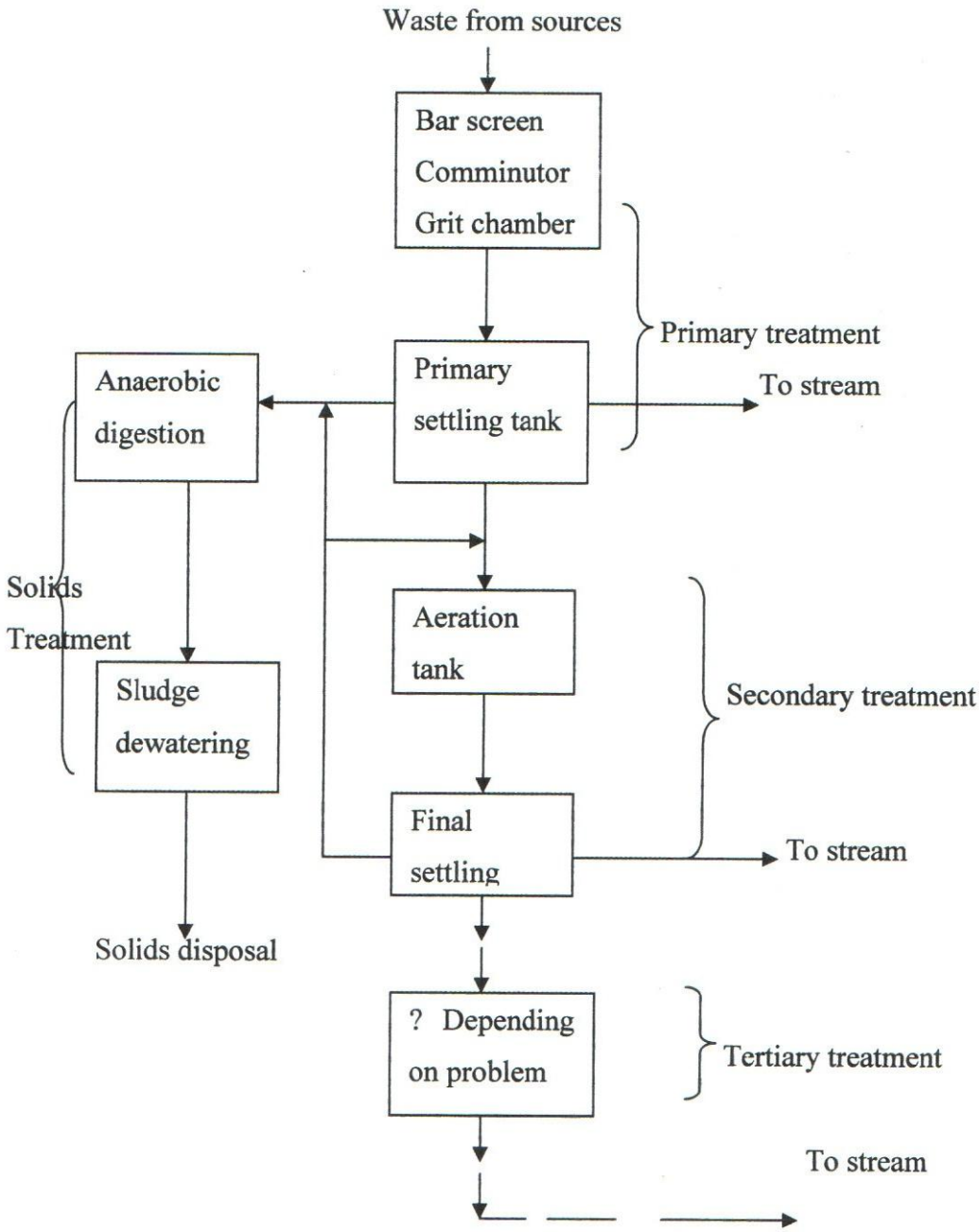


Figure 2.3 Block diagram of a complete wastewater treatment plant. (Weiner and Mathews, 2007).

2.3.2 Constraints of the current wastewater treatment approaches

The biological approaches to wastewater treatment that are popular in the developing world are gradually becoming unsustainable if high treatment efficiency is to be maintained. The need to dispose of high quantities of domestic, industrial wastewater and commercial sewage in a centralized manner in big towns has all along favoured them. However the advent of smaller urbanizing areas reduces the economy of scale advantages and has rendered such techniques uneconomical and unsustainable (Nhapi, 2004). High costs are making many treatment plants to become white elephants. Properly operated ponds alone may be as effective as trickling filters and activated sludge systems in BOD removal. These ponds have been used extensively in small communities where land constraints are not so critical. The amount of pond surface area required is considerable, with 1 hectare per 240 people often being recommended (Masters, 1991). Another problem with such systems is that they fail to meet the set effluent standards as regards suspended solids and BOD_5 (Linsley and Franzini, 1979) without resorting to using a series of several settling tanks. In such a scenario, the three important goals of environmental sustainability, investment and operational efficiency can be best achieved by striving to develop small but efficient sewage treatment plants for each development with treatment particular to the type of waste being generated (Nhapi, 2004). It is in this view that modern researchers are now advocating for natural treatment methods coupled with recovery and reuse measures in a decentralized approach to wastewater management (Oron, 1994; USEPA, 1997).

2.3.3 The Role of Vegetation in Wastewater Treatment

The use of aquatic plants in wastewater treatment is becoming widely adopted particularly in the new wastewater management approaches that integrate treatment, recycling and reuse. Phytoremediation (the use of plants for environmental remediation) is a new technology that exploits plants' potential to absorb pollutant compounds to renovate contaminated soil and water (Lasat, 2002). It is environmentally friendly, inexpensive and can be carried out at the polluted place (remediation in situ). The plants employed can be classified into submerged algae and plants, floating macrophytes and emergent vegetation (Dingles, 1982). The floating macrophytes

(duckweeds, water ferns among others) use atmospheric oxygen and carbon dioxide but obtain the remaining nutrients from the wastewater. The roots provide a substrate on which the heterotrophic microorganisms grow. Most reductions in the levels of TSS and BOD are due to settlement rather than biological activity (Gray, 2009). The plants exhibit a luxury uptake of nutrients, far in excess of the normal requirements and also accumulate other components from wastewater such as the heavy metals and synthetic organic compounds. This becomes disadvantageous where the concentration of these components prohibits subsequent use of the biomass for conversion into energy by digestion or its use as an animal feed supplement. The flow charts of waste stabilization ponds and aquatic systems (phytoremediation) are contrasted in Figures 2.4 and 2.5 below:

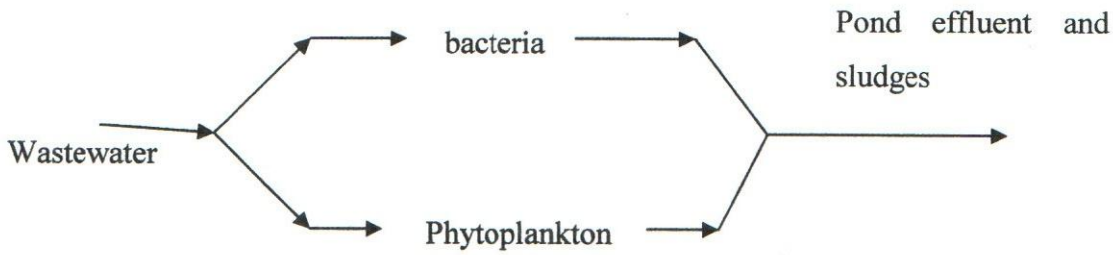


Figure 2.4: Stabilization pond flow chart (Linsley and Franzini, 1979)

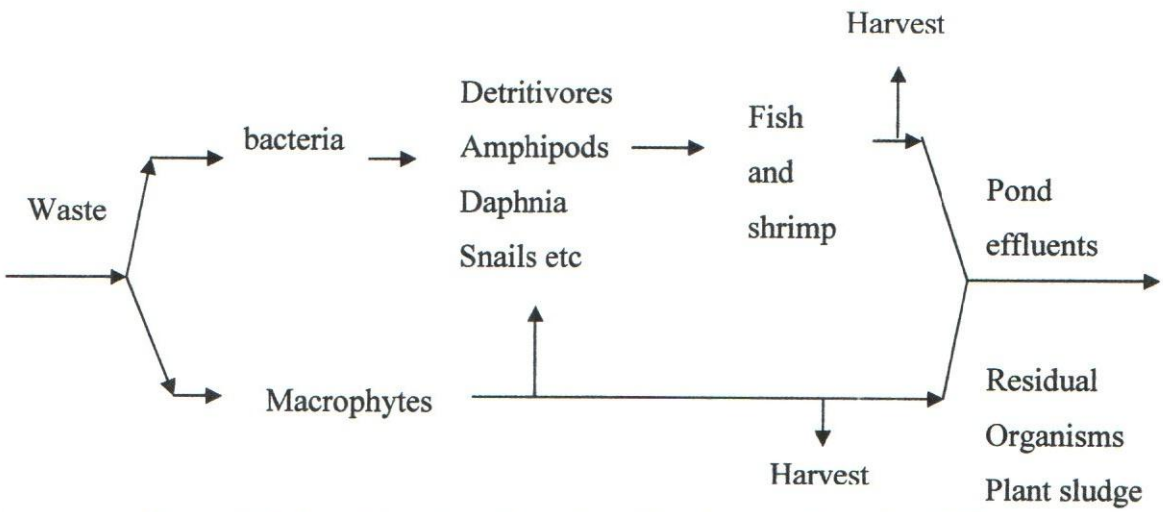


Figure 2.5: Aquatic system flow chart (Linsley and Franzini, 1979)

Additional conversion and harvesting steps are involved in the aquatic system. Under ideal conditions, the volume of sludge produced in the first conversion is reduced down the series since a portion is converted into end products to obtain energy. Nutrients are removed from wastewater by incorporation into plant and animal tissue, while the plant and animal tissue are removed at each harvesting step. Consequently there should be a greater reduction in the concentration of wastewater constituents and in the volume of residual material to be disposed of. Additionally, useful plant and animal protein is produced (Linsley and Franzini, 1979).

2.3.4 Constructed wetlands

Natural wetlands are wetland ecosystems variously referred to as bogs, and fens among others, at, above, or below the existing land surface which naturally served to cleanse wastewater. When artificially engineered by man, they are referred to as constructed wetlands (CW). They use free-floating aquatic plants, or sediment-rooted emergent wetland plants, either with water flowing through the root zone (subsurface flow) or amongst the stems (surface flow). Horizontal subsurface flow constructed wetlands are commonly referred to as reed beds. A reed bed typically consists of a substrate such as gravel confined in a container, supporting macrophytes such as reeds. Water enters via an inlet structure and flows horizontally over a period of days to the outlet structure. Treatment occurs within the bed as a result of a number of physical, chemical and biological processes that occur as the water flows through. The reed bed is mainly used as a secondary treatment for primary settled domestic wastewater.

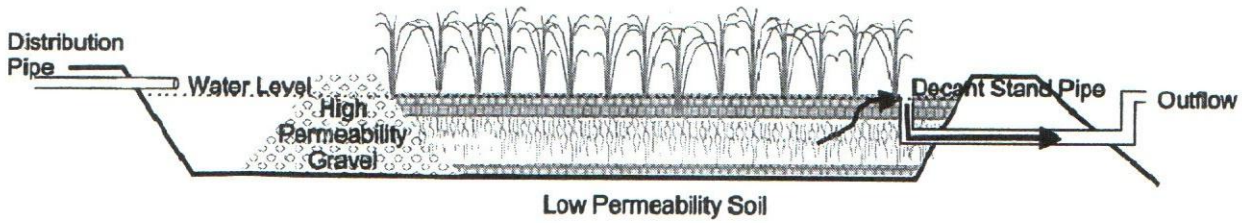


Figure 2.6: Basic features of a horizontal flow hydroponic reed bed (Smith and Kalin, 2000).

Flooding the bed encourages a horizontal flow of wastewater through the bed. This is because the flooding conditions create aerobic, anoxic and anaerobic treatment zones. The substrate and roots provide a large surface area for the growth of heterotrophic microorganisms. Through the roots, the plant avails oxygen to the soil, creating an aerobic zone. Within the rhizosphere there are also anoxic zones. This combination allows both aerobic and anaerobic bacteria to survive, allowing carbonaceous oxidation, nitrification, denitrification and anaerobic degradation to occur (Gray, 2009). The plants take up nutrients and store them in their tissues that are removed from the system when harvested.

Studies by the Queensland Department of Natural Resources (QLDNR, 2000) indicated that constructed wetlands are unable to produce an effluent similar to that produced by an advanced treatment system and that if incoming effluent nitrogen is mainly nitrate and low dissolved oxygen regime is maintained, nitrate removal is very efficient. The studies further concluded that ammonia could increase when initial concentrations are 5-10 mg/L. COD was dismissed as a poor indicator of wetland performance because the degradation products from wetland treatment could increase it. Phosphorus removal was noted to be fair in the early period of wetland operation as the macrophytes become established. After establishment, poor removal performance was expected.

2.3.5 Design Considerations for Constructed Wetlands

The strength of a reed bed is its capacity to remove BOD and TN from effluents. Therefore a reed bed's size is usually based on the need to achieve a certain treatment objective with respect to one or both of these pollutants, usually BOD_5. The decline in concentration of some pollutants as a function of residence time can be approximated using the first order model presented in equation 2.5.

$$C_o = C^* + (C_i - C^*)e^{-K_T HRT}; \quad (2.5)$$

Where:

C_o is the pollutant concentration at reed bed outlet (mg/L)

C_i is the pollutant concentration at reed bed inlet (mg/L)

C* is background concentration due to return of pollutant (mg/L)

K_T is the temperature dependent first order reaction rate, (d^{-1}).

HRT is the hydraulic retention time

Sizing beds for a residence time of approximately 5 days has become standard practice (Headly and Tanner, 2006). The temperature dependent first order reaction rate, K_T, varies with temperature according to the equation:

$$K_T = K_{20} * \theta^{(T-20)} \text{ (Davison et al., 2005),} \quad (2.6)$$

where:

K_{20} is the value of volumetric rate constant at 20°C;

θ is the temperature correction factor; and

T is the water temperature (°C)

For BOD and TN the values for the model parameters K_T, C* and θ were empirically estimated (Headley and Davison, 2003) as presented in Table 2.4 below.

Table 2.4: First order model parameters for TN and BOD removal from wastewater by gravel reedbeds (Headley and Davison, 2003).

Pollutant	volumetric flow rate Constant, K_{20}, (d^{-1})	Background concentration mg/l	Temperature correction factor
BOD	0.52	5	0.953
TN	0.18	1.5	1

Assuming first order Kinetics and plug flow reaction, the surface area of a reed bed can be determined as given by Ogombe, (2001):

$$A = \frac{Q.\ln\frac{Ce}{Co}}{K_T.Y.N}, \quad (2.7)$$

where;

A is the surface area of the reedbed, m^2;

N is the porosity of the sand medium, usually taken as 35%, (Linsley and Franzini);

Y is the depth (m); and

Q is the effluent flow rate in cubic metres per day.

The recommended length to width ratios of the reed bed area are 3:1 and 5:1 (GSADH, 2005). The bed slope, S, is computed using Darcy's law:

$$S = Q/K_c * A_{c,} \quad (2.8)$$

Where:

K_c is the hydraulic conductivity, taken to be 0.0001 m/s (Ogombe, 2001); and

A_c is the cross-sectional area.

Two parameters are commonly used to compare the performance of different reed beds. The first one is the organic loading rate (OLR), which refers to the amount (mass) of organic matter per hectare per day, contained in the wastewater supplied to the system. It has a limiting value of 112 kg/ha.d (Ogombe, 2001).

$$OLR = 10 * BOD_5 * Q/A \quad (2.9)$$

where:

A is the surface area in m^2; and

Q is effluent flow rate in m^3day^{-1} and BOD_5 is in $mg.L^{-1}$.

The second parameter is the hydraulic loading rate (HLR, cm/d). It refers to the ratio of the volume of wastewater applied per day to the surface area of the aquatic system. Its limiting value is 4.7, and it is obtained by the equation:

$$HLR = Q/A \quad (2.10)$$

Generally the organic loading rate will control the hydraulic loading rate (Ogombe, 2001). Research on constructed wetlands is ongoing in many sites around the world. A wetland has been constructed at Egerton University's main campus for community sewage treatment. At Haller Park in the Kenyan coastal town of Mombasa, a biofilter system of mangroves is being used to remediate fishpond effluents (de Mowbray, 2009). In Zimbabwe, the potential for use of pond systems using duckweed plants for wastewater treatment has been established (Nhapi, 2004). Wetlands have many individual and group characteristics related to plant species present and their adaptation to specific hydrologic, nutrient, toxicity and substrate conditions (Njau and Mlay, 2003). In Sub-surface Flow systems (SSF), the major contribution from the vegetation is the service of the root/rhizome structure as a substrate for microbial activity and as a limited oxygen source for nitrification (Reed *et al.*, 1988). This suggests that if the plant is expected to play a major role, the depth of the bed should not exceed the potential root length development for the plant species selected. Recent research findings have singled out vetiver plants as exceptionally good performers in wastewater treatment, out from a list of many other grasses that include Napier grass, Kikuyu grass, Rhodes grass, *and Sorghum vulgare* among others (Njau and Mlay, 2003; Ash and Truong, 2003).

2.3.6 The Use of Vetiver Grass in Wastewater Treatment

The Vetiver System (VS) is a new technology based on the use of vetiver grass (*Vetiveria zizaniodes*) for numerous environmental protection applications. It was first developed for soil and water conservation purposes but its role has been extended into environmental protection field, particularly in the field of wastewater treatment (Hart *et al.*, 2003). *Vetiveria zizanioides* is a C_4 perennial grass whose origins can be traced to India. It has been promoted by the World Bank since the 1980s for various applications such as soil erosion, riverbank erosion and recently for environmental protection (Boonsong and Chansiri, 2005). The plant is not prevalent in Kenya. However due to its unique morphological and physiological characteristics that make it tolerant to many adverse climatic and edaphic conditions, it has been successfully introduced for trials in Kenya (Owino, 2002). Njau and Mlay (2003) reckon that for a plant to be useful and accepted as safe for agricultural and biological engineering, it should:

• Exhibit xerophytic and hydrophytic characteristics if it is to survive the forces of nature. Vetiver grass, once established, is little affected by droughts and floods;

• Have a deep penetrating root system, capable of withstanding tunneling and cracking characteristics of soils. The roots should penetrate vertically below the plant to at least 3 metres;

• Be capable of growing in extreme soil types, regardless of nutrient status, pH, sodicity, acid sulphate or salinity, and toxic minerals. This includes sands, shales, gravels, mine tailings, and even more toxic soils;

• Be capable of developing new roots from nodes buried by trapped sediment, and continue to grow with the new ground level, to eventually forming natural terraces;

• Be totally free of pests and diseases and should not be an intermediate host for pests or diseases of any other plants;

• Be cheap and easy to establish as a hedge and easily maintained by the user at little cost; and

• Be easily removed when no longer required.

Vetiver grass has all the above characteristics. Vetiver grass is both a xerophyte and a hydrophyte (Njau and Mlay, 2003) but it prefers a wet and waterlogged habitat where it can grow and develop even though a large portion of its shoots are submerged in water for relatively long periods (Boonsong and Chansiri, 2005). Vetiver grass can grow in wastewater at different levels of 5-15 cm depth within 6 months (Ta-oun *et al.,* 2003). It has an exceptionally wide pH range, seems to be able to grow in any type of soil, can withstand extreme drought and is unaffected by temperatures as low as –9° centigrade (Njau and Mlay, 2003). It is reported to have absorbed and tolerate elevated levels of nitrogen of up to 100,000 kg/ha/yr (Wagner, 2003; Mayorca, 2007). It is propagated by root divisions, or slips. It has a deep root system, high biomass production and photosynthetic ability. It is however reported to have slow growth rates in high altitude areas whose temperatures are predominantly lower than its optimum range of 25-30 °C (Liao *et al.*, 2003; Owino 2002)).

The performance of Vetiver Constructed Wetlands (VCW) in wastewater treatment has been remarkable. Many scientists have confirmed that it is a powerful system in the removal of nitrogen and phosphorus from water and, therefore, a good purifier of eutrophic water (Zheng *et*

al., 1997). It has been reported to reduce septic plant effluents' by 99%, 85% and 95% of nitrogen, phosphorous and faecal coliforms respectively (Ash and Truong, 2003). Vetiver has a high dry matter production rate hence capable of yielding 1920 kg/ha/yr and 198 kg/ha/yr of nitrogen and phosphorous respectively (Cameron *et al.*, 2003). Trials on vetiver (Hart *et al.*, 2004) showed that on-site hydroponic vetiver treatment of domestic effluent had the potential of being more effective than other on-site treatments, and that hydroponic vetiver reduces far more nitrogen and phosphorous than any other plants (Appendix Table II). However results from studies by Bonsoon and Chansiri (2005), Headley and Tanner (2006) and Mng'anya *et al.*,(2001) indicate that hydroponic techniques posted lower nitrogen and phosphorus removal efficiencies when compared with results from other studies which had soil media.

Vetiver grass can also be used as the main plants when treating wastewater effluents by land irrigation. The rate of removal of pollutants from domestic wastewater applied on land by vetiver for an 8-day period was modeled by Liao *et al.*, (2004) as following the equation:

$$Y_t = Y_o e^{-kt}; \qquad (2.11)$$

Where:

Y_t is the pollutant (mg/l) concentration in the effluent water;
Y_o is the pollutant concentration in the influent water (mg/l);
t is the hydraulic retention time; and
k is the degradation coefficient, d^{-1}.

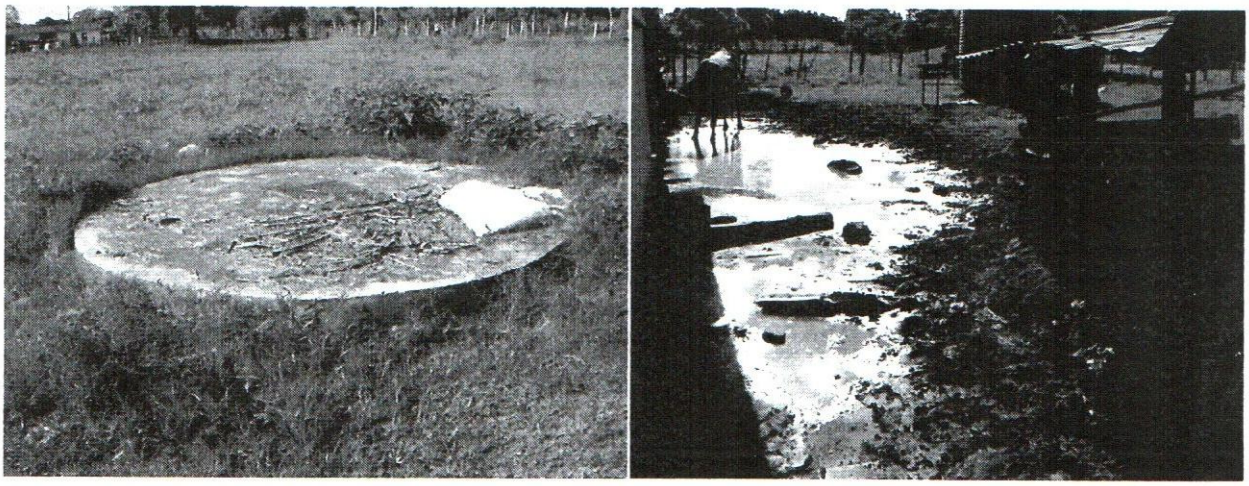
Besides wastewater treatment, vetiver has been proven as a low cost option for soil and moisture conservation and slope stabilization (Owino, 2003). The by-products from vetiver systems has a range of uses from handicrafts, thatches, animal feed, mulch, manure to a source of composting material (Smeal, *et al.*, 2003; Ash and Truong, 2003; Liao *et al.*, 2003). Given the reported wastewater treatment abilities of vetiver, effluents from vetiver systems are likely to meet standards that allow them to be reused for irrigation.

CHAPTER THREE: MATERIALS AND METHODS

3.1 Description of the Study Area

This study was conducted at the Pwani University College flower nursery farm between 15th July 2009 and 30th September, 2009. The actual running of the experiment was however done during the last six weeks from 15th august to 30th September 2009. The College is located in Kilifi Town which lies 62 km to the North of Mombasa City, on latitudes 2° South and longitudes 40° East. It has a current population of over 2500 students. Kilifi district receives an average rainfall of 900-1,100 mm annually and has mean temperatures of 25-30°C. It has a marked dry season from January to March and a wet one from April to June. However, variations in amount and distribution of the rainfall throughout the year are large and erratic. The soils are mainly coarse grained sands that are well-drained, and generally of low fertility. The wind speeds range between 4.8-10.9 km/hr with the air being contaminated with traces sodium bicarbonate salts (MoPND, 2002). The prevailing weather conditions during the research period were generally dry and hot with high relative humidity. The highest rainfall recorded during the study period was 10 mm, while temperatures and relative humidity ranged at 20-29°C and 79-81% respectively as observed at the Pwani University Meteorological Station (Appendix Table A4).

The predominant method of sewage handling in Kilifi is through the use of septic tanks and pit latrines. Other forms of wastewater, mainly from small industrial sources, are usually let to percolate underground or flow without any treatment directly into the Indian Ocean. This is detrimental to both the ocean and the underground water resource, besides being unsightly. Figure 3.1 shows one of the several septic tanks and overland flowing wastewater at Pwani University College.



a. Septic tank b. Overland flow of effluents

Figure 3.1: A septic tank and wastewater flowing overland at Pwani University College.

3.2 Experimental Set-up and Design

The wastewater treatment units were fabricated from plain sheet metal in a local workshop. The sizing of the units was done by taking into consideration the quality of the raw wastewater to be used in terms of the mean BOD_5 levels, C_o, together with the desired effluent quality, C_e. The C_o and C_e were 100 and 10 mg/l respectively, with the mean minimum temperature, T, of Kilifi being 25°C. A volume of 40 litres of wastewater was chosen for the design, equivalent to an approximate average flow rate of $0.008m^3$/day for a five day detention time that has become the standard (GSADH, 2005). First order Kinetics and plug flow reaction were assumed for the reed bed surface area (A, m^2) to be estimated by the equation:

$$A = \frac{Q \cdot \ln\frac{Ce}{Co}}{K_T.Y.n} \qquad (3.1)$$

Where:

n = 35% is the porosity of the soil medium as determined at Pwani University;

Y = 0.4m is the depth of the medium; and

K_T is the temperature dependent first order reaction rate constant.

$$K_T = K_{20} * \theta^{(T-20)}$$

Where:

$\theta = 0.953$ is the temperature correction factor (Tchobanoglous *et al.*, 2003); and

$K_{20}=0.52\ d^{-1}$ is the temperature dependent first order reaction reference rate constant (Davison *et al.*, 2005). Using the mean minimum temperature of Kilifi of T = 25°C;

$$K_{20} = 0.52 * 0.953^{25-20}$$
$$= 0.41\ d^{-1}$$
$$A = \frac{0.008 * \ln \frac{10}{10}}{0.41 * 0.4 * 0.35} = 0.32\ m^2$$

The Organic Loading Rate, OLR (kg/ha.d) was calculated for this surface area by the following relationship used by Ogombe (2005):

$$OLR = \frac{10 * BOD_5 * Q}{A} \qquad (3.2)$$

where:

A is the surface area in square metres,

Q is in cubic metres per day and BOD_5 is in mg/L.

By using BOD and Q values of 100mg/l and 0.008 m^3/day respectively as used in the design, OLR was found to be 18.75 kg/ha. This value is less than the limiting value of 112 kg/ha.d (Tchobanoglous *et al.*, 2003) and was therefore considered acceptable. Similarly, the hydraulic loading rate, HLR (cm/d), was determined by the equation;

$$HLR = Q/A \qquad (3.3)$$

This yielded a value of 1.9 cm/d, well below the limiting value of 4.7 cm/day (Tchobanoglous *et al.*, 2003), and therefore was acceptable. Consequently, the treatment unit was sized considering that for plug-flow conditions, the recommended length to width ratios are 3:1 and 5:1 (GSADH, 2005). Using the 3:1 ratio and taking the length (L) to be equal to 1.0m, the width (W) was

determined as 0.32m for each treatment unit. Twelve boxes of dimensions 1.0 x 0.3 x 0.45 m dimensions were fabricated from plain sheet metal for use in the establishment of the three vetiver systems and their controls. The 0.05m increment in design height of the box was meant to serve as a freeboard.

3.2.1 Establishment of vetiver in the treatment units

The main experimental materials used were vetiver plants, sandy soil from the locality and domestic wastewater collected from the septic tanks of the college. The soil, which was predominantly coral limestone sand, had a porosity of 0.35 and pH of 5.8 as determined in the Pwani University laboratories. The vetiver plant tillers (*Vetiveria zizanioides*) were sourced from the Kenya Agricultural Research Institute (KARI) station at Mtwapa in the Kilifi County. The tillers were first made to stay overnight in diluted sewage to enhance chances of sprouting as recommended by Charanasri *et al.,* (1996). They then were planted in polythene bags and placed in the farm greenhouse. They were routinely irrigated with diluted sewage for a week after which they all were found to have successfully attained a satisfactory vegetative stage. Before being transplanted into the treatment units, the plants were pruned to a shoot and root height of 30 cm and 5cm respectively, in order to have identical biomass as possible from the onset of the research.

The experiment comprised of three treatments namely the soil-based unit, hydroponic unit, hybrid unit and the control, all of which were replicated thrice. The control was in the form of an empty box filled with wastewater that served to mimic miniature wastewater stabilization ponds. Into each of the units, 120 vetiver plants were transplanted planted in clumps of two tillers spaced about 10 cm apart.

The soil based unit consisted of the metal box filled with soil to a depth of 0.4m. The vetiver plants were planted in this soil as described above. Figure 3.2 below depicts one such treatment unit. Note that the population and arrangement (pattern) of plants in the figure is not indicative of the actual one used.

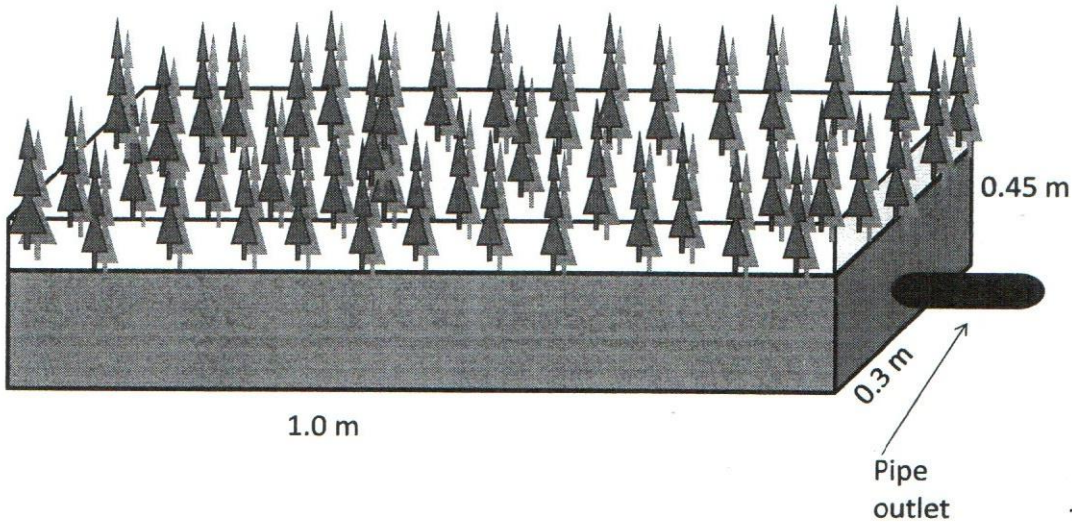


Figure 3.2: The soil-based treatment unit

The purely hydroponic (no soil medium) treatment unit was established with the vetiver plants without the soil medium. The plants were supported by a bamboo platform above the box, with their roots suspended in water (hydroponics). The platform was constructed as a meshwork of bamboo sticks onto which the plants were attached by loosely tying them with a sisal twine. Figure 3.3 below depicts one such unit.

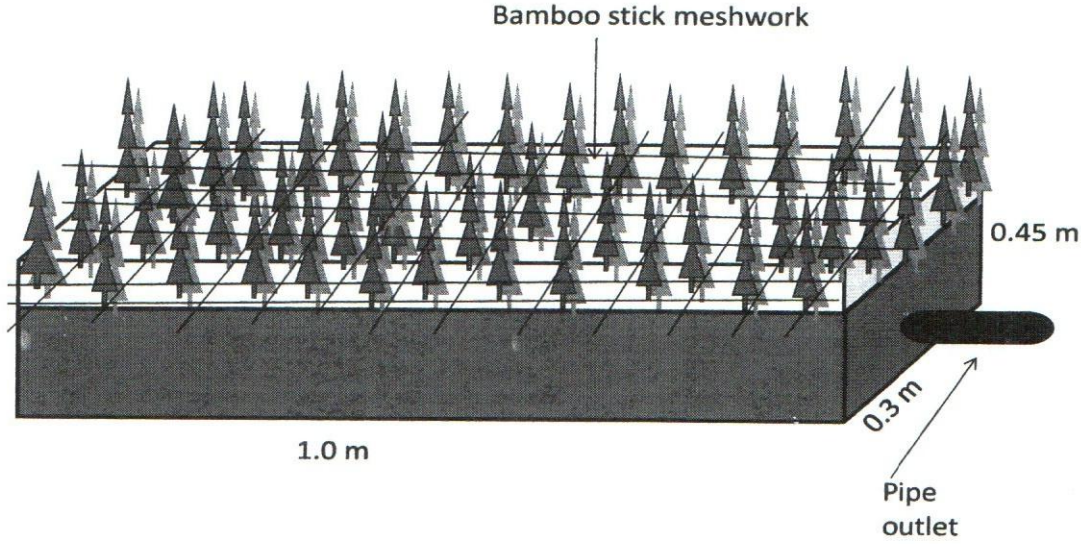


Figure 3.3: The purely hydroponic experimental unit

The hybrid unit (combination of the soil-based and the hydroponic) consisted of a metal box similar to the ones described above, but partitioned transversely into two equal halves using a perforated metallic plate. One half was filled with soil to a depth of 0.4m while the other half remained empty. Sixty (60) vetiver plants were transplanted in to each of the halves. One half had the plants established in the soil medium (soil based system) while the other half had the plants established using the hydroponic system.

Figure 3.4 below depicts one such unit. Note that again, the pattern and population of the plants in the figure is only representative and not precisely the actual situation

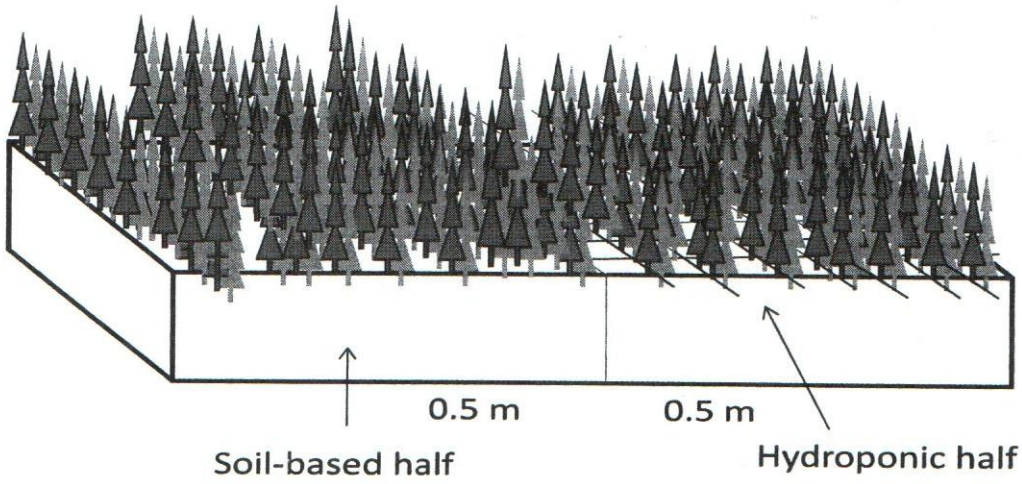
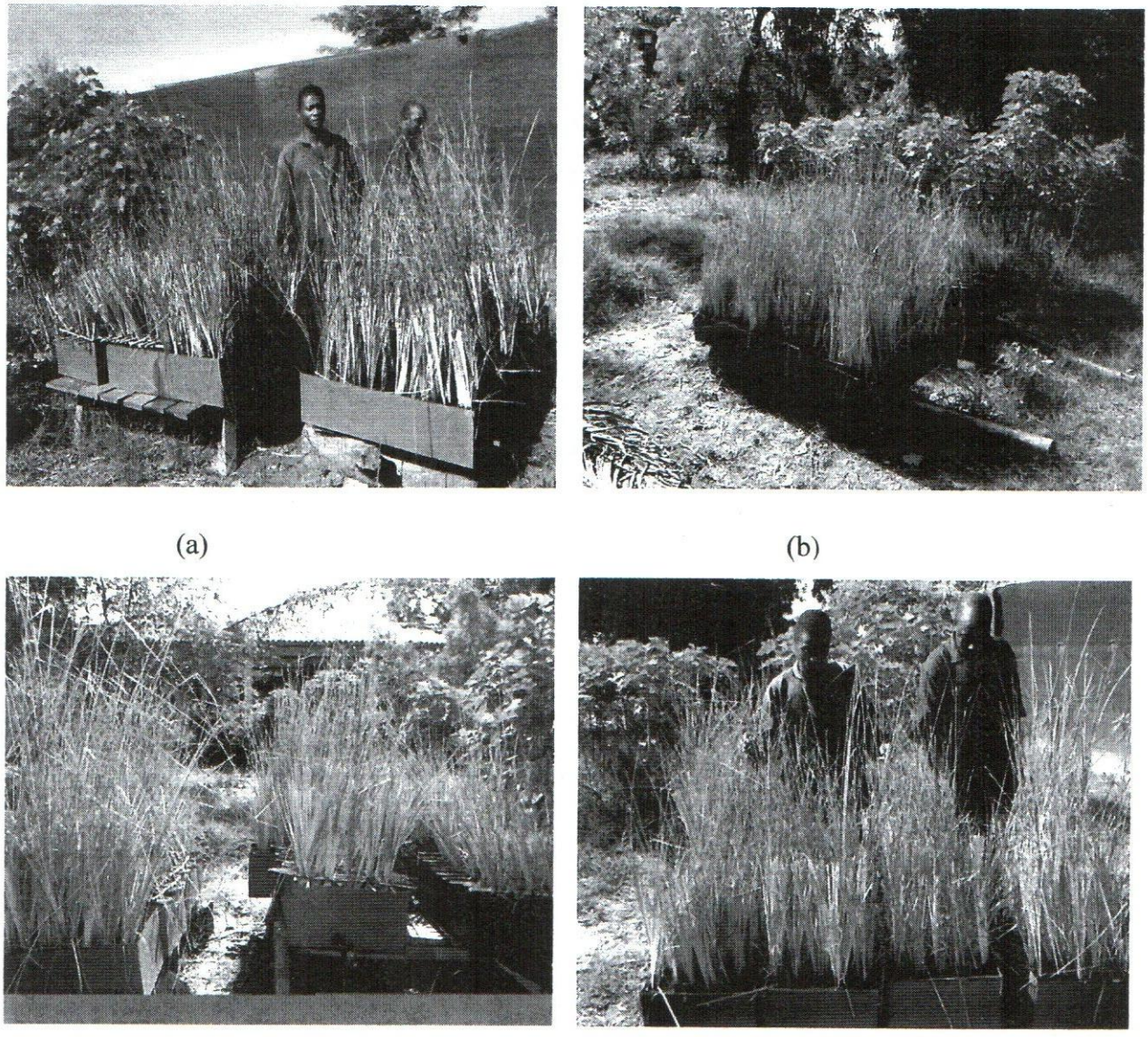


Figure 3.4: The hybrid treatment unit

After transplanting, the plants in all the units were nourished with diluted sewage of similar characteristics and quantity for four weeks.

The control for this experiment consisted of empty metallic boxes of similar dimensions as the ones used in the cases above. It was neither established with any vetiver plants nor filled with soil but just left open to the atmosphere to mimic a miniature waste stabilization pond. During the experiment, they too were supplied with wastewater of similar and equal amounts to the other treatments, which was detained for the same duration of time as the rest.

Figure 3.5 below contains the pictures of the various complete treatment units from different views four weeks after the plants had been transplanted.



(a) (b)

(c) (d)

Figure 3.5: Plates showing the vetiver plants in the treatment units four weeks after transplanting Note the bamboo stick meshwork for the hydroponics in photograph (c).

A Completely Randomized Design (CRD) experiment was applied in this experiment. It consisted of the three treatments and a control, replicated thrice. Trial runs commenced four weeks after transplanting the plants in the boxes. Six trial runs of the experiments were made. In

each trial run, a drum that acted as a common reservoir was filled with wastewater sourced from the septic tank serving the University's Resource Centre. The wastewater was first sampled before gently pouring 40 litres of it at the upper end of each unit. Effluents from the units were sampled after every 3, 5 and 7 days as per the recommendations of Bonsoon and Chansiri (2005). This was achieved by unclogging the pipe outlets and drawing the outflow. Before a new charge of wastewater was applied for the next trial run, each of the units was flushed with excess fresh water to minimize amounts of residual pollutants. Samples collected for each trial run were put in darkened plastic bottles (covered with an aluminium foil) and immediately refrigerated at 4°C as recommended by Owino (2002). They were taken for testing within two hours after collection.

3.3 Effects of the Vetiver Systems on the Wastewater Parameters

The raw and treated samples were taken for chemical analysis at the Mombasa Water and Sewerage Company Laboratories. Standard Methods for the Examination of Water and Wastewater (Andrew, *et al.*, 2005) were adopted. The samples were analyzed for Total Kjeldahl Nitrogen (TKN), Orthophosphate-Phosphorous (PO_4-P), Total Suspended Solids (TSS), BOD and COD as outlined in the following subsections.

3.3.1 Effects of the Systems on the Level of Total Nitrogen

The concentration of nitrogen in the wastewater was determined as Total Kjeldahl Nitrogen (TKN). Total nitrogen is the sum of Kjeldhal nitrogen and the oxidized nitrogen. There being no oxidized nitrogen present in domestic wastewater the Kjeldhal nitrogen is equal to the total nitrogen (Weiner and Mathews, 2007). The method used consisted of heating the sample in sulfuric acid, which decomposed its organic content by oxidation to liberate the reduced nitrogen as ammonium sulfate. Potassium sulfate was added in order to increase the boiling point of the medium (169°C to 189°C). When the solution became clear and colourless (end of the reaction), it was then distilled with sodium hydroxide (added in small quantities) to convert the ammonium salt to ammonia. The amount of ammonia (hence the amount of nitrogen) present in the sample was determined by back titration. This involved dipping the end of the condenser into a solution

of boric acid. The ammonia reacted with the acid and the remainder of the acid was then titrated with a sodium carbonate solution with a methyl orange pH indicator. The processes can be expressed by the following chemical reactions:

Degradation: Protein + $H_2SO_4 \rightarrow (NH_4)_2SO_4(aq) + CO_2(g) + SO_2(g) + H_2O(g)$ (3.4)

Liberation of ammonia: $(NH_4)_2SO_4(aq) + 2NaOH \rightarrow Na_2SO_4(aq) + 2H_2O(l) + 2NH_3(g)$ (3.5)

Capture of ammonia: $B(OH)_3 + H_2O + NH_3 \rightarrow NH_4^+ + B(OH)_4^-$ (3.6)

Back-titration: $B(OH)_3 + H_2O + Na_2CO_3 \rightarrow NaHCO_3(aq) + NaB(OH)_4(aq) + CO_2(g) + H_2O$ (3.7)

$$Nitrogen(mg/L) = mgN * 1000/mL\ sample \quad (3.8)$$

where;

mgN = quantity of nitrogen in the sample in milligrams

mL sample = volume of the sample in millilitres

The results are given in Table 4.2.

3.3.2 Effects of the Systems on the Levels of Total Phosphorous

The total phosphorus content was determined by first digesting samples in an acid persulphate solution. This involved heating the sample in sulfuric acid with potassium persulphate. The digested sample containing orthophosphate reacts with Ammonium Molybdate to form heteropoly Molybdophosphoric acid. The Stannous chloride method was then used to test for the resulting orthophosphate content. In this method, the Molybdophosphoric acid was reduced by stannous chloride to intensely coloured molybdenum blue. The reagents used included Phenolphthalein indicator aqueous solution, strong-acid solution, Ammonium molybdate reagent, standard phosphate solution and stannous chloride reagent I. A drop of phenolphthalein indicator was added to 100 ml sample, then the sample diluted depending on the colour range. 4.0 ml Molybdate reagent I and 0.5 ml of the stannous chloride reagent I was added with thorough mixing after each addition. After 10 to 12 minutes the colour was measured photometrically at 690 nm and compared with the calibration curve using distilled water blank. Phosphate concentration was then calculated using the equation:

$$Phosphate(mg/L) = mgP * 1000/mL\ sample \quad (3.9)$$

Where:

mgP = quantity of phosphorous in the sample in milligrams

mL sample = volume of the sample in millilitres

The results are presented in Table 4.3.

3.3.3 Effects of the Systems on the Level of Total Suspended Solids

In the determination of total suspended solids, the Whatman glass fiber filter with a nominal pore size of 1.5μm was used. It was dried, weighed and placed onto a filtering flask – wrinkled side up. The sample bottle was first shaken before the water (500ml) got poured on to the filter. The suction pump was turned on and the water forced through the filter. The volume of water filtered was noted. The filter was dried for one hour at 105° C. It was left to cool to room temperature, and weighed. Further drying and reweighing was done until the fiber reached a constant weight, which was noted. The increase in weight represented TSS. The TSS was calculated by using the equation below.

$$TSS\ (mg/L) = [(A - B) * 1000]/C \quad (3.10)$$

Where:

A = End weight of the filter

B = Initial weight of the filter

C = Volume of water filtered

These results are presented in Table 4.4.

3.3.4 Effects of the Systems on the Levels of BOD

Level of BOD in both the raw and treated wastewater was determined from wastewater samples drawn from the treatment units. The apparatus used for the determination of the BOD level consisted of incubation bottles, an air incubator that was thermostatically controlled at 20±1°C, a

1 liter volumetric flask, a 500 ml beaker and a dissolved oxygen meter. The reagents consisted of a phosphate buffer solution, magnesium sulfate solution, a calcium chloride solution, a ferric chloride solution, dilute sulphuric acid and a sodium hydroxide solution.

The procedure involved the preparation of 'dilution water' by adding 1mL each of phosphate buffer, magnesium sulfate, calcium chloride and ferric chloride solution into a 1L volumetric flask and filling to one liter with distilled water. 1mL wastewater sample was put into a 500mL beaker and dilution water added up to 300mL into the same beaker. The pH value was adjusted to between 6.5 and 7.5 by adding acid/alkali. 300mL dilution water was prepared as control and all prepared samples and control were put in a 300mL-incubation bottle. The DO for each sample was measured by using Dissolved Oxygen Meter and all the bottles put in the BOD incubator for 3, 5 and 7 days at a temperature of 20°C. The final DO value after each of the periods was measured and the BOD_n calculated according to the formula below:

$$BOD_n\ (mgL^{-1}) = (D_1 - D_2) * Dilution\ factor, \qquad (3.11)$$

Where:

D_1 = DO value in initial sample

D_2 = DO value in final sample

Dilution factor = Bottle volume (300mL) / Sample volume

n = Number of days the samples were incubated

3.3.5 Effects of the Systems on the Levels of COD

In the determination of the COD level, reagents used were Potassium dichromate (Standard solution): $K_2Cr_2O_7$ –0.004167 M (0.0250 N), Mohr's Salt· Ferrous ammonium sulphate (Standard solution): $FeSO_4$. $(NH_4)_2SO_4$ (0.025 M), Mercuric Sulphate: Powdered $HgSO_4$, Silver Sulphate: Powdered Ag_2SO_4, Phenanthroline ferrous sulphate indicator solution and Concentrated Sulphuric acid: 18 Molar H_2SO_4.

A sample of 50mL was taken into a refluxing flask and several boiling stones added. 0.1 g $HgSO_4$ was added to the solution. 5 ml of concentrated H_2SO_4 was also added to the solution. To ensure that $HgSO_4$ dissolved completely, the solution was swirled slowly while adding sulphuric acid. 0.1 g of Silver Sulphate (Ag_2SO_4) was added to this solution. Finally Potassium dichromate was added. Thorough mixing of the solution was ensured by swirling the flask in a water bath to recover any volatile substances that may have escaped from the liquid state. The flask was then attached to the condenser and further cooling was done. 20 ml of sulphuric acid was added to the solution in the flask continuing with cooling and swirling to mix the solution. The solution was refluxed for 1 hour. A blank run (using 50 ml distilled water instead of sample) was simultaneously conducted with the same procedure after cooling; the solution was transferred to an Erlenmeyer flask. The reflux flask was rinsed thrice, pouring the rinsing water to the Erlenmeyer flask. The solution was diluted to about 300 ml and about 8 drops of Phenanthroline ferrous sulphate was added to the solution as an indicator. The solution was titrated against the Mohr's salt and the titer volume required for the color change from blue-green to reddish blue was noted. The procedure was repeated for the blank run. In each case, the COD was calculated by the equation:

$$COD = 8000 * (V_{bl} - V_s) * M/V_o \quad (3.13)$$

Where;

V_{bl} = Titer volume for the blank

V_s = Titer volume for the sample

M = Molarity of Mohr's solution

V_O = Original volume of sample taken mg/l

The results are given in Table 4.5

3.4 Effects of Contact Period on the Wastewater Parameters

To monitor the effect of contact period on the levels of the various parameters, results of the initial analysis of the wastewater before application to the treatment units were recorded under day zero (initial). The results of the analysis of treated samples collected after 3, 5 and 7 days

(Bonsoong and Chansiri, 2005) were recorded under their respective contact time. The analysis was carried out as described in section 3.3. The overall results, presented in Tables 4.10-4.14, were later analyzed statistically.

3.5 The Effect of Vetiver's Age on the Wastewater Parameters

To study the effect of the age of the vetiver plants on the abilities of the systems to reduce pollutant levels in wastewater, the age of the plants since the commencement of the experiment (in weeks) was noted for each trial run. Since the experiment commenced when the plants had attained the age of four weeks in their units, the first trial run corresponded to a plant age of 4 weeks. Subsequent weekly trial runs corresponded to vetiver ages of 5, 6, 7, 8 and 9 weeks respectively. The mean of the pollutant levels in treated wastewater for each experimental run was taken to indicate the systems' ability to reduce pollutant levels at the corresponding age. The results are presented in Tables 4.15-4.19.

The effect of age on the performance of the systems was monitored alongside the changing quantity of biomass. Biomass changes were studied in terms of vertical growth rate. In order to study the growth rates in the experimental units, plant height was measured. The plants having been pruned to a uniform seedling height of 30cm at the onset had the height of selected stems measured on a weekly basis for four consecutive weeks. The selected stems were the five longest stems in each of the twelve rows of plants in each unit. Their mean growth rate was recorded to represent the mean growth rate for the particular unit. These observations are presented in Table 4.6.

3.6 Data Analysis

The percentage changes in the pollutant levels (P%) for each treatment were determined using the equation:

$$P(\%) = \frac{(C_r - C_t) * 100}{C_t} \qquad (3.14)$$

where ,

C_r is the pollutant concentration in raw wastewater and C_t is the pollutant concentration in treated wastewater.

The Statistical Analysis Software (SAS, 2008) was used to analyze the raw data pertaining to the levels of pollutants in the wastewater at 5% level of significance. To test the data relating to the differences in the performances of the vetiver systems relative to each other, four treatments were considered for the SAS system; the control (C), the hydroponic (H), the soil-based (S) and the hybrid (SH). These were in three replicates and run six times. The ANOVA procedure was then performed on the levels of pollutants of all the dependent variables TN, TP, BOD, COD and TSS. This was done separately for the three, five and seven days contact times. To test the data concerning the levels of pollutants in the wastewaters at the different contact periods, four treatments were considered; initial (0), three hour contact (3), five hour contact (5) and seven hour contact (7). These were in three replications with six trials of the experiment. For data regarding to the percentage pollutant level reduction in relation to the plants' age, six treatments of ages 4, 5, 6, 7, 8, and 9 weeks were considered, each in three replications.

CHAPTER FOUR
RESULTS AND DISCUSSIONS

4.1 Effects of the treatment systems on pollutant levels

The levels of Total Nitrogen, Phosphorus, Suspended Solids, BOD and COD T in the six batches of wastewaters before being supplied to the treatment units are presented in Table 4.1 below. The Appendix Table A5 shows the data for the characteristics of wastewater before and after treatment by the different treatment units.

Table 4.1: Pollutant levels (mg/L) in the raw wastewaters before loading onto the treatment units

RUN	DATE	TN	TP	TSS	BOD	COD
1	15/8/09	47.65	6.30	183.5	91.35	210.33
2	22/8/09	47.63	6.23	168.33	89.30	193.90
3	29/8/09	48.22	7.05	172.55	89.83	193.91
4	5/8/09	40.98	6.13	165.29	85.91	159.19
5	12/5/09	45.08	6.67	165.94	97.54	173.52
6	17/8/09	44.26	7.01	183.34	93.37	163.40
	Mean	**45.30**	**6.57**	**173.65**	**92.72**	**186.55**

NB: A run refers to every event of supplying a new batch of raw wastewater to the systems.

Over the experimental period, the table shows pollutant levels in the raw wastewater varied for each run/week. Generally, the levels were at their least in week four which coincided with the date when the area recorded a light rain shower of 3.5 mm, on 5th September, 2009. During this week, the TN, TP, TSS, BOD and COD were at their lowest levels of 40.98, 6.13, 165.29, 85.91 and 159.19 mg/L respectively. The reason for this could be that the septic tank from which the raw wastewater was sourced had its contents diluted by rainwater.

4.1.1 Effects of the Treatments on the Levels of Total Nitrogen

The mean levels of total nitrogen in the wastewater after the various treatments for the five day contact time are presented in Table 4.2 and Figure 4.1 below.

Table 4.2: TN levels in wastewater before and after five days in the treatment units.

Treatment	Initial TN Level	Final TN, (mg/L)	% Change
Control	45.64	33.7233[a]	26.14
Hydroponic	45.64	23.1122[b]	49.36
Hybrid	45.64	22.9228[b]	49.78
Soil based	45.64	19.5939[c]	57.07
LSD	1.4252		

*Means with the same letter in the same column are not significantly different at $\alpha = 0.05$

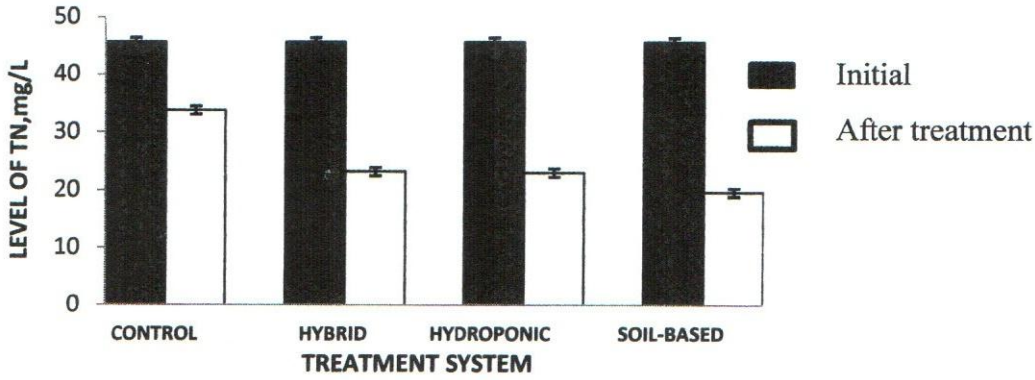


Figure 4.1: TN Levels in treated wastewater for a five-day contact period.

The mean levels of TN in the samples from the four treatments varied from a low of 19.6 mg/L for the soil-based unit to 33.7 mg/L for the control. The analysis of variance (ANOVA) computed using SAS Programme (Appendix A6) show that mean levels of total nitrogen in the samples from the four treatments were significantly different at 5% level of significance. A comparison of the means using the least significant difference (LSD) test at $P < 0.05$ indicated that the mean TN level for the control was significantly higher than for the hydroponic, hybrid

and soil based treatments. There were no significant differences between the mean TN levels in samples from the hydroponic and hybrid treatments, but the differences between either of them and the soil based were significant. The high mean TN level for the control relative to the rest confirmed the findings of other researchers such as Ash and Truong (2003), Mayorca (2005), Boonsong and Chansiri (2005) among others, that vetiver grass inclusion in the treatments boosts their nitrogen removal efficiency. The significant difference at $\alpha = 0.05$ in TN levels between the soil-based unit and either of the other two vetiver systems is indicative of the role of the soil medium as a matrix for nitrogen adsorption (Ogombe, 2001) in TN removal from wastewater. Xia (2002) noted that the reasons why constructed wetlands have high purifying rates for amoniacal nitrogen (AN) and by extension TN are probably due to the strong volatility of AN on one hand, and its easy uptake by plants on the other hand. This explains why the treatments containing vetiver performed better than the controls.

The observed TN removal rates are less than others posted from other researches over the same period, such as those by Kantawanichkul *et al* (1999), Njau and Mlay (2003). They reported that the total Kjedahl nitrogen was removed at rates of up to 90% and 83.8% respectively by constructed wetlands with vetiver grass, compared to the recorded maximum of 57.1% by the soil based system (Table 4.2). With regard to the Kenyan standards regarding guideline limits for wastewater discharge into public water, the effluent quality does not meet the level of 2 mg/L as dictated by the National Environment Management Authority (NEMA) regulations of 2006. (Appendix Table A3).

4.1.2 Effects of the Treatment Systems on the Levels of Total Phosphorus

Table 4.3 and Figure 4.2 show the mean levels of Total Phosphorous (TP) in the wastewater initially and after five days. The level of TP was least in the soil-based unit (4.4 mg/L) and highest in the control (5.4 mg/L). These results are in conformity with others from similar works by Boonsong and Chansiri (2005), Njau and Mlay (2003) among others, since they indicate that although vetiver boosts the abilities of aquatic systems to remove phosphorous from wastewater, the performance is generally low. Despite this performance, the achieved TP levels for all the

treatments fail to meet the standards of a maximum of 2 mg/L set by NEMA (2006) for wastewater discharges into public water.

Table 4.3: TP levels in wastewaters before and after five days in the treatment units

Treatment	Initial TP	Final TP, mg/L	% Reduction
Control	6.57	5.4228[a]	21.16
Hydroponic	6.57	4.6539[b]	41.17
Hybrid	6.57	4.6422[b]	41.53
Soil based	6.57	4.4050[c]	49.15
LSD		0.2228	

*Means with the same letter in the same column are not significantly different at $\alpha = 0.05$

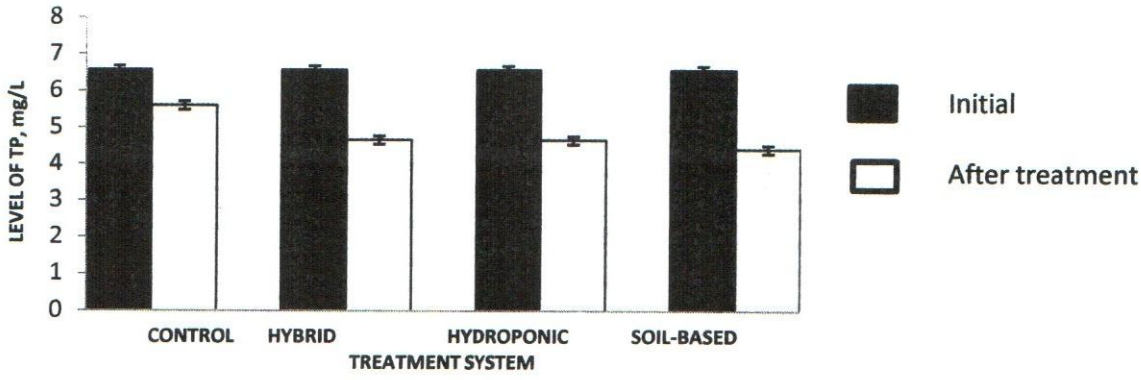


Figure 4.2: TP levels in the treated wastewaters for a five-day contact period

ANOVA revealed that the mean levels of total phosphorus were significantly different at 5% significance level (Table 4.3). They were significantly higher for the control than all the rest, and between the soil-based treatment and both the hydroponic and the hybrid. There was no significant difference in the means between the hydroponic and the hybrid treatment. The explanation as to why the hybrid and hydroponic (without soil) techniques reduced lesser phosphorus than the soil-based one is obtained from the findings of Boonsong and Chansiri (2005), who observed that phosphorus in wastewater is removed through the processes of sedimentation and burial, adsorption and precipitation, and exchange processes between soil and

the overlying water column. Headly and Tanner (2006) further explained that phosphorus removal by floating wetlands (relative to the other wetland systems) is poor partly due to the lack of a substrate for adsorption of PO_4. The soil in the soil-based treatment therefore availed a medium for burial and adsorption of phosphorus, hence enabling it to perform better. Experimental units planted with vetiver plants achieved lower TP levels than the control units because they could absorb phosphate-P and their roots could slow water velocity. This increased TP removal through sedimentation of organic phosphorus rather than plant uptake, since past studies show that plants contribute very little in phosphorus removal, only about 3% (Mng'anya *et al.*, 2001). This means that removal mechanisms in the units containing vetiver were mainly sedimentation of particulate phosphorus aided by good substrate porosity and followed by the sorption of soluble phosphorus.

4.1.3 Effects of the Treatment Systems on the Levels of Total Suspended Solids

The results for the mean levels of the total suspended solids (TSS) in the wastewater samples after five days are presented in table 4.4 and figure 4.3 below.

Table 4.4: TSS levels in wastewater before and after five days in the treatment units

Treatment	Initial TSS Levels	Final TSS Levels	% Reduction
Control	173.65	99.926[a]	42.46
Hydroponic	173.65	81.317[b]	53.17
Hybrid	173.65	80.531[b]	53.62
Soil based	173.65	73.412[c]	47.72
LSD		4.0385	

*Means with the same letter are not significantly different at $\alpha = 0.05$

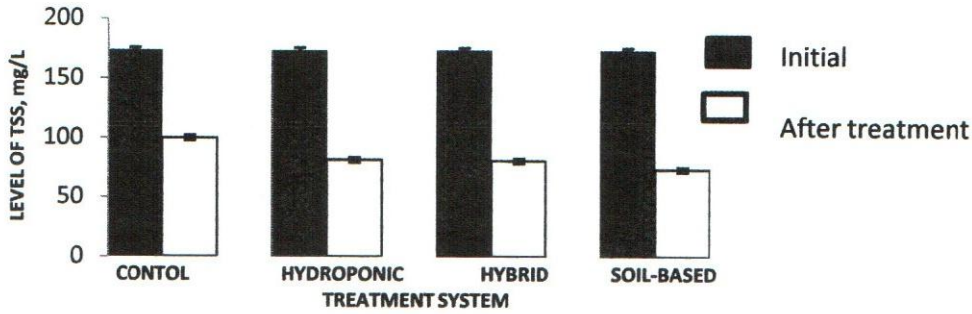


Figure 4.3: TSS levels in the treated wastewaters for a five-day contact period

The mean levels of TSS were significantly different at 5% significance level for the various treatments. The mean for the control was significantly higher relative to the rest of the treatments. The differences between the mean of the soil-based unit on one hand, and the hydroponic and hybrid treatments on the other, were significantly different too. However the difference between TSS mean for the hybrid and the hydroponic treatments was insignificant.

These results indicate that vetiver plants play a significant role in the removal of suspended solids from wastewater. It is reported that total suspended solids are removed from secondary domestic wastewater mainly through the processes of settlement and filtration (Weiner and Mathews, 2007). The better performance exhibited by the vetiver containing units are therefore attributed to the contribution of vetiver roots in the trapping of suspended solids in the wastewater, and for continuous flow systems, the stabilization of the flow as explained by the works of Smith and Kalin (2000). In a study regarding the extent of the trapping of TSS by plant roots, they measured the mass of solids trapped amongst roots of a two year old floating *Typha* vegetation mat on an acid mine drainage pond. They estimated that a mature system would capture approximately 2.2 kg of solids per m^2 of floating vegetation and postulated that the actual long term trapping of suspended solids would be substantially higher. They argued that this was because the trapped solids would be periodically sloughed from the roots and settle to the bottom of the pond, thereby opening up more root surfaces for entrapment.

The soil-based treatment achieved significantly lower TSS levels owing to the contribution of the soil medium, which acted as a filter for the solid particles. Njau and Mlay (2003) obtained a

mean TSS removal rate of 81.4% compared to 57.6 % posted by the soil-based treatment in this research study. The wide variation may be attributed to the differences in the medium (soil) properties and plant density. The achieved minimum TSS level of 73.4 by the soil based system is far beyond the stipulated maximum level of 30 mg/L in NEMA (2006) for wastewater discharges into public water sources in Kenya. Longer contact times, deeper medium and higher plant densities could help achieve the stipulated levels.

4.1.4 Effects of the Treatment Systems on Levels of Biological Oxygen Demand

The levels of the five day biological oxygen demand (BOD_5) in the wastewater samples initially and after five days are presented in Table 4.5 and Figure 4.4 below.

Table 4.5: BOD_5 levels in wastewater before and after five days in the treatment units

Treatment	Initial BOD_5 Level	Final BOD_5 Level	% Reduction
Control	92.72	56.865^a	38.66
Hydroponic	92.72	31.342^b	66.20
Hybrid	92.72	28.788^c	68.94
Soil based	92.72	22.698^d	75.51
LSD		2.2908	

*Means with the same letter in the same column are not significantly different at $\alpha = 0.05$

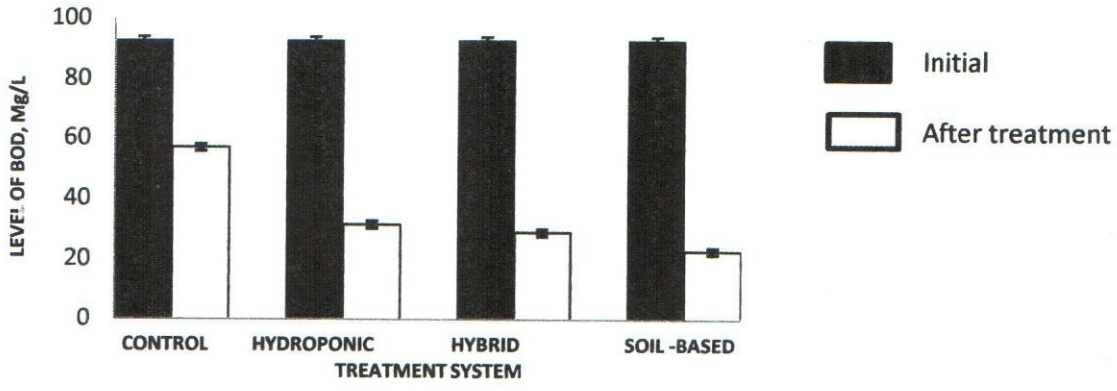


Figure 4.4: BOD levels in the treated wastewater for a five-day contact period

The mean level of BOD_5 is shown to have varied by a wide range from 22.7 mg/L as posted by the subsurface unit to 56.9 by the control. The treatment means were found to be significantly different at $\alpha = 0.05$. The difference in the mean BOD levels between the control treatment mean and the next nearest mean (56.9 and 31.3 mg/L) was considerably high. This showed the extent of the beneficial effect of including vetiver in biological wastewater treatment plants. The results are in conformity with others from other research studies (Njau and Mlay, 2003; Boonsong and Chansiri, 2005). The four researchers reported BOD level reductions of 67.4 and 91.5 % respectively against the maximum of 75.2% achieved by the soil-based unit in this research study (Table 4.5). The BOD levels of 22.7 and 28.8 achieved by the soil based and hybrid systems respectively meet the standards of a maximum 30 mg/L stipulated by Kenyan authorities in NEMA (2006).

Njau and Mlay (2003) explained these achievements by stating that aquatic plants support the BOD level reduction processes by availing atmospheric oxygen in their submerged stems, roots and tubers, which is then utilized by the microbial decomposers attached to them below the level of the water to digest the organic matter in wastewater. These results also implied that the use of the soil medium impacted positively on the abilities of the units to lower the level of BOD in wastewater, since the hybrid and the soil based units reduced this level by greater margins. This observation can be attributed to the input of the soil medium in form of either better nutrition for the plants, or playing host to a wider variety of microorganisms that digest the organics (Gray, 2009). The postulation of better nutrition is evidenced by the relatively faster biomass development observed for plants in soil-based units. The differences in plant heights in the soil based and hydroponic systems, which was used to infer growth rate, were significantly different at $\alpha = 0.05$. Table 4.6 shows the variation of plant heights with time, weeks.

Table 4.6: Plant heights at beginning of each week, in centimetres

Treatment	Plant height, cm						
	Wk1	Wk2	Wk3	Wk4	Wk5	Wk6	Mean
Soil Based	30.0	47.5	61.9	75.8	82.3	97.6	**65.85[a]**
Hybrid	30.0	41.2	62.1	73.6	80.3	95.9	**63.85[ab]**
Hydroponic	30.0	38.5	61.2	72.5	78.4	95.1	**62.62[b]**
LSD							**2.14**

*Means with the same letter are not significantly different at $\alpha = 0.05$

4.1.5 Effects of the Treatments on the Levels of Chemical Oxygen Demand

The mean levels of Chemical Oxygen Demand (COD) in the samples drawn from the treatment units for the five days' contact time were determined and subjected to ANOVA at 5% significance level. The results are presented in Table 4.7 and Figure 4.5. The data pattern is similar to that exhibited for the other pollutants where vetiver containing treatments attained lower pollutant levels as compared to the control, while the soil-based vetiver system attained the least. The control treatment had the highest mean COD levels at 121.87 mg/L while the soil-based unit had the lowest at 55.194 mg/L.

Table 4.7: COD levels in wastewater before and after five days in the treatment units

Treatment	Initial COD Level	Final COD, mg/L	% Reduction
Control	186.55	121.874[a]	34.67
Hydroponic	186.55	67.615[b]	63.76
Hybrid	186.55	64.899[b]	65.21
Soil based	186.55	55.194[c]	70.41
LSD		3.8386	

*Means in the same column with the same letter are not significantly different at $\alpha = 0.05$

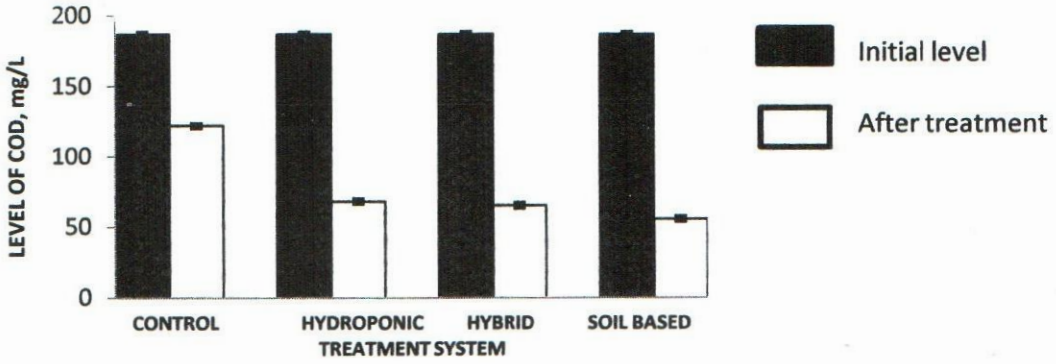
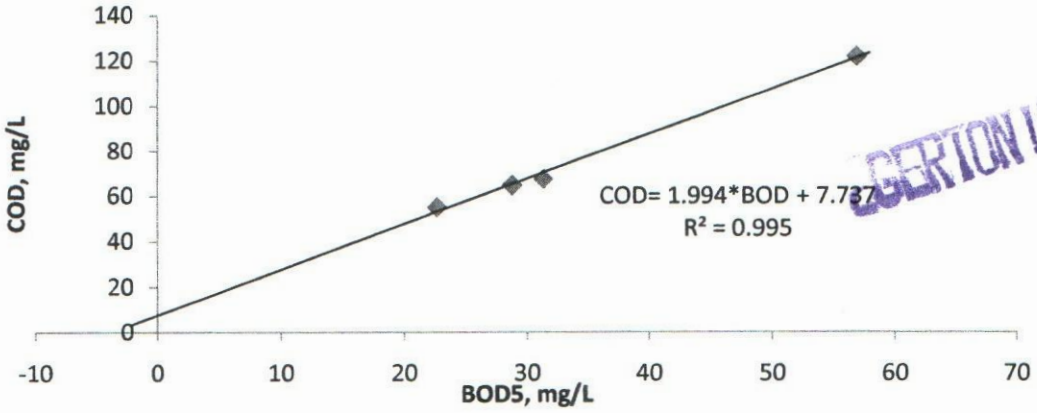


Figure 4.5: COD levels in the treated wastewaters for a five-day contact period

None of these treatments achieved the Kenyan standard maximum level of 50 mg/L for wastewater discharges into public water sources as stipulated by NEMA (2006). The differences in the final levels of COD were significant between the control and all the other treatments, and between the soil-based treatment and both the hydroponic and hybrid systems. There were no significant differences between the means for the hydroponic and the hybrid treatments. The change in COD levels in wastewater is known to correlate closely with the BOD and either can be statistically estimated from the other (Linsley and Franzini, 1979). In this particular case, the two are related with a strong correlation of 0.995 (Figure 4.6) by:

$$COD = 1.994 * BOD_5 + 7.737 \text{ mg/L} \qquad \text{Eqn 4.2}$$



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Figure 4.6: The COD-BOD_5 Regression Line

The graph indicates that even if the BOD level was to be reduced to zero, COD would still have a value. In a study on the removal of COD by wetlands, Revitt *et al.* (1997) found that the wetland systems achieved a mean COD concentration reduction of 31%. The authors hypothesized that COD removal occurred through the process of filtration of particulate organics by the root system hanging beneath the rafts. This explains why the units containing vetiver plants achieved lower COD levels, and therefore better results, than the control. This treatment effect was enhanced by the soil medium in the soil-based medium, explaining why it achieved the lowest levels of COD. The highest COD removal rate achieved by this research stood at 69.74% as achieved by the soil-based treatment, in comparison to 37.9% achieved by Njau and Mlay (2003). However, their system was a vertical flow one, compared with the horizontal flow employed system for this research.

4.2 Effects of Contact Period on Pollutant Reduction

To study the effects of the contact period, levels of pollutants in wastewater samples from each system were determined at the start and then after three, five and seven days respectively.

4.2.1 Effects of Contact Time on the Levels of Total Nitrogen

Table 4.8 below gives the mean TN levels in wastewater samples from the different treatments for the zero (initial), three, five and seven days contact periods.

Table 4.8: Levels of Total Nitrogen in the wastewater for different contact periods

Contact periods,	Level of TN, mg/L			
(days)	Control	Hydroponic	Hybrid	Soil based
0 (Initially)	45.30^{a}	45.30^{a}	45.30^{a}	45.30^{a}
3	39.83^{b}	33.45^{b}	32.43^{b}	30.01^{b}
5	33.72^{c}	23.11^{c}	22.92^{c}	19.59^{c}
7	31.20^{d}	19.69^{d}	18.70^{d}	14.76^{d}
LSD	1.3592	1.8537	1.8411	2.0697

*Means followed by the same letter in the same column are not significantly different at $\alpha = 0.05$

The least level of TN achieved (by the soil-based system) was 14.6 mg/L for the 7-day contact period. The TN levels for each of the contact periods differed significantly across the systems. With regards to the control, this shows that natural purification that goes on even without human intervention. For all the systems, the means for all the contact periods were significantly different. The longest contact period of 7-days resulted in the least TN levels, in agreement with the assertions of Boonsong and Chansiri (2005). They reported that of the four retention times they tested in their study, the 7-day one was ideal for the operation of hydroponic vetiver wastewater treatment systems. The levels of TN in the vetiver experimental systems were lower than those in the controls. This showed that if a limiting contact period of say 5 days was applied; planting with vetiver would be very beneficial, as attested to by the works of Bonsoong and Chansiri (2005), Mayorca (2007), Xia *et al* (2003), among others. These results imply that under the prevailing weather and other conditions, contact period impacts substantially on the performance of a system regardless of its type. It means that even without the intervention of artificially engineered systems, wastewater would naturally get cleansed if left exposed to the environment for a sufficiently long period. Figure 4.7 shows the trend followed by the various treatments in the reduction of TN in wastewater.

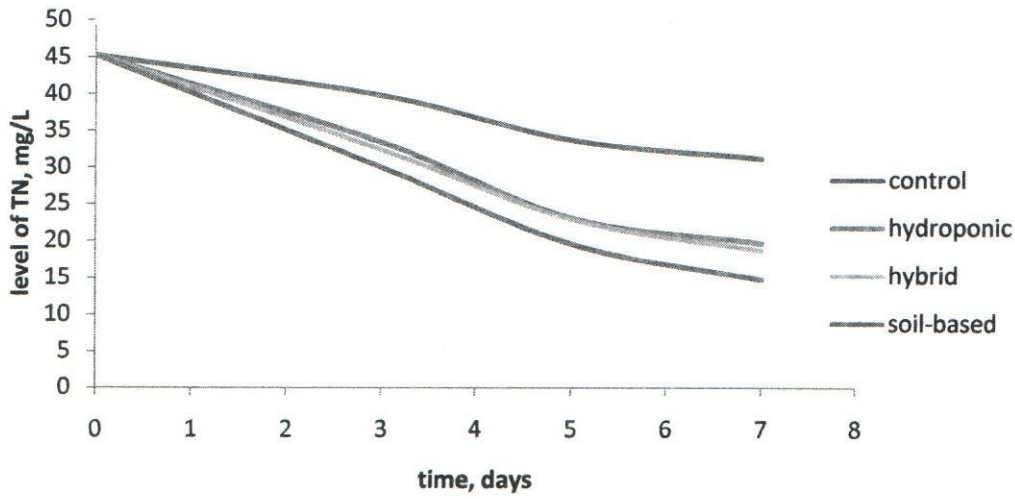


Figure 4.7: Variation of the level of Total Nitrogen with time

The trends indicate that the amount of TN removed from wastewater reduced with increasing contact period for all the treatment systems. The shape of the curve leads to the conclusion that

in the long run, the performance rate of each of the systems would approach their limiting value. These results were confirmed to conform, with a strong correlation of 0.991 to the exponential equation 2.11 by Liao et al., (2002):

$$Y_t = Y_0 * e^{-kt};$$

Where:

$Y_0 = 45.30$ mg/L is the initial concentration of the pollutant (TN);

Yt is the concentration at any time; and

k is the degradation constant.

The values of the degradation constant 'k' were found for the treatment systems using linear regression of the above equation transformed into the form:

$$lnY_t = -kt + lnY_0 \qquad 4.1$$

These exponential and regression relationships for the soil-based system are shown in Figures 4.8 and 4.9. Similar graphs for the control, hydroponic and hybrid systems are presented in Appendix Figure A1.

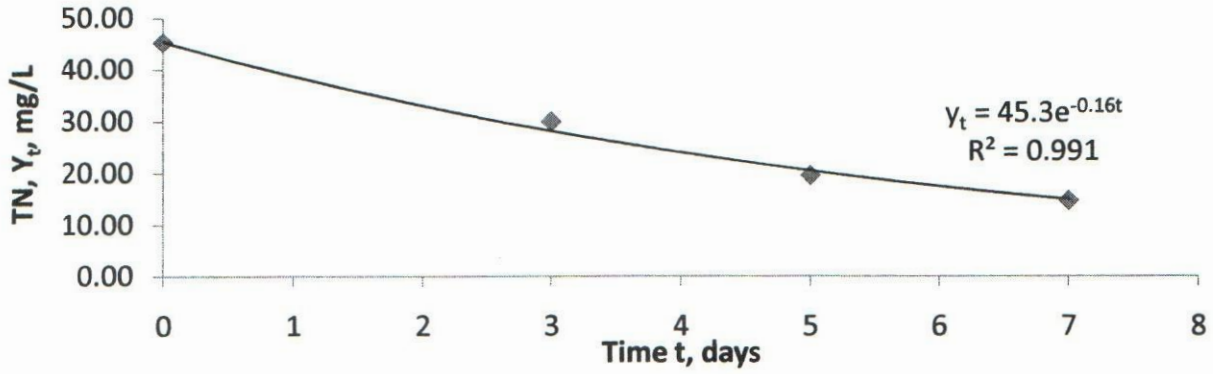


Figure 4.8: The Exponential Relationship Curve for the Soil Based System for TN

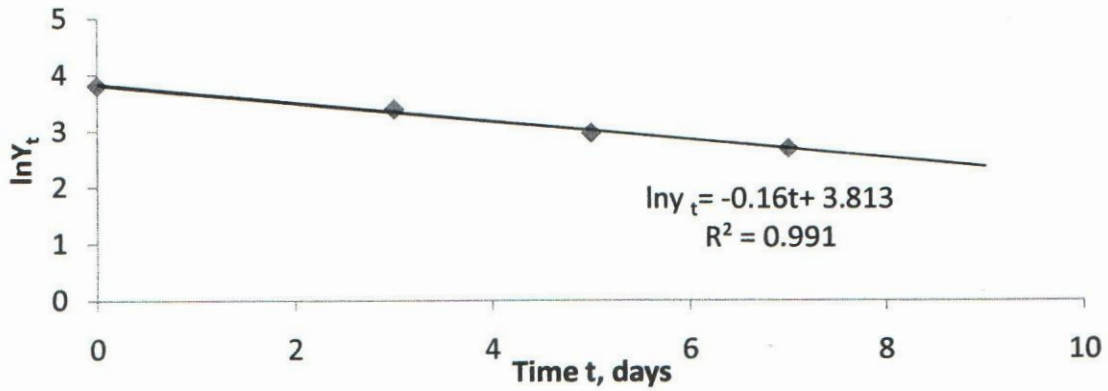


Figure 4.9: The Linear Regression Form of the Decay Equation for the Soil Based System, TN

The values of 'k' for the control, hydroponic, hybrid and soil based systems were determined to be 0.053, 0.121, 0.127 and 0.160 respectively for reduction of total nitrogen levels. From these findings, the required contact times require to achieve the NEMA standards of 2 mg/L were determined using equation 2.11 as being 58.9, 25.8, 24.6 and 19.5 days for the control, hydroponic, hybrid and soil based systems respectively. To reduce these times, it is suggested that higher plant densities be used for the vetiver systems.

4.2.2 Effect of Contact Time on the Levels of Total Phosphorous

Table 4.9 below contains the mean total phosphorus levels of the samples drawn from the treatment systems for different contact periods. It shows that treatments containing vetiver plants had higher mean TP removal rates than the control. The TP levels decreased with contact time for all the systems, with the minimum being 3.5372 mg/L for the soil-based over the 7-day contact period. As noted by Boonsong and Chansiri (2005), the TP reduction rates are generally low (from 3.53 mg/L for soil based system), owing to its predominant removal mechanisms. Phosphorous removal is done less by plant intake. Statistical analysis indicated that the differences between treatment means were significant for all the contact periods for each treatment. This shows that contact period does significantly influence the reduction of TP levels in wastewater.

Table 4.9: Levels of Total Phosphprus in wastewater for different contact times

Contact periods, (days)	Level of TP, mg/L			
	Control	hydroponic	Hybrid	soil based
0 (Initially)	6.5650[a]	6.5650[a]	6.5650[a]	6.5650[a]
3	6.0706[b]	5.6333[b]	5.5872[b]	5.3539[b]
5	5.4428[c]	4.6539[c]	4.6422[c]	4.4050[c]
7	4.8494[d]	3.9462[d]	3.7400[d]	3.5372[d]
LSD	0.211	0.2467	0.2428	0.2422

*Means followed by the same letter in the same column are not significantly different at $\alpha = 0.05$

Figure 4.10 shows the TP removal trends exhibited by the various treatments.

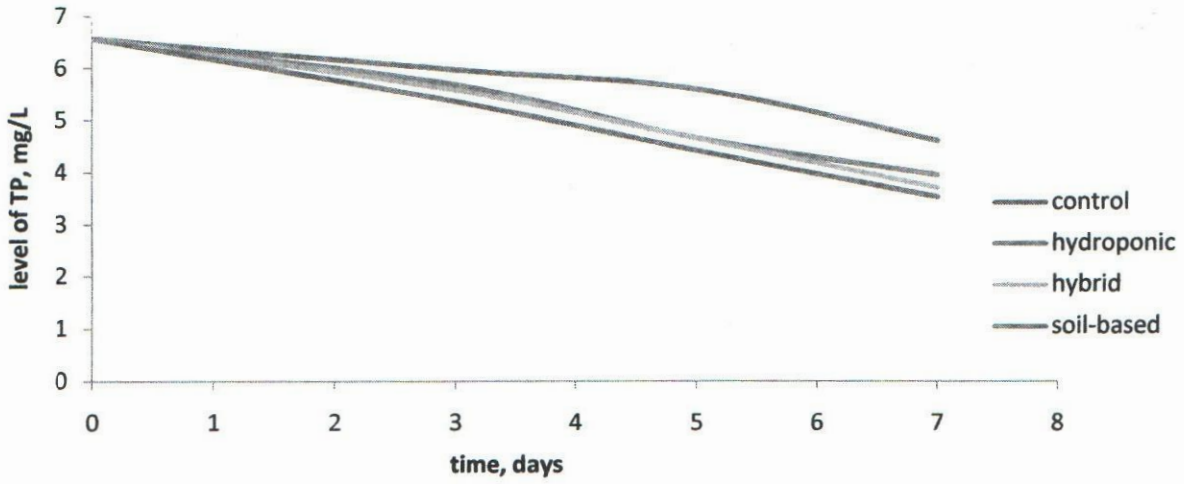


Figure 4.10: Variation of the level of Total Phosphorus with time

The trend reveals that for all the vetiver treatments, the slopes of their curves, which represent treatment rates, became steeper, albeit slightly after the third day. This suggests that the intervention of the plants in the reduction of TP levels was felt after the third day. The reduction of the levels of total phosphorous too obeyed equation 2.11 as revealed by figures 4.11 and 4.12 for the soil based system.

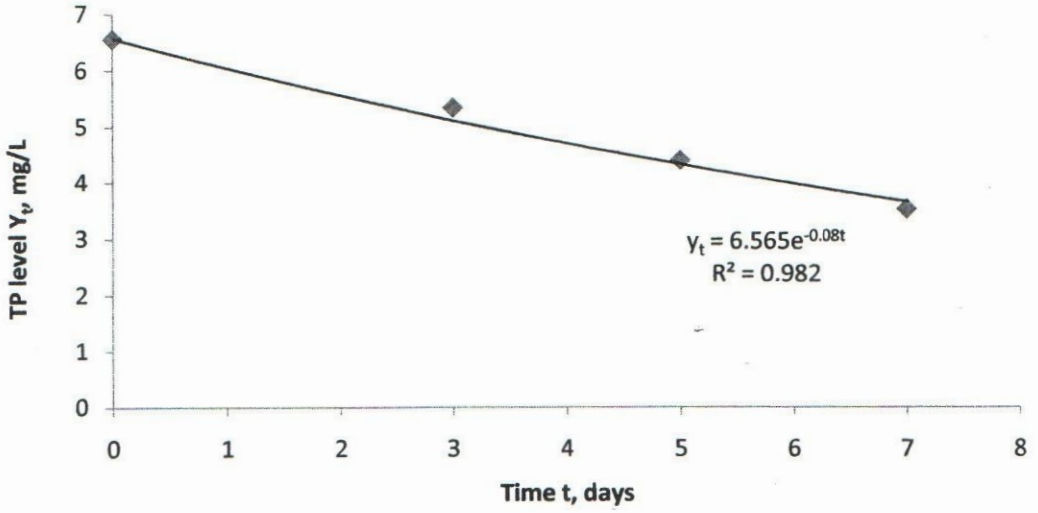


Figure 4.11: The Exponential Relationship Curve for the Soil Based System for TP

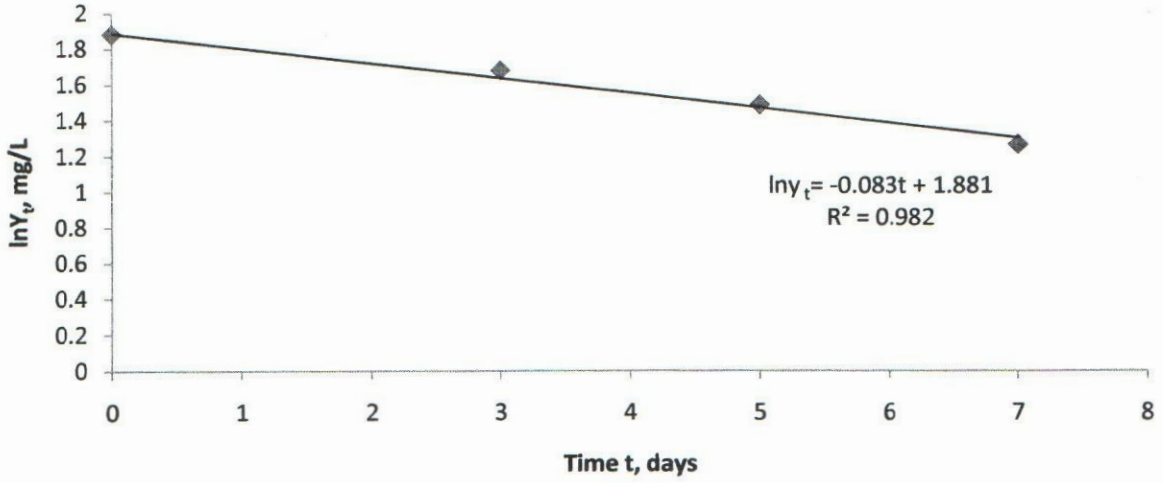


Figure 4.12: The Linear Regression Form of the Decay Equation for the Soil Based System, TP

The exponential and linear forms of the other vetiver systems are shown in Appendix Figure A2. The degradation constants for the control, hydroponic, hybrid and soil based systems were determined empirically as 0.039, 0.069, 0.074 and 0.083 respectively. These lead to the prediction of the contact time required to achieving NEMA limits of maximum 2 mg/L as 30, 17, 16 and 14 days for the control, hydroponic, hybrid and soil based units respectively.

4.3.3 Effect of Contact Time on the Levels Total Suspended Solids

The mean levels of TSS in the wastewater samples drawn from the various treatment units at different times are presented in Table 4.10 below.

Table 4.10: Levels of Suspended Solids in wastewater for different contact times

Contact periods	Level of TSS, mg/L			
(days)	Control	hydroponic	Hybrid	soil based
0 (Initially)	173.653[a]	173.653[a]	173.653[a]	173.653[a]
3	137.082[b]	119.982[b]	116.947[b]	106.568[b]
5	99.926[c]	81.317[c]	80.531[c]	73.317[c]
7	90.273[d]	70.145[d]	68.393[d]	61.248[d]
LSD	6.9607	7.9258	7.41	7.8171

*Means followed by the same letter in the same column are not significantly different at $\alpha = 0.05$

The least level of TSS obtained was 61.25 mg/L by the soil based system for the 7-day contact time. The reduction in COD level was relatively substantial for all the treatments by the third day, dropping by between 36.6 (control) and 67.1 mg/L (soil-based). The drop in the TSS levels on the third day is attributed to the settlement of the solids, most of which occurs within three days. Statistical analysis at 5% significance level revealed the existence of significant differences between all the means on the basis of contact period. The vetiver-based treatments recorded lesser TSS levels of 61.3 to 70.2, as compared to the control's 90.3 mg/L. This, according to Smith and Kalin (2000), are attributable to the contribution of the vetiver roots in trapping of solids. The contribution of the soil medium in the reduction of TSS level by the filtering action is responsible for the better performance by the treatments that contain it, relative to the purely hydroponic ones. Figure 4.13 reveals that TSS level reduction is reducing to a limit for every treatment, of about 60 mg/L for the soil based.

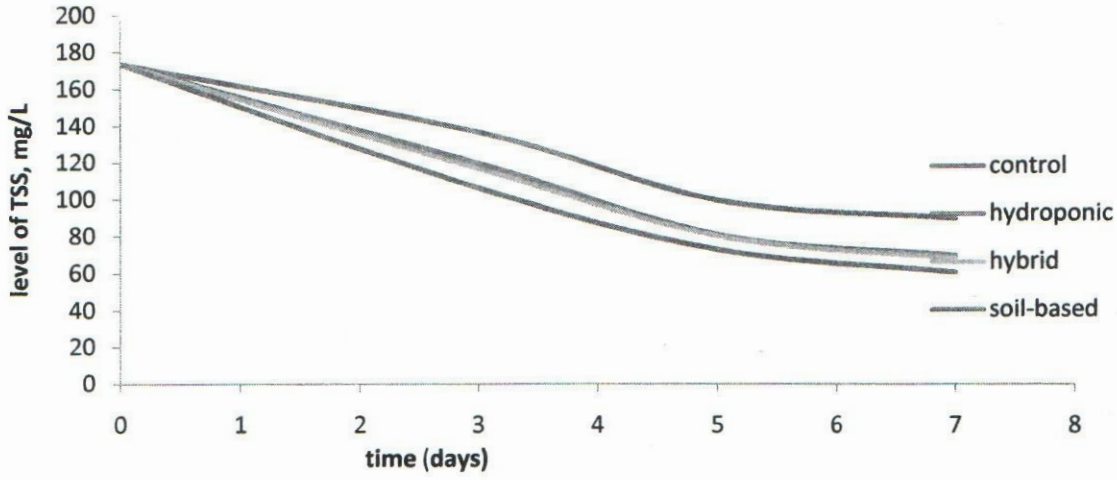


Figure 4.13: Variation in the level of Total Suspended Solids with ime

Figures 4.14 and 4.15 exhibits the exponential and the linear regression graphs that describe the TSS level a function of contact time, for the soil based system. More such graphs for the other systems are shown in Appendix Figure A3.

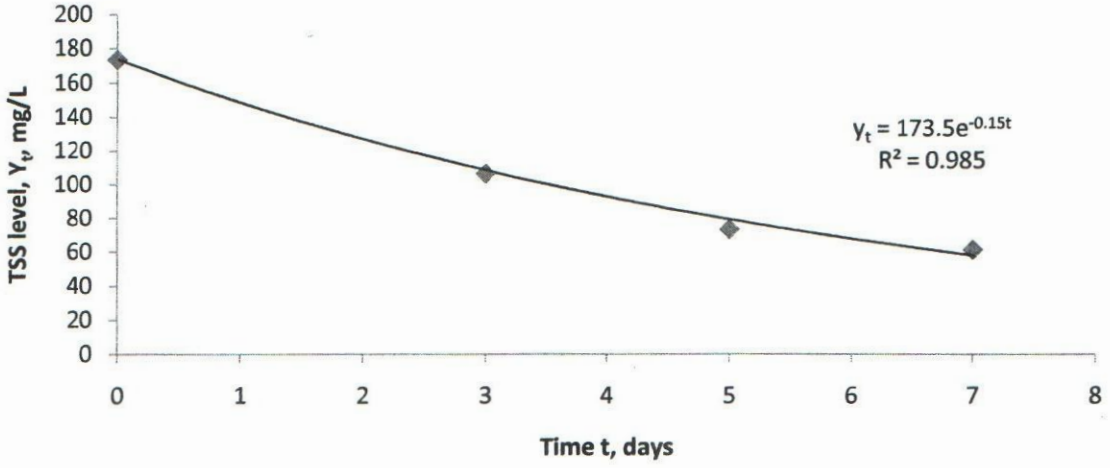


Figure 4.14: The Exponential Relationship Curve for the Soil Based System for TSS

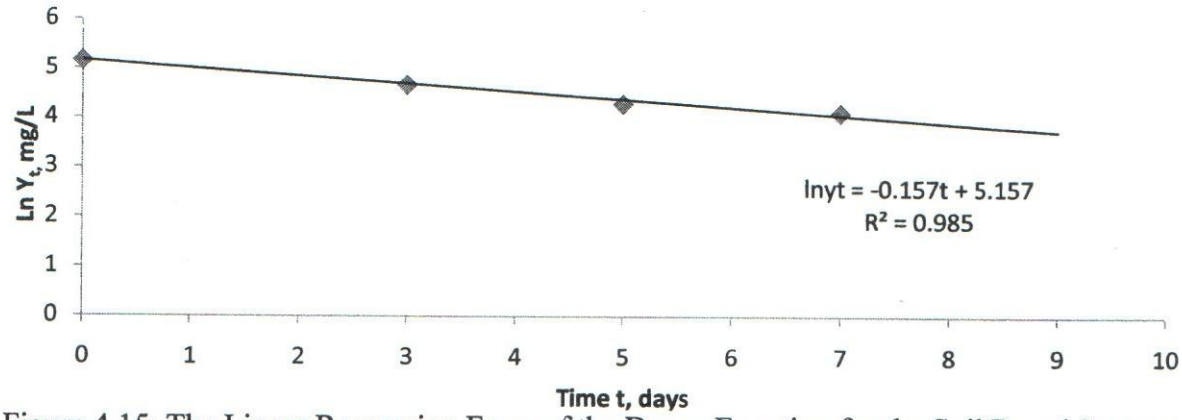


Figure 4.15: The Linear Regression Form of the Decay Equation for the Soil Based System, TSS

The values of the degradation constant 'k' for TSS removal from wastewater for the control, hydroponic, hybrid and soil based systems were found to be 0.097, 0.135, 0.139 and 0.157 respectively. These yield predicted contact times for achieving NEMA's standards of 30 mg/L of TP as 18.1, 13.0, 12.6 and 11.2 days in the same order.

4.3.4 Effect of Contact Time on the Biological Oxygen Demand

The mean BOD levels in the wastewater effluents from treatment units at different contact periods are presented in Table 4.11.

Table 4.11: Levels of Biochemical Oxygen Demand in wastewater for different contact times

Contact period (days)	Level of BOD, mg/L			
	Control	hydroponic	Hybrid	soil based
0 (Initially)	92.724^{a}	92.724^{a}	92724^{a}	92.724^{a}
3	78.916^{b}	56.578^{b}	52.557^{b}	46.567^{b}
5	56.865^{c}	31.342^{c}	28.788^{c}	22.698^{c}
7	52.496^{d}	24.373^{d}	23.863^{d}	17.842^{d}
LSD	6.9607	7.9258	7.41	7.8171

*Means followed by the same letter in the same column are not significantly different $\alpha = 0.05$

The results show that the BOD level was reduced from the mean of 92.7 mg/L to 28.79 and 22.7 mg/L by the hybrid and the soil based systems respectively within five days. These levels are below the recommended standards of 30 mg/L (EMCA, 2006), meaning that the required standards were met. The three day contact time resulted in lesser treatment rates as compared to the five and seven day contact times. Based on the BOD level reduction and by analogy, the results confirm as valid the decision by many reed-bed designers to use 5 days as the standard design retention time (GSADH, 2005), since any further increase in time causes marginal improvement in the performance. Statistical analysis revealed that there were significant differences between these means. Vetiver containing units are also noted to have achieved far lesser BOD levels than the control. The BOD level reduction trends are shown in figure 4.16 below.

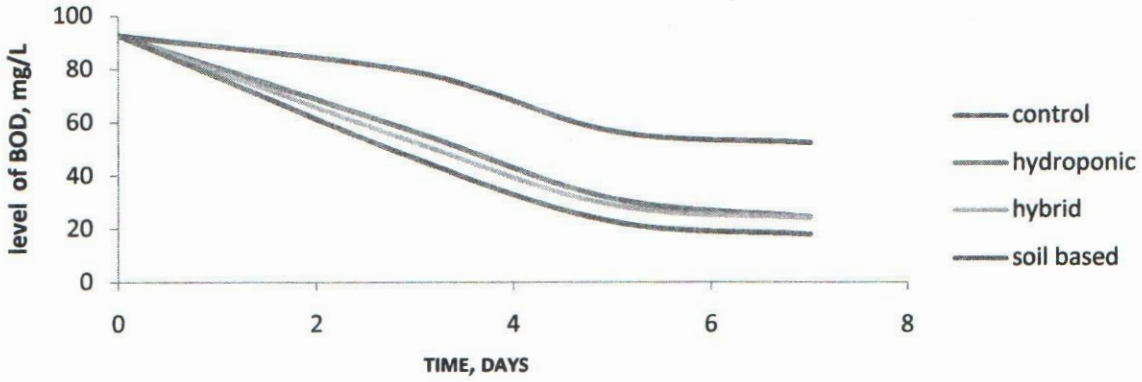


Figure 4.16: Variation of BOD Level with Contact Time

The trends in Figure 4.16 show that much of the meaningful drop in BOD level is achieved by the fifth day by all the treatments. Beyond this, the trends approach a limiting value of about 20 mg/L where no meaningful BOD level reduction may be expected. Figures 4.17 and 4.18 respectively depict this variation graphically for the soil based system. Graphs for the other systems are presented in the Appendix Figure A4.

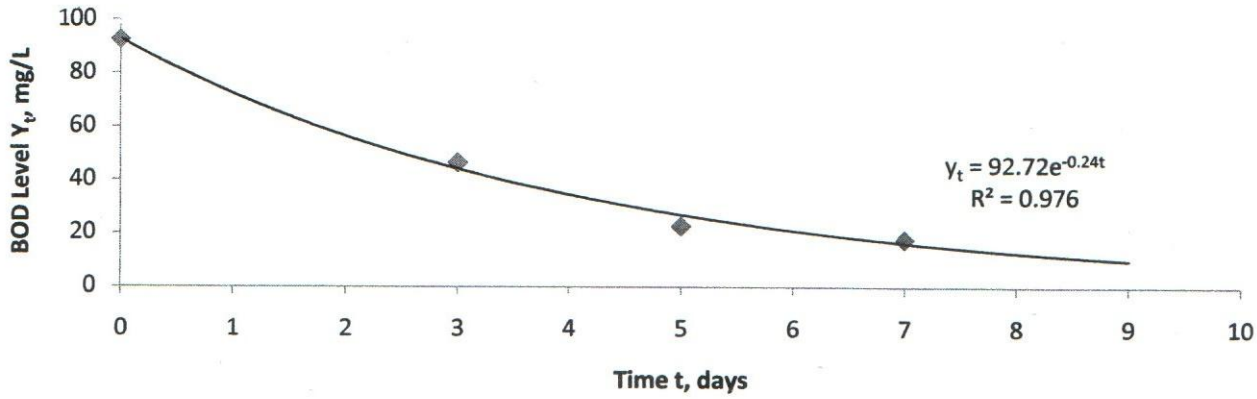


Figure 4.17: The Exponential Relationship Curve for the Soil Based System for BOD

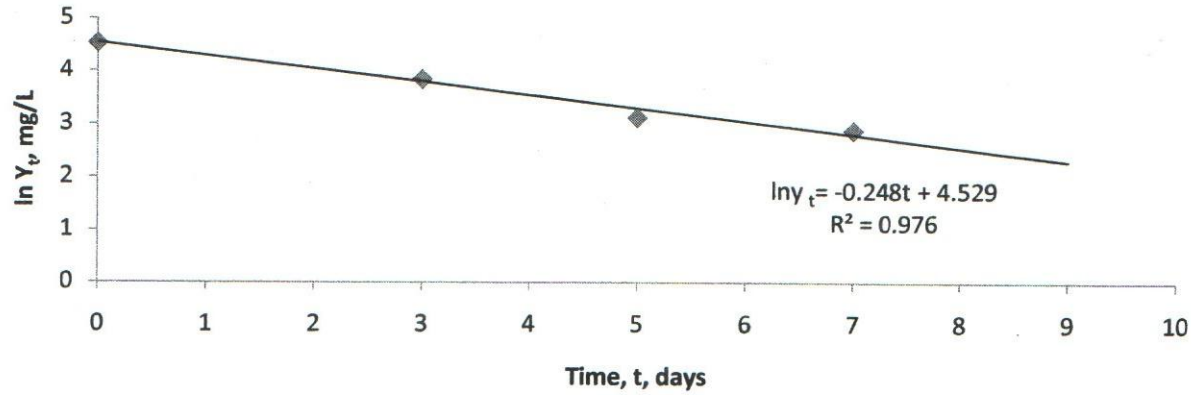


Figure 4.18: The Linear Regression Form of the Decay Equation for the Soil Based System, BOD

The values of the decay constant for the control, hydroponic, hybrid and the soil based system were determined as 0.083, 0.195, 0.205 and 0.248 respectively. Based on these observations, the contact times to meet the standards of maximum 30 mg/L of BOD for discharge of wastewater into river bodies prescribed by NEMA were predicted. These were 13.6, 5.8, 5.5 and 4.6 days for the control, hydroponic, hybrid and soil based systems respectively. The soil based system achieved this standard within the recommended design period of 5 days (GSADH, 2005).

4.3.5 Effect of Contact Time on the Levels of the Chemical Oxygen Demand

The mean COD levels on the basis of contact time in wastewater samples from the experimental units are presented in Table 4.12 below.

Table 4.12: Levels of Chemical Oxygen Demand in wastewater for different contact times

Contact period	Level of COD, mg/L			
(days)	Control	hydroponic	Hybrid	soil based
0 (Initially)	186.545[a]	186.545[a]	186.545[a]	186.545[a]
3	158.151[b]	119.055[b]	115.569[b]	109.016[b]
5	121.874[c]	67.615[c]	64.899[c]	52.175[c]
7	109.273[d]	56.979[d]	52.175[d]	42.246[d]
LSD	6.9442	10.959	10.924	11.945

*Means in the same column with the same letter are not significantly different at $\alpha = 0.05$

The results show that the minimum level of COD achieved was 42.2 mg/L by the soil-based unit for a 7-day contact time. This level meets the standards prescribed by NEMA (2006) which sets 50 mg/L as the maximum acceptable COD level for discharge into public water. Moreover, the efficiencies of experiment sets planted with vetiver were higher than the control sets, especially during 5- and 3-d contact periods. This observation reveals the benefits of using vetiver in wastewater treatment systems. The means were significantly different at 5% level of significance for all the contact times. The variation of COD with contact time is depicted Figure 4.19.

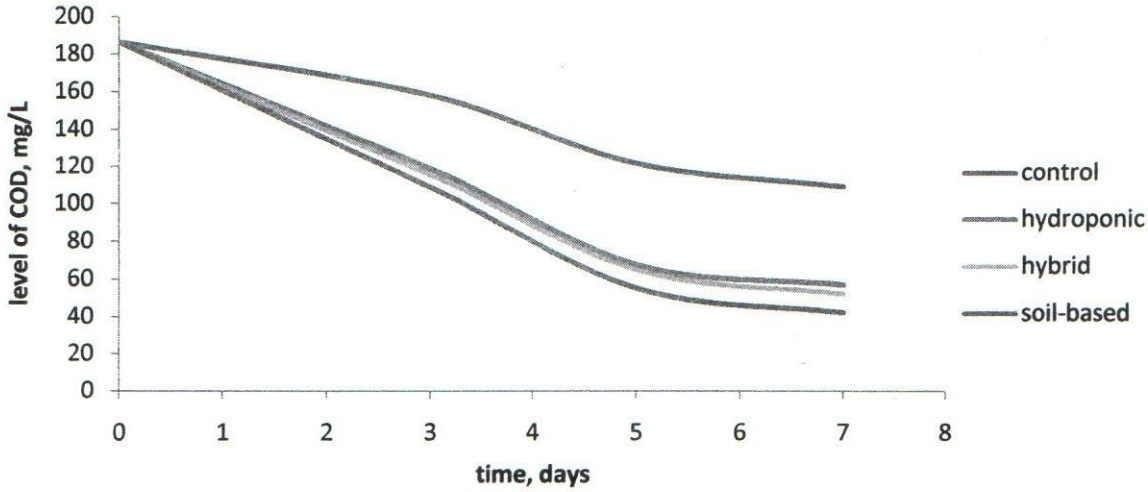


Figure 4.19: Variation of COD Level with time

This trend shows a wide margin of difference between the vetiver based treatments and the control. Revitt *et al.* (1997) hypothesized that COD removal occurred through the process of filtration of particulate organics by the root systems. This explains why plant based systems post better results than those without. Like for the case of BOD, the trend suggests a tendency towards a limiting value of about 40 mg/L (soil based) as the contact period increases. Figures 4.20 and 4.21 show the exponential curve and its linear form that describe the reduction of COD levels in wastewater. More graphs are shown in Appendix Figure A5.

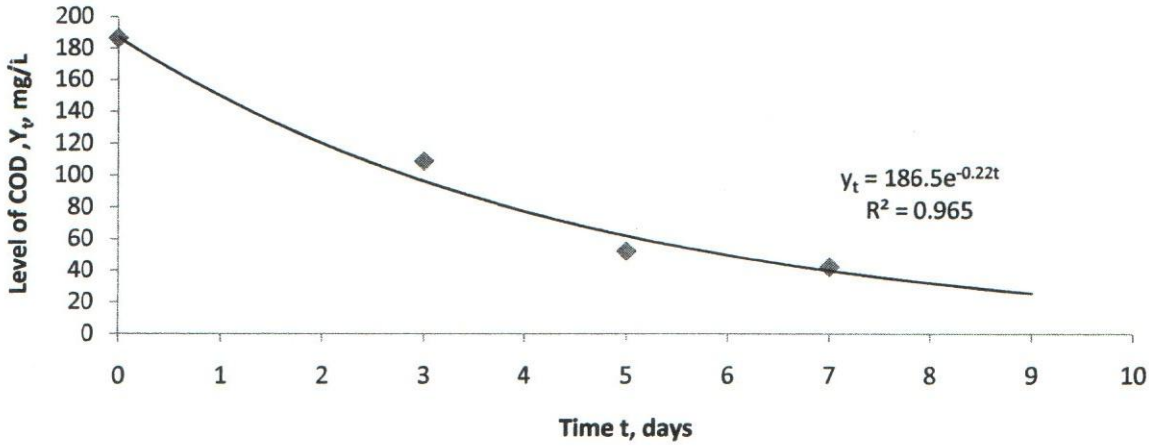


Figure 4.20: The Exponential Relationship Curve for the Soil Based System for COD

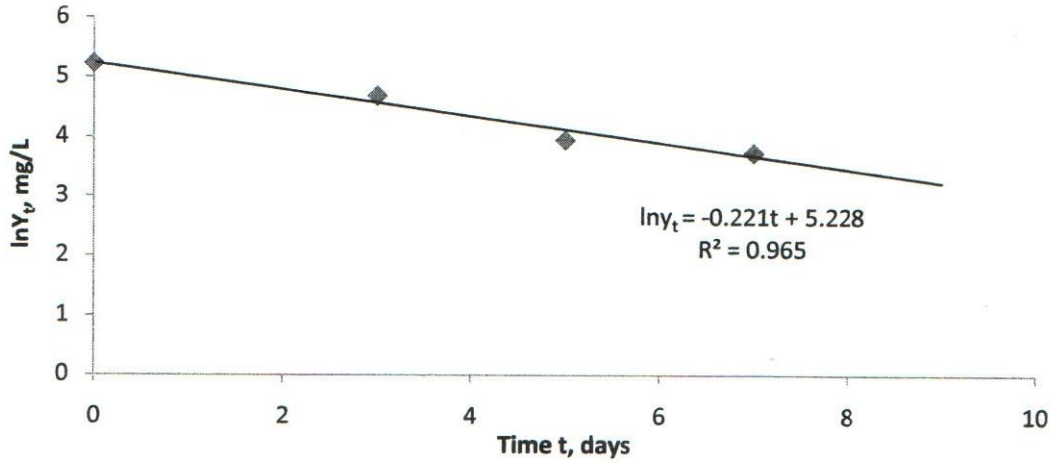


Figure 4.21: The Linear Regression Form of the decay equation for the soil based system, COD

4.4 Effects of Plant Age on the Ability of the Systems to Reduce Pollutant Levels

The effects of plant age on the abilities of the treatment systems to reduce pollutant levels in wastewater were explored on percentage basis. It was not possible to study this on the basis of actual levels because qualities of the wastewater supplied for every trial run of the experiment were different. These percentages were calculated using equation 3.14.

4.4.1 Effects of Plant Age on the Levels of Total Nitrogen

Table 4.13 below shows the percentage reduction in TN levels in wastewater in relation to the age of the vetiver plants. With the exemption of the control, the units were found to marginally improve in their abilities to remove TN with time (age). This was attributed to the increasing biomass which demanded more nutrition, and improving adaptability to the existing conditions. There were significant differences in TN removal rates across the weeks at 5% significant level for the three vetiver based treatments. The differences between weekly levels were insignificant for the control. Hence the age of the plants impacted positively on the abilities of the vetiver systems to reduce the level of TN in wastewater during the study period.

Table 4.13: Variation of Total Nitrogen reduction rates, %, with plant age

Age (Weeks)	Nitrogen Reduction			
	Hydroponic	Soil based	Hybrid	Control
4	42.39^{b}	48.56^{a}	43.29^{b}	24.89^{a}
5	43.48^{b}	55.05^{ab}	45.37^{b}	25.18^{a}
6	48.20^{ab}	56.15^{abc}	46.48^{b}	26.35^{a}
7	50.42^{ab}	57.17^{bc}	50.00^{ab}	25.86^{a}
8	54.56^{a}	61.36^{c}	55.03^{a}	25.10^{a}
9	55.67^{a}	62.89^{c}	57.03^{a}	26.02^{a}
LSD	8.0688	5.8777	7.6555	10.8660

*Means followed by the same letter in the same column are not significantly different at $\alpha = 0.05$

Figure 4.22 depicts the percentage reductions in TN levels in relation to age (weeks) the trend curve.

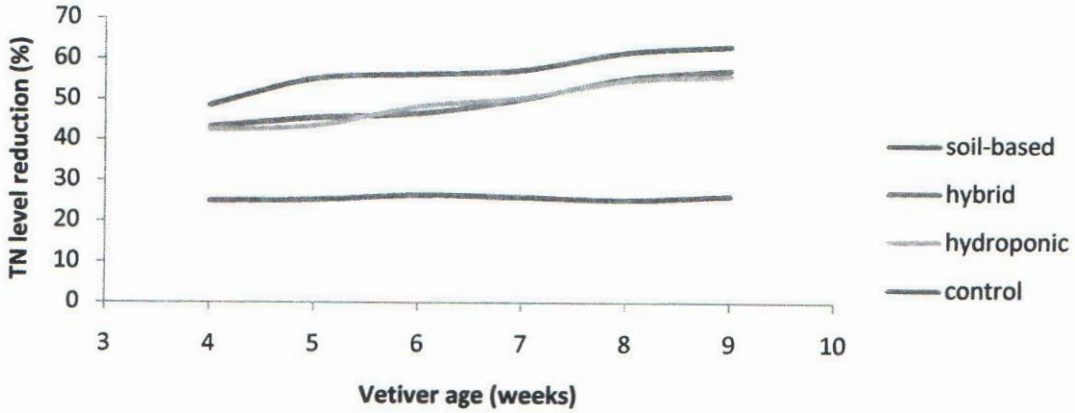


Figure 4.22: Variation of Total Nitrogen removal rate (%) with plant age

The shape of the curve is characteristic of 'a growth to a limit' relationship: the tendency towards attaining a phase where the performance would become more of constant with age.

4.4.2 Effects of Plants' Age on the Levels of Total Phosphorous

The mean percentage total phosphorous removal rates for the various treatments are presented in Table 4.14.

Table 4.14: Variation of Total Phosphorous removal rates (%) with plant age

Age (Weeks)	Phosphorous Reduction			
	Hydroponic	Soil based	Hybrid	Control
4	30.69^{ab}	33.49^{ab}	29.21^{ab}	18.74^{ab}
5	30.98^{a}	33.60^{ab}	28.63^{ab}	19.74^{a}
6	21.94^{b}	25.15^{c}	23.59^{b}	18.74^{ab}
7	26.43^{ab}	30.13^{bc}	29.58^{ab}	13.81^{ab}
8	33.73^{a}	36.28^{ab}	34.73^{a}	18.74^{ab}
9	31.19^{a}	38.75^{a}	30.24^{ab}	21.70^{a}
LSD	8.9008	7.9074	8.9008	10.927

*Means followed by the same letter in the same column are not significantly different at $\alpha = 0.05$

The difference between the treatment rates with age was significant between a few systems and insignificant between others. For instance for the soil based system, the differences between the rates for ages 4, 5, 8 and 9 as well as between age 6 and 7 were insignificant, while those between age 4 and 6 were significant. For all the systems, there were no significant differences at 5% level of significance between the age of four and five weeks treatment rates. For the control, generally, there were no significant differences between the treatment rates with age. These observations indicate the variations are caused by the vetiver plants, since the performance of the control remains generally uniform. The removal of total phosphorus from wastewater fluctuated with age for all the units except the control, but showed a general increasing trend. This shows that the vetiver plants' contribution to the removal of phosphorous was not much dependent on the plant age, owing to the main mechanisms of phosphorus removal from wastewaters. This is in conformity with research findings by Mng'anya *et al.* (2001) that plants play an insignificant role in phosphorous removal from wastewater. Figure 4.23 depicts the trend followed by these systems in their performance.

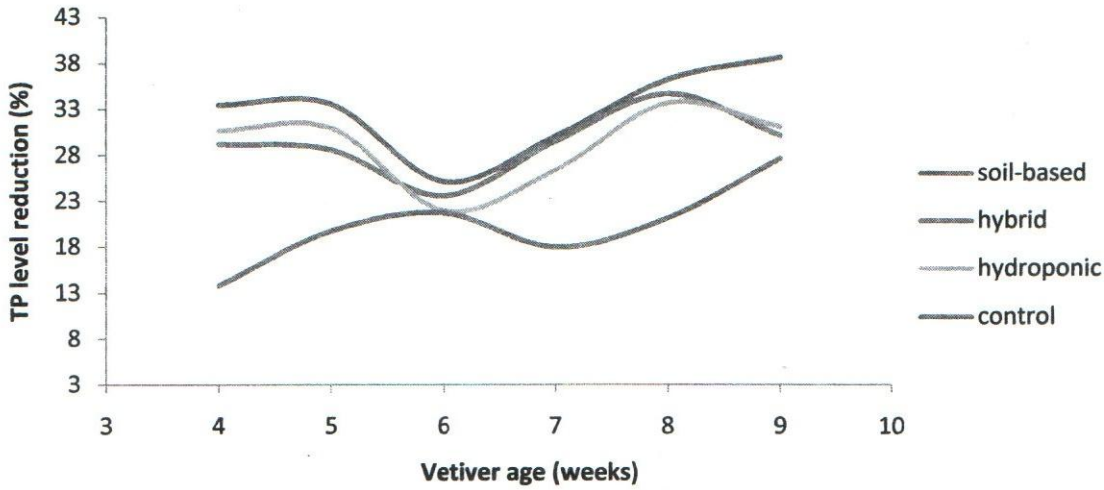


Figure 4.23: Variation of total phosphorous removal rates (%) with age

The lines reveal a drop in performance during the age of six weeks. This is not totally surprising as TP levels in constructed wetlands have been reported to be temporal with the possibility of increasing (Davison *et al*, 2005). The general impression exhibited by the trend lines is that the TP removal performance was unpredictable with respect to the age of the vetiver plants.

4.4.3 Effects of Plants' Age on the Removal of Total Suspended Solids

The percentage rates of reduction of total suspended solids from wastewater by the systems in relation to the plants' ages are presented in Table 4.15 below. It is noted that maximum TSS reduction was achieved at the oldest age by all the units. This implies that the between the ages of four to nine weeks, a higher age translates to better performance of vetiver plants to remove TSS from wastewater. With the exemption of the control, the units were found to marginally improve in their abilities to remove TN with time (age). This was attributed to the increasing biomass which demanded more nutrition, and improving adaptability to the existing conditions. There were significant differences in TN removal rates across the weeks at 5% significant level for the three vetiver based treatments. The differences between weekly levels were insignificant for the control. Hence the age of the plants impacted positively on the abilities of the vetiver systems to reduce the level of TN in wastewater during the study period.

Table 4.15: Variation of total suspended solids' removal rates with plant age

Age (Weeks)	Suspended solids' reduction			
	Hydroponic	Soil based	Hybrid	Control
4	52.52^{b}	54.97^{c}	54.20^{ab}	44.18^{ab}
5	51.72^{b}	55.65^{c}	51.06^{c}	43.64^{ab}
6	52.30^{b}	55.45^{c}	50.23^{d}	45.69^{ab}
7	53.34^{ab}	55.20^{c}	53.26^{bc}	29.30^{c}
8	53.30^{ab}	60.41^{b}	55.77^{ab}	41.62^{b}
9	55.72^{a}	64.73^{a}	56.96^{a}	49.45^{a}
LSD	3.012	2.9284	2.8779	5.8778

*Means followed by the same letter in the same column are not significantly different at $\alpha = 0.05$

Figure 4.24 illustrates the variation of treatment rates with the age of plants in the treatment units.

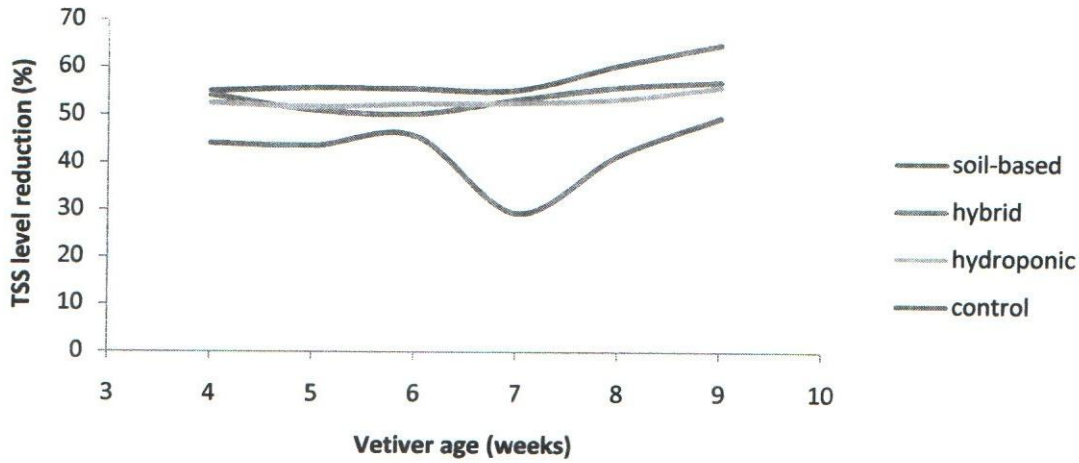


Figure 4.24: Variation of TSS removal rates with plant age

Generally, for all the vetiver units the removal of suspended solids steadily increased with the increasing age of the plants because of the corresponding increase in root and stem biomass. These increased the contribution of root entrapment of suspended solids and flow retardation which improved filtration and settlement (Smith and Kalin, 2000).

4.4.4 Effect of Plant Age on the Biological Oxygen Demand Level Reduction Rate

The percentage reduction in BOD levels with respect to plants' age is presented in Table 4.16. Cases of significant differences in BOD level reduction rates at 5% level are fewer than otherwise. This shows that the age of vetiver plants within the 4-9 weeks bracket has a limited impact on the extent of reduction in BOD.

Table 4.16: Variation of BOD level reduction rates (%) with plant age

Age (Weeks)	BOD reduction			
	Hydroponic	Soil based	Hybrid	Control
4	58.17^{c}	67.51^{d}	61.23^{b}	36.41^{b}
5	58.69^{c}	68.96^{d}	62.42^{b}	37.21^{b}
6	66.54^{b}	74.23^{c}	69.58^{a}	37.37^{b}
7	69.97^{a}	77.81^{bc}	72.19^{a}	37.62^{b}
8	71.09^{a}	81.39^{ab}	73.69^{a}	39.34^{ab}
9	72.19^{a}	82.56^{a}	74.09^{a}	44.02^{a}
LSD	3.012	2.9284	2.8779	5.8778

*Means followed by the same letter in the same column are not significantly different at $\alpha = 0.05$

Generally, for all the vetiver based systems, significant differences in treatment existed between the rates for earlier ages (4, 5 and 6 weeks) and those of later ages (7, 8 and 9 weeks). It can be argued that at the later ages, sufficient increase in biomass had been achieved to cause discernible differences in treatment rates. Figure 4.25 shows the trend exhibited by the systems in the BOD level changes.

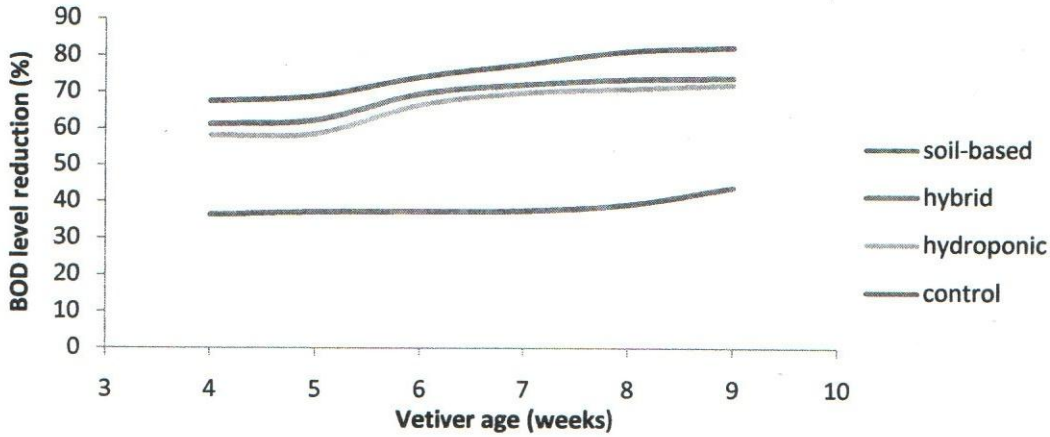


Figure 4.25: Variation of BOD reduction rates with the age of plants

For all the units except the control, a steady trend of improving performance of the plants with age was evident. This is due to the increasing contribution of plants to BOD level reduction in wastewater. As the plants got more established with age, the increasing biomass resulted in an increase in demand for nutrition from the wastewater hence an enhanced reduction in BOD level. The accompanying increase in root biomass also contributed to the increased performance by availing a surface for the availability of more microorganisms to break down carbonaceous matter (Gray, 2009).

4.4.5 The Effects of Plant Age on Chemical Oxygen Demand Level Reduction Rate

Table 4.17 and Figure 4.26 show the variation of COD level reduction rates with the age of plants. There are significant differences between the COD reduction rates for different ages at 5% level for the vetiver based systems. The highest percentage COD reduction was shown by the soil based system as 76.18%. This was more than the 46.2% reported by Njau and Mlay (2003) but less than the 80% reported by Mayorca (2007). The differences, as observed by Boonsong and Chansiri (2005), Njau and Mlay (2003), Xia *et el.*,(2003) are due to the differences in the types and characteristics of the raw wastewater used. Also while Njau and Mlay (2003) used a vertical flow system; Mayorca (2007) used a multi-stage vetiver treatment system. For the control, these differences were not significant between any two means. This is because there being no plants in those units, differences in treatment rates could only be influenced by such extraneous factors such as weather pattern.

Table 4.17: Variation of COD level reduction rate (%) with plant age

Age (Weeks)	COD reduction rate			
	Hydroponic	Soil based	Hybrid	Control
4	57.28^{d}	62.06^{e}	55.74^{e}	35.23^{a}
5	58.51^{d}	67.18^{d}	61.14^{d}	33.78^{a}
6	62.12^{c}	71.59^{c}	66.46^{c}	32.79^{a}
7	67.21^{b}	$72.78b^{c}$	69.17^{b}	35.21^{a}
8	70.34^{a}	75.05^{ab}	59.50^{b}	37.38^{a}
9	70.04^{ab}	76.18^{a}	72.14^{a}	34.09^{a}
LSD	2.9248	2.9309	2.5867	6.9957

*Means followed by the same letter in the same column are not significantly different at $\alpha = 0.05$

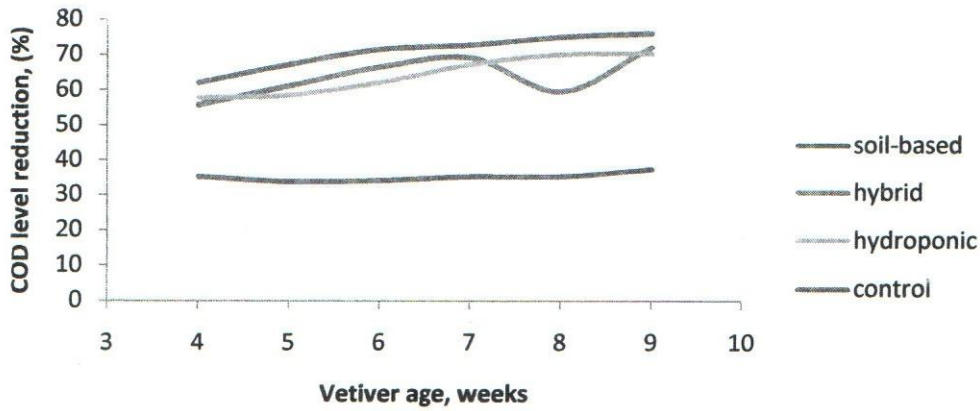


Figure 4.26: Variation of COD level reduction rate with plants' age

There is a gradually increasing trend for the vetiver systems with a drop at the age eight weeks for the hybrid system. The fluctuations in COD removal rates are expected, given that it is a measure of all the material that can be chemically oxidized, regardless of source. The steady marginal increase in removal of COD is, like the BOD, attributed to the increasing biomass. As plant age advances, the biomass increases and accelerates the rate of BOD removal. Since BOD forms part of COD, any effect on it (BOD) has a proportionate effect on COD.

CHAPTER FIVE: CONCLUSSIONS AND RECOMMENDATIONS

5.1 Conclusions

The performance of vetiver systems established under hydroponic, hybrid and soil based systems confirm that vetiver is a useful tool in wastewater treatment. It was concluded that soil based vetiver systems perform better than the hybrid and hydroponic ones in wastewater treatment. This is because the soil medium enhances their performance by offering better nutrition, filtering action and increased adsorption capacity. All the treatment units that contained vetiver achieved significantly lower pollutant levels for the 5-day contact period than the control which was in the form of a miniature waste stabilization pond. The soil based system achieved the least pollutant levels in all the parameters (BOD, COD, TN, TP and TSS) than both the hydroponic and the hybrid systems. Quoting the findings (for the 5-day contact period) in the order of soil based, hybrid, hydroponic and control, the achieved levels in mg/L for BOD_5 were 22.7, 28.8, 31.3 and 56.9. The achieved levels for the other parameters in mg/L were: 55.2, 64.9, 67.6, and 121.9 (COD); 19.6, 22.9, 23.1, and 33.7 (TN); 4.4, 4.6, 4.7, and 5.4 (TP) and; 73.4, 80.5, 81.3 and 99.9 (TSS). For all the parameters, in most cases, there were no significant differences between the levels achieved by the hydroponic and hybrid systems at $\alpha = 0.05$. However the levels achieved by the soil based system were significantly lower than those of the hybrid and hydroponic systems.

Contact time was found to greatly influence the treatment of wastewater. The pollutant levels achieved for the three contact times considered in the experiment were in a majority of the cases significantly different at $\alpha = 0.05$. For instance the soil based system reduced BOD_5 levels from 92.7mg/L to 17.8, 22.7 and 46.6 mg/L under 7, 5 and 3-day contact times respectively, all significantly different with an LSD of 2.3 mg/L. The pollutant level reduction was confirmed to follow the exponential relationship $Y_t = Y_0e^{-kt}$ suggested earlier by Liao *et al.*, (2003). This was used to predict that to achieve the 30 mg/L BOD level stipulated by NEMA (2006), it would take the soil based, hybrid, hydroponic and control systems 4.6, 5.5, 5.8 and 13.6 days respectively. Quoting the estimates in that order, the time estimates for other parameter are 6.0, 7.0, 7.4 and

17.3 days (COD); 19.5, 24.6, 25.8 and 58.9 days (TN); 14.3, 16.1, 17.2 and 30.5 days (TP) and; 11.2, 12.6, 13.0 and 18.1 days (TSS). It was concluded that for BOD, a 5-day contact period was sufficient for the soil based system since it achieved the NEMA stipulated standard of 30 mg/L within the period.

Within the time period of 0-10 weeks of the experiment, the age of the vetiver plants was found to significantly influence the treatment efficiency of wastewater treatment systems studied. The levels achieved by the soil-based system for the ages of four, six, seven and nine weeks were 67.51, 74.23 and 82.56 mg/L of BOD, significantly different at $\alpha = 0.05$ with an LSD of 2.9284. The ability of the systems to treat wastewater approached a limiting value as age progressed indicating that continual growth of the vetiver plants is important for sustained good performance. This can be ensured by regular harvesting of the vetiver plants.

5.2 Recommendations

This study has prompted the need for further study and investigation into the grey areas of the research topic including:

1. Further research work is required to study the performance of vetiver systems in wastewater treatment with regard to the other parameters such as the dissolved oxygen, pathogens and electrical conductivity among others.
2. It is recommended that trials of this nature be done using larger experimental units using continous flow of wastewater over a wide range of flow rates and hydraulic retention times.
3. Similar experiments should be done using many trials in order to model the performance of the plants with respect to time, initial concentration and climatic factors.
4. More research should be done regarding the effects of vetiver growing in different types of media such as peat and gravel, amongst others.
5. Studies should be made regarding the comparative abilities of hydroponic and soil based vetiver systems to treat other types of wastewaters under different climatic conditions.

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APPENDIX

Appedix Table A1: Typical composition of untreated domestic wastewater

Contaminant	Units	Conc.(weak)	Conc.(medium)	Conc.(Strong)
Solids, total(TS)	mg/l	350	720	1200
Dissolved, total(TDS)	mg/l	250	500	850
Fixed	mg/l	145	300	525
Volatile	mg/l	105	200	325
Suspended Solids(SS)	mg/l	100	220	350
Fixed	mg/l	20	55	75
Volatile	mg/l	80	165	275
Settleable Solids	mg/l	5	10	20
$B.O.D_5$, 20°C	mg/l	110	220	400
Total Organic Carbon	mg/l	80	160	290
C.O.D.	mg/l	250	500	1000
Total N	mg/l	20	40	85
Organic N	mg/l	8	15	35
Free ammonia	mg/l	12	25	50
Nitrites	mg/l	0	0	0
Nitrates	mg/l	0	0	0
Total Phosphorous	mg/l	4	8	15
Organic P	mg/l	1	3	5
Inorganic N	mg/l	3	5	10
Chlorides[a]	mg/l	30	50	100
Sulphates[a]	mg/l	20	30	50
Alkalinity($CaCO_3$)	mg/l	50	100	200
Grease	mg/l	50	100	150
Total coli form	No./100 ml	10^6-10^7	10^7-10^8	10^7-10^9
Volatile Org. Comp.	µg/l	<100	100-400	>400

[a]Values should be increased by amount present in domestic wastewater.

Source: Ogombe, 2001

Appendix Table A2: Hydroponic Vetiver and nutrient of uptake selected crops ((Hart *et al.*, 2003).

Plant species	Nitrogen (kg/ha/year)	Phosphorous (Kg/ha/year)
Trial 1 Vetiver hydroponic*	21216	2053
Trial 2 Vetiver hydroponic**	6524	358
Trial 3 Vetiver hydroponic***	13688	1026
Vetiver pot trials (1)	2040	153
Vetiver MEDLI model (2)	1200	100
Vetiver field trial (3)	1142	149
Rhodes grass (4)	600	90
Kikuyu (4)	500	90
Green panic (4)	430	70
Forage sorghum (4)	360	70
Sorghum+ Rye grass (4)	620	110
Bermuda grass (5)	280	30-35
Eucalyptus trees (5)	90	15
Clover (5)	180	20
Rye grass (5)	200-280	60-80
Oats (5)	60	50
Lucerne (6)	269-504	20-39
Wheat	23-20	83-27

* Still effluent, small size containers (25L), **Still effluent, medium container (240L).

*** Flow trough effluent at 20L/min, large size containers (600L).

Appendix Table A3: Schedule 7; Guideline Values for Discharge into Public Water (NEMA, 2006)

Systems Parameter	Unit Guideline	value
1,1,1-trichloroethane	mg/l	3
1,1,2-trichloroethane	mg/l	0.06
1,1-dichloroethylene	mg/l	0.2
1,2-dichloroethane	mg/l	0.04
1,3-dichloropropene	mg/l	0.02
Alkyl Mercury compounds	mg/l	Nd
Ammonia, Ammonium compounds, NO_3 compounds and NO_2 compounds	mg/l	100
Arsenic	mg/l	0.02
Arsenic and its compounds	mg/l	0.1
Benzene	mg/l	0.1
PH	PH	6.5-8.5
BOD (5 days at 20oC) max	mgO_2 /l	30
COD,	max mgO2 /l	50
Temperature, max	^{O}C	±3°C of ambient temp. of the water body
Boron	mg/l	1.0
Boron and its compounds – non marine	mg/l	10
Boron and its compounds – marine	mg/l	30
Cadmium	mg/l	0.01
Cadmium and its compounds	mg/l	0.1
Carbon tetrachloride	mg/l	0.02
Chromium VI	mg/l	0.05
Chloride mg/l 250		
Chlorine free residue	mg/l	0.10
Chromium total	mg/l	2
Cis-1,2-dichloro ethylene	mg/l	0.4
Copper	mg/l	1.0
Dichloromethane	mg/l	0.2
Dissolved Iron	mg/l	10
Dissolved Manganese	mg/l	10
E.coli	Counts/100ml	Nil
Flouride	mg/l	1.5
Flouride and its compounds (marine and non-marine)	mg/l	8
Lead	mg/l	0.01
Lead and its compounds	mg/l	0.1
n-Hexane extracts (animal & vegetable fats)	mg/l	30
Oil and grease		Nil
Phenols	mg/l	0.001
Selenium	mg/l	0.01

Selenium and its compounds	mg/l	0.1
Hexavalent Chromium VI compounds	mg/l	0.5
Sulphide	mg/l	0.1
Simazine	mg/l	0.03
Total Suspended Solids	mg/l	30
Tetrachloroethylene	mg/l	0.1
Thiobencarb	mg/l	0.1
Thiram	mg/l	0.06
Total coliforms	Counts/100ml	30
Total Cyanogen	mg/l	ND
Total Nickel	mg/l	0.3
Total Dissolved Solids	mg/l	1200
Colour	Hazen Units (H.U)	15
Detergents	mg/l	Nil
Total Mercury	mg/l	0.005
Trichloroethylene	mg/l	0.3
Zinc	v	0.5
Whole effluent toxicity		
Total Phosphorous	mg/l	2
Total Nitrogen	mg/l	2

Appendix Table A4: Weather record at Pwani University during the period of the experiments

AUGUST 2009					SEPTEMBER 2009				
Date	Temp (°C) Max	Min	Rainfall (mm)	RH (%)	Date	Temp (°C) Max	Min	Rainfall (mm)	RH (%)
1	28	20	nil	80	1	29	21	nil	76
2	29	21	nil	80	2	29	21	nil	80
3	29	21	nil	84	3	29	22	0.5	83
4	28	21	6.5	95	4	28	22	nil	83
5	28	21	nil	87	5	29	21	3.5	91
6	28	22	3.0	69	6	29	22	1.5	73
7	28	21	1.0	91	7	29	21	1.5	83
8	28	20	1.0	69	8	29	21	5.5	80
9	28	21	nil	63	9	29	21	nil	83
10	29	21	nil	76	10	29	21	nil	80
11	30	20	5.0	91	11	29	21	nil	80
12	29	21	nil	69	12	29	21	nil	63
13	28	21	1.0	83	13	29	22	nil	77
14	28	20	nil	69	14	29	21	nil	80
15	28	21	1.0	80	15	29	20	nil	63
16	28	21	3.0	87	16	29	21	nil	69
17	27	20	2.5	83	17	30	22	nil	92
18	27	20	0.5	72	18	29	23	nil	80
19	28	21	nil	87	19	30	22	nil	96
20	28	22	0.5	80	20	30	22	0.5	92
21	28	21	3.0	73	21	29	22	nil	70
22	28	22	nil	84	22	29	22	Trace	88
23	28	21	10.0	84	23	30	23	nil	84
24	29	22	7.0	88	24	29	22	nil	76
25	28	22	0.5	80	25	29	22	nil	73
26	28	21	nil	80	26	30	22	nil	73
27	28	21	nil	80	27	31	23	0.5	70
28	29	21	2.0	80	28	30	22	nil	57
29	29	21	1.0	80	29	31	23	nil	55
30	28	22	1.0	88	30	30	24	nil	55
31	29	20	nil	79					

Appendix Table A5: Pollutant Levels in the Wastewater

a. Levels of nitrogen, phosphorous and suspended solids for batch 1

RAW CHARACTERISTICS: TN-47.65, TP-6.3 and TSS-183.5 mg/L

3 DAY CONTACT TIME

	TOTAL N				TOTAL P				TSS			
	H	S	SH	C	H	S	SH	C	H	S	SH	C
	33.12	28.75	35.23	42.06	5.01	4.53	4.86	5.95	99.57	90.37	93.95	132.64
	30.32	33.15	32.48	37.27	5.15	5.26	5.62	5.88	93.57	91.93	96.36	129.93
	34.09	27.46	28.57	41.93	5.56	5.38	5.65	6.02	97.10	94.03	98.03	136.23
Mean	32.51	29.79	32.07	40.42	5.24	5.06	5.38	5.37	96.71	92.11	96.71	132.93

5 DAY CONTACT TIME

	H	S	SH	C	H	S	SH	C	H	S	SH	C
	28.11	23.15	30.25	38.66	4.04	3.86	3.99	5.35	89.85	80.85	83.85	102.17
	25.20	28.12	27.28	32.21	4.41	4.21	4.83	5.02	83.61	85.85	85.37	105.20
	29.05	22.26	23.54	36.52	4.65	4.50	4.56	5.92	87.88	81.17	89.20	99.93
Mean	27.45	24.51	27.02	35.80	4.37	4.19	4.46	5.43	87.11	82.62	84.04	102.43

7 DAY CONTACT TIME

	H	S	SH	C	H	S	SH	C	H	S	SH	C
	22.91	17.93	22.65	35.96	3.04	3.36	3.09	4.35	80.47	65.74	78.56	99.38
	23.34	21.06	25.03	30.03	3.41	2.91	3.83	4.62	83.47	62.93	74.99	101.94
	24.55	15.43	19.54	32.65	3.65	3.15	3.56	4.99	80.65	68.18	79.63	97.83
Mean	23.60	18.14	22.41	32.88	3.37	3.14	3.32	4.65	81.53	65.62	77.72	99.72

b. Levels of BOD and COD for batch 1 of wastewater

RAW CHARACTERISTICS: BOD-91.35, TSS-210.33

3 DAY CONTACT TIME

	BOD				COD			
	H	S	SH	C	H	S	SH	C

	48.35	39.96	49.26	63.67	109.98	105.03	113.20	149.85
	47.63	37.87	44.87	67.88	120.87	99.88	115.26	153.92
	48.73	43.01	54.92	70.02	100.78	100.78	149.85	157.05
Mean	48.24	40.28	49.68	67.19	110.54	101.90	113.00	153.61

5-DAY CONTACT TIME

	H	S	SH	C	H	S	SH	C
	38.25	29.08	39.60	53.24	89.65	80.65	90.20	129.65
	37.54	27.27	34.28	57.81	92.05	78.97	93.88	138.55
	38.85	32.69	32.36	60.59	87.85	79.78	95.20	140.44
Mean	38.21	29.68	35.41	57.21	89.85	79.80	93.09	136.21

7-DAY CONTACT TIME

	H	S	SH	C	H	S	SH	C
	34.91	25.83	33.76	51.33	80.47	65.74	78.56	126.45
	32.97	21.05	30.76	53.91	83.47	62.93	74.99	126.45
	34.02	23.98	29.07	55.08	80.65	68.18	79.63	137.03
Mean	33.98	23.62	31.20	53.37	81.53	65.62	77.73	131.42

d. Levels of nitrogen, phosphorous and suspended solids for batch 2

RAW CHARACTERISTICS: TN-47.63, TP-6.23 and TSS-168.33

3 DAY CONTACT TIME

TOTAL N				TOTAL P				TSS			
H	S	SH	C	H	S	SH	C	H	S	SH	C
40.87	37.90	39.85	43.03	5.99	5.43	5.75	5.95	128.83	109.78	123.98	138.94
42.65	35.29	41.03	42.97	5.73	5.26	5.93	6.03	126.93	118.57	122.32	129.89
40.34	32.76	38.96	43.97	5.66	5.65	5.78	6.19	129.93	107.83	122.32	136.68
Mean 41.29	35.32	39.95	43.32	5.79	5.45	5.8	6.06	128.41	112.06	124.20	135.17

5 DAY CONTACT TIME

	H	S	SH	C	H	S	SH	C	H	S	SH	C
	24.01	20.14	23.27	34.61	4.52	3.84	4.49	5.45	83.65	75.22	83.56	91.68
	30.20	21.16	25.22	30.29	4.01	4.24	4.83	5.12	80.48	78.12	80.07	103.35

	23.25	20.23	26.29	37.52	4.37	4.33	4.00	4.43	79.67	70.65	83.52	89.56
Mean	25.82	20.51	24.93	34.14	4.30	4.14	4.45	5.00	81.27	74. 66	82.38	94.86

7 DAY CONTACT TIME

	H	S	SH	C	H	S	SH	C	H	S	SH	C
	21.72	14.26	19.38	31.92	3.96	3.09	3.44	4.94	68.38	54.59	60.03	86.99
	24.91	16.23	21.91	29.69	3.75	3.11	3.19	5.02	65.03	58.35	65.46	97.92
	20.37	16.96	22.18	33.26	3.88	2.96	3.36	4.29	64.95	51.63	9.575	84.89
Mean	22.33	15.82	21.16	31.62	3.86	3.05	3.33	4.75	66.12	54.86	61.69	89.93

e. Levels of BOD and COD for batch 2 of wastewater

RAW CHARACTERISTICS: BOD-89.3, COD-193.9 mg/L

3 DAY CONTACT TIME

	BOD				COD			
	H	S	SH	C	H	S	SH	C
	57.85	51.21	53.44	80.98	142.98	135.94	142.03	172.07
	59.44	49.93	55.98	82.03	146.03	140.03	149.37	178.35
	59.93	48.97	54.09	84.41	144.95	138.37	141.93	170.08
Mean	59.07	50.04	54.50	82.47	144.65	138.11	144.44	173.50

5-DAY CONTACT TIME

	H	S	SH	C	H	S	SH	C
	36.85	25.82	35.98	57.85	79.65	60.63	76.23	117.64
	34.69	27.95	33.83	59.06	79.05	66.70	70.81	125.21
	39.79	29.88	31.47	51.21	82.65	63.87	79.01	142.35
Mean	37.11	27.88	33.76	56.04	80.45	63.64	75.31	128.40

7-DAY CONTACT TIME

	H	S	SH	C	H	S	SH	C
	23.87	18.96	25.37	52.96	58.75	27.34	46.73	106.58
	22.98	19.84	23.83	54.46	53.09	26.94	42.98	112.03
	24.05	17.82	27.73	49.91	55.68	24.58	44.48	109.87
Mean	23.63	18.87	25.64	52.44	55.84	26.29	44.73	109.49

f. Levels of nitrogen, phosphorous and suspended solids for batch 3

RAW CHARACTERISTICS: TN-48.22, TP-7.05 and TSS-172.55 mg/L

3 DAY CONTACT TIME:

	TOTAL N				TOTAL P				TSS			
	H	S	SH	C	H	S	SH	C	H	S	SH	C
	41.23	33.83	38.54	43.21	6.66	6.21	6.35	6.72	120.23	109.91	114.82	149.83
	41.09	35.02	39.98	41.65	6.89	6.07	6.45	6.89	121.43	112.24	117.36	151.38
	39.79	32.17	40.23	45.36	6.93	6.44	6.56	6.83	124.24	110.11	114.67	154.17
Mean	40.70	33.67	39.58	43.41	6.83	6.24	6.45	6.81	121.97	110.75	115.62	151.79

5 DAY CONTACT TIME

	H	S	SH	C	H	S	SH	C	H	S	SH	C
	22.96	20.22	23.65	39.68	5.54	5.08	5.42	5.42	83.82	78.51	80.11	83.46
	25.67	20.94	25.67	34.99	5.89	5.60	5.66	5.20	82.27	77.85	85.74	96.88
	26.30	22.28	28.1	31.87	5.08	5.15	5.08	5.94	80.85	74.25	91.58	100.79
Mean	24.98	21.15	25.81	35.51	5.50	5.28	5.39	5.52	82.31	76.87	85.81	93.71

7 DAY CONTACT TIME

	H	S	SH	C	H	S	SH	C	H	S	SH	C
	19.37	13.08	20.23	37.78	4.93	4.25	4.63	5.12	75.83	70.36	72.18	79.11
	21.05	11.35	17.87	33.52	4.88	4.32	4.73	5.04	74.45	70.09	77.71	92.92
	22.76	12.89	16.89	28.93	4.72	4.46	4.81	5.72	72.18	66.28	82.44	95.06
Mean	21.06	12.44	18.33	33.41	4.84	4.34	4.72	5.29	74.31	68.91	77.44	89.03

g. Levels of BOD and COD for batch 3 of wastewater

RAW CHARACTERISTICS: BOD-89.83, COD-193.91mg/L

3 DAY CONTACT TIME

	BOD				COD			
	H	S	SH	C	H	S	SH	C
	74.92	66.88	72.01	85.43	136.94	130.42	134.21	193.76
	73.22	69.24	69.63	86.22	139.43	129.27	135.25	196.02
	73.96	65.83	71.09	82.63	140.22	131.25	136.17	189.23

Mean	74.03	67.32	70.91	84.76	138.86	130.31	135.20	193.00

5-DAY CONTACT TIME

	H	S	SH	C	H	S	SH	C
	30.98	27.81	29.32	64.28	85.64	62.42	73.94	147.63
	31.28	23.62	28.71	59.02	74.79	63.97	74.48	151.91
	33.54	22.36	29.07	56.51	87.80	60.13	71.81	141.71
Mean	31.93	24.60	29.03	59.94	82.74	62.17	73.41	147.08

7-DAY CONTACT TIME

	H	S	SH	C	H	S	SH	C
	27.97	25.28	26.83	57.85	77.67	56.87	65.63	132.73
	28.25	21.26	25.98	53.12	67.11	57.73	67.26	136.93
	29.86	20.21	26.63	50.95	79.20	54.17	64.63	127.95
Mean	28.69	22.25	26.48	53.97	74.66	56.26	65.84	132.54

g. Levels of nitrogen, phosphorous and suspended solids for batch 4

RAW CHARACTERISTICS: TN-40.98, TP-6.13 and TSS-165.29 mg/L

3 DAY CONTACT TIME

	TOTAL N				TOTAL P				TSS			
	H	S	SH	C	H	S	SH	C	H	S	SH	C
	31.75	24.91	29.65	36.34	5.85	5.75	5.61	5.94	132.85	104.73	126.73	143.54
	33.25	25.54	30.35	33.45	5.76	5.45	5.45	5.86	133.45	102.87	129.74	139.56
	31.62	26.32	26.87	35.14	5.72	5.27	5.71	5.88	135.74	105.89	130.11	146.15
Mean	32.21	25.59	28.96	34.98	5.78	5.49	5.59	5.89	134.01	104.50	128.86	143.08

5 DAY CONTACT TIME

	H	S	SH	C	H	S	SH	C	H	S	SH	C
	19.94	18.68	21.55	29.83	4.93	4.58	4.04	5.54	78.94	74.59	79.46	122.05
	20.34	17.19	19.69	30.20	4.58	4.24	4.57	5.64	78.91	75.71	78.81	115.56
	20.67	16.79	20.23	31.12	4.02	4.03	4.34	5.74	77.72	75.87	77.69	119.35
Mean	20.32	17.55	20.49	30.38	4.51	4.28	4.32	5.64	78.52	75.39	78.65	118.99

7 DAY CONTACT TIME

	H	S	SH	C	H	S	SH	C	H	S	SH	C
	15.59	14.49	17.42	27.68	4.33	4.31	3.55	4.78	67.9	63.04	67.45	98.58
	16.72	13.57	15.75	28.61	4.34	3.37	4.21	4.69	67.07	64.53	66.89	96.82
	16.63	13.34	16.81	26.98	3.54	3.45	3.18	4.71	66.26	64.84	66.3	100.52
Mean	16.31	13.80	16.66	27.76	4.07	3.71	3.65	4.73	67.08	64.14	66.88	98.64

h. Levels of BOD and COD for batch 4 of wastewater

RAW CHARACTERISTICS: BOD-85.91, COD-159.19 mg/L

3 DAY CONTACT TIME

	BOD				COD			
	H	S	SH	C	H	S	SH	C
	50.62	35.76	44.53	80.34	94.21	70.66	80.34	139.98
	48.54	38.83	41.90	78.94	92.34	74.67	79.45	140.40
	47.89	40.14	46.01	78.56	89.91	75.98	81.34	138.54
Mean	49.02	38.23	44.15	79.28	92.15	73.77	80.38	139.64

5-DAY CONTACT TIME

	H	S	SH	C	H	S	SH	C
	25.92	18.03	24.93	50.10	54.54	40.03	48.71	107.41
	24.32	16.19	20.96	54.91	52.31	44.24	46.50	102.81
	27.15	22.97	25.78	51.34	49.75	45.69	52.03	99.85
Mean	25.80	19.06	23.89	52.12	52.20	43.32	49.08	103.15

7-DAY CONTACT TIME

	H	S	SH	C	H	S	SH	C
	19.64	13.25	18.96	46.86	40.09	30.02	36.35	90.65
	18.28	12.41	15.27	47.77	39.32	33.81	34.78	86.35
	20.43	17.22	19.33	49.34	37.13	34.62	39.20	84.98
Mean	19.45	14.29	17.85	47.99	38.85	32.82	36.78	87.33

i. Levels of nitrogen, phosphorous and suspended solids for batch 5

RAW CHARACTERISTICS: TN-45.08, TP 6.67, and TSS 165.94 mg/L.

3 DAY CONTACT TIME

	TOTAL N				TOTAL P				TSS			
	H	S	SH	C	H	S	SH	C	H	S	SH	C
	32.75	37.43	32.13	40.62	5.01	4.97	4.74	5.55	149.43	140.55	143.03	156.36
	35.26	37.44	31.65	41.29	4.84	4.75	4.83	6.28	146.98	139.72	142.92	154.27
	33.57	35.86	31.31	39.77	4.78	4.61	5.01	5.98	150.02	142.72	145.02	151.72
Mean	33.86	36.91	31.70	40.56	4.88	4.78	4.86	5.94	148.81	141.00	143.66	154.12

5 DAY CONTACT TIME

	H	S	SH	C	H	S	SH	C	H	S	SH	C
	21.25	18.03	20.47	37.81	4.51	4.48	4.23	5.62	80.61	62.80	70.64	90.76
	20.64	17.26	20.42	33.45	4.36	4.12	4.32	5.65	77.28	64.82	74.59	105.75
	19.57	16.97	19.93	30.03	4.39	4.15	4.51	4.99	74.61	69.47	74.95	94.12
Mean	20.49	17.42	20.27	33.76	4.42	4.25	4.35	5.42	77.50	65.70	73.39	96.88

7 DAY CONTACT TIME

	H	S	SH	C	H	S	SH	C	H	S	SH	C
	19.12	16.72	18.43	33.92	4.28	4.18	4.08	4.93	68.51	53.83	61.29	83.45
	18.57	15.34	18.38	30.51	4.29	4.09	4.14	5.36	65.19	55.76	63.47	90.34
	17.13	15.73	17.39	28.02	4.26	3.94	4.28	4.79	64.81	59.49	63.87	89.03
Mean	18.27	15.93	18.07	30.82	4.28	4.07	4.17	5.03	66.17	56.93	62.88	87.61

j. Levels of BOD and COD for batch 5 of wastewater

RAW CHARACTERISTICS: BOD-97.54, COD-173.52 mg/L

3 DAY CONTACT TIME

	BOD				COD			
	H	S	SH	C	H	S	SH	C
	72.82	53.83	57.88	88.93	105.96	95.23	99.87	149.65
	68.03	52.89	59.24	83.95	106.94	94.72	102.61	148.45
	70.45	54.02	61.22	86.23	105.02	92.09	97.32	147.98

Mean	70.43	53.58	59.45	86.37	105.97	94.01	99.93	148.63

5-DAY CONTACT TIME

	H	S	SH	C	H	S	SH	C
	29.69	20.75	23.97	56.02	89.34	88.76	85.03	143.05
	26.93	15.56	25.33	55.96	86.72	85.03	80.89	132.46
	27.98	18.16	27.68	51.82	84.36	82.07	82.84	138.47
Mean	28.20	18.16	25.66	54.60	86.81	85.29	82.92	137.99

7-DAY CONTACT TIME

	H	S	SH	C	H	S	SH	C
	23.57	16.96	19.67	49.85	55.87	44.86	50.78	107.67
	21.54	13.44	20.26	49.07	53.65	38.78	47.72	104.55
	22.84	14.16	22.41	47.37	55.55	42.86	48.79	111.54
Mean	22.65	14.85	20.78	48.76	55.02	42.17	49.10	107.92

k. Levels of nitrogen, phosphorous and suspended solids for batch 6

RAW CHARACTERISTICS: TN-44.26, TP-7.01 and TSS-183.34 mg/L.

3 DAY CONTACT TIME

	TOTAL N				TOTAL P				TSS			
	H	S	SH	C	H	S	SH	C	H	S	SH	C
	21.96	18.36	21.33	34.23	5.43	5.09	5.33	5.71	92.34	76.77	93.9	106.09
	22.05	19.07	22.17	35.83	5.54	5.23	5.51	5.75	96.38	80.56	92.28	101.33
	23.87	18.96	23.42	38.82	5.34	5.02	5.43	5.86	91.54	79.64	93.54	108.77
Mean	22.63	18.80	22.31	36.29	5.44	5.11	5.42	5.77	93.42	78.99	93.24	105.40

5 DAY CONTACT TIME

	H	S	SH	C	H	S	SH	C	H	S	SH	C
	18.84	15.98	18.78	32.76	4.95	4.31	4.96	5.69	76.6	60.77	77.06	89.45
	19.89	16.34	18.93	32.22	4.78	4.53	5.09	5.32	81.05	67.69	78.45	98.01
	20.13	16.95	19.34	33.25	4.74	4.04	4.62	5.57	85.91	65.51	8I.2	90.6
Mean	19.62	16.42	19.02	32.74	4.82	4.29	4.89	5.53	81.19	64.66	78.90	92.69

7 DAY CONTACT TIME

	H	S	SH	C	H	S	SH	C	H	S	SH	C
	21.96	11.66	14.97	30.08	3.13	2.99	2.96	4.96	64.54	42.73	61.09	76.65
	22.05	12.71	15.45	29.99	3.22	3.31	3.05	4.23	67.49	49.39	62.55	75.21
	23.87	13.01	16.34	31.98	3.422	2.42	3.23	4.75	61.21	45.91	63.92	78.28
Mean	16.56	12.46	15.59	30.68	3.26	2.91	3.08	4.65	64.41	46.01	62.52	76.71

l. Levels of BOD and COD for batch 6 of wastewater

RAW CHARACTERISTICS : BOD-96.37, COD-163.47 mg/L

3 DAY CONTACT TIME

	BOD				COD			
	H	S	SH	C	H	S	SH	C
	41.44	30.34	33.82	75.94	86.35	73.60	82.06	126.20
	42.67	27.45	37.23	73.28	82.14	70.82	89.65	130.98
	39.95	32.04	38.91	71.04	84.46	73.54	88.32	134.20
Mean	41.35	29.94	36.65	73.42	84.32	72.65	80.01	130.46

5-DAY CONTACT TIME

	H	S	SH	C	H	S	SH	C
	27.44	17.93	29.12	63.91	51.34	39.97	47.12	107.88
	27.84	14.12	20.31	60.71	46.45	36.12	45.91	104.71
	25.12	18.38	25.49	59.23	49.13	40.73	43.59	110.63
Mean	26.80	16.81	24.97	61.28	48.97	38.94	45.54	107.74

7-DAY CONTACT TIME

	H	S	SH	C	H	S	SH	C
	25.04	13.73	24.15	59.92	48.24	34.92	43.32	107.82
	24.84	11.15	17.11	57.37	43.40	31.32	41.93	104.31
	23.66	14.58	22.41	58.03	46.23	35.75	40.39	108.69
Mean	24.51	13.15	21.22	58.44	45.96	34.00	41.88	106.94

Appendix Table A6: Sample SAS analysis Results

a. Sample SAS system input and output for treatment systems

Obs	trt	rep	run	TN	TP	TSS	BOD	COD
1	H	1	1	28.11	4.04	89.85	38.25	89.65
2	H	2	1	25.20	4.41	83.61	37.54	92.05
3	H	3	1	29.05	4.65	87.88	38.85	87.85
4	S	1	1	23.15	3.86	80.85	29.08	80.65
5	S	2	1	28.12	4.21	85.85	27.27	78.97
6	S	3	1	22.26	4.50	81.17	32.69	79.78
7	SH	1	1	30.25	3.99	83.85	39.60	90.20
8	SH	2	1	27.28	4.83	85.37	34.28	93.88
9	SH	3	1	23.54	4.56	82.90	32.36	95.20
10	C	1	1	38.66	5.35	102.17	53.24	129.65
11	C	2	1	32.21	5.02	105.20	57.81	138.55
12	C	3	1	36.52	5.92	99.93	60.59	140.44
13	H	1	2	24.01	4.52	83.65	36.85	79.65
14	H	2	2	30.20	4.01	80.48	34.69	79.05
15	H	3	2	23.25	4.37	79.67	39.79	82.65
16	S	1	2	20.14	3.84	75.22	25.82	60.36
17	S	2	2	21.16	4.24	78.12	27.95	66.70
18	S	3	2	20.23	4.33	70.65	29.88	63.87
19	SH	1	2	23.27	4.49	83.56	35.98	76.23
20	SH	2	2	25.22	4.83	80.07	33.83	70.81
21	SH	3	2	26.29	4.02	83.52	31.47	79.01
22	C	1	2	34.61	5.45	91.68	57.85	117.64
23	C	2	2	30.29	5.12	103.35	59.06	125.21
24	C	3	2	37.52	4.43	89.56	51.21	142.35
25	H	1	3	22.96	5.54	83.82	30.98	85.64
26	H	2	3	25.67	5.89	82.27	31.28	74.79
27	H	3	3	26.30	5.08	80.85	33.54	87.80
28	S	1	3	20.22	5.08	78.51	27.81	62.42
29	S	2	3	20.94	5.60	77.85	23.62	63.97
30	S	3	3	22.28	5.15	74.25	22.36	60.13
31	SH	1	3	23.65	5.42	80.11	29.32	73.94
32	SH	2	3	25.67	5.66	85.74	28.71	74.48
33	SH	3	3	28.10	5.08	91.58	29.07	71.81
34	C	1	3	39.68	5.42	83.46	64.28	147.63
35	C	2	3	34.99	5.20	96.88	59.02	151.91
36	C	3	3	31.87	5.94	100.79	56.51	141.71

The SAS System 04:53 Wednesday, May 21, 2010

The ANOVA Procedure

Class Level Information

Class	Levels	Values
trt	4	C H S SH
rep	3	1 2 3
run	6	1 2 3 4 5 6

Number of Observations Read	72
Number of Observations Used	72

The SAS System 04:53 Wednesday, May 21, 2008

The ANOVA Procedure

Dependent Variable: TN

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	10	2519.126442	251.912644	55.10	<.0001
Error	61	278.875486	4.571729		
Corrected Total	71	2798.001928			

R-Square	Coeff Var	Root MSE	TN Mean
0.900330	8.608404	2.138160	24.83806

Source	DF	Anova SS	Mean Square	F Value	Pr > F
trt	3	2035.732228	678.577409	148.43	<.0001
rep	2	2.691036	1.345518	0.29	0.7461
run	5	480.703178	96.140636	21.03	<.0001

The SAS System 04:53 Wednesday, May 21, 2008

The ANOVA Procedure

t Tests (LSD) for TN

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	61
Error Mean Square	4.571729
Critical Value of t	1.99962
Least Significant Difference	1.4252

Means with the same letter are not significantly different.

t Grouping	Mean	N	trt
A	33.7233	18	C
B	23.1122	18	H
B			
B	22.9228	18	SH
C	19.5939	18	S
B			
B	29.8394	72	SH
C	27.4185	72	S

b. Sample SAS input and output for plants' age

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Obs	Age	rep	TN	TP	BOD	COD	TSS
1	4	1	51.4166	38.7302	68.1664	61.6555	55.9401
2	4	2	40.9864	33.1746	70.1478	62.4542	53.2153
3	4	3	53.2844	28.5714	64.2146	62.0691	55.7657
4	5	1	55.8624	38.3628	71.2568	68.8722	55.3140

5	5	2	53.6270	31.9422	68.8857	65.6026	53.5912
6	5	3	55.6651	30.4976	66.7372	67.0620	58.0289
7	6	1	58.0672	27.9433	70.8643	71.4782	54.5001
8	6	2	56.5740	20.5674	75.2541	70.7699	54.8826
9	6	3	53.7951	26.9504	76.5741	72.5246	56.9690
10	7	1	54.4168	25.2855	79.0129	74.8539	55.6777
11	7	2	58.0527	30.8320	81.1547	72.2093	55.0122
12	7	3	59.0288	34.2577	73.2627	71.2984	54.9171
13	8	1	60.0044	32.8336	78.7267	73.0521	62.1550
14	8	2	61.7125	38.2309	84.0476	75.2017	60.9377
15	8	3	62.3558	37.7811	81.3820	76.9076	58.1355
16	9	1	63.8952	38.5164	81.3946	75.5490	66.8539
17	9	2	63.0818	35.3780	85.3481	77.9042	63.0795
18	9	3	61.7036	42.3680	80.9277	75.0841	64.2686

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The ANOVA Procedure

Class Level Information

Class	Levels	Values
Age	6	4 5 6 7 8 9
rep	3	1 2 3

Number of Observations Read 18
Number of Observations Used 18

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The ANOVA Procedure

Dependent Variable: TN

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	401.2131577	57.3161654	5.49	0.0083
Error	10	104.3812851	10.4381285		
Corrected Total	17	505.5944427			

R-Square	Coeff Var	Root MSE	TN Mean
0.793547	5.681766	3.230809	56.86276

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Age	5	388.0680173	77.6136035	7.44	0.0038
rep	2	13.1451404	6.5725702	0.63	0.5526

The ANOVA Procedure

t Tests (LSD) for TN

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	10
Error Mean Square	10.43813
Critical Value of t	2.22814
Least Significant Difference	5.8777

Means with the same letter are not significantly different.

t Grouping	Mean	N	Age
A	62.894	3	9
A			
B A	61.358	3	8
B A			
B A C	57.166	3	7
B C			
B C	56.145	3	6
C			
C	55.052	3	5
D	48.562	3	4

c. Sample SAS input and output for contact periods

Soil based
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Obs	trt	rep	week	TN	TP	BOD	COD	TSS
1	0	1	1	47.65	6.30	91.35	210.33	183.50
2	0	2	1	47.65	6.30	91.35	210.33	183.50
3	0	3	1	47.65	6.30	91.35	210.33	183.50
4	3	1	1	28.75	4.53	39.96	105.03	90.37
5	3	2	1	33.15	5.26	37.87	99.88	91.93
6	3	3	1	27.46	5.38	43.01	100.78	94.03
7	5	1	1	23.15	3.86	29.08	80.65	80.85
8	5	2	1	28.12	4.21	27.27	78.97	85.85
9	5	3	1	22.26	4.50	32.69	79.78	81.17
10	7	1	1	17.93	3.36	25.83	65.74	74.93
11	7	2	1	21.06	2.91	21.05	62.93	78.85
12	7	3	1	15.43	3.15	23.98	68.18	77.86
13	0	1	2	45.63	6.23	89.83	193.91	168.33
14	0	2	2	45.63	6.23	89.83	193.91	168.33
15	0	3	2	45.63	6.23	89.83	193.91	168.33
16	3	1	2	37.90	5.43	51.21	135.94	109.78
17	3	2	2	35.29	5.26	49.93	140.03	118.57
18	3	3	2	32.76	5.65	48.97	138.37	107.83
19	5	1	2	20.14	3.84	25.82	60.36	75.22
20	5	2	2	21.16	4.24	27.95	66.70	78.12
21	5	3	2	20.23	4.33	29.88	63.87	70.65
22	7	1	2	14.26	3.09	18.96	27.34	54.59
23	7	2	2	16.23	3.11	19.84	26.94	58.35
24	7	3	2	16.96	2.96	17.82	24.58	51.63
25	0	1	3	48.22	7.05	95.45	218.85	172.55
26	0	2	3	48.22	7.05	95.45	218.85	172.55
27	0	3	3	48.22	7.05	95.45	218.85	172.55
28	3	1	3	33.83	6.21	66.88	130.42	109.91
29	3	2	3	35.02	6.07	69.24	129.27	112.24
30	3	3	3	32.17	6.44	65.83	131.25	110.11
31	5	1	3	20.22	5.08	27.81	62.42	78.51
32	5	2	3	20.94	5.60	23.62	63.97	77.85
33	5	3	3	22.28	5.15	22.36	60.13	74.25
34	7	1	3	13.08	4.25	25.28	56.87	70.36
35	7	2	3	11.35	4.32	21.26	57.73	70.09
36	7	3	3	12.89	4.46	20.21	54.17	66.28
37	0	1	4	40.98	6.13	85.91	159.19	168.29
38	0	2	4	40.98	6.13	85.91	159.19	168.29

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39	0	3	4	40.98	6.13	85.91	159.19	168.29
40	3	1	4	24.91	5.75	35.76	70.66	104.73
41	3	2	4	25.54	5.45	38.83	74.67	102.87
42	3	3	4	26.32	5.27	40.14	75.98	105.89
43	5	1	4	18.68	4.58	18.03	40.03	74.59
44	5	2	4	17.19	4.24	16.19	44.24	75.71
45	5	3	4	16.79	4.03	22.97	45.69	75.87
46	7	1	4	14.49	4.31	13.25	30.02	63.04
47	7	2	4	13.57	3.37	12.41	33.81	64.53
48	7	3	4	13.34	3.45	17.22	34.62	64.84
49	0	1	5	45.08	6.67	97.54	173.52	165.94
50	0	2	5	45.08	6.67	97.54	173.52	165.94
51	0	3	5	45.08	6.67	97.54	173.52	165.94
52	3	1	5	37.43	4.97	53.83	155.23	140.55
53	3	2	5	37.44	4.75	52.89	154.72	139.72
54	3	3	5	35.86	4.61	54.02	162.09	142.72
55	5	1	5	18.03	4.48	20.75	46.76	62.80
56	5	2	5	17.26	4.12	15.56	43.03	64.82
57	5	3	5	16.97	4.15	18.16	40.07	69.47
58	7	1	5	16.72	4.18	16.96	40.86	53.83
59	7	2	5	15.34	4.09	13.44	38.78	55.76
60	7	3	5	15.73	3.94	14.16	35.86	59.49
61	0	1	6	44.26	7.01	96.37	163.47	183.34
62	0	2	6	44.26	7.01	96.37	163.47	183.34
63	0	3	6	44.26	7.01	96.37	163.47	183.34
64	3	1	6	18.36	5.09	30.34	53.60	76.77
65	3	2	6	19.07	5.23	27.45	50.82	80.56
66	3	3	6	18.96	5.02	32.04	53.54	79.64
67	5	1	6	15.98	4.31	17.93	39.97	60.77
68	5	2	6	16.34	4.53	14.12	36.12	67.69
69	5	3	6	16.95	4.04	18.38	40.73	65.51
70	7	1	6	11.66	2.99	13.73	34.92	42.73
71	7	2	6	12.71	3.31	11.15	31.32	49.39
72	7	3	6	13.01	2.42	14.58	35.75	45.91

The SAS System

The ANOVA Procedure

Class Level Information

Class	Levels	Values
trt	4	0 3 5 7
rep	3	1 2 3

week 6 1 2 3 4 5 6

Number of Observations Read 72
Number of Observations Used 72

The SAS System

The ANOVA Procedure

Dependent Variable: TN

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	10	10385.12687	1038.51269	107.90	<.0001
Error	61	587.12126	9.62494		
Corrected Total	71	10972.24813			

R-Square	Coeff Var	Root MSE	TN Mean
0.946490	11.31503	3.102409	27.41847

Source	DF	Anova SS	Mean Square	F Value	Pr > F
trt	3	9862.997749	3287.665916	341.58	<.0001
rep	2	8.709419	4.354710	0.45	0.6382
week	5	513.419707	102.683941	10.67	<.0001

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The ANOVA Procedure

t Tests (LSD) for TN

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

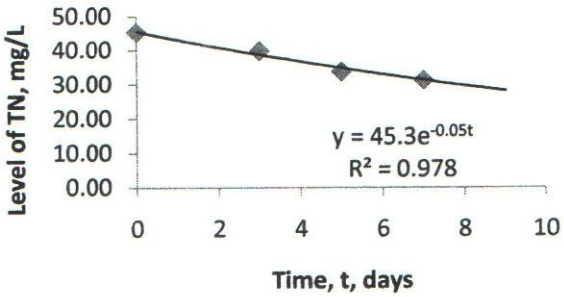
Alpha	0.05
Error Degrees of Freedom	61
Error Mean Square	9.624939
Critical Value of t	1.99962
Least Significant Difference	2.0679

Means with the same letter are not significantly different.

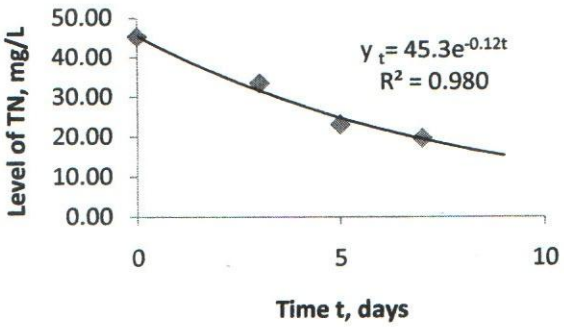
t Grouping	Mean	N	trt
A	45.303	18	0
B	30.012	18	3
C	19.594	18	5
D	14.764	18	7

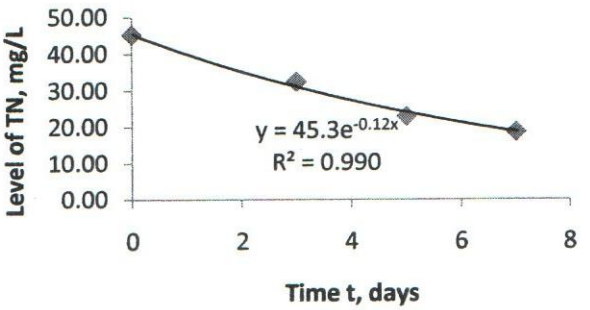
Appendix Figures A1: Exponential and Linear Regression graphs for TN

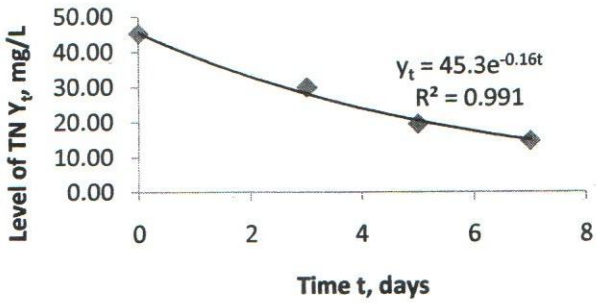
i. Control



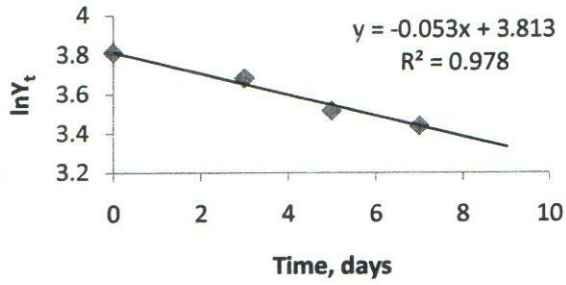
ii. Hydroponic



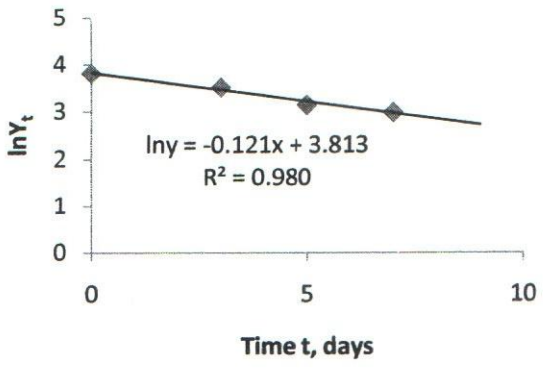


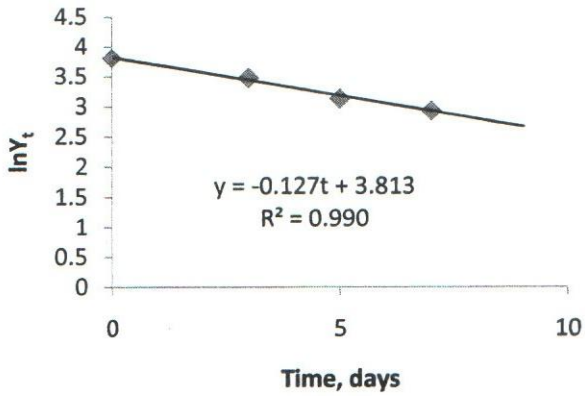


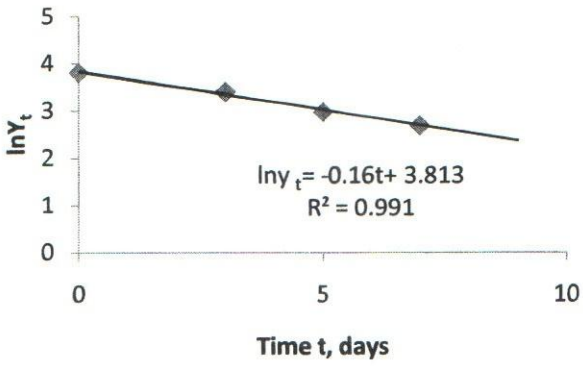
iii. Hybrid



Soil based



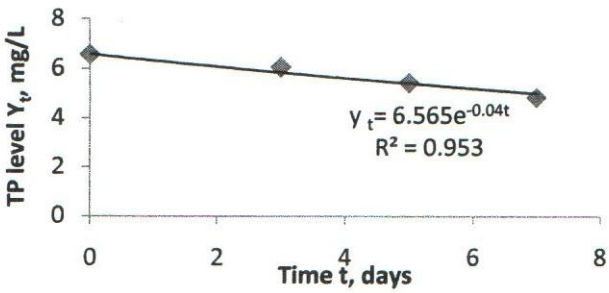


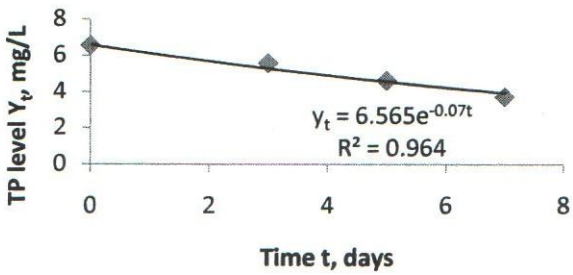


Appendix Figure A2: Appendix Figures A1: Exponential and Linear Regression graphs for TP

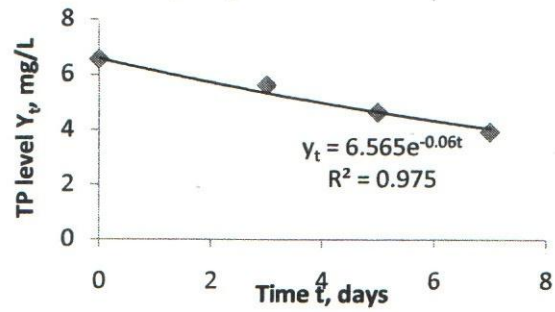
a. Exponential Forms

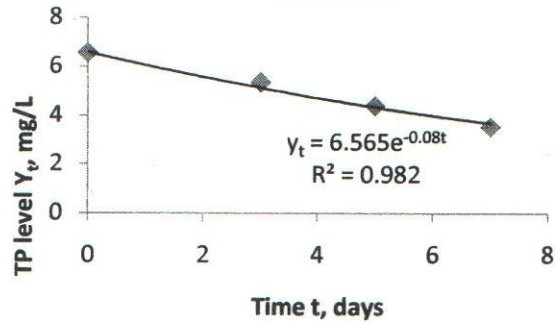
i. Control





ii. Hydroponic

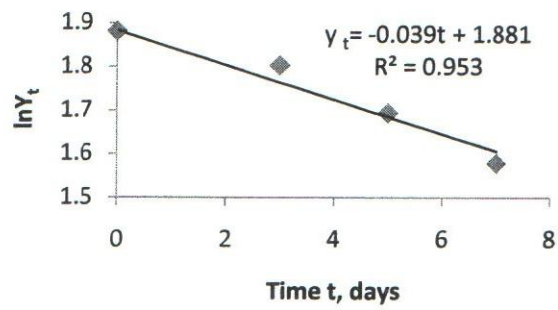


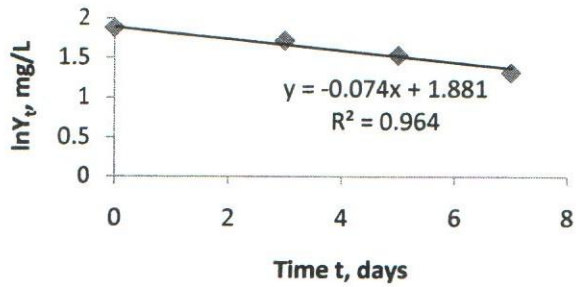


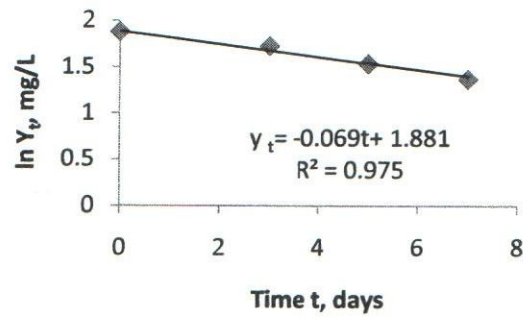
iii. Hybrid

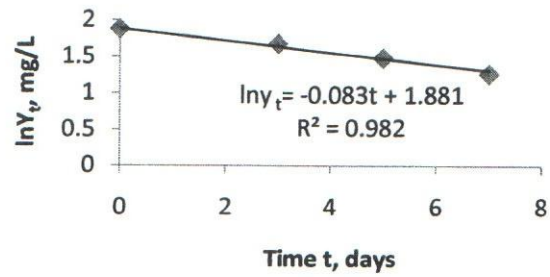
iii. Soil based

b. Corresponding Linear Forms:





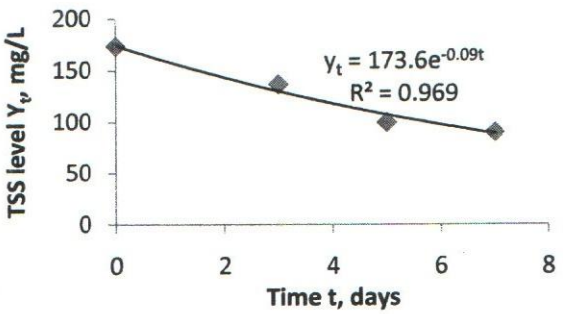


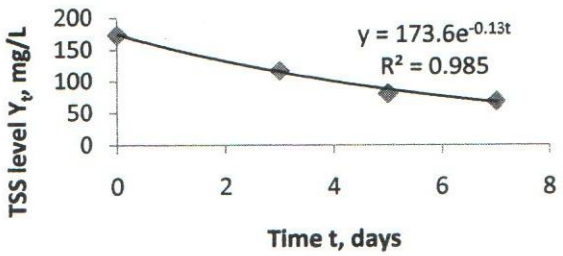


Appendix Figure A3: Appendix Figures A1: Exponential and Linear Regression Graphs for TSS

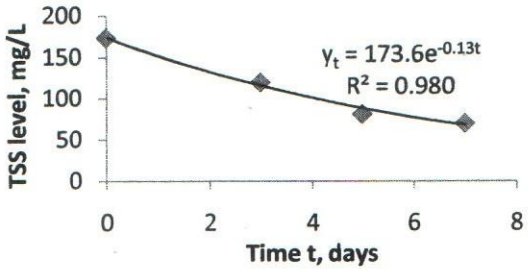
a. Exponential Form

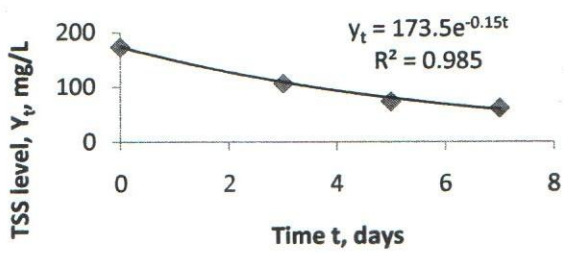
i. Control



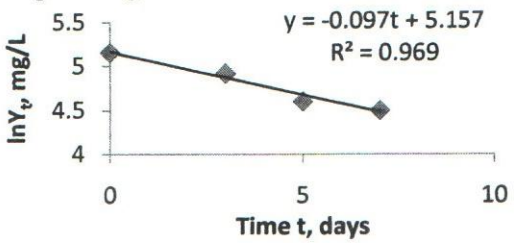


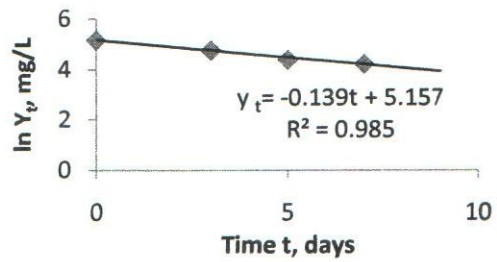
ii. Hydroponic

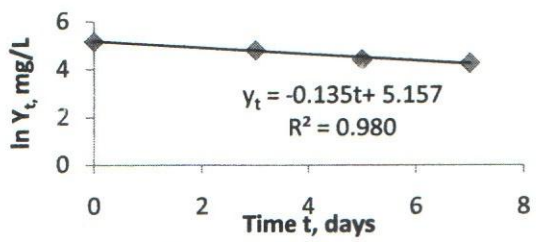


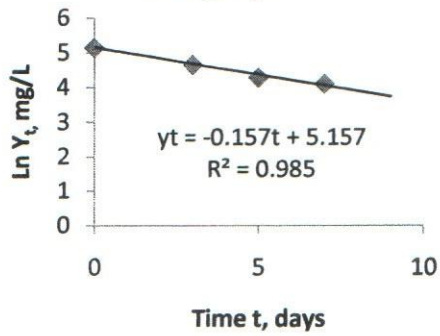


b. Corresponding Linear Forms





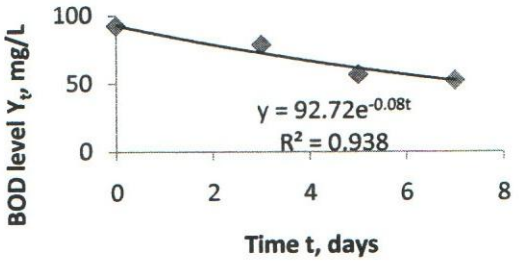




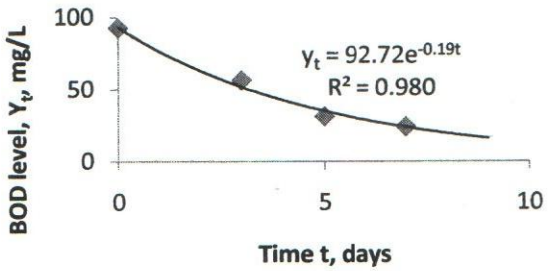
Appendix Figure A4: Appendix Figures A1: Exponential and Linear Regression graphs for BOD

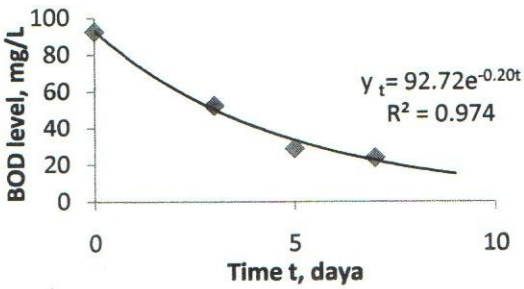
a. Exponential Form

i. Control

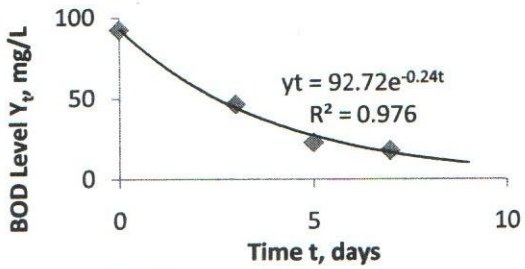


b. Hydroponic



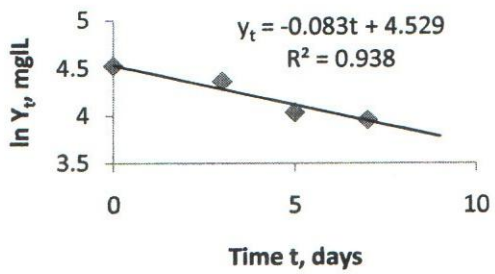


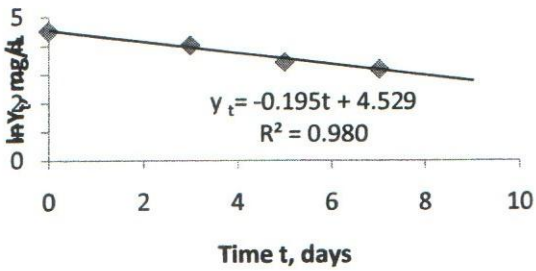
iii. Hybrid

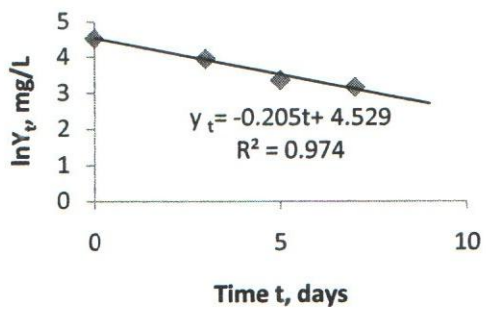


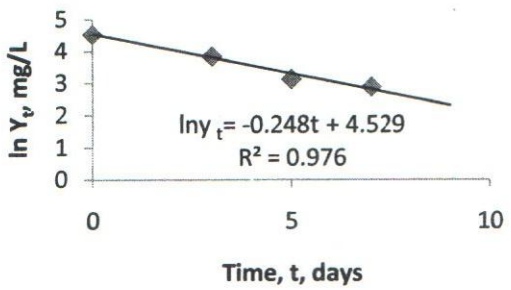
iv. Soil based

b. Corresponding Linear Forms





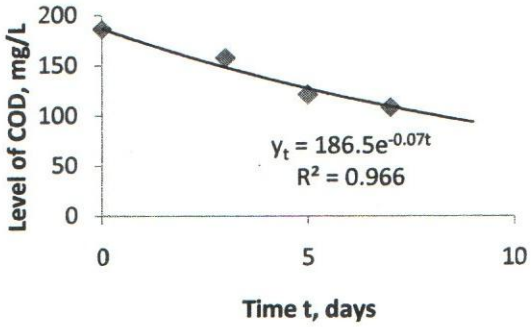




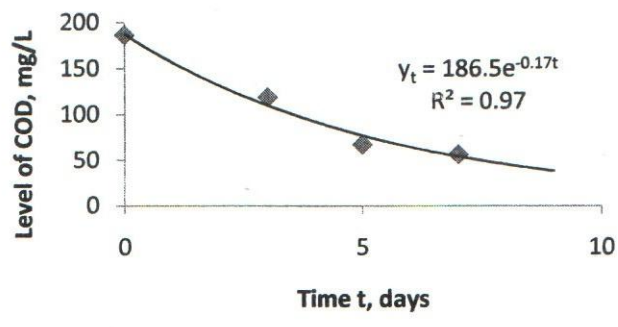
Appendix Figure A5: Appendix Figures A1: Exponential and Linear Regression graphs for COD

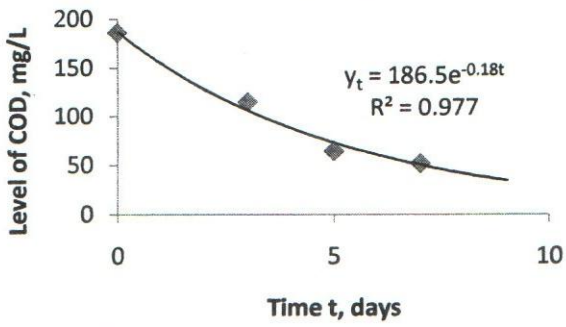
a. Exponential Form

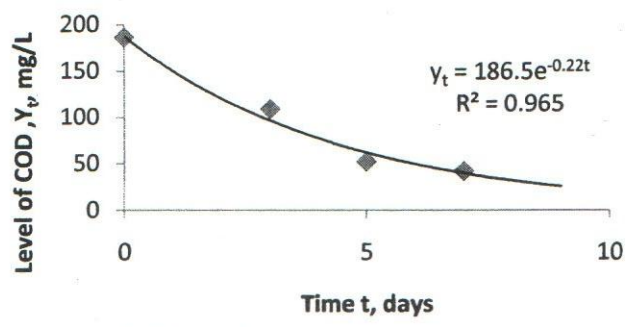
i. Control



ii. Hydroponic







iii. Hybrid

iv. Soil based

b. Corresponding Linear Form

