KYAMBOGO UNIVERSITY

THE LOCALLY DESIGNED WATER TREATMENT TECHNOLOGY FOR A VEHICLE WASHING BAY'S EFFLUENT IN WAKISO DISTRICT, UGANDA

(KANSIIME IMPROVED SMALL SCALE CONSTRUCTED WETLAND)

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A RESEARCH DISSERTATION SUBMITTED TO THE DIRECTORATE OF RESEARCH AND GRADUATE TRAINING IN PARTIAL FULFILMENT FOR THE AWARD OF MASTER OF SCIENCE IN CONSERVATION AND NATURAL RESOURCES MANAGEMENT DEGREE OF KYAMBOGO UNIVERSITY

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DECLARATION

I Baker Kansiime, declare that this research report is my own work and all the contents presented are truly original and have never been presented by any other person except where stated by the references.

Signature ……………………………….

Date……………………………………

APPROVAL

This report has been developed under my guidance and supervision and submitted with my approval as the appointed university supervisor

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DEDICATION

This research is dedicated to my dear children, Kansiime Lisa and Kansiime Leith who endured my absence during the study period in addition to encouraging and reminding me to do my homework so as to accomplish my Master's Degree studies.

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NTU	Nephelometric Turbidity Unit
NWSC	National Water and Sewerage Corporation
URA	Uganda Revenue Authority
NRW	Non-Revenue Water
NEA	National Environment Act
ICA	International Car Wash Association
TSS	Total Suspended Solids
COD	Chemical Oxygen Demand
WW-WB	Waste Water Washing Bay
NEMA	National Environment Management Authority
TDS	Total Dissolved Solids
VFP	Vertical Flow Planted
VFUP	Vertical Flow Unplanted
HFP	Horizontal Flow Planted
HFUP	Horizontal Flow Unplanted
EC	Electric Conductivity
pH	Alkalinity and Acidity
ORTHO	Orthophosphates
WW	Waste water
QWC	Queensland Water Commission
WWTP	Waste Water Treatment Plant

ABSTRACT

Vehicle washing is a very lucrative industry that is rapidly growing in Uganda due to the increased demand for transport services. In an event of washing vehicles, a lot of water is used that transform into waste water. Therefore, the study focused mainly on quantifying the daily volume of water used, characterizing the pollutants, designing waste water treatment technology and quantifying volume of water recovered. The study used a jerrycan model, Auto card to implement and design the technology, and used Microsoft Excel and R data analysis to organize and analyze data. Daily, 29.3±6 saloon vehicles of weight less than 3.5 tons and 9.4±3.3 heavy truck vehicles of weight at least 3.5 tons and more were washed. However, 4,841±314 litres of water were used daily 97.2±26 litres of water for each saloon vehicle and 212±48 litres for each heavy truck.

The designed technology was effective in treatment of the vehicle washing bay waste water for turbidity from (1139±13.4 NTU to 57.5±24.1 NTU), TSS (2878±2.5 mg/l to 46±25.8 mg/l), COD (458±2.5 mg/l to 46±7.3 mg/l), orthophosphates (5±0.5 mg/l to 1.86±0.375±0.5 mg/l) and TDS (107±18.8 mg/l to 96.7±4.33), EC (413±24.3 µS/cm to 372±16) and pH (7 ±0.3 to 7.58±0.21) conforming to the recommended waste water discharge standards at 100% (NEMA, 2014). However, pH, EC and TDS values were within the recommended waste water discharge standards before treatment. In summary, 80% of the waste water was recovered as treated water and 20% of waste water lost by the treatment system.

In conclusions, the waste water from Vehicle washing bays is polluted with pollutants levels that do not qualify it to be discharged into the environment without treatment. Therefore, there is a need to adopt a locally designed constructed wetland technology in the treatment

and recycling of waste water from the vehicle washing bays, for both environmental protection and reuse.

CHAPTER ONE: INTRODUCTION

1.1 Background to the study

Eutrophication in lakes, rivers and oceans has become a very serious concern in most tropical countries in the world and this has threatened the marine and terrestrial ecosystems. The polluted water sources have caused shortages in water supply due to high costs of production and competition for clean water. The above interfere with the sustainable development goal number six of clean water and sanitation and sustainable development goal number fourteen of life below water. This environmental challenge is linked to un treated municipal wastes directed to the environment due to underdeveloped cities and municipalities infrastructure networks (Sekabira *et al*., 2010).

Nevertheless, vehicle washing bays consume large quantities of water of which these large volumes of water used translate into waste water and the evidently toxic waste water effluents contain diverse chemical pollutants. These pollutants include petroleum hydrocarbon wastes; (petrol, diesel, and motor oil) and nutrients such as phosphorous and nitrogen, surfactants, asphalt, salts, organic matter together with heavy metals. These chemicals damage water quality which in turn affects both terrestrial and aquatic ecosystems. This summarily impairs the use of water for household, industrial, agricultural, and recreational purposes (Hashim & Zayadi, 2016) .

The poor waste water disposal methods demonstrated in developing countries is due to lack of awareness on its negative environmental impacts, unaffordable waste water treatment systems due to high operating costs of treatment plants and less attention from the policy makers on wastes managing. The organic and inorganic waste pollutants from the vehicle washing bays are directed into the streams, inland and largely to water bodies causing damage to the environmental ecosystems (Sekabira *et al*., 2010).

However, the large volumes of water consumed by these automobiles increase the water bills and demand for clean water, ultimately propelling washing bay operators to engage in illegal water use practices. These bad practices increase NRW (Non-Revenue Water) of water supply utility companies for example National Water and Sewerage

Corporation's non-revenue water stands at 39% and such washing bays involved in water theft have been fined and disconnected from water supply pipe network (MWE, 2017). Additionally, the overwhelming water demand has also forced washing bay proprietors to encroach and damage many wetlands in an attempt to access free water and space. Consequently, the soapy water combined with other pollutants end up in the fresh waters and ruins the aquatic life (Mafabi, 2017).

Therefore vehicle washing bays have been identified as one of the areas among others that discharge un treated waste water into the environment (International Carwash Association, 2002).

The studies show that in places where waste water management systems are poor and not affordable; there are many adverse effects to the environment and the economic growth of nations. In this setting, the waste water treatment and recycling is the most operative and reliable ways of environmental conservation (Zaneti *et al* 2011). Therefore, this research focused on designing an efficient locally made prototype technology for treating vehicle washing bay waste water for conservation and reuse.

1.2 Problem statement

Globally, vehicle washing bays are known for using high masses of detergents for example liquid soap, powered soap, car shampoo and others that are rich in phosphates and Nitrates (Hashim & Zayadi, 2016). Remarkably, washing bays situated alongside streams and wetlands discharge raw effluent direct to the environment ecosystems.

Therefore, Uganda’s water bodies are polluted with heavy loads of nutrients from human activities like vehicle washing bays, agricultural wastes and municipal waste disposal systems (Gikuma-Njuru *et al.*, 2005). Therefore, the phosphates and nitrates present in the waste water have a high nutrient content thus cause eutrophication in the lakes and rivers.

More so in Uganda's capital city of Kampala and its metropolitan area, most of the washing bays are located in areas with no sewer pipe network connected to sewage treatment plants. As a result the waste water generated from the washing bay is discharged into the storm water drainage channels and the open land. Ultimately the waste water pollute the rivers, lakes and swampy areas thus contributing to eutrophication; a danger to the aquatic life. (Al-Gheethi *et al.*, 2016)

Therefore, there is a need to design an affordable and effective conventional treatment technology to treat vehicle washing bay's waste water before being discharged into the environment.

1.3 Research objectives

The study is to design a relatively affordable treatment technology for the waste water from vehicle washing bays in Namugongo Parish, Kira municipality, Wakiso District, Uganda

The specific objectives of this study were;

1. To quantify the amount of water used for washing a single vehicle.
2. To analyze the water quality of the waste water from the vehicle washing bay.
3. To design and establish the efficiency of the locally made technology for treating vehicle washing bay waste water.
4. To establish the volume of water recovered from the locally designed water treatment technology for reuse.

1.4 Research questions

The research study aimed at answering the following questions.

Objective one

1. What is the volume of water used to wash a single vehicle?
2. What is the source of water used?
3. What is the cost of water used?

Objective two

1. What is the chemical quality of waste water from vehicle washing bays?
2. What are the major pollutants present in the vehicle washing bay waste water?
3. What is the concentration of the pollutants compared to the NEMA, 2014 quality of waste water standards?
4. Is there any seasonal variation in the pollutants?

Objective three

1. What is the design layout of the treatment system?
2. Is there a difference in parameters after treatment?
3. Which treatment unit performs better in removing the pollutants?
4. Is the treatment technology reliable and affordable?

Objective four

1. How much water is recovered from the treatment technology?
2. Is the recovered water enough for reuse?

1.5 Justification for the study

Water pollution is rising in Ugandan water bodies due to poor waste management; this has led to increased destruction of aquatic ecosystems and drinking water. This very challenge has raised high demand for clean water causing the water utilities to spend a lot of money on treatment and setting up high tech plants in managing water production. In Kampala for example, demand for water services is at higher rise due to a rapid population growth with an average estimate of per capita water consumption of seventy litres (70 litres) per person per day.

Furthermore, washing bays have been identified as one of areas that uses a large volume of water on a daily basis for washing and maintaining motor vehicles in good operating conditions. Motor vehicles provide transportation of goods and services and because of the poor road infrastructure networks they contract dirt that require proper maintenance of which washing is a critical one.

Commercial washing bays have a challenge of managing high water bills because they use a lot of water from the water utility. As and when they failure to pay water bills, they are normally disconnected for non-payment, consequently washing bay operators resort to water theft (meter by-passes) causing non-revenue water and also encroaching on wetlands to get free water.

Therefore, there is a need to adopt a locally designed waste water treatment technology purposely to treat the waste water and remove the contaminants before being discharged into the environment and also for reuse.

1.6 Significance of the study

The study will help the ministry of water and environment and other water resources departments to come up with rules, guidelines, requirements and standard operating procedures on the construction and layout of washing bays.

The study will help the implementers to use the advanced and modern methods of technology in water recycling, reuse and eliminating contaminants from the waste water of washing bay.

The study will help the proprietors of the washing bays to save on water bills.

The study will lay ground for further research in the fields of water conservation and water pollution.

1.7 Scope of the study

The research study aimed at washing bays discharging waste water into the storm drainage channels, designing and constructing an on-site treatment technological experiment. Thus the experiment was set up at Namugongo (32.662144 longitudes and 0.39356 latitude), 300 meters to the Namugongo protestant shrine. On the treatment of the vehicle washing bay waste water; sampling, laboratory testing, quantitative data analysis were done. Finally reporting the findings of the study. For objective one, the study focused on the amount of water used for every vehicle, source of water and the cost of water used. Objective two focused on chemical qualities of the waste water particularly pH, EC, TSS, TDS, COD, turbidity and orthophosphates. Objective three focused on the efficiency of the treatment methods (VFP, VFUP, HFP, and HFUP). Objective four focused on the volume of water recovered after treatment.

CHAPTER TWO: LITERATURE REVIEW

2.1 Quantification of the volume of water used in vehicle washing bays

Development of transport sector demands vehicle washing installations, causing the amount of water use to rise. However, with the raising consumption of water, the amount of discharged waste water and loads of pollutants rise too (Monney *et al.*, 2020).

Professional car wash uses little amount of water with proper pressure to safely and effectively clean the vehicle whereas home car wash requires more water in which most people do not realize how much water is being wasted. This is because the computer controlled systems, high pressure nozzles and pumps used in commercial car wash centers minimizes the water usage (International Carwash Association, 2002).

In Queensland, Australia, it is mandatory to use at most seventy litres (70ltrs) of fresh water in a single car wash (Zaneti *et al.*, 2011). Compliance with this water efficiency guideline is demonstrated by the operator keeping a weekly written record of the number of vehicles washed and the amount of water used. Consequently, some countries restrict water usage especially for vehicle washing bays and most times these sanctions include the closure of the business and fines.

In European countries of Netherlands and the Scandinavian, they restrict the water consumption ranging from 60 – 70 liters per car and impose reclamation percentage (70 – 80%) whereas in Belgium, a recycling percentage of 70% is needed to obtain an environmental license. This has led to about fifteen percent (15%) of the Belgian car washers purify and re-use fifty five percent (55%) of their waste water (Zaneti *et al*., 2013).

2.2 Characterization of selected pollutants present in the vehicle washing bay waste water

The large volumes of water used to wash vehicles transforms into untreated effluent and are discharged into the storm water drainage channel systems. Hashim & Zayadi (2016) analyzed waste water samples from snow car wash and two full hand service car wash stations for pH and the presence of PO_4^{3-}, TP, O&G, alkalinity, TSS, NO_3^-, NO_2^-, COD and surfactant. Two full hand wash service stations and one station of snow foam service were investigated in this study. Amongst the stations, snow foam car wash station indicated the highest concentration of PO_4^{3-}, TP, O&G, TSS, COD and surfactants with the average value of 10.18 ± 0.87 mg/L, 30.93 ± 0.31 mg/L, 85.00 ± 0.64 mg/L 325.0 ± 0.6 mg/L, 485.0 ± 0.3 mg/L and 54.00 ± 2.50 mg/L as MBAS (Methylene Blue Active Substances, respectively. Whereas, in parameters characterization in different stages throughout the car wash process, O&G was found to be the highest in pre-soak stage, PO_4^{3-}, TP, TSS and COD in washing stage and NO_3^- and NO_2^- in rinse stage.

Zaneti & Rubio (2011) used a system that comprised of new flocculation-column flotation (FCF), sand filtration and final chlorination. Water usage and savings audits (20 weeks) showed that almost 70% recovery was possible, and less than 40 L of fresh water per wash was achieved. Waste water and reclaimed water were fully characterized by monitoring chemical, physicochemical and biological parameters. Results were presented and discussed in terms of reclamation aesthetic quality (water clarification and odor), health (pathological) and chemical (corrosion and scaling) risks.

2.2.1 Regulations on the industrial effluent discharge into the public sewers

According to the Water Act, (1997) Ugandan municipalities and authorities have the responsibility to issue bylaws on waste water effluent discharge standards to guide a number of different industries. Walakira, (2011) noted that there are no clear waste water effluent discharge regulations in place for especially the vehicle washing bay industry in Uganda. However, National Environment Act cap 153 describes only the environmental laws stating the standards and guidelines relating to the discharge of untreated wastes and control of toxic substances into environment. The guidelines are for all industrial effluents, however, there are no regulations specific to carwash effluent discharges. The bylaw clearly states that all persons who discharge industrial effluent into the public sewer must have written permission from the Kampala Capital City Authority, any facility that generates any liquid or effluent other than potable water must prevent any discharge, leakage or escape of such liquid into the streets, watercourse and storm water drain. It further states that no person shall discharge industrial effluent or any other liquid with a higher concentrations of substances as opposed to the World Health Organization (WHO) effluent standards.

2.3 Efficiency of the locally designed waste water treatment technology

Water is a critical resource used for both domestic and industrial purposes and it is purified by removing particular contaminants to make it safer for the intended purpose. Nevertheless, access to clarified water in adequate quantities is a challenge for most countries around the world, therefore there is a need to manage water carefully to avoid wastages and pollution (Ofumbi, 2020).

The commercial vehicle washing industry is one of the industries that require large quantities of quality water for their operations. In this business, water is required for cleaning the interior and exterior of motor vehicles and their accessories. The quantity of water used depends on the technology used or method of washing (Zaneti *et al.*, 2013) .

The Car wash waste water recycling is the science of using clean water then collecting it as waste water, treating it and purifying it for reuse. The car wash proprietor chooses the way of handling and managing the waste water in his or her locality and provides the treatment system in place. He/she has to consider the volume of water used per day, chemicals and procedures used in the wash or rinse process, the water quality desired to obtain the intended use of the reclaimed water, and the desired quantity for its use, the nature of contamination to be treated and its concentration, discharge limits (Ofumbi, 2020).

2.3.1 Constructed wetlands for waste water treatment

Constructed wetlands (CWs) are defined as systems that are designed and engineered to imitate natural wetlands mainly for treating waste water by using; wetland vegetation, soils and their microbial accumulations (Sudarsan *et al.,* 2018).

Vymazal (2014) added that like any other natural wetlands, constructed wetlands work best in a more controlled environment with no close supervision. Constructed wetlands were designed and constructed to treat industrial wastes including the petrochemical, abattoir, meat processing, and diary and paper industries. However, to date, constructed wetlands have been designed to treat domestic and municipal waste water.

2.3.2 Types of constructed wetlands

Constructed Wetlands (CWs) are categorized into two types of wetlands depending on the aquatic vegetation and the flow of water. They include; the surface and subsurface wetlands as indicated below. The surface wetland is also called the free water surface (FWS) and viewed as marshes as termed by Kadlec and Wallace (2009) and Wu *et al*. (2015). The second type of wetland is subsurface flow wetland which is further broken down into Horizontal subsurface flow and vertical subsurface flow wetlands. The horizontal subsurface flow (HSSF) is where water flows horizontally from the inlet to the outlet below gravel ground with vegetation rooted inside as illustrated in (Figure 2-1). However, the vertical flow (VF) is where water is spread over the surface and is treated as it percolates vertically through the gravel and the plants (Kadlec & Wallace 2009).

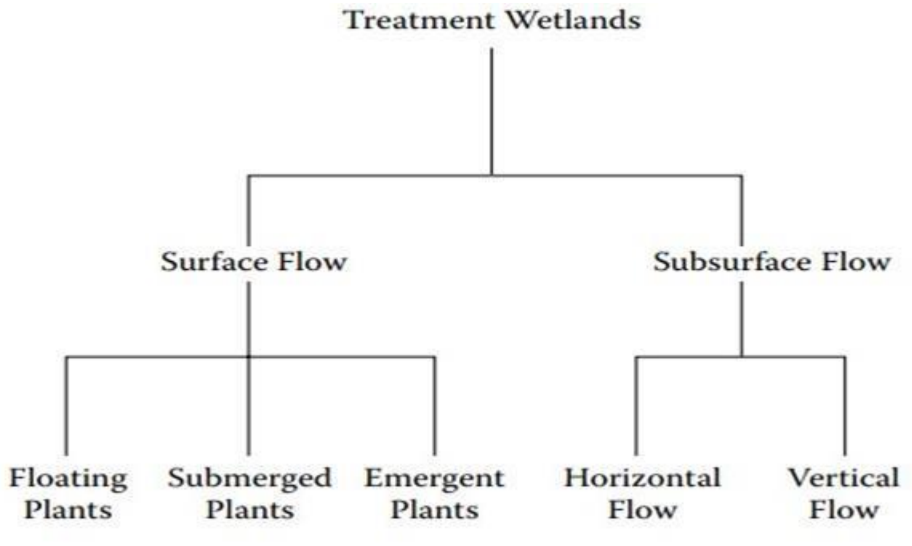

Figure 2-1: Types of constructed wetlands (Kadlec & Wallace, 2009)

2.3.3 Use of constructed wetlands

Constructed Wetlands (CWs) have been studied to aid in the treatment of grey water, landfill leachate and other wastes removal of high concentrations (Wetzel, 1993). CWs have recently been used for industrial waste treatment. China is one of the heavily industrialized areas of the world and they have used CWs as an efficient and cost friendly way of waste water treatment technology (Liu *et al*., 2009). However, very little is known and has been summarized about the concepts of CWs treating industrial effluents containing various pollutants (Wu *et al*., 2015).

2.4 Determination of water recovery from the waste water treatment technologies for reuse

Janik & Kupiec (2007) study indicated that some countries have made significant progresses in reusing the waste water. This was done by setting up rules and regulations, investing in strategic projects that eliminate pollutants and makes the waste water purified readily for reuse, while other countries still lack adequate planning and regulations.

The activities of the vehicle washing bays involve; the use of chemicals and generating waste water with a high concentration of pollutants for example, oils, greases, waxes and other contaminants which make waste water effluent toxic to aquatic life. These large volumes of waste water generated flow and pollute water bodies (Monney *et al.,* 2020).

Switzerland, Germany and the Netherlands no longer allow their citizens to wash cars at home (Janik & Kupiec, 2007). In these countries, waste water in facilities has to be pre-treated in terms of chemical composition before being discharging into the sewer systems.

CHAPTER THREE: MATERIALS AND METHODS

3.1 Study area

The study was conducted in Uganda, 21 km east of Kampala City Metropolitan areas of Wakiso District, Kira Municipality and the areas visited included; Namugongo, Kyaliwajjala, Kireka and Bweyogerere. This study area was chosen because it is the fastest-growing area in Kampala metropolitan area in terms of structural developments. And once given an attention, a lot of ecosystems can be safeguarded. Therefore, specific areas of interest were vehicle washing bays located on the main roads connected to the storm drainage channels and swampy areas. There were 40 vehicles washing bays visited, and their construction layouts, mode of operation and waste water disposal procedures recorded. By observation all the washing bays visited had the same operational procedures in administering their services. Finally, the experiment was designed and constructed at a washing bay 300 meters to the Namugongo protestant shrine at grid reference (32.662144 longitudes and 0.39356 latitude) to treat the waste water generated by the vehicle washing bay.

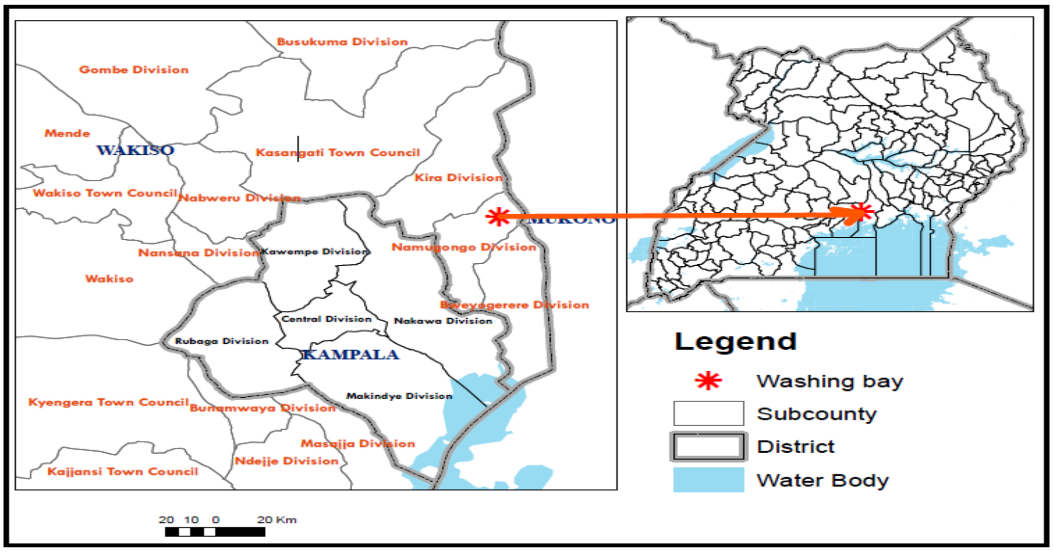

Figure 3-1: Map showing the washing bay where the experiment was carried out

Selecting a washing bay

After a number of washing bays were visited and consulted, one washing bay was chosen as the site for the experiment. This washing bay is located on Namugongo- Kireka road (32.662144 longitudes and 0.39356 latitude) 300 meters to the Namugongo protestant shrine, draining its waste water into Nakiyanja swamp. This followed a verbal communication to the owner of the washing bay requesting for permission to carry out the technological experiment, working space and full participation in the exercise of treating waste water generated by their washing bay.

3.2 Study design

3.2.1 Study approach

This study followed a cross-sectional research design method to answer the questions that the study sought to satisfy. The collection of datasets included the use of the following data collection techniques; interviews, site selection, site layout design and collecting water samples for laboratory analysis. Both the qualitative and quantitative data sets were merged to inform the objectives of the research study, that is, to establish the quantity of water used wash each vehicle, quality of the waste water generated by the vehicle washing bays, performance values obtained from the locally designed treatment technology and volume of water recovered from the treatment system.

3.2.2 Sampling strategy and data collection

The study aimed at surveying Vehicle washing bays in the area of Kira Municipality that were located and connected to the storm drainage channels, and swampy areas. Forty (40) out of sixty (60) washing bays were visited , assessed and examined .It was established that forty (40) washing bays had no significant difference in their mode of operation which gave the researcher an opportunity to select five suitable washing bays to set up the technological experiment for analysis. However one out of the five vehicle washing bays consented and provided space for setting up the experiment.

To collect data on the vehicle washing bay practices, guided oral interviews in form of structured examination and observations were engaged. The organized interviews based on the objectives of the study were used to gather responses. These structured questions aimed at evaluating; the vehicle washing bay practices and designs, volume of water used and waste water disposal approaches in place.

To quantify the amount of water used at the vehicle washing bay, the study focused on the use of a jerrycan model. Welden. T., (2013) describes the use and purpose of a jerrycan as a recognized measuring tool for liquid substances. Therefore, at the study area, water was pumped from an underground well with the help of a 15-meter head submersible water pump. Through a network of pipes, water was pumped and stored in a ground water tank of 10,000 litres capacity. The ground water tank had an outlet with an installed water tap to allow fetching of water for use. A 20 litre jerrycan capacity was used to fetch water, then poured in a water collection trough and its volume recorded.

Samples were collected once a week for eight weeks at the inlet and outlet of (four treatment drums) sampling points from the month of October 2021 to January 2022. Every week, one sample was collected on each of the sampling sites; one sample of an influent at the inlet and four samples of the effluent at the outlet of the drums (Horizontal Flow unplanted (HFUP), Horizontal Flow planted (HFP), Vertical flow unplanted (VFUP) and Vertical flow planted (VFP)).

A total number of 16 Samples were collected on each of the sampling sites. Waste water samples and treated water samples from the experiment were collected using High Density Poly Ethylene (HDPE) acid washed plastic bottle. Samples were transported in a cool box to maintain the temperatures and parameters qualitatively and quantitatively analyzed in the laboratory. Sample bottles were shaken vigorously before carrying out the analysis as per Standard methods for the American Public Health Association (APHA, 2005). For each of the 1000ml water sample taken to the laboratory, analysis was conducted, and results recorded on a raw data sheet. PH and EC were done using a pH/EC multi- meter senSIONTM+ M^{M3}74.

Measurement of physical-chemical water quality parameters

Turbidity

Turbidity was analyzed using a TL2300 Tungsten Lamp Turbidimeter. The turbidimeter directly gives the value of turbidity in terms of Nephelometric Turbidity Units (NTU). A known secondary turbidity standard (20NTU) was read to ensure the machine is still in good measuring range. The obtained samples were then read and the results recorded.

Total suspended solids

The TSS was analyzed using a DR6000TM UV VIS spectrophotometer. Where the machine was calibrated using distilled water. The obtained samples were read and the results recorded.

Phosphates

The phosphate content in the waste water and the treated effluent was analyzed using Standard methods for the American Public Health Association (APHA, 2005) at a wavelength of 880 nm. The samples were filtered using 0.45µm Whatman GF/C filter paper. 25 mls of the sample were then picked off and placed in a digestion bottle. A blank was then prepared by measuring 25mls of distilled water into a digestion bottle. A phosphate standard of known concentration was also prepared. The standard, the blank and the sample were set to the same conditions and reacted with 3ml of combined reagent which comprise (50 ml of 5N H_2SO_4 + 5 ml potassium antimony tartrate +15 ml ammonium molybdate only). 1 ml of ascorbic acid was added to each sample. Swirl to mix and react for 15minutes for blue color development. The samples were then read at 880nm wavelength and the values were recorded.

Chemical oxygen demand

The chemical oxygen demand was analyzed using the DR6000TM UV VIS spectrophotometer and after digestion a COD reactor was used. The digestion tubes were washed with 4M H_2SO_4 before use to prevent contamination. 2 mls of the sample were measured and placed in the digestion tube. A 2.0 ml of dichromate and 2 mls of H_2SO_4 / Ag2SO_4 into the digestion tube containing the sample were added. The vials were tightly caped and swirl several times to mix completely, not inverting the tubes. The tubes were then placed in a preheated oven of 150^o C for 2 hours. The vials were allowed to cool before reading on the DR spectrophotometer.

Design and layout of the waste water treatment system

The drive of the study was to design a cost-effective treatment facility that would offer adequate treatment to the waste water generated by a vehicle washing bay. The waste water treatment prototype system was designed using an Auto Card Software for hydraulic modelling based on the studies done by (Brix, H., 2020). However, the system construction for the experiment was done using the available materials for example 0.7-1.0 mm of sand of height 0.4 m with a volume of 0.08 m^3, 3-5 mm of gravel of height 0.25 m with a volume of 0.05 m^3, polymer drums (0.9 m high, 0.5 diameter and 0.19 m^3) and the papyrus vegetation. Papyrus plants were used because they are one of the most common plants in Uganda wetlands. Cyprus papyrus, commonly referred to as papyrus and cheap to obtain, belongs to the Cyperaceous family and is one of the most prolific emergent macrophytes in African subtropical and tropical wetlands. The designed flow rate was one litre per minute.

The experiment design and construction costed UGX 450,000 (four hundred and fifty thousand Uganda shillings only) which is an affordable cost compared to the monthly bill charges on sewer connections. Therefore, a single flow constructed wetland was economically designed containing two vertical flows (one being a control and second one with papyrus plants) and two horizontal flows (one being a control and second one with papyrus plants) (Figure 3-2).

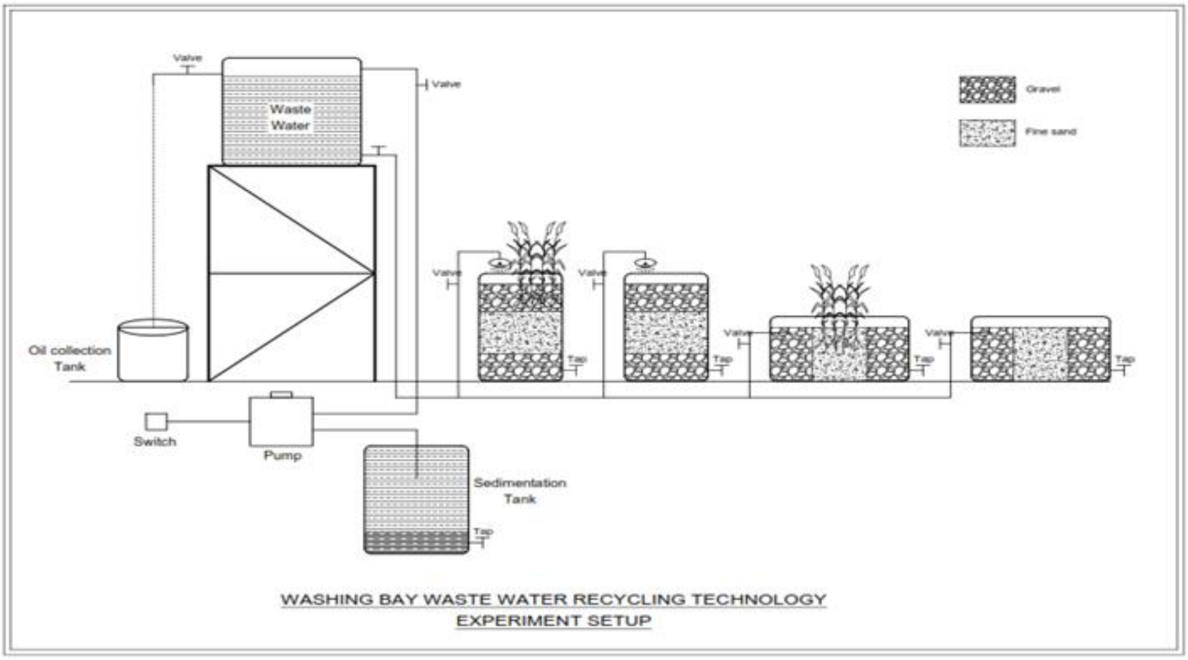

Figure 3-2: A plan of waste water treatment plant.

Figure 3-3: Samples collected from the waste water treatment system

Components of the designed waste water treatment system

The experiment set up on the washing bay had these detailed components of waste water treatment system shown in (Figure 3-4), (Figure 3-5) and (Figure 3-6). The components comprised of treatment media (sand, gravel and plants (papyrus) and the modelled experimental drums. Each of the experimental drums comprised of sand (0.7-1.0 mm) and gravel (3-5 mm).

Figure 3-4: Experimental set up at the washing bay

Figure 3-5: Waste water planted treatment systems.

Right to left be the vertical flow planted drum and horizontal flow planted drum. The red arrows show the direction of flow of the waste water flowing through the treatment system.

Figure 3-6 : Waste water treatment systems layout (Right to Left: overhead tank, Vertical flow drum (planted and unplanted) and Horizontal flow drum (planted and unplanted).

Quantification of water recovered after treatment

A Jerrycan model was used to measure the volume of water recovered after treatment. Therefore, the amount of waste water fed into the treatment system was measured in terms of a twenty litre jerrycan (20ltr) (Welden. T., 2013). The collected waste water was stored in a sedimentation tank and manually elevated to the overhead tank. Thereafter, the waste water was allowed to flow through the treatment system units by gravity. Water containers were placed on taps at the end of each of the treatment process units to collect the treated water. The collected treated water was then measured in terms of volume of water filling a 20 litre Jerrycan as a technique described by (Welden. T., 2013).

3.2.3 Data analysis

Quantification of water used

The registered water used values were entered in Microsoft Excel, where they were organized for analysis using mean and standard deviation. At first the researcher converted the volumes of water expressed in jerrycan into litres. The study compared the mean values for water used to wash saloon cars and also heavy truck vehicles. The study focused on how much water is required to wash a single vehicle and the daily amount of water required to wash vehicles at the washing bay.

Water quality

Based on standard laboratory tools and techniques by WHO (2022), the pH, EC, TDS, COD, TSS, Turbidity and Orthophosphates values were entered in Microsoft excel, organized and analyzed using mean and standard deviation. The study made a comparison between the mean and standard deviation values of waste water, VFP, VFUP, and HFP AND HFUP for the pH, EC, TDS, COD, TSS, Turbidity and Orthophosphates. However, these parameter values were got at different sampling points of waste water treatment system during different months. The study checked for the relationship between these parameters in the different treatment designs and the waste water using graphs and the R data analysis. This was aimed at finding out the efficient experimental design in treating the waste water from the vehicle washing bay. The rainfall data that defined the seasons was that of the Kampala Kireka area, retrieved from the Uganda Meteorological Authority.

Efficiency of locally designed waste water treatment technology

The technological experiment was designed using AutoCAD 2021, version 24.0 released March 25, 2020. The experiment was built on-site, the water in the treatment system units was tested and examined for hydraulics and gravity flow. The pH, EC, TDS, COD, TSS, Turbidity and Orthophosphates values of the reclaimed water were entered in Microsoft excel 2013 and organized based on the standard tools and techniques (WHO, 2022) for analyzing mean and standard deviation. The study tested for the relationship between the above parameters of water quality in the different treatment design systems using graphs and the R programming data analysis software version 4.1.0 with ANOVA tables for significance differences at P-value < 0.05. This was aimed at understanding the best experiment orientation that would give better results in treating the vehicle waste water. The ANOVA on R programming software assumes that data is uniformly distributed, the variance of the groups being compared are equal and observations are independent. It also assumes that the model is correctly specified and there are no outliers or influential observations. However, the most notable changes include; improvement to the user interface, the addition of new statistical functions and packages, enhancements to graphics capabilities and updates to underling code to improve performance.

Water recovery after treatment

The calculated values of water recovered from each of the treatment systems were entered in Microsoft excel, where they were organized for analysis expressed as percentages. The clear water was measured in a jerrycan and later the researcher converted the volumes of water expressed in jerrycan into litres. The study focused on how much clear water was recovered from the unit measure of waste water fed into the treatment system.

3.2.4 Ethical Considerations

This research work followed a voluntary participation for the scientific integrity, human rights and dignity and the collaboration amongst all the participants. This approach was ideal having understood that majority of the washing bay proprietors raised fear on what would happen if the authorities found out that they were polluting the environment. The following were considered in the process of conducting the study:

Verbal permissions were sought from the vehicle washing bay owners to allow oral interviews for randomly selected participants at their premises. This was done to obtain important information not found documented in their files and their work procedures.

The research ensured to cause no harm to the participants and the environment as safety precautions were observed during the course of the experimentation and data collection.

This research considered necessary protective gear including the research assistants to avoid accidents during the experiment set up and direct contact with the waste water.

This study ensured consent thought from the relevant parties involved especially the washing bay proprietors however, the requests were asked in kind verbally because making it official seemed threatening the washing bay owners of fear to be penalised after the study.

The study guaranteed confidentiality and anonymity of data obtained from the washing bay, this was a requisite to ensuring continuity for data collection and oral interviews.

The study ensured that all generated wastes were disposed off properly to avoid any nuisance and contamination. For example, the biomass was burnt, added to agricultural areas and dust bins. The study also observed a high level of professionalism in regard to researching norms all through the study period.

CHAPTER FOUR: RESULTS

4.1 Quantification of water used to wash a vehicle

Overall, on a daily basis 29.3±6 saloon vehicles and 9.4±3.3 heavy truck vehicles were washed. The volume of water used was 97.2±26 litres for each saloon vehicle and 212±48 litres for each heavy truck vehicle. On average the vehicle washing bay was using 4,841±314 litres of water to wash both the saloon and heavy truck vehicles daily.

Table 4-1: Daily water used by the washing bay

Parameters	Daily washed vehicles (Numbers) (Mean±SD)	Water used per vehicle (Jerrycans) (Mean±SD)	Water used in (Liters) (Mean±SD)	Total volume of water used daily (Litres) (Mean±SD)
Saloon vehicles	29.3±6	4.86±1.35	97.2±26	2848±156
Heavy trucks	9.4±3.3	10.6±2.4	212±48	1993±158

***SD: Standard deviation.**

4.2 The water quality of waste water from the vehicle washing bay

The major pollutants that were identified in the waste water from the vehicle washing bay included; nitrates, phosphates, suspended solids, silt and organic matter. Averagely, it had Turbidity of (1139±13.4 NTU), total suspended solids of (2878±2.5 mg/l), chemical oxygen demand of (458 ±2.5 mg/l), orthophosphates of (5±0.5 mg/l), pH of (7±0.3), electric conductivity of (413±24.3 µS/cm) and total dissolved solids of (107±18.8 mg/l) (Table 4-2). The parameters such as electric conductivity (EC), pH and total dissolved solids (TDS) are not pollutants but very important parameters because they are indicators of water quality, therefore, their levels have an effect on the quality of water.

Table 4-2: Quality of raw waste water

Parameters	Range	Average± STDEV	Recommended WW- discharge standard levels (NEMA, 2014)	Percentage (%) of samples that did not meet recommended standards for Environmental discharge (NEMA, 2014)
Turbidity (NTU)	1113 – 1152	1139±13.4	300	100
TSS (mg/l)	2340 -3650	2878± 2.5	100	100
COD (mg/l)	344 – 680	458 ±2.5	100	100
Orthophosphate (mg/l)	4 – 7	5±0.5	5	25
pH	7 – 8	7.4±0.3	6.5-8.0	0
EC (µS/cm)	319 – 478	413±24.3	1500	0
TDS (mg/l)	83 – 124	107±18.8	500	0

***STDEV: Standard deviation, WW = waste water, NEMA = National Environment Management Authority.**

All the waste water samples (100%) tested for turbidity, total suspended solids, and chemical oxygen demand did not meet the recommended waste water discharge standards (NEMA, 2014). For orthophosphates, its only 25 % of the samples that did not meet the recommended standards. It should be further noted that, for pH, electric conductivity and total dissolved solids, none of the samples did not meet the standards according to NEMA (2014).

4.3 Designing and constructing a locally made waste water treatment technology

The treatment technology was designed onsite and it comprised of the following units; vertical flow planted (VFP), vertical flow unplanted (VFUP), horizontal flow planted (HFP) and horizontal flow unplanted (HFUP). The polymer drums were used to construct and hold the media (sand, aggregates and plants) of the treatment system because of their suitability and easy to plumb. The plumbing water pipe network was constructed to transport the waste water from the over tank into different treatment units flowing by gravity (Figure 4-1). However waste water was manually fed into the overhead tank from the segmentation tank because there was no source of electricity to connect the water pump.

Figure 4-1: The designed treatment system layout

4.3.1 Variations in the treatment system units

To build an in-depth understanding on the treatment system based on design, a Vertical Flow Planted (VFP), Vertical flow unplanted (VFUP), Horizontal flow planted (HFP) and Horizontal flow unplanted (HFUP) were used. The different system units treated the waste water from the vehicle washing bay differently for all the parameters under the study. Hence, treated water samples were tested for turbidity, chemical oxygen demand, total suspended solids, total dissolved solids, electric conductivity, pH and Orthophosphates (Table 4-3).

The R data analysis of variations, shows significance levels for all the parameters at different sampling points. Where [a] parameter had letter "[a]" for both waste water and treated water, it implied no significance difference between waste water and treated water whereas "[a] and [b]" denoted significance difference between waste water and treated water. The pH, electric conductivity and total dissolved solids values of waste water were not statistically different from the values of treated water in all the different designs (VFP, VFUP, HFP, and HFUP). However, turbidity, total suspended solids, chemical oxygen demand and orthophosphates values for waste water were statistically different from the values of treated water in all the different treatment designs (VFP, VFUP, HFP, and HFUP).

pH

It is important to note that the pH of the reclaimed water increased in the treatment systems from a mean value of 7.363±0.3 of waste water to 7.835±0.3 in the VFP, 7.638±0.4 in the VFUP, 7.585± 0.4 in HFUP and equal to 7.350±0.3 in the HFP. However there was no statistical difference between the waste water and the treated water.

Electric conductivity

The values for electric conductivity in the waste water reduced after the treatment from 412.75±24.3 µs/cm to 374.25±27.4 µs/cm in the VFP, 376.50±20.6 µs/cm in the VFUP, 388.00±19.2 µs/cm in the HFP and 348.75±16.4 µs/cm in the HFUP and this showed a no statistical differences amongst the different treatment system units.

Total dissolved solids (TDS)

The values for total dissolved solids reduced from 107.23 ±18.8 mg/l to 97.35±105 mg/l in the VFP, 97.98 ±105.8 mg/l in the VFUP, 100.93±111 mg/l in the HFP and 90.70± 2.1

mg/l in the HFUP, however, this difference in values showed a no statistical differences amongst the different treatment system units.

Turbidity

The values for turbidity reduced from 1138.50±13.4 mg/l to 66.50±5.4 mg/l in the VFP, 86.25±4.2 mg/l in the VFUP, 30.75±5 mg/l.in the HFP and 45.75±4.22 mg/l in the HFUP. However, the recorded differences in values showed a no significant differences amongst the different treatment system units.

Total suspended solids (TSS)

The values for total suspended solids reduced from 107.23 ±18.8 mg/l to 62.50±0.8 mg/l in the VFP, 71.50±1.0 mg/l in the VFUP, 20.25±0.6 mg/l.in the HFP and 26.50±1.1 mg/l in the HFUP and this can be due to the processes of electro-oxidation in the treatment system. However, the registered differences in values showed a no significant differences amongst the different treatment system units.

Chemical oxygen demand (COD)

The values for chemical oxygen demand reduced from 457.50 ±2.5 mg/l to 41.75±0.8 mg/l in the VFP, 54.00 ±1.0 mg/l in the VFUP, 38.00±0.6 mg/l in the HFP and 50.25±1.1 mg/l in the HFUP and this showed statistical differences amongst the different treatment system units.

Orthophosphates

The values for orthophosphates reduced from 5.03± 0.5 mg/l to 1.47±0.3 mg/l in the VFP, 2.02±0.5 mg/l in the VFUP, 1.63±0.1 mg/l.in the HFP and 2.33±0.5 mg/l in the HFUP and this showed a statistical differences amongst the different treatment system units.

The designing and construction of the constructed wetland technology is reliable and affordable since the materials used were readily available. The papyrus plants were from a nearby Nakiyanja swamp, and the treatment media (sand and aggregates) were got from a nearby stone quarry.

Table 4-3: Water quality parameters for the raw waste water

TREATMENT DESIGN	pH	EC (µs/cm)	TDS (mg/l)	TURBIDITY (NTU)	TSS (mg/l)	COD (mg/l)	ORTH (mg/l)
WB-WW	7.363±0.3[a]	412.75±24.3[a]	107.23 ±18.8[a]	1138.50 ±13.4 [a]	2877.50±2.5 [a]	457.50 ±2.5 [a]	5.03± 0.5[a]
VFP	7.835±0.3[a]	374.25±27.4[a]	97.35±105 [a]	66.50±5.4 [b]	62.50±0.8 [b]	41.75±0.8 [b]	1.47±0.3[b]
VFUP	7.638±0.4[a]	376.50±20.6[a]	97.98 ±105.8[a]	86.25±4.2 [b]	71.50±1.0 [b]	54.00 ±1.0 [b]	2.02±0.5[b]
HFP	7.350±0.3[a]	388.00±19.2[a]	100.93±111[a]	30.75±5.4 [b]	20.25±0.6 [b]	38.00±0.6 [b]	1.63±0.1[b]
HFUP	7.585± 0.4 [a]	348.75±16.4 [a]	90.70± 2.1 [a]	45.75±4.22[b]	26.50±1.1 [b]	50.25±1.1 [b]	2.33±0.5[b]

WB-WW = washing bay waste water, VFP = vertical flow planted, VFUP = vertical flow unplanted, HFP = horizontal flow planted, HFUP = horizontal flow unplanted. Letters [a] and [b] are constants denoting levels of significance

4.3.2 Waste water quality parameters as compared to NEMA 2014 waste water discharge standards

All the treated water samples (100%) tested for turbidity, total suspended solids, chemical oxygen demand, total dissolved solids, orthophosphates and electric conductivity met the recommended waste water discharge standards (NEMA, 2014). However, it is only pH of 50% in the VFP, 25% in the VFUP and 25% in the HFUP that met the recommended waste water discharge standards (NEMA, 2014) (Table 4-4).

Table 4-4: percentage of samples that met recommended water quality standards after treatment

SYSTEM DESIGN	pH (%)	EC (µS/cm)(%)	TDS (mg/l) (%)	TURB (mg/l) (%)	TSS (mg/l)(%)	COD (mg/l) (%)	ORTHO (mg/l) (%)
VFP	50	100	100	100	100	100	100
VFUP	75	100	100	100	100	100	100
HFP	100	100	100	100	100	100	100
HFUP	75	100	100	100	100	100	100

The pH of waste water and treated water

The mean pH for the sampled raw waste water from the vehicle washing bay was 7.4±0.3. After treatment, the vertical flow planted showed the highest pH of 7.8±0.3 whereas the horizontal flow planted showed the lowest pH of 7.35±0.3. However, there was no significant difference ($p = 0.5$) between waste water and treated water for pH in the different months. It was also observed that, the month of November received the highest rain fall of 9.58 mm whereas the month January received the lowest rain fall of 2.08 mm (Figure 4-2).

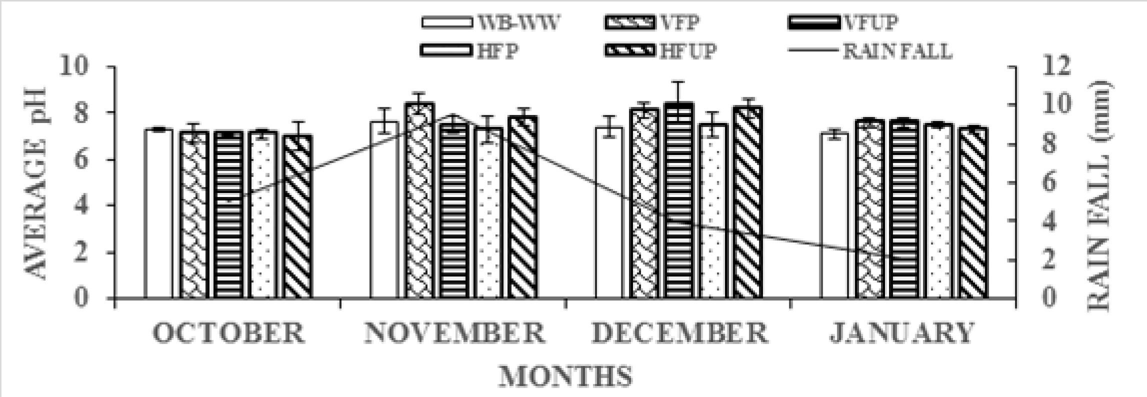

Figure 4-2: The pH of waste water and treated water

Variations in electric conductivity (EC) of waste water and treated water

The mean electric conductivity of the sampled waste water from vehicle washing bay was 412.8 µs/cm. After treatment, the horizontal flow plant showed the highest electric conductivity of (388 µs/cm) whereas horizontal flow unplanted showed the lowest electric conductivity (348.6 µs/cm). However, there was no significant difference (p = 0.5) between waste water and treated water for EC in the different months. It was also noted that, the month of November received the highest rainfall (9.58 mm) whereas the month of January received the lowest rainfall (2.08 mm) (figure 4-3).

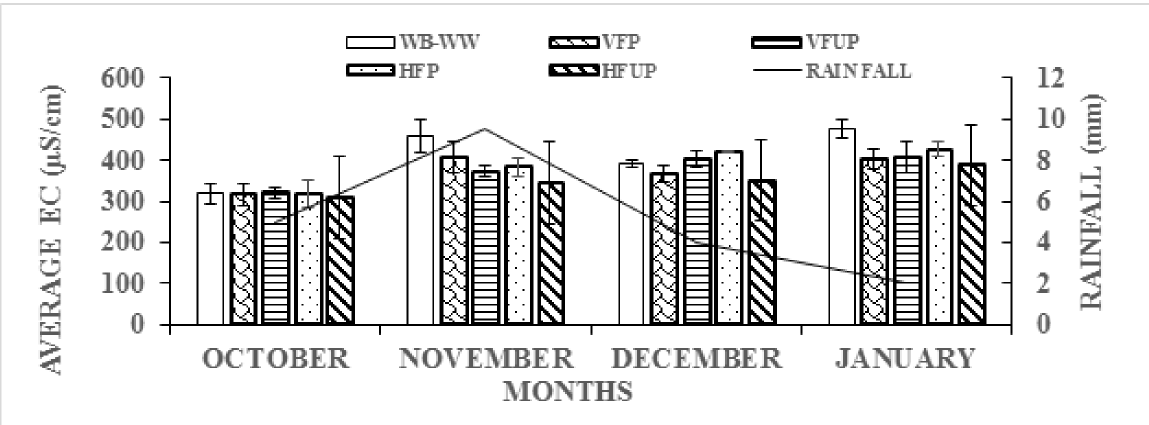

Figure 4-3: Variations in electric conductivity.

Variations in total dissolved solids of the waste water and treated water

The mean in total dissolved solids of the sampled waste water from vehicle washing bay was 107±24.3. After treatment, the horizontal flow plant showed the highest total dissolved solids of (101 mg/l) whereas horizontal flow unplanted showed the lowest total dissolved solids (90.7 mg/l). However, there was no statistical difference ($p = 0.5$) between waste water and treated water for TSS in the different months. It was also noted that, the month of November received the highest rainfall (9.58 mm) whereas the month of January received the lowest rainfall (2.08 mm) (Figure 4-4).

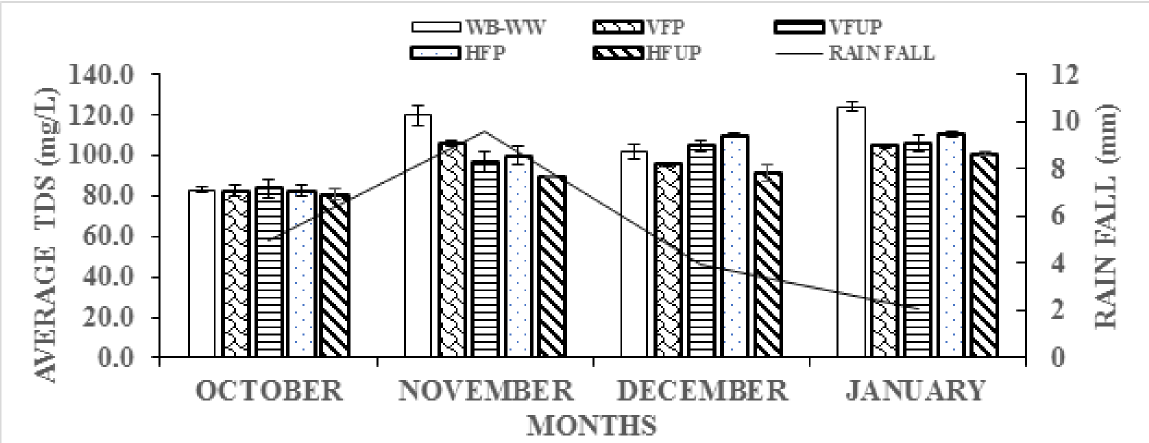

Figure 4-4: Variations in the total dissolved solids

Variations in turbidity of the waste water and treated water

The mean turbidity of the sampled waste water from vehicle washing bay was 1138.5 ±13.4 mg/l. After treatment, vertical flow unplanted showed the highest turbidity of (86.3±4.2 mg/l) whereas horizontal flow planted showed the lowest turbidity of (30.8±5.4 mg/l). However, there was a significant statistical difference ($p < 0.01$) between waste water and treated water for turbidity in the different months. It was also noted that, the month of November received the highest rainfall (9.58 mm) whereas the month of January received the lowest rainfall (2.08 mm) (figure 4-5).

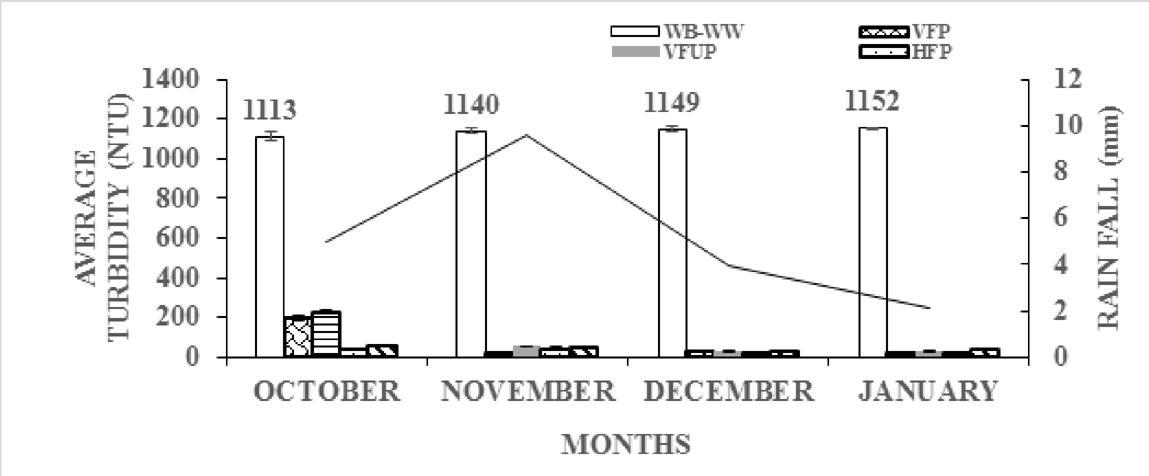

Figure 4-5: Variations in turbidity

Variations in total suspended solids (TSS) of waste water and treated water

The mean total suspended solids of the sampled waste water from vehicle washing bay was 2877.5±2.5 mg/l. After treatment, vertical flow unplanted showed the highest total suspended solids of (71.5±1.0 mg/l) whereas horizontal flow planted showed the lowest turbidity of (20.25±0.6 mg/l). However, there was a statistical difference ($p < 0.01$) between waste water and treated water for total suspended solids in the different months. It was also observed that, the month of November received the highest rainfall (9.58 mm) whereas the month of January received the lowest rainfall (2.08 mm) (Figure 4-6).

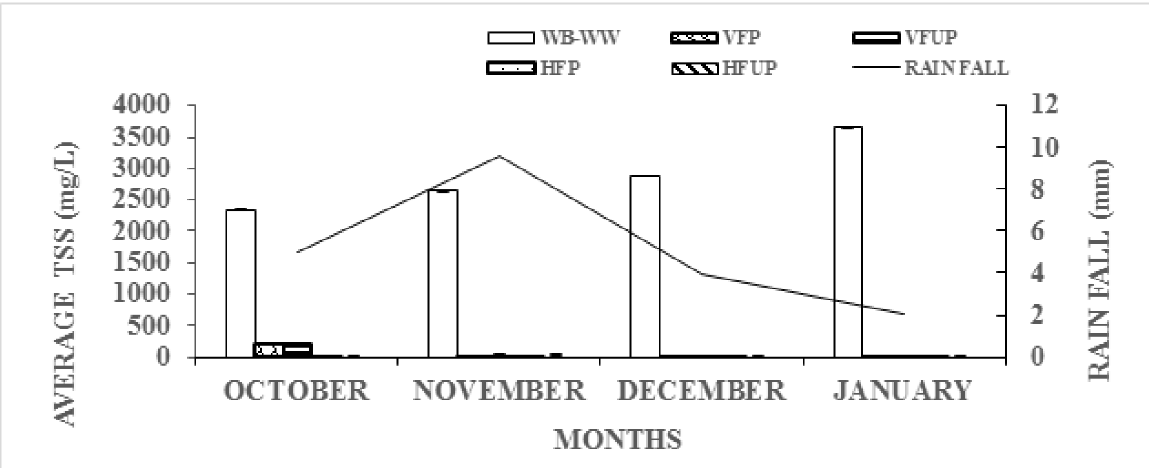

Figure 4-6: variations in the total suspended solids

Variations in the chemical oxygen demand of the waste water and treated water

The average chemical oxygen demand of the sampled waste water from vehicle washing bay was 458 ±2.5 mg/l. After treatment, vertical flow unplanted showed the highest chemical oxygen demand of (54.0 ±1.0 mg/l) whereas horizontal flow planted showed the lowest turbidity of (38.0±0.6 mg/l). However, there was a statistical difference ($p < 0.01$) between waste water and treated water for chemical oxygen demand in the different months. It was also observed that, the month of November received the highest rainfall (9.58 mm) whereas the month of January received the lowest rainfall (2.08 mm) (Figure 4-7).

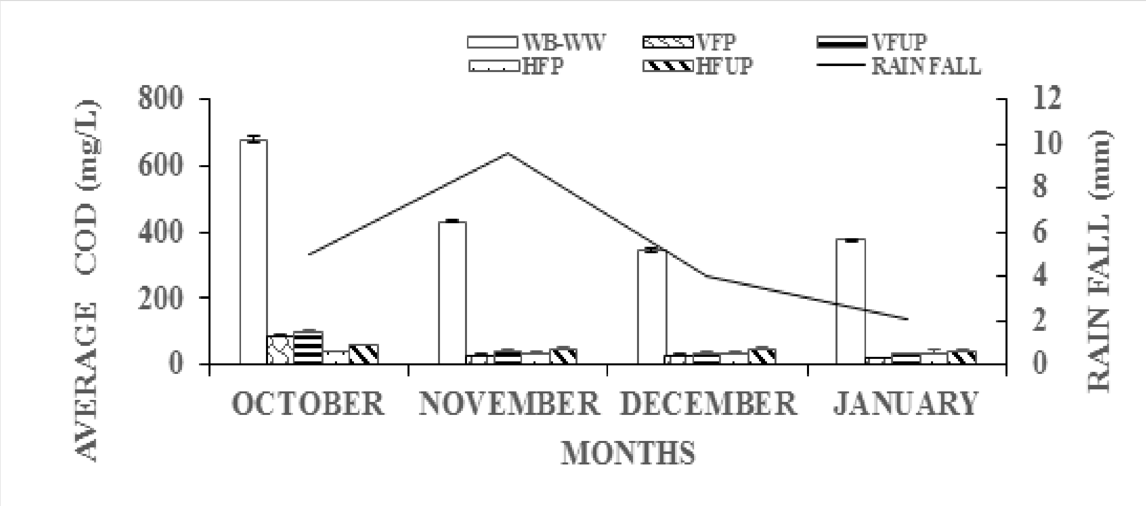

Figure 4-7: Variations in the chemical oxygen demand

Variations in the orthophosphates of the treated and waste water

The average Orthophosphate of the sampled waste water from vehicle washing bay was 5.03± 0.5 mg/l. After treatment, horizontal flow unplanted showed the highest chemical orthophosphates of (2.3±0.5 mg/l) whereas vertical flow planted showed the lowest turbidity of (1.5±0.3 mg/l). However, there was a statistical difference ($p < 0.02$) between waste water and treated water for orthophosphates in the different months. It was also observed that, the month of November received the highest rainfall (9.58 mm) whereas the month of January received the lowest rainfall (2.08 mm) (Figure 4-8).

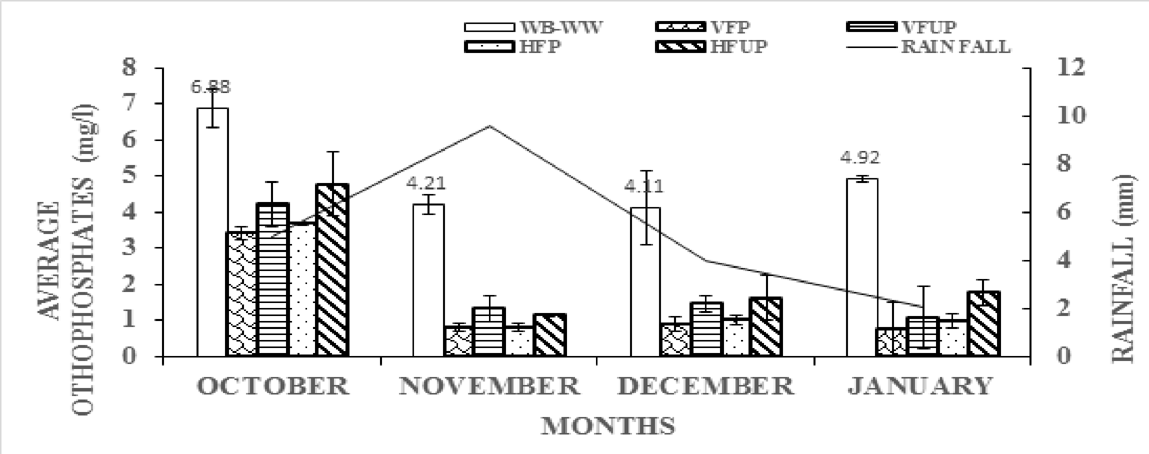

Figure 4-8: variation in the orthophosphates

4.4 The volume of water recovered after treatment

Overall, approximately 80% of the waste water fed into the system was recovered as reclaimed water. Individually, the waste water recovered were 75% in the vertical flow planted, 78% in the vertical flow unplanted, 85% in the horizontal flow planted and 80% in the horizontal flow unplanted (Table 4-5). The HFP showed a higher percentage of water recovered compared to the VFP, VFUP and HFUP though there was no statistical difference amongst the different treatment units.

Table 4-5: Water recovered after treatment

SYSTEM DESIGN	WATER RECOVERED (%)	WATER LOST (%)
VFP	75	25
VFUP	78	22
HFP	85	15
HFUP	80	20

CHAPTER FIVE: DISCUSSION

5.1 Quantification of water used to wash a vehicle

Overall, the daily average amount of water used was 4,841litres. A saloon vehicle used the least amount of water compared to the heavy truck vehicle. Saloon vehicles were the most washed with an average of 97.2±26 litres of water per vehicle whereas heavy truck vehicles were least washed but with an average of 212±48 litres of water per vehicle. Nonetheless both the saloon vehicles and heavy truck vehicles used a lot of water. These results contradict with QWC 2008; Boussu *et al.*, 2007 who found out that Queensland and Australia used 70 litres of water to wash each vehicle. Additionally, Europe recommended 60–70 litres of water to wash each vehicle. However, Zaneti *et al.* (2013) found out that the volume of water used to wash the vehicles depended on the technology used or method of washing. Therefore, the variations in results can be attributed to the differences in technology and method of washing used. Nevertheless, the road networks in Uganda are dusty and at times muddy compared to those in Europe and Australia. This demands a proper maintenance and thorough washing of the vehicles.

5.2 The chemical quality of waste water from the vehicle washing bay

Generally, the waste water samples from the vehicle washing bay had high pollution levels for turbidity (1139±13.4 NTU), total suspended solids (2878± 2.5 mg/l), chemical oxygen demand (458 ±2.5 mg/l), and Orthophosphates (5.03± 0.5mg/l). Therefore, these parameters were above the recommended waste water discharge standards (NEMA, 2014). These results are similar to those obtained by Hashim et al. (2016) who found out that Phosphates, turbidity, total suspended solids, chemical oxygen demand, NO2 and NO3 in a vehicle washing bay waste water were on average above the discharge standards.

However, pH (7±0.3), electrical conductivity (413±24.3 µS/cm) and total dissolved solids (107±18.8 mg/l) parameters of waste water of the vehicle washing bay had acceptable waste water discharge standards. These results of compliance according to the different countries are in agreement with the findings of several studies (Al-Gheethi *et al.*, 2016; Lau *et al.*, 2013; Mazumder and Mukherjee 2011).

High turbidity values highly affect the environment and its habitats especially the aquatic life (Hashim *et al.*, 2016). High TSS levels may lead to a decrease in the dissolved oxygen levels and increase the water temperature as the particles tend to store some heat (Campbell, 2021). The higher levels of COD could be related to the different detergents that are used when washing the vehicles. These detergents cause oxidation of all the available organic compounds leading to an increase in COD (Al-Gheethi *et al*., 2016; Bousuu *et al*., 2007).

5.3 Designing and constructing a locally made waste water treatment technology

Generally the horizontal flow systems showed the highest treatment efficiency compared to the vertical flow system. However, the results contradict with Thalla *et al*. (2019) who found out that the vertical flow had a better treatment efficiency than horizontal flow by 7.14%. Therefore, in general, constructed wetlands can be considered as a sustainable alternative to the tertiary conventional treatment of waste water from the vehicle washing bay, thus making waste water possible for reuse. However, Vymazal (2014) discloses that constructed wetlands have been used to treat waste water for more than fifty years. In addition, Vymazal (2014) findings discovered that there are 138 constructed wetlands which are 90% efficient in 33 countries worldwide.

Turbidity

The turbidity of the waste water from the vehicle washing bay significantly reduced ($p < 0.01$) after treatment. These results are similar to the study by Liu *at al*. (2009) who found out that the constructed wetland treated the dam's turbid water from > 1,000 NTU to < 10 – 50 NTU from Nadisaito dam in Monduli District, Tanzania. This took a retention time of three days, yet, constructed wetlands need retention time of 5 days to achieve turbidity (0 NTU).

Total suspended solids (TSS)

The total suspended solids of the waste water from the vehicle washing bay significantly reduced ($p < 0.01$) after treatment. These results are similar to the study done by Thalla *et al.* (2019) who found out that the treated waste water through a constructed wetland had removal efficiency of 82% for TSS.

Chemical oxygen demand (COD)

The chemical oxygen demand of the waste water from the vehicle washing bay significantly reduced ($p < 0.01$) after treatment. These results are similar to the study done by Thalla *et al*. (2019) who found out that the waste water treated through a constructed wetland had removal efficiency of 80% for COD. However, there was no significant differences in COD values for treated water in all the treatment units.

Orthophosphates

The orthophosphates of the waste water from the vehicle washing bay significantly reduced ($p < 0.02$) after treatment. These results are in line with Hashim *et al.* (2016) who used hybrid reed bed constructed wetland, planted with Malaysian native aquatic plants (S*cirpus grossus*) and reached average removal of nutrients at 84.7% and 71.0% for NH_4-N and PO_4-P respectively. Therefore the use of constructed wetlands is a potential technology for treating waste water from vehicle washing bay.

5.4 The volume of water recovered after treatment

All the waste water fed into the overhead tank was gravitated through the treatment units and no possibility of a leakage or over flow was observed. The valves were opened to allow the waste water flow through each different treatment unit separately. Generally, 80% of the waste water was recovered from the system and 20% of the waste water lost as a result of being retained in the filter media, evaporation and as sludge. These results are comparable to Zaneti *et al.* (201[3]) who observed a 70% water recovery from a full-scale treatment of the textile waste water by the constructed wetland planted with phragmites. The amount of water which may be reused can range from 55% to 80% of the effluents from the waste water treatment plant (WWTP) compared to the 80% water provided by the aquifers. The horizontal flow planted recovered more water compared to the vertical flow thus contradicts with the study by Liu *et al*. (2009) who found out that vertical flow constructed wetlands recovered water ranging from 66% to 99% of waste water. Therefore, the 80% of waste water recovered as treated water can safely be reused or discharged to the environment.

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The vehicle washing bays generally use high volumes of water in their daily operations. Saloon vehicles are more washed compared to heavy truck vehicles. However, washing heavy truck vehicle requires higher volumes of water than washing saloon vehicles because of their body sizes and activities they are involved in.

The waste water from the vehicle washing bays have high levels of turbidity, orthophosphates, total suspended solids and chemical oxygen demand above the recommended waste water discharge standards NEMA (2014).

The treatment technology is efficient at treating the vehicle washing bay waste water for turbidity, orthophosphates, total suspended solids and chemical oxygen demand, pH, electric conductivity and total dissolved solids

The designed technology recovered approximately 80% of the waste water generated and subjected to treatment. These large volumes of clean water recovered can be reused targeting the sustainable development goal number six (SGD 6; clean water and sanitation) however, the recovered clean water can safely be discharged to the environment targeting the sustainable development goal number fourteen (SGD 14; life below water)

6.2 Recommendations

Modern washing systems should be adopted by vehicle washing bays in order to minimize the amount of water used in their operation.

Well calibrated water meters should be installed at washing bays´ piped water systems in order to quantify all the volumes of water used, recovered and discharged.

The policy makers should put-up guidelines, by-laws and give out waste water discharge permits to regulate the operations of vehicle washing bays where there are no public sewer networks.

More research should be conducted to characterize all the pollutants especially heavy metals in waste water of the washing bays so that the environment and its habitants are free from harmful toxic chemicals contained in the waste water.

The policy makers should advocate for proven waste water recycling technologies for vehicle washing bays in order to reclaim the waste water for reuse and protect the environment and its habitants.

6.3 Limitations

The researcher followed a cross-sectional approach to study the pollutants and washing bay activities in Namugongo Division. However, most of the researches undertaken on washing bays use longitudinal approaches which yield better results compared to cross-sectional approaches.

Secondary, the study was narrowed to Kampala Metropolitan areas of Namugongo Division due to failure to due to limited study period and finance especially to analyze all the pollutants in the washing bay waste water, for example oils and grease. The Kampala Metropolitan area is reasonably developed and the conclusion made here is generalized however the results could be much better if all the washing bays in Kampala metropolitan areas and Uganda at large are brought under the study.

The current jerrycan is slightly bigger than the calibrated jerrycan model, in addition to being heavy to carry, water samples spilling over, mild odor when filling and emptying the jerrycan.

The researcher had a challenge of finding a suitable vehicle washing bay to set up the technological experiment because washing bay proprietors had fear of facing penalties if found polluting the environment.

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APPENDICES

Appendix One: Photo showing the site layout

APPENDIX Two; Tables of the analysis of variance (ANOVA)

The pH of Sampled Water

Table 8-1: One-way ANOVA analysis of the pH data

Source of variation	*Df*	*Sum Sq*	*Mean Sq*	*F value*	*Pr(>F)*
Treat design	*4*	*0.6607*	*0.1652*	*0.875*	*0.502*
Residuals	*15*	*2.8317*	*0.1888*		

Electric Conductivity

Table 8-2: One-way ANOVA analysis of the EC data

Source of variation	*Df*	*Sum Sq*	*Mean Sq*	*F value*	*Pr(>F)*
Treat design	*4*	*8634*	*2158*	*0.896*	*0.49*
Residuals	*15*	*36127*	*2408*		

Total Dissolved Solids

Table 8-3: One-way ANOVA analysis of the TDS data

Source of variation	*Df*	*Sum Sq*	*Mean Sq*	*F value*	*Pr(>F)*
Treat design	*4*	*575.5*	*143.9*	*0.88*	*0.499*
Residuals	*15*	*2453.8*	*163.6*		

Turbidity

Table 8- 4: One-way ANOVA analysis of the turbidity data

Source of Variation	*Df*	*Sum Sq*	*Mean Sq*	*F value*	*Pr(>F)*
Treat design	*4*	*3747737*	*936934*	*266*	*9.93e-14 ****
Residuals	*15*	*52830*	*3522*		

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Total Suspended Solids

Table 8-5: One-way ANOVA analysis of the TSS data

Source of variation	*Df*	*Sum Sq*	*Mean Sq*	*F value*	*Pr(>F)*
Treat design	4	25678234	6419558	96.97	1.57e-10 ***
Residuals	15	993057	66204		

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’

Chemical Oxygen Demand

Table 8-6: One-way ANOVA analysis of the COD data

Source of variation	*Df*	*Sum Sq*	*Mean Sq*	*F value*	*Pr(>F)*
Treat design	*4*	*542520*	*135630*	*26.84*	*1.1e-06 ****

Residuals	*15*	*75799*	*5053*

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Orthophosphates

Table 8-7: One-way ANOVA analysis of the Orthophosphates data

	Df	*Sum Sq*	*Mean Sq*	*F value*	*Pr(>F)*
Treat design	*4*	*33.93*	*8.481*	*4.192*	*0.0178 **
Residuals	*15*	*30.35*	*2.023*		

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix Three: Raw data obtained from the laboratory

MONTH	TREATMENT DESIGN	Ph	EC (µs/cm	TDS (mg/l)	TURBIDITY (NTU)	TSS (mg/l)	COD (mg/l)	ORTHOPHOSPHATES (mg/l)
OCTOBER	Waste Water	7.3	319	82.9	1113	2340	680	6.88
OCTOBER	VFP (Vertical Flow Planted)	7.2	318	82.7	200	197	88	3.41
OCTOBER	VFUP (Vertical Flow Unplanted)	7.1	322	83.7	228	213	100	4.22
OCTOBER	HFP (Horizontal Flow planted)	7.1	318	82.7	42	20	42	3.68
OCTOBER	HFUP (Horizontal Flow Un planted)	7.02	311	80.9	61	26	58	4.78
NOVEMBER	Waste Water	7.64	461	120	1140	2640	431	4.21
NOVEMBER	VFP (Vertical Flow Planted)	8.4	408	106	22	18	31	0.81
NOVEMBER	VFUP (Vertical Flow Unplanted)	7.47	374	97.2	53	30	43	1.32
NOVEMBER	HFP (Horizontal Flow planted)	7.3	385	100	42	27	38	0.82
NOVEMBER	HFUP (Horizontal Flow Un planted)	7.8	344	89.4	50	30	51	1.15
DECEMBER	Waste Water	7.4	393	102	1149	2880	344	4.11
DECEMBER	VFP (Vertical Flow Planted)	8.13	368	95.7	26	20	28	0.9
DECEMBER	VFUP (Vertical Flow Unplanted)	8.4	403	105	31	22	38	1.46
DECEMBER	HFP (Horizontal Flow planted)	7.5	422	110	16	14	35	1.01
DECEMBER	HFUP (Horizontal Flow Un planted)	8.2	352	91.5	32	24	48	1.63
JANUARY	Waste Water	7.11	478	124	1152	3650	375	4.92
JANUARY	VFP (Vertical Flow Planted)	7.61	403	105	18	15	20	0.76
JANUARY	VFUP (Vertical Flow Unplanted)	7.58	407	106	33	21	35	1.08
JANUARY	HFP (Horizontal Flow planted)	7.5	427	111	23	20	37	1
JANUARY	HFUP (Horizontal Flow Un planted)	7.32	388	101	40	26	44	1.77

	PH					EC (µS/cm)					TDS (mg/l)				
	WW	VFP	VFUP	HFP	HFUP	WW	VFP	VFUP	HFP	HFUP	WW	VFP	VFUP	HFP	HFUP
NUMBER SAMPLED	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
AVERAGE	7.363	7.815	7.638	7.35	7.585	412.8	374.3	376.5	388	348.75	107	97.31	97.89	101	90.675
MINIMUM	7.1	7.1	7.1	7.1	7.02	319	318	322	318	311	82.9	82.68	83.7	82.7	80.86
MAXIMUM	7.6	8.4	8.4	7.5	8.2	478	408	407	427	388	124	106.1	105.82	111	100.88
STANDARD DEVIATION	0.221	0.568	0.508	0.22	0.521	72.49	41.51	39.19609	50.29	31.61619	18.8	10.79	10.191	13.1	8.2202
% Compliance by the experiment	100%	50	75	100	75	100%	100	100	100	100	100%	100	100	100	100
Average % complaince		75%					100%					100%			

	TURBIDITY (NTU)					TSS (mg/l)					COD (mg/l)					ORTHOPHOSPHATES (mg/l)				
	WW	VFP	VFUP	HFP	HFUP	WW	VFP	VFUP	HFP	HFUP	WW	VFP	VFUP	HFP	HFUP	WW	VFP	VFUP	HFP	HFUP
NUMBER SAMPLED	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
AVERAGE	1139	66.55	86.33	31	46	2878	63	71.5	20.25	26.5	458	42	54	38	50.3	5.03	1.47	2.0	1.63	2.3
MINIMUM	1113	18	31	16	32	2340	15	21	14	24	375	20	35	35	44	4.11	0.76	1.08	0.82	1.15
MAXIMUM	1152	200	228	42	61	3650	197	213	20	30	680	88	100	42	58	6.88	3.41	4.22	3.68	4.78
STANDARD DEVIATION	17.75	89.03	94.95	13.4	12.5	560.4	90	94.42	5.315	2.52	153	31	30.84	2.9	5.91	1.28	1.29	1.48	1.37	1.65
% Compliance by the experiment	0%	100	100	100	100	0%	100	100	100	100	0%	100	100	100	100	75%	100	100	100	100
Average % complaince		100%					100%					100%					100%			

WW= Waste Water, VFP= Vertical Flow Planted, VFUP = Vertical Flow Unplanted,

HFP = Horizontal Flow Planted, HFUP = Horizontal Flow Unplanted, pH = Alkalinity and Acidity, TSS = Total Suspended Solids, COD = Chemical Oxygen Demand, EC = Electric Conductivity.