ASSESSMENT OF COMPOSITE FILTER PERFORMANCE AND COMMUNITY KNOWLEDGE ON QUALITY OF EFFLUENT AT SHIRERE WASTEWATER TREATMENT PLANT IN KAKAMEGA MUNICIPALITY, KENYA

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Thesis Submitted in Fulfillment for the Requirements of the Conferment of the Degree of Doctor of Philosophy in Disaster Preparedness and Engineering Management of Masinde Muliro University of Science and Technology

March, 2024

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DEDICATION

I dedicate this work to my family, my late parents and our siblings. My family especially my lovely wife Anne was inspirational and understanding during the writing of this thesis.

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I implore upon the grace of Almighty God in the name of our lord Jesus Christ for life and precious health during the time of my study. I thank my wife Anne Elizabeth Musumi for her patience and support during the study.

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ABSTRACT

Release of effluent directly from aerobic maturation ponds into natural water bodies has presented not to be very efficient. Consequently, people downstream are exposed to greater risk of contracting waterborne diseases such as cholera, dysentery and typhoid. Skin problems, eye infections, and diarrhea have all been linked to lack of clean water and inadequate sanitation among community members. Introduction of filtering technologies such as sand, biochar, coconuts shells, pumice and crushed stone aggregates have been used to treat the municipal wastewater. However, these have proved to be inadequate. Even then no effort has been made to apply such technologies in the removal of wastes discharged into River Isiukhu from Shirere waste water oxidation ponds. As a consequence, its waters have been shown to be increasingly getting covered by algae which indicate the presence of cyno-bacteria and other compounds toxic to human and animal health. The overall objective of the study was to assess composite filter performance and community knowledge on quality of effluent at Shirere wastewater treatment plant in Kakamega municipality. Specific objectives included; to determine the silica-pumice composite filter performance efficiency at its optimal conditions; To develop a mathematical model for the removal of waste from effluent by composite granular filter at Shirere wastewater treatment plant; to evaluate the trend of effluent quality before and after installation of composite granular filter from Shirere wastewater treatment plant upto river Isukhu; to asses community knowledge, attitude and perception towards effluent quality discharged from Shirere wastewater treatment plant upto river Isukhu. Effluents, drinking water from Shirere WWTP, Shikoye stream, River Isiukhu and protected spring along Shikoye stream, were collected using pre sterilized water sampling containers for microbial quality analysis at MMUST and KACWASCO laboratories. The measurements were carried out using UV-VIS spectrophotometer at 752 nanometer wavelengths. Sampling strategies were purposeful and random. Sample size was 8 for water, 28 for wastewater. Research design was experimental. Data analysis used, regression and correlation methods. The average reduction of COD in the mid-season of June to August was 42.2 ±4.6%, being the highest. Concomitantly, the BOD removal by the filter in the season of June to August was19.6±7% and 15.6 ±3.5% for September to November. The average rate of TSS removal in June to August was 19.3±4.5% followed by 16.6±3.8% of September to November and 11.6±7% of March to May. The average rate of Nitrate removal in June to August was 41.8±7.6% followed by 30.0±2.2% for March to May and 25±8.6% for September to November. Phosphates had an average rate of removal in June to August as 31.9±2.7% followed by 20.6±4.8% for September to November and 20.0 ±4.3% for March to May. The use of filters in wastewater treatment reduced the organic matter intake, resulting in oxygen levels that were within natural values. Specifically, for the first season of March – May 2021 at 200mm filtration depth were carried out at effluent flow rate of 0.0032 and volume, 0.234 the model arrived at was .The model results showed minimal variation from the measured values. The first season measured COD as 0.236kg/m and model gave 0.2174kg/m. The model will be used in prediction of parameter concentrations at any given time. Concentrations of most parameters were above NEMA standards, like COD was322mg/l yet maximum should be 100mg/l. Community members need more sensitization on matters pollution as revealed by this study. Therefore, it was concluded that silica pumice composite filter performance is evidenced by big variations in the concentrations of COD, BOD, TSS, Phosphates and Nitrates at Shirere WWTP after filtrations which was attributed to effective filtering capacity. Similarly, the developed model, C=C_in (1-e^(-t(Q⁄V))) was found to be reliable in depiction of pollutant concentration by substituting time. The effluent concentrations from sampling sites S1-S3 and S5-S7 were found to above the NEEMA standards implying the high risk of Isukhu water and catchment area. It was also concluded that the level of knowledge of the community around Shirere Waste Water Treatment Plant had a negative attitude and no bearing on the effluent pollution into River Isiukhu. The study recommends that the composite filter should be applied in non-compliant WWTPs and the developed mathematical should be adopted for prediction of waste removal by substituting the values for time.

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ACRONYMS AND ABBREVIATIONS

BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
CN	Curve Number
DEM	Digital Elevation Model
EWS	Early Warning System
FAO	Food Agricultural Organization
IFM	Integrated Flood Management
LBDA	Lake Basin Development Authority
LIDAR	Laser Imaging Detection and Ranging
LVEMP	Lake Victoria Environmental Management Programme Mitigation Project
MoH	Ministry of Health
MoRPW	Ministry of Roads and Public Works
MWI	Ministry of Water and Irrigation
NEMA	National Environmental Management Authority
NGO	Non-Governmental Organization
USACE	US Army Corps of Engineers
USGS	U.S. Geographical Surveys
WMO	World Meteorological Organization
WRMA	Water Resources Management Authority
RSL	Return deactivated sludge
WWTP	Waste Water Treatment Plant
DO	Dissolved Oxygen
TSS	Total Suspended Solids
C	Concretion of pollutant in water (mg/<)
IR	Water ingestion rate
EF	Exposure frequencies, 365 days/y
ED -	Exposure period, 70 years for an adult and 6 years for a child
BW	Body weight, 70kgs for adults and 20kgs for a child
AT	Average lifespan, 25,550 days for adult and 2190 days for a child
DR	Daily consumption rate (L.d-1)
RfD	Is the reference dose for the pollutants (mg/Kg.day).

MMUST	Masinde Muliro University of Science and Technology
KACWASCO	Kakamega County Water and Sanitation Company limited
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNEP	The United Nations Environment Programme
UNDESA	United Nations Department of Economic and Social Affairs
WWDR	World Water Development Report
KEWASNET	The Kenya Water and Sanitation CSOs Network
NACOSTI	National Commission for Science, Technology and Innovation
WASSIP	Water and Sanitation Service Improvement Project
ADV	Archrotic Doppler Velocimeter
ADCP	Archrotic Doppler Current Profiler
PSP	Private Sector Participation
KNBS	Kenya National Bureau of Statistics
LVNWSB	Lake Victoria North Water Service Board
LVNWWDA	Lake Victoria North Water Works Development Agency
GAC	granular activated carbon
WWTP	Waste water treatment plant
CGF	Composite granular filter

OPERATIONAL DEFINATIONS

Effluent Quality	This is the level of concentration of waste discharged from the last oxidation pond of a wastewater treatment plant
Optimal Composite filter performance	It is a filter achieved after several tests that give highest expected filtration level
Knowledge	Refers to familiarity gained by experience
Perception	Interpretation of a situation
Attitude	Feeling about something
Granular filter	A filter that uses particle as a media for filtration
Wastewater	Water generated by domestic, industrial and urban activities utilizing water
Municipality	An urban area designated for centralized services
Pumice stones	Refers to naturally occurring porous stones found in rift valley in Africa
Silica	It refers to clean sharp sand
Composite Filter	Refers blend of two or more different constituents that impart unique filtration characteristics that enable quality water to be improved. In this study it is a mixture of clean sharp sand and pumice stone
Total Suspended Solids (TSS)	Refers to the number of particles that suspend in a sample of water.
Community	This included all the stakeholders. I.e community in the catchment area and KACWASCO staffs

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Water quality is essential for social economic development, environmental sustainability and human health. Due to the high population density, particularly in Africa, pollution exposure projected in low and middle-income nations has increased (Boretti, A., & Rosa, L., 2019). Nevertheless, as the global population grows, adequate and clean water sources for all are increasingly becoming scarce. Around 1.8 billion people consume contaminated water, placing them at risk of cholera, dysentery, typhoid, and polio, (Castella, et al 2017). Thus, effective wastewater treatment would aid in the protection of our ecosystems while also providing fertilizers and other recyclable resources (Corocoran, 2010; Afroz et al, 2014; Jayaswal et al 2018).

A number of parameters such as , temperature, electrical conductivity, total dissolved solids (TDS), anions fluorides, sulfates, phosphates, nitrates, chlorides, carbonates, and bicarbonates in river waters, are used in evaluating water quality, (Chebet *et al* 2020). Similarly, researchers have done assessment of portability of groundwater resource using Water Quality Index (Ochungo, et al (2019). In this case, the quality of groundwater in Langata Sub County, Nairobi-Kenya was indexed using a five-category grading scale (A- excellent, B- very good, C- good, D- fairly good, E-suitable, F-unsuitable). The concentration ranges were defined on the basis on WHO standards. Using the Index they developed, grade of ‘C’ was achieved meaning good. Therefore, the index is very useful for the management of groundwater. This is because water related diseases such as cholera, liver damage, vomiting, amoeba, diarrhea, typhoid, among others, affect birds, fish and animals’ when at concentrations greater than

recommended levels by WHO. These problems are exacerbated in areas with poor waste disposal infrastructure as is the case with many unplanned urban settlements.

Athi River, for example, supports millions of people along the 390-kilometer channel and it is polluted by high levels of cyanobacterial (Takawira, 2021). These effluents come from Nairobi River which is a tributary of Athi river. During the rainy season, the water in the latter often turns brown in color due to surface run off. It later becomes greenish over a period of time as a result of cyanobacteria algae formation on the water surface. According to the World Health Organization (WHO, 2005), some cyanobacteria species produce toxins that harm both animals and humans. In a similar scenario, the sources of water in Kakamega Town and its vicinity are River Isiukhu and River Yala. Its old water intake was built in 1956 while the current intake in 1992.These collect water from River Isiukhu at Savona while River Yala waters is abstracted at Tindinyo as reflected in Nzoia Cluster Two Assessment (WHO, 2005). The average production of water from these sources' accounts for 44% of the total demand and estimated to be 8696m3/day against an average daily consumption of 12,796 m^3/day. To bridge the short fall, most business owners have sunk shallow wells. However, majority of people in slum dwellings within Kakamega collect water from unguarded springs polluted by pit latrines and some utilize ' roof catchment and tanks to collect rainwater from their rooftops for domestic use.

Water quality in Kakamega Town, like in other urban areas, is affected by poor municipal solid waste disposal management systems. Other than stand-alone septic tanks for domestic wastes in residential areas, the rest of the town is served by Kakamega County sewerage network. Wastes from the sewerage end up into the Shirere Waste Water Treatment Plant and eventually into River Isiukhu. Other

treatment plants in the town include Kambi Somali Treatment Works and MMUST Treatment Works. The study site was Shirere Waste Water Treatment Plant (WWTP) which was identified with poor filtration efficiency.

Various techniques have been examined for wastewater treatment. Examples include electrochemical processes, aerobic biodegradation, flocculation, adsorption, and froth floatation. However, majority of these have had to be combined so as to overcome shortcomings, and others include photo-electro-Fenton, electro-Fenton and electrooxidation (Natarajan F.a et al,.2018). Even then, the desire for identifying potentially efficient, low-cost and locally available filter media as an adsorbent has been considered critical for sustainable environmental management (Aregu *et al. (2018*). Thus, a number of naturally occurring adsorbents like pumice, sand scoria and different biochar materials, vermin-filtration methods have been adopted.

1.2 Statement of the problem

The 2019 population census indicated that 31% of the population live in urban areas, (KNBS, 2020). Increasing number of populations into towns without equivalent planned urban infrastructure has resulted into allot of environmental problems which are increased by the inability of urban authorities to manage large quantities of generated wastewater, (Ogara 2019).

Residents of Kakamega town, like their counterparts in other urban areas, face the risk of contracting diseases as a result of inefficient sewerage systems (Okari, 2019). Current practices such as onsite treatment, offsite treatment, conventional treatment and stabilization ponds for water and wastewater treatment in African countries are insufficient (Wang, et al 2014). These Urban areas have faced challenges emanating from inadequate resources, poor infrastructure and defective cleanup technologies

(Koop, & Leeuwen, 2017). Other challenges include lack of effluent quality monitoring procedures at wastewater treatment plants.

Efforts have been made to improve the quality of wastewater discharged into water bodies. Examples include a study by Aregu *et al* (2018), in which a vertical orientation of effluent flowing in the reactors from top to bottom was adopted. In this case identification of low cost and locally available filter media was investigated. They found that pumice removal of BOD was more efficient than scoria and vice versa to COD.

In another study by Hannadeh *et al* (2017), in a vertical composite filter using biochar and sand as filter media was adopted. The flow of effluent was from top to bottom with high hydraulic transient. Similarly, Philiphi *et a*l (2021), used a vertical column of filters composed of sand and pumice for removal of phosphates under top to bottom flow by gravity. However, none of these have been applied to improve wastewater discharged into River Isiukhu from Shirere Wastewater Treatment Plant.

Data from WHO research (2005), revealed that most patients in affected areas were being treated for Amoeba infections, bilharzia, typhoid, malaria, dysentery and cholera

due to exposure to water from streams and rivers around the plant. The same study informed that disposal of sludge along the plant embankment was not environmentally friendly hence increasing green layer of algae scum into the effluent which indicated presence of cyanobacteria that produces toxins that affect humans and animals when exposed to.

The current study adopted a horizontal flow-based reactor filled with composite filter at exit maturation pond in Shirere Wastewater Treatment Plant to mitigate on the

inadequate removal of waste from effluents. The filter materials consisted of granular sand and pumice stone at depths of 200mm, 400mm and 600mm.The effluent entered in a lateral manner by gravity through perforations in the front screen. It was controlled by the principle of differentials in hydraulic heads of effluents before and after filtration. Naturally, waste materials get adsorbed onto the composite materials as it passes through the filter.

1.3 Research Objectives

The general objective of this study was to assess composite filter performance and community knowledge on quality of effluent at Shirere wastewater treatment plant in Kakamega municipality.

Specific objectives:

i. To determine the silica-pumice composite filter performance efficiency at its optimal conditions.
ii. To develop a mathematical model for removal of waste from effluent by composite granular filter at wastewater treatment plant.
iii. To evaluate the trend of effluent quality before and after installation of composite granular filter from Shirere WWTP up to river Isiukhu.
iv. To assess community knowledge, attitude and perception towards effluent quality discharged from Shirere wastewater treatment plant upto river Isukhu.

1.4 Research Hypotheses

i. **HO_1.** The varying conditions of the composite filter does not significantly affect its performance on waste removal from effluent.

ii. **HO_2.** Development of the mathematical model for the composite filter does not significantly depict its efficiency.

iii. **HO_3.** The composite filter installation has no significant effect on the trend of quality of the effluent discharged from Shirere WWTP into river Isiukhu.

iv. **HO_4.** The level of community knowledge, attitude and perception towards effluent quality discharged from Shirere Wastewater Treatment Plant has no significant effect on the effluent pollution into River Isiukhu.

1.5 Research Significance

The study will help the academicians in investigating the performance of the silica pumice composite filter and developing a mathematical model for waste removal from effluent contribute to the advancement of knowledge in the field of wastewater treatment. Academicians can use the findings to expand upon existing research and develop innovative solutions for improving water quality. The study also will provide an opportunity to test and refine methodologies for evaluating wastewater treatment processes and assessing their impact on effluent quality. This can lead to the development of standardized protocols and best practices for future research endeavors in similar contexts. Scholars can use this interdisciplinary approach as a model for future research initiatives aimed at tackling complex environmental and societal challenges. Through this study academicians will be able to build their literature review and make reference as well as additional of knowledge.

The findings of the study will inform policymakers on the effectiveness of silica pumice composite filters in wastewater treatment and their potential to improve effluent quality. This information can guide the development of policies and regulations aimed at promoting the adoption of sustainable and efficient wastewater treatment

technologies. Policymakers will use the study's insights to strengthen environmental regulations related to wastewater discharge standards. By understanding the impact of composite granular filter processes on effluent quality, policymakers can set more stringent guidelines to protect water resources and ecosystems. Assessing the knowledge, attitudes, and perceptions of the Shirere community towards wastewater treatment can also help policymakers understand community needs and concerns. This knowledge can inform the development of outreach and education programs aimed at increasing public awareness and participation in wastewater management initiatives.

Philosophically, the study aligns with principles of sustainability by promoting the use of innovative and environmentally friendly technologies in wastewater treatment. By assessing the long-term impact of composite granular filter processes, the study contributes to philosophical debates about sustainable development and resource management. The study addresses ethical considerations related to environmental stewardship and human well-being. By evaluating the impact of wastewater treatment processes on effluent quality and community health, the study will contribute to ethical discussions surrounding environmental protection and social justice. The study acknowledges the value of local knowledge and perspectives in shaping sustainable development initiatives.

1.6 Scope of the study

The main aim of this study was to assess composite filter performance and community knowledge on quality of effluent at Shirere wastewater treatment plant in Kakamega municipality. The study sought to investigate four objectives which were presented as ;determination of the silica pumice composite filter performance efficiency at its optimal conditions; development of a mathematical model for removal of waste from

effluent by composite granular filter at wastewater treatment plant; evaluation of the effect of composite granular filter processes on quality of the effluent discharged from Shirere WWTP up to river Isiukhu; finally the assessment of community knowledge, attitude and perception towards effluent quality discharged from Shirere wastewater treatment plant up to river Isukhu.

This study targeted sites in the stretch of 600m from Shirere WWTP, along Shikoye stream up to the confluence of River Isukhu. It aimed at establishing the efficiency of filter, mathematical model, the trend of concentrations; COD, BOD, TSS, NO_3 AND PO_3 and community awareness. The study was carried out from March to May, June to August, and September to November, periods of 2021.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter deals with literature review on factors affecting performance of composite granular filter specifically made of sand and pumice stone. It presents a review of effects of concentration of BOD, COD, TSS, nitrates and phosphates in effluent discharged before and after filter incorporation. Pollutants accumulation in water and environment associated health risk and the methodologies for analyzing water quality parameters are also reviewed. Management of the pollutants in Kenya wastewater treatment plants as mitigation measures were reviewed. The gaps identified were outlined in a conceptual framework that guided the study.

2.2 Pollutants in wastewater effluent and their impact on the environment

The world is facing wastewater management issues as a result of increasing industrialization and increased population density. The United States Environmental Protection Agency (EPA) estimated that over 850 gallons of untreated waste go into aquatic bodies each year, (Biswas et al, 2013). These untreated or inadequately treated wastewater effluent contains a number of compounds that are hazardous to plants and animals. These compounds are classified as chemicals of emerging concerns (CECs), persistent organic pollutants (POPS), and polyaromatic hydrocarbons (PAHs) among others. Since the inception of the Stockholm Convention in 2004 the assessment of risks associated with brominated diphenyl ethers and perfluorinated alkyl acids and associated compounds in waste waters has been intensified. Previous researchers such as Mwamburi, (2018) and Gawlik *et al* (2009), carried research on pollution of natural

water bodies and found high levels of contaminants. Common persistent organic pollutants (POPs) found in Africa include aldrin, chlordane, chlordecone, DDT, dieldrin, endrin, endosulfan, HBCDD, HCB, HCHs, heptachlor, hexabromobiphenyl, mirex, PBDEs, PCBs, PCDDs, PCDFs, PeCB, PFOA, and PFOS. Their distribution is shown in Figure 2.1 below.

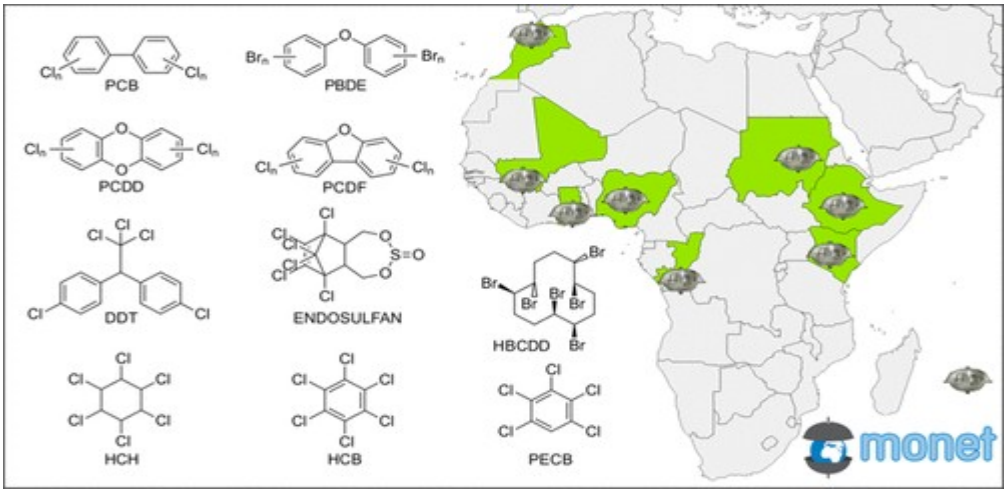


Figure 2.1: Persistent organic pollutants commonly found in Africa

Source; Adopted from Environ. Sci. Technol. (2021, 55, 14, 9413–9424).

These compounds which include pesticides, pharmaceuticals and personal care products (PPCPs) amongst other industrial and domestic wastes have the ability to bioaccumulate and biomagnifies in the different trophic levels, thus causing both acute and chronic toxicity in the different organisms.

Heavy metal contamination in sediments has been noted to affect the quality of water bodies (Khan et al2022). Other inorganic pollutants of similar nature include nitrates, phosphates amongst others (Moazzem, et al 2018). These inorganic pollutants may affect the body by affecting hemoglobin levels, damage both kidney and liver, nerve system and can cause cancer (Verma, R., & Dweivedi, P., 2013). Consequently, discharge of poorly treated effluent into rivers like River Isiukhu could result in contamination of its waters.

2.3. Indicators of Water Quality

2.3.1Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD)

The overall organic content available to organisms, as well as any compounds that spontaneously react with oxygen, is measured by biochemical oxygen demand (Ledakowicz, 1998). The process entails analyzing incubated water in sealed bottles and tracking the reduction in oxygen over time. During the incubation period, naturally occurring heterotrophic organisms employ oxygen to respire biologically accessible organic carbon and any molecule that spontaneously reacts with oxygen (Ledakowicz, 1998). The BOD value is the most typically seen number in milligrams of oxygen used per liter of sample in 5 days of incubation at 20°C, and it is frequently used as an estimate for the degree of organic contamination of water (Murcia *et al*, 2019). Severely polluted rivers have a BOD of value over 8m/L (Shah *et al* 2017). The major effect of BOD include oxygen consumed by the respirators of the algae. The photosynthetic action of plants and algae available may significantly alter the polluting effect of effluent of water bodies.

Water-borne bacteria feed on natural organic detritus as well as biological waste from town and cultivated runoff, sewage treatment facilities, and failed septic systems. Bacteria need dissolved oxygen to breakdown these organic compounds, lowering the dissolved oxygen (DO) available to fish. BOD (Biochemical Oxygen Demand), is a measurement of how much oxygen bacteria require while degrading organic materials in aerobic settings. The biochemical oxygen requirement is calculated by incubating a sealed water sample for five days and quantifying the oxygen loss from start to finish. If samples are not diluted before incubation, the microorganisms will consume all of the oxygen in the jug before the test is finished. The reduction of BOD in sewage

released to regular waters is the primary goal of waste water treatment plants. Treatment of Waste Water Plants are designed to act as bacteria farms, providing oxygen and organic material to bacteria. Excess microbes in the system are collected as sludge and disposed of as "solid" waste on land. COD is a measure of the total of oxygen demand all organic matter into water and carbon dioxide. It does not distinguish between physiologically accessible and inert organic materials. COD levels are always higher than BOD levels, and BOD measurements require five days. When wastewater with a high BOD level is dumped into a stream or river, it accelerates bacterial growth and depletes oxygen levels in the river. Most fish and many aquatic insects may perish if oxygen levels drop to dangerous levels. The oxygen levels will gradually rise downstream as the river re-aerates due to air mixing and algae photosynthesis adds oxygen to the water. The DO sag curve is the decline and rise in DO levels downstream from the source of BOD.

Table 2.1: Basic wastewater Pond Specification

Pond	Application	Typical Loading (BOD_5)*	Typical Detention Time(d)	Typical Depth (m)	Comments
Anaerobic	Industrial Waste water	280-4500kg/ $1000m^{2/d}$	5-50	2.5-4.5	Subsequent treatment normally required
Facultative		22-56kg/$1000m^{2/d}$	7-50	0.9-2.4	Most commonly used wastewater treatment pond. May be aerobic through entire depth if lightly loaded
Aerobic		112-225kg/ $1000m^{2/d}$	2-6	0.18-0.3	Maximizes algae production and if algae are harvested nutrient removal

*BOD_5 = biochemical oxygen demand measured over 5 days

Source; adapted from Curi and Eckenfelder (1980)

Table 2.2: Constituents of Urban Storm water runoff and sewage effluent

Constituents of Urban Storm water runoff and sewage effluent.

Constituents	Convectional water quality parameters	Unsuitable water quality parameters
PH	The safe aquatic habitat range is between 6.5 and 8.5	If extremely high or extremely low pH values occur, it would result in the death of all aquatic life
Electrical Conductivity	Good for drinking by people and livestock 0-800m/s/cm. Drinking but with salty taste. Some plants will not tolerate over 1500m/s (grapes/peas/apricots) 800-2,500	Unsuitable for people, most livestock and crop 2,500-10,000
Temperature	Optimal temperature ranges for trout 13-15^{0}c	Critical temperature which if exceed will harm or kill fish 23^{0}c
Total Coli form	Drinking water<1.0 E. Coli /100 contact recreation 126 E. Coli/100ml or 200FC/100ml	
Aggregate: Dissolved Oxygen	Trout need DO levels in excess of 8mg/l, striped bass prefer DO levels above 5 mg/l Most warm water fish need DO in excess of 2mg/1	
Solids; Total dissolved solids	Dissolved solids (TDS) in mg/1 usually range from 0.5 to 1.0 times the electrical conductivity	The greater the TSS in the water, the higher its turbidity and the lower its transparency (clarity)
Total suspended solids	They must have a relatively low density or specific gravity, be relatively small in size	

Source; adapted from Curi and Eckenfelder (1980)

2.3.2 Total Suspended Solid

Suspended solids are small solid particles suspended in water as a colloid or due to water motion. It is utilized as one of the water quality indicators. It's commonly abbreviated as SS, and it adds to sewer pipe blockage. Pollutants as well as pathogens are conveyed on the surface of particles, hence suspended solids are significant. The

greater the surface area per particle mass, the greater the carbon emissions load likely to be undertaken. To be permanently suspended in water (or suspended for an extended period of time), particles must be light in weight (have a low population or relative density), small in size, and/or have such a large surface area in connection to their weight (have a shape like a sheet of paper). The greater the TSS in the water, the much more turbid and opaquer it becomes (Hogan, & Walbridge, 2007).

2.3.3 Nutrients

In general, urbanization causes higher nutrient concentrations in storm runoff (Hogan, & Walbridge, 2007). Phosphorus and nitrogen are necessary nutrients for the algae growth and other plants. These photosynthesizes, which are found in low concentrations in superficial water, are essential for aquatic life. However, excessive nutrient concentrations can promote the growth of aquatic plants and algae. Organic decomposition and bacterial respiration can deplete liquefied oxygen in the water, depriving invertebrates and fish of oxygen.

2.3.4 Nitrogen

There are three types of nitrogen in urban runoff and streams: Organic form (Nitrate, Nitrites, and Ammonia), Organic form (Nitrogen and Ammonia) (Biological material e.g., Protein). Nitrates can be found in natural vegetation breakdown, overflow from grassland and agricultural manures, and wastewater. Feedlot runoff can comprise high levels of nitrates and ammonia. Septic tank failures, poorly treated sewage, and watercourses supplied by nitrate-rich aquifers can all contribute to increased levels of nitrogen in channels. Nitrogen levels that are too high can harm ecosystems. This could lead to algae blooms and an overpopulation of oxygen-dependent microorganisms, depleting oxygen levels in the water. High levels of nitrate can be

detrimental to livestock. In bottle-fed newborns, extreme nitrates in aquatic can lead to methemoglobinemia (blue baby). Ammonia at high amounts is hazardous to aquatic animals. 0.1-0.75 mg/l algal growth limit (Total Nitrogen). Human consumption limit: 11.3 mg/I (Nitrate-nitrogen).

2.3.5 Phosphorous

Phosphorous is found in low absorptions in nature and is necessary for all life forms. It results from natural methods such as organic matter breakdown and rock weathering. Phosphorous levels indicate nutrient quality, organic enrichment, and the water body's overall health. Erosion, sewage or detergent discharge, urban runoff, including rural runoff comprising fertilizers, plants and animals' debris can all cause higher amounts. Problems including as algal blossoms, loss of species variety and increased weed growth can occur when concentrations are too high. Increased pH and turbidity are caused by abundant plant growth, such as algal blooms, as well as the generation of toxins and odor: growth of algal in streams can range from 0.01 to 0.1 mg/l (Total Phosphorous), 0.006 mg/l (Dissolved Reactive Phosphorous), and 0.001 mg/l (Aquatic Ecosystem Balance) (Dissolved Reactive Phosphorous).

2.3.6 pH

On a scale of 1 to 14, pH represents the acidity or alkalinity of water (1 is very acidic, 7 neutrals and 14 very alkaline). The pH of water affects the stability of many harmful as well as nutritious chemicals, affecting their accessibility to aquatic biota. As acidity increases, most metals are becoming more soluble in water and poisonous. The toxicity of cyanides and sulfides increases when the pH drops (increase in acidity). However, even a small increase in pH makes ammonia more dangerous (Ertl, G., 1980). Acidity or alkalinity can be caused by a variety of factors including runoff, sewage, geology

(limestone is associated with more alkaline conditions), and excessive nutrient levels. High nutrient levels promote the growth of algae and plants, raising pH levels. Outside of what is regarded the typical pH range, there may be a loss of sensitive species. All aquatic life would perish if pH levels reached dangerously high or low. Other contaminants, such as ammonia, can be made more harmful by alkaline circumstances. The safe range for aquatic habitat is 6.5 to 8.5.

2.3.7 Electrical Conductivity

Electric conductivity is a substance's ability to carry electricity. Water conductivity is a linear function of solubilized ion concentrations. Although conductivity does not pose a risk to human or aquatic health, it can be used as an indicator of other water quality issues due to its ease of measurement (it is used to give an indication of the number of inorganic materials in the water including, calcium, bicarbonate, nitrogen, phosphorous, irons, sulfur and others). When the permittivity of a stream begins to increase, it indicates the presence of a nearby dissolved ion source. As a consequence, permeability performance measures could be used to identify possible water quality issues. Micro Siemens/cm or meters of permittivity per unit length are the units of measurement for conductivity. Stormwater, wastewater effluent, watershed geology, and farmland effluent flowing into streams all have an impact on stream conductivity. 0-8oom/s/cm is suitable for human and cattle consumption. Drinkable, but a little salty. Some plants (grapes, peas, and apricots) will not survive speeds more than 1500m/s. Most animals and crops 2,500-10,000 are unsuitable for people.

2.3.8 Temperature

Temperature has a direct impact on many of the biophysical properties of waterways. The water depth, season, time of day, haziness of the sky, and air temperature all

influence the temperature. Temperature can also be affected by discharges, such as cooling water. Temperature changes affect dissolved oxygen. (As the temperature rises, the amount of dissolved oxygen in the water decreases.) Temperature affects the distribution and abundance of aquatic organisms. The temperature of the water is strongly influenced by its time of day, depth, cloudiness, air temperature, and season.

Temperature can also be affected by discharges, such as cooling water. Temperature changes affect dissolved oxygen. (As the temperature rises, the amount of dissolved oxygen in the water decreases.) As the temperature changes, so does the distribution as well as number of aquatic organisms. Even if the temperature is okay for the rest of the year, each year, a brief time of high temperatures can render the water body inappropriate for sensitive ecosystems. Temperatures between 13 and 150 degrees Celsius are ideal for trout. 230°C is the critical temperature that, if exceeded, will harm or kill fish.

2.3.9 Total Coliform

Total coliforms include bacteria found in warm-blooded animals' intestines as well as those found in vegetation, soil, and water. They are commonly found in feces-polluted water and are frequently linked to illness outbreaks. Despite the fact that they are not usually pathogenic, their existence in drinking and recreational water indicates the presence of pathogens. E. coli is a coliform bacterium that is continuously originate in feces, making it a more direct sign of the presence of enteric pathogens and fecal contamination (Graczyk et al, 2010). Based on the median value, some of the recommended coli form limits are:

Water for drinking $< 1.0\ E$. Coli/100. recreation contact 126 E. coli/100ml or 200FC/100ml

2.3.10 Solids

Storm water runoff solids are classified using a variety of methods, the vast bulk of which are based on size. Total solids (TS) refer to all suspended and dissolved solids in runoff. The amount of solids present and their size distribution are affected by watershed land use, construction activity, and the time since the catchment was first disturbed (Scott, et al 2002). Brake wear, vehicle emissions, engine, tire, and as well as air deposition, and pavement wear all contribute to solids entering the runoff stream (Muller, et al 2020).

What passes through a 0.45-µm filter distinguishes TSS from TDS (APHA, 2005): (APHA, 1988). Solids are further classified into size ranges using a PSD analysis. Clay, gravel, silt, and sand and are the size classes for solids according to the AASHTO. Gravel is defined as solids greater than 2,000 meters, sand between 75 and 2000 meters, silt between 2 and 75 meters, and clay less than 2 meters, with any particles smaller than 75 meters referred to as fines (Mitchell, J. K., & Soga, K., 2005). Storm water runoff particles are colloidal if their diameter is less than 1.0 micrometer (um), as well as macro colloidal if their diameter is between 0.45 and 20um (Characlis, & Wiesner,1997). The particle sizes in storm water runoff can have a significant impact on many biochemical reactions. PSD may fluctuate throughout the longitudinal course of storm water runoff due to agglomeration of fine particles (Scott et al, 2002). Larger particles sink more quickly than tiny ones. This settling mechanism influences the relative concentrations of different particle sizes depending on the runoff velocity and depth of flow.

2.3.11 Total Dissolved Solids

Any metals, anions, minerals, cations, or salts dissolved in water are referred to as "dissolved solids." This encompasses anything other than pure water molecules and suspended particles in water. The combination of the cations (positive charge) and anions (negative charges) ions in the water is the total suspended solids concentration. The weight-to-weight proportion of any ion to water is measured in parts per million (PPM). When represented as equivalents, conductivity is usually roughly 100 times the total cations or anions. The electrical conductivity is commonly 0.5 to 1.0 times the total dissolved solids (TDS) in mg/l. Organic sources of dissolved solids include leaves, silt, plankton, including industrial urban wastewater.

Runoff from cities, fertilizers, and pesticides used on lawns and farms are among the other causes. Inorganic materials such as rocks and air can also contain dissolved solids such as bicarbonates, ammonia, iron phosphorus, sulfur, and other minerals. Many of these substances combine to generate salts, which are compounds which contain both metal and non-metal elements. Salts dissolve in water and form ions. Ions are charged particles that can be positive or negative. Metals like lead and copper can be picked up by water as it travels through pipes. The higher the TSS in the water, the more turbid it is and the less transparent it is.

2.4 Wastewater filtration type and design consideration.

2.4.1 Wastewater filtration type

Filters for wastewaters vary from system to system. This is due to variety of reasons, including conditions of the water entering the system and desired purity of the filtered

water. Amongst these, there are; particle and membrane forms of filtration used in wastewater treatment plants (WWTPs) of which, particle filtration is mostly used.

2.4.1.1 Membrane filtration

Membrane technology used for removing solids in wastewater treatment is usually based on ultra-filtration or microfiltration. The membranes can be introduced into the biological wastewater treatment process either as separate unit operation downstream of the biological step, or integrated into a biological process, (Judd Water, 2019). If the membranes are added as a separate unit operation, they are often referred to as polishing step and are usually based on the hollow fibre membrane configuration. According to Blšťáková, A. et al (2009), Domestic wastewater treatment plant monitoring was performed at the municipal wastewater treatment plant and the Parallel operation of flat sheet and hollow fiber membrane modules showed effective removal of organic matter in effluent water quality.

Zahid and Saber, (2011), evaluated three different textile materials (Acrylate, Polyester, and Nylon) as filter media for Membrane Bioreactor (MBR) treating municipal wastewater. The actual hydraulic retention times were 8.6, 8.9 and 8.0 h in R1, R2 and R3. At 5.3–5.5 g/l mixed liquor suspended (MLSS) and 26.3 days solid retention time (SRT) the membrane bioreactors were effective in removing 93–95% of COD, 99% of total suspended solids (TSS) and turbidity, 89–94% of total kjeldahl nitrogen (TKN) and 90–96% of total ammonia nitrogen. Phosphorous removal was limited to 51–55% while faecal coliform was reduced by four logs.

Membrane bioreactors (MBR) is one of an emerging treatment technology applied to various types of wastewaters including municipal solid waste leachate, (Chiemchiasri, et al 2023). Solid waste leachate usually contains high organic matter, nutrients,

inorganic salts, and toxic compounds with its characteristics highly varied. A combination of biological treatment and membrane filtration in membrane bioreactor makes this technology unique for the removals of organics, nutrients, and organic micro-pollutants containing in solid waste leachate.

2.4.1.2 Particle filtration

Particle filtration is a system that uses physical or mechanical ways to separate particulates from liquids. Small scale wastewater treatment that produces less amount of solid wastes compared often employ bag filters. In this case, solid particles larger than one micron are retained in the bag while allowing water to pass through (Svarovsky, 2000). Filtration of particles smaller than micron is better achieved using cartridge in which solid particles, and microorganisms like bacteria and viruses are trapped within the particles as water flows out at the outlet end. Particle filtration has also seen the development of sand filters as natural materials for the treatment of wastewater (Racha et al 2020). The efficiency of these processes depends among others on filter porosity, size and shape of filtration grains and fluid characteristics that often that often affect hydrodynamics and fixation rates of wastes on the granular materials used. Attempts have also been made to improve the granular filtration properties of sand by augmenting it with activated carbon, biochar and membranes.

2.4.1.2.1 Composite filters

Composites filters are blend of two or more different constituents that impart unique filtration characteristics that enable quality water to be improved. The desire to have cost-effective technologies for wastewater treatment has seen the development of a number of particles based natural composite filter materials. Examples include sand and pumice stone used as filtration media for rapid removal of turbidity. Variables investigated included component of filtration rate, bed depth, and particle size, (Farizoglu et al, 2013). Similarly, volcanic rocks of pumice and scoria have been used in lowering concentrations of BOD, COD, TSS, nitrates, phosphates, ammonia, sulphates and chromium, (Aregu M. et al 2018). Furthermore, Hannadeh *et al* (2017), using a vertical composite filter comprising biochar and at a depth of 150 mm was used in the removal of effluents and of BOD, COD, TSS, nitrates, phosphates filtrate quantities determined. Similarly, residual phosphates in filtrates were determined by Philiphi Et al (2021), using a vertical column filter of sand and pumice at 550mm depth.

2.4.2 Wastewater Granular Filtration designs

There are three important design elements considered while designing wastewater granular filters. These filter elements were: Temporal loading, Hydraulic loading rate and the direction or method of delivery. The temporal loading, has three varieties which includes the intermittent, pulsed and continuous, while hydraulic loading rate contains, high rate, rapid rate, and slow rate. The direction or method of delivery includes two varieties of flow, trickling or downward flow, and pressure which is upward flow, (Starke media 2020). Filter media may consist of different grades of filter medium ranging from gravel to sand. Finer particles in a granular filter are more effective at

filtration of wastewater and give better results, (Starke media, 2020). According to Eliasson (2002), the granular media must be coarse enough to permit a sufficient flow rate yet fine enough to provide adequate treatment. Media that is too coarse lowers the wastewater retention time to a point where treatment becomes inadequate. Media with small grain size slow the water movement and increase the chance of clogging.

Wastewater granular filters have a filtering medium consisting of silica, pumice, scoria, anthrocites, and gravel. Sand filters are commonly used everywhere as sand is easily available around the world. Fine sand of the lower layer requires very fine opening in the strainer and clogging problems might result. Design factors affecting performance or filters are; type of material, size of granular, depth of filter, flow rate and material combination. Number of suspended solids in the flow also affects the filter performance (Cleasby, 1974). Dual media filter has more advantage in improving filtrate quality. Dual media filter is known as composite filter.

Based on granular type design, Hamoda, Ghusian & Jasem (2004), conducted a study where laboratory experiments were carried out at room temperature (20–25 C) using four identical filter columns made of Plexiglas, each of 1 m height and 15 cm internal diameter, packed with granular media of 70 cm depth. Each filter was operated at a constant filtration rate; thus, four rates were tested in the range of 2–15 m3 m 2 d 1. Mono-media (sand) and dual-media (sand and anthracite) were tested and three types of municipal wastewaters, namely raw, primary and secondary-treated effluents were applied. The results obtained indicate that considerable improvements in effluent quality could be attained by tertiary sand filtration. The highest removal efficiency was obtained at low filtration rate of 2 m3 m 2 d 1, but higher filtration rates achieved

acceptable removal efficiencies and provided effluents of good quality to satisfy the irrigation water quality standards.

According to Eliasson (2002), the granular media must be coarse enough to permit a sufficient flow rate yet fine enough to provide adequate treatment. Media that is too coarse lowers the wastewater retention time to a point where treatment becomes inadequate. Media with small grain size slow the water movement and increase the chance of clogging. The effective size (D10) and uniformity coefficient (Uc) are the principal characteristics of granular media treatment systems. The ideal sand media for intermittent sand filters is a coarse sand with an effective size between 0.3 mm and 0.5 mm.

Sheikh et al, (2007) studied the impact of hydraulic loading rate on tertiary filtration of wastewater using a pilot-scale, dual-media, rapid depth filtration system of latex particles and spherical glass bead collectors. In their study, loading rates of 12.2, 15.3, 18.3, 21.4, and 24.4 m/h were tested on parallel filter columns treating the same coagulated secondary wastewater to determine the impact on removal of turbidity, particles (2–15 μm), total coliform bacteria, *Escherichia coli*, and MS2 bacteriophage, as well as on the particle deposition profile in the filter bed. The result revealed that Increasing the loading rate from 12.2 to 24.4 m/h decreased the removal efficiencies for all metrics.

Additionally, Sheikh et al, (2007), revealed that the impact of loading rate on particle removal was similar to the one predicted by a clean-bed filtration model, although the model significantly under estimated the removal efficiencies of the smaller particles. The results of their research indicated that loading rates higher than those typically used

in tertiary filtration can produce acceptable effluent quality, and support a regulatory approach based on filter effluent turbidity.

Using different granular type design Grasset, (2011) evaluated granular media filtration for the removal of a suite of chemical contaminants which are found in wastewater. Laboratory and pilot-scale sand and granular activated carbon (GAC) filters were trialed for their ability to remove atrazine, estrone (E1), 17α-ethynylestradiol (EE2), N-nitroso dimethylamine (NDMA), N-nitroso morpholine (NMOR) and N-nitrosodiethylamine (NDEA). Generally, sand filtration was ineffective in removing the contaminants from a tertiary treated wastewater, with the exception of E1 and EE2, where efficient removals were observed after approximately 150 d. Batch degradation experiments confirmed that the removal of E1 was through biological activity, with a pseudo-first-order degradation rate constant of $7.4 \times 10{-}3\ h{-}1$. GAC filtration was initially able to effectively remove all contaminants; although removals decreased over time due to competition with other organics present in the water. The only exception was atrazine where removal remained consistently high throughout the experiment.

2.4.2.1 Composite filter porosity

Porosity is the ratio of volume of space in between the mineral particles and total volume of the media. (M S Worth, 2018) earth science journal.

$$\text{Porosity} = \frac{\text{Pore Volume}}{\text{Total volume}} \times 100\%$$

2.4.2.2 Depth of the filter

Granular filter media bed-depth to grain-size ratio is optimum between the ranges 1000 – 1200 according to French, (2012). Whatever filtration theory is used, whether

Brownian motion, Inertia obstruction, clogging, straining, or permeation, filtration increases the amount of media. It also increases with decreases in grain sizes. If say the grain size is 0.5 mm and depth 600mm the L/d ratio is 1200.

2.4.2.3 Effluent flow rate of wastewater

Wastewater was measured by the following equipment; ADV- Archostic Doppler Velocimeter, ADCP- Archostic Doppler Current Profiler. This is used in deep and wider river channels or canal and takes profile of the river or channel as a flow rate in meters cube per second (m^3/s). Current metre is propelled by the push of the water and is the most basic equipment. V Notch is installed at the design stage and is the most convenient for monitoring. Once installed the operator sees the head installed and uses the head against the calibrated chart to know the effluent volume.

The choice of the equipment will depend on the effluent conditions. If the effluent doesn't have a lot of solids, then you use current metre or ADV. If it has a lot of solids, the V Notch was recommended. (French.,2012).

2.5 Methodologies in effluent parameters analysis

2.5.1 BOD

BOD is currently measured using a standardized method known as the closed bottle, developed by (Jouanneau S. et al., 2014). International standards explain this (ISO 5815-1-2003). The test is based on microbiological samples collected from the environment in general, unknown microbial diversity, 105 cells/ml.) Allylthiourea Addition dilution and seeding technique (Kim, *et al* 2003). This takes 5 days to complete. The biggest downside of this strategy is the amount of time it takes to achieve (5 days), according to Gram *et al* (2002). Due to unpredictability, the approach

does not perform well for most acceptable equipment for real-time environmental monitoring. Alternatives have been developed primarily to do a classified BOD analysis.

2.5.2 COD

Most COD tests currently employ potassium dichromate as an oxidant. Digestion is carried out on materials containing a predetermined amount of oxidants, sulfuric acid, and heat (150°C). Metals and salts are commonly used to decrease interference and catalyze digestion which takes two hours. The two most prevalent titration and colorimetric methods, (Han et al., 2021).

2.5.2.1 Titrimetric method

An analogous point is reached when all excess dichromate reacts. This means that the amount of ammonium hydroxide you used was equivalent to the excess dichromate. This endpoint can likewise be signaled by a color indicator; however, the process may be paired with a potentiometric indicator (Like an electrode).

2.5.2.2 Colorimetric method

The absorbance of a sample can alter as a result of dichromate consumption. Because of the color of chromium, the samples absorb at a specific wavelength. In a photometer, the absorbance of a sample at wavelength 600 mm can be determined. The steps in the procedure are to digest the samples and the reagent blank, cool the samples, zero the instrument with a blank vial, and read the samples. (Han et al., 2021)

2.5.3 TSS

The total solids portion is collected on a filter for TSS analysis. For the analysis, a man934-AH glass micro-fiber or its equivalent with a nominal pore size of 1.5 mm is

often employed, and a pre-determined amount, typically 0.1 liter, is passed through the filter. Before the sample is filtered, the filter is weighed, and then it is dried at 103-1050 degrees Fahrenheit. The filtration process is best for samples containing roughly 200mg/L of clay-size particles. Evaporation as well as wet-sieving filtration are the other two ways (Kagey, 2019).

2.5.4 Nitrates

Methods used in nitrate analysis are four namely; Diphenylamine spot plate method (SPOT), Spectrophotometric plate method (SPEC), Nitrate-selective electrode method. (NSE) and High-performance liquid chromatographic method (Cathyl et al,1995)

2.5.4.1 Diphenylamine spot plate method

0.25 ml of samples are mixed with 0.25 mm of diphenylamine solution (0.25 diphenylamine in 100ml) of concentrated sulphuric acid in a white spot plate well, and the color is allowed to develop for ten minutes. The unknown color intensity is compared visually to that of standards. (Cathyl et al, 1995)

2.5.4.2 Spectrophotometric plate method

10 mL of the sample is transferred to 25mm volumetric flasks and diluted with deionized water. Add a reagent pillow to each volumetric flask that has been paraffin-sealed and mixed. After at least a 5-minute reaction time, the absorbance is measured spectrophotometrically at 500 mm. (Cathyl *et al* 1995)

2.5.4.3 Nitrate-selective electrode method

A microprocessor-based ionalyzer with reference and nitrate electrodes. The analyzer is calibrated with 100 and 25ppm, followed by an appropriate dilution and measurement. (Cathyl *et al* 1995)

2.5.4.4 High performance liquid chromatographic method

An automated HPLC system that filters samples through a 0.45mm filter. The primary injection volume was 100 mm. Nitrate is eluted from a high-capacity anionic and cationic column with a 1.7 mm carbonate/1.8 mm anion exchange ratio (Bedwell, et al 1995)

2.6 Previous Studies on Wastewater Treatment Improvement

Pollution of river water by wastewater has the potential to have a severe negative impact on aquatic sustainability (Wang, et al 2021). Njunguna, et al, (2017) conducted research on the quality of water in the Nairobi River, focusing on the presence of metals. They discovered that the amounts of lead, copper, zinc, and manganese in the water exceeded WHO and NEEMA guidelines. They also found that harmful levels of bacteria and E. coli use incredibly high. Pollution impacts on health of those who rely on Nairobi River for agriculture and consumption. Sample at Thwake River where Nairobi River flows found four of these metals and the water had concentration of sewage at 120 times higher than what is recommended. Dark green color in wastewater effluent indicates algae scum with high level of cyanobacteria. They further proposed Waste Water Treatment Plant to handle the waste produced in the county must be upgraded and expanded.

In different study, Geem et al (2018) applied improved optimization through the use of analytic differentiation to find the crucial shortfall position of evolved oxygen gas for sewage treatment as well as reuse systems utilizing computational intelligence. The study developed an improved sewage water treatment as well as reuse optimization model that includes three options: filtration, nitrification, and redirected irrigation. The model developed could be compared to the current research in terms of prediction of several parameters.

Recent advances in water and wastewater treatment with a focus on membrane treatment Zoubouilis, & Katsoyiannis, (2018), classified published papers in major categories. That is, (a) Those that investigate the application of membrane treatment processes. (b) studies that investigate application of adsorptive processes for the removal contaminants from water or wastewater. (c) studies that include novel aspects of oxidative treatment such as bubbleless ozonation. Using vacuum membrane distillation and hollow fiber modules, (Suga et al, 2022) investigated the efficiency of a modified membrane method. Vacuum membrane distillation is a revolutionary membrane distillation technique that has the potential to be used for a variety of separations, including water desalination and bioethanol recovery.

2.7 Conceptual Framework

Astalin (2013), identified Phenomenology, Ethnography; Grounded theories as case studies and types of research theories commonly used in qualitative techniques. Kitchel, & Ball, (2014) with respect of quantitative research listed grand, middle range and substantive as research theories. The study employed grand research methodologies for qualitative data in the development of conceptual framework. The link between the influent flow rate, composite filter porosity, filter depth and effluent quality discharged

were displayed. From objective one, the variables identified as composite filter depth, influent flow rate, parameter concentrations were independent variables while effluent quality whose parameters were COD, BOD, Nitrates, Phosphates and TSS were the dependent variables. Objective two independent variables were, time, filter volume, effluent flow rate, and time. In objective three of the study, the explanatory variable was distance of effluent flow from the plant to River Isukhu. The last objective was indicated by the demographic characteristics of community members. Other factors affecting the effluent quality were also conceptualized. A conceptual frame work serves to describe the overall research objectives involved in this study.

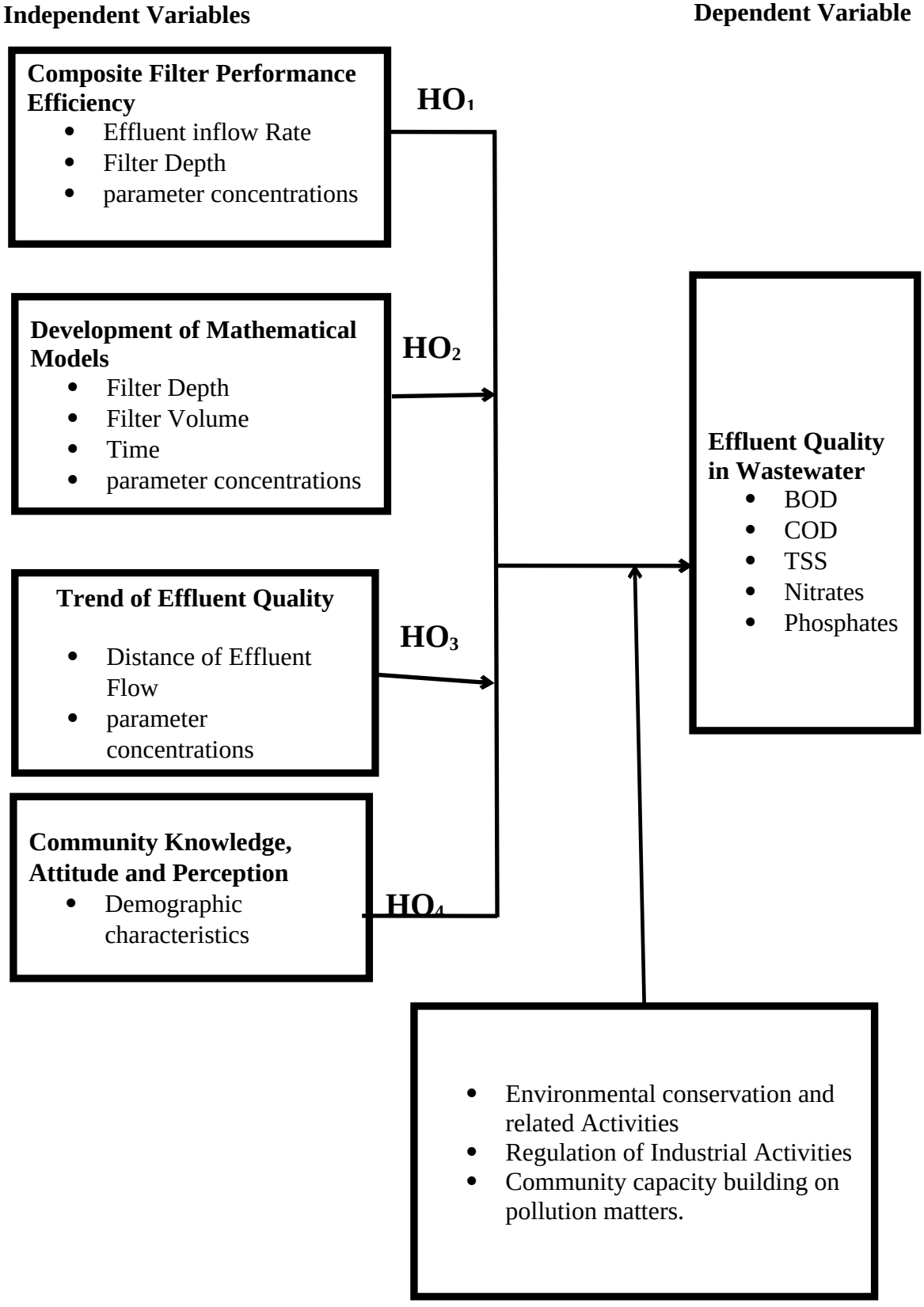


Figure 2.2: Conceptual Framework

Source: Author, (2023)

CHAPTER THREE

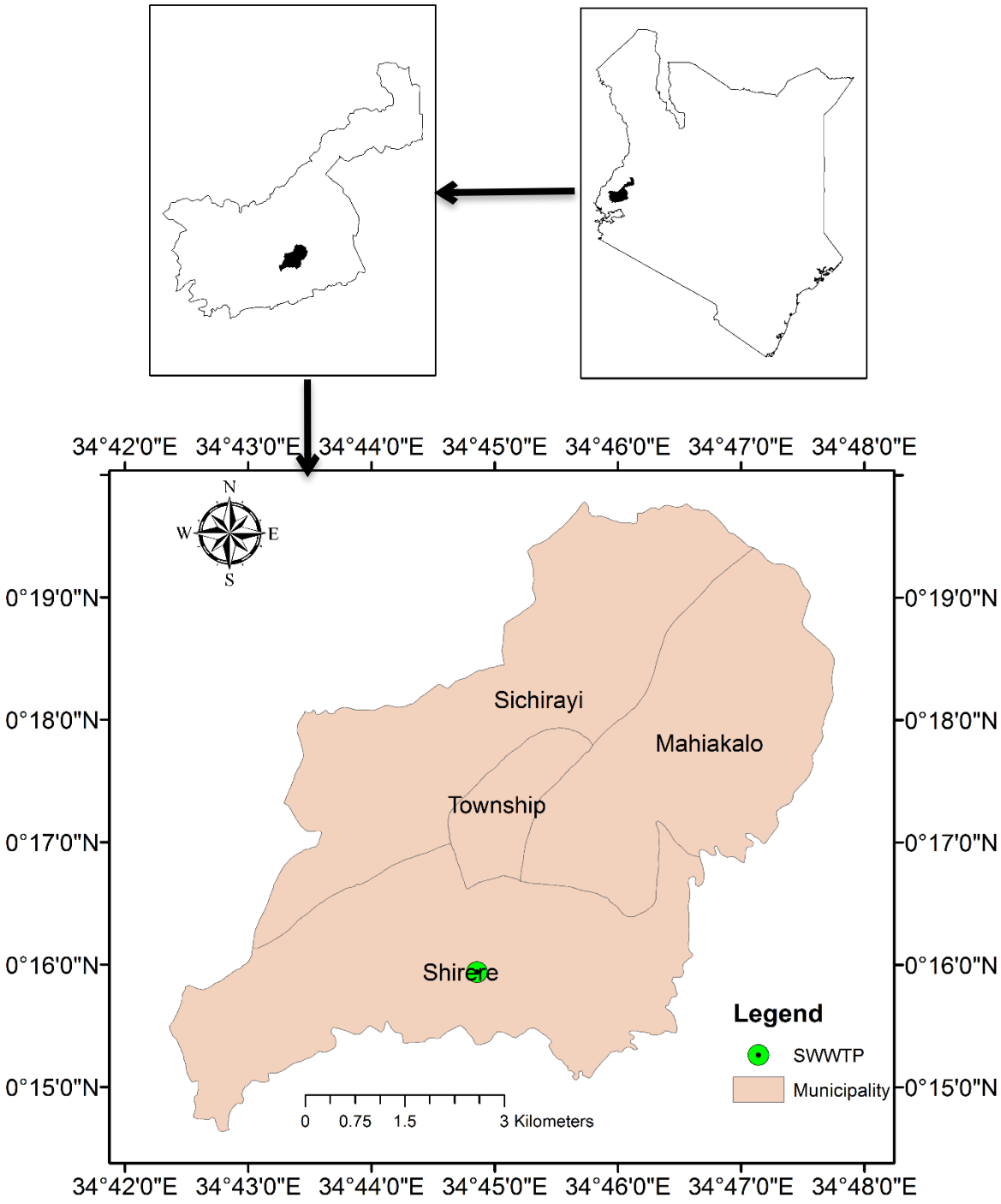
MATERIALS AND METHODS

3.1 Introduction

This chapter describes the research design adopted during the study. It provides information on area of study, sample strategy and sample size. This study was conducted in the Kakamega Municipality which comprises Mahiakalo, Sichirayi, Kakamega Township, and Shirere locations

3.2 Study Area

Sampling was done at Shirere WWTP, Shikoye stream and river Isiukhu as shown Figures 3.1- 3.2. Shikoye stream receives wastewater discharged from Shirere WWTP. The catchment area for Shirere WWTP, Shikoye stream and river Isiukhu is defined by longitude $34^0 44^{'} 36.40''$E, $34^0 45'8.65''$ E and latitude $0^0 16'4.61''$ N, $0^0 15'11.01''$ N. The location of the treatment plant is longitude $34^0 44'55.85''$E, $34^0 44'53.93$E and latitudes $0^0 15'58.76''$ N, $0^0 15'55.79''$ N. The stream joins river Isiukhu at river Isiukhu at $0^0 15'19.74''$ N,$34^0 44'43.27''$ E. River Isiukhu is a major tributary of River Nzoia. Its waters are used by the community for domestic use, agricultural irrigation and abstraction by water companies and institutions. The wastewater from the plant is discharged into River Isiukhu via Shikoye stream.



SWWTP – Shirere Waste Water Treatment Project (Kakamega Municipality)

Figure 3. 1: Study Area

Source; Author (2021)

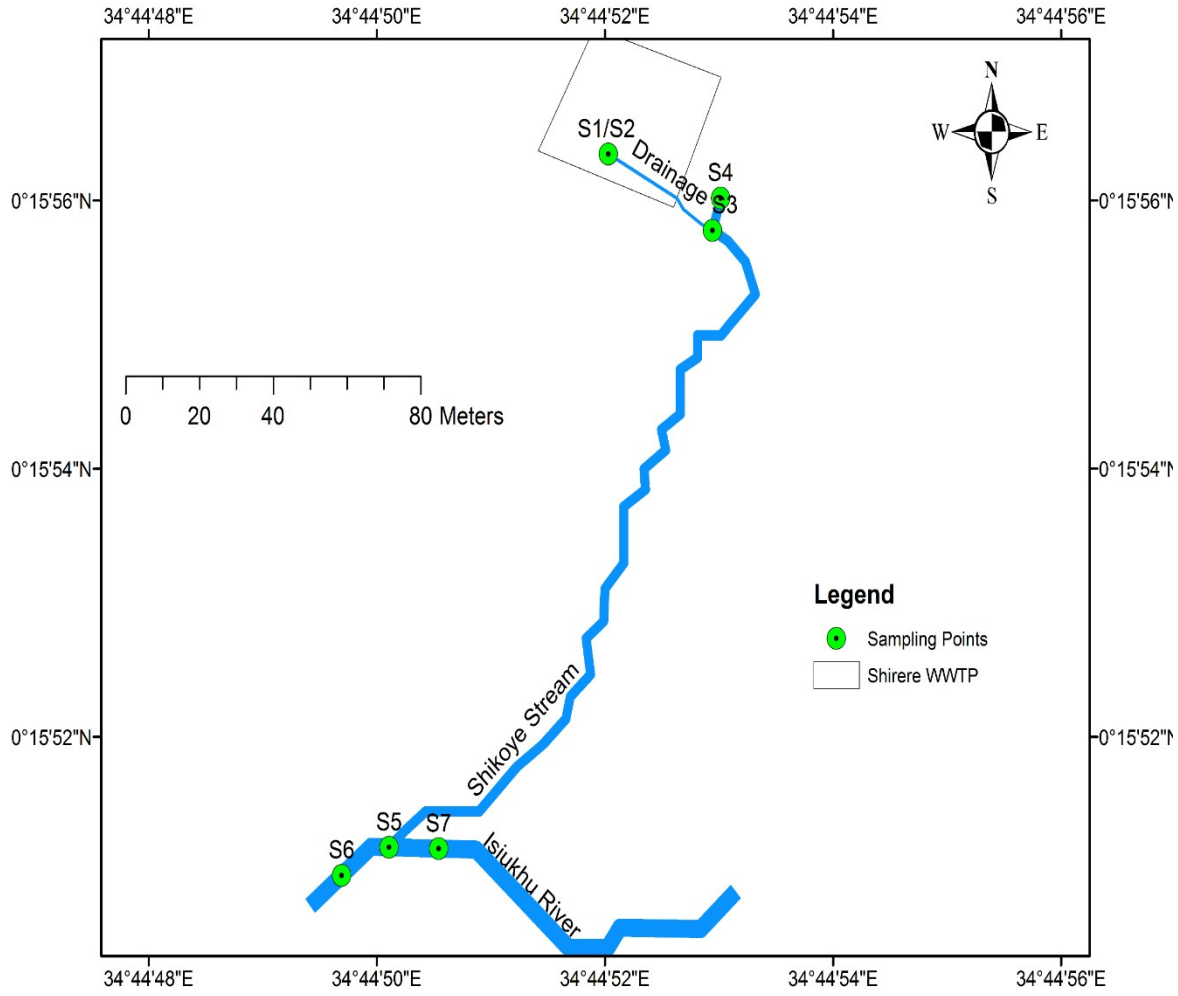


Figure 3.2: Sampling sites. The details of sampling sites in Figure 3.2 are given Table 3.1

Source; Author, (2021)

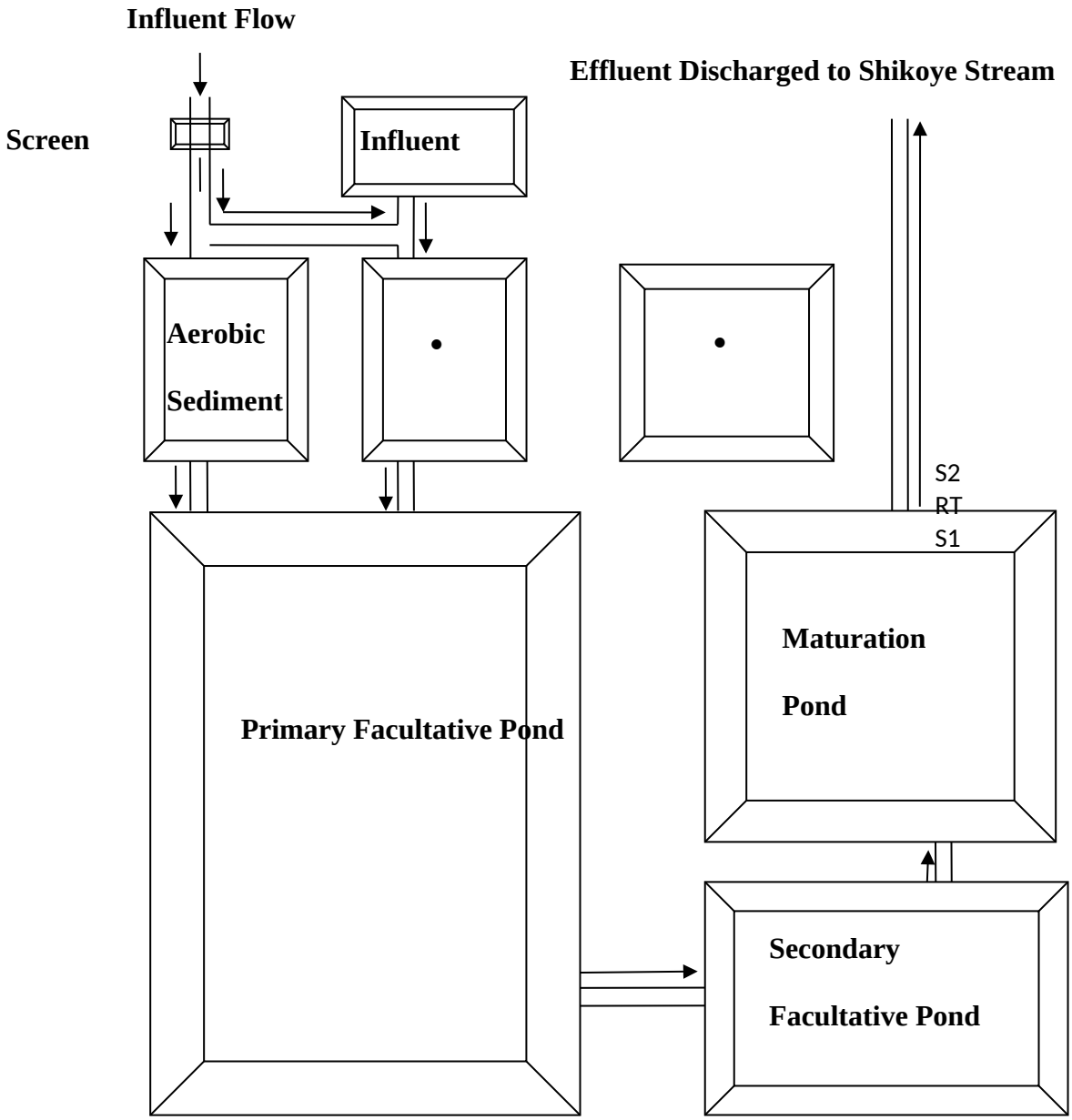


Figure 3.3: Schematic Diagram of Shirere Wastewater Treatment Plant Showing ponds, sampling point 1, Reactor Location and Sampling point 2

Source; Author, (2021)

Table 3.1: Water and waste water sampling sites

Water				
Sampling station	Station name	GPS coordinates		Sampling station Description
S4	Shikoye water spring	0^0 15’51.37” N	4^0 44’56.47” E	Drinking water point
WASTEWATER				
S1	outlet of maturation pond	0^0 15’55.79” N	34^0 44’53.93” E	Maturation pond point outlet
S2	outlet of maturation pond after filter	0^0 15’55.79” N	34^0 44’53.93” E	Maturation pond point outlet after the filter
S3	effluent confluence	0^0 15’51.88” N	34^0 44’56.07” E	Shikoye stream confluence with effluent
S5	Confluence	0^0 15’19.74” N	34^0 44’43.27” E	Shikoye stream confluence Isiukhu river
S6	lower Isiukhu river	0^0 15’20.52” N	34^0 44’41.40” E	Lower Isiukhu point
S7	upper Isiukhu river	0^0 15’19.40” N	34^0 44’44.97” E	Upper Isiukhu point

Source; Author, (2021)

3.3 Study population

According to the KNBS (2019), Kakamega town has a population of 120,000 people. Local inhabitants are mostly Luhya whose economic activity is farming and fishing. The unit of analysis in the community of the sample area was composed of 84 people in the River Isiukhu catchment area consuming the water for agricultural and domestic

use. The points for analysis used in the scientific phase of the study included water spring at S4 and wastewater S1-S3 and S5-S7.

3.4 Research design

The research used a multiple design of experimental and socio-economic approaches. Scientific analysis involved sample collection, preparation and laboratory analysis to determine among others concentration of COD, BOD, phosphates, total suspended solids (TSS) and nitrates. Data was collected using purposeful and random sampling techniques. This was followed by a descriptive socio-economic survey to obtain data (age, gender and level of knowledge on pollution) details of which are shown in Table 3.2 below.

Table 3.2: Research design for the study

Specific objectives		Approach	Measurable Indicators	Research Design	Results
i.	To determine the silica pumice composite filter performance efficiency at its optimal conditions.	Measure, Depth, effluent flow rate.	Flowrate (Q)and Depth(L).	Experimental	Tables and Graphs
ii.	To develop a mathematical model for wastewater treatment plant for managing the quality of the Isiukhu River	Measure concentrations of COD, BOD Nitrate, Phosphates and TSS.	Filter depth, volume, time and parameter concentrations	Correlation and experimental designs.	Tables and Graphical presentation
iii.	To evaluate the trend of effluent quality before and after installation of composite granular filter from Shirere WWTP up to river Isiukhu.	Measure the parameters of wastewaters	Measure concentrations of COD, BOD Nitrate, Phosphates and TSS	experimental designs.	Tables and graphical Presentations
iv.	To assess community knowledge, Attitude and perception on effluent pollution into River Isiukhu	Measure knowledge, perception and attitude of the community members, plus KACWASCO staff.	No. people of willing to learn more about pollution control, time taken for judgement, and time taken to solve problem	Correlation and descriptive survey.	Tables and graphical presentations.

Source; Author, (2021)

3.5 Sampling Strategy

Also, measured was effluent discharge flow rate before filtration by Acostic Dopler Velocitimeter (ADV) method. As for socio-economic phase, KNBS, (2019) population census indicated that Shirere community area had 800 community members and stakeholders while KACWASCO had seconded 40 workers to WWTP. Following Shen & Fisher, (1999) formular for determining sample size a scale factor of 0.1, that is 10% was applied in sampling both the community members and KACWASCO staff. The maximum sample for the study was 84. The sampling strategy was shown in Table 3.3.

Sample size= 10%* population size

Where; 10% (800) =80

10% (40) =4

Table 3.3: Sampling strategies

Study unit	Sampling methods	Sample size
	Phase 1: scientific	
Water	purposeful	4 from Shikoye Water Spring (drinking water)
Wastewater	purposeful/random	24, 4 from each point of 6 sampling sites; S1, S2, S3, S5, S6, and S7.

Study unit	**Sampling method**	**Population Size**	**Sample size**
	Phase 2: Socio- economic		
Community members	stratified	800	80
KACWASCO workers	random	40	4

Source; Author, (2021)

The sample size (n) for the questionnaires was estimated using Eq. (3.1) (Shen, Y., & Fisher, L.,1999).

(3.1)

This formula was selected due its reliability and efficiency and flexibility. By computation (

3.6 Reagents and Materials

The following analytical grade reagents were obtained in Masinde Muliro University of Technology Chemistry Laboratories: magnesium sulphate; calcium chloride; sodium phosphate; ferric chloride; ammonium heptamolybdate tetrahydrate; sodium hydroxide; distilled water; acetic acid; potassium hydrogen phthalate; and potassium iodine. Similarly obtained were 500-mL sampling bottles and ice boxes while pumice stone was purchased from Naivasha and sand from Ministry of Public Works, Kakamega County. The tools used in the measurement were 300 ml BOD bottles, BOD metre, 100 ml beakers, 200ml for flask, Pipette bulb, stirring bass and 25ml measuring pipettes all obtained in the Chemistry laboratory.

3.6.1 Data collection

Control sample conditions included triplicates collected at sites S1-S7 using labeled 500 milliliters sampling bottles and kept in ice boxes. Briefly, samples were collected at the outlet of the maturation pond before filtration (S1) and along the streams and rivers labeled S3-S7. The above was repeated with experimental sample conditions collected after the introduction of sand-pumice composite filter within S1 that created a three section of S1 namely $S1_2$, Composite Filtering Unit (CFU) and S2. New Samples were therefore collected in $S1_2$, S2-S7. All samples were transported to the laboratory for further analysis. This was done during the dry season, wet season and short rain season.

3.6.2 Preparation of standard solutions

A stock solution of 0.01mole of potassium dihydrogen phosphate was prepared by dissolving 1.36 g of the salt into 500 milliliters of distilled water. Using this, standard solutions of 5 ppm, 10 ppm, 15 ppm, 20 ppm, 25 ppm and 30 ppm concentrations were prepared. To equal amounts of 20 milliliters of each was added 5 milliliters ammonium molybdenum and 3 milliliters of ascorbic acid. These were then topped to 100 milliliters by use of distilled water.

Standard solution of one normal sodium hydroxide (NaOH) was prepared by adding 40 g of NaOH to 900 millilitres of deionized water. The mixture was stirred and brought to one litre mark with distilled water. Similarly, one normal sulphuric acid (H_2SO_4) was prepared by adding 28 millilitres to 900millitres of deionized water. 1.575 g of sodium sulphate (Na_2SO_3) and a few crystals of cobalt chloride ($CoCl_3$) were dissolved in 1 Litre of deionized water and used immediately as required. Magnesium sulphate solution was prepared by dissolving 25 grams of magnesium sulphate distilled water and diluting it to 2 Litre mark. Similarly, calcium chloride and ferric chloride hexahydrate solutions were prepared by dissolving 55 g and 0.5 g respectively into 2 litters. Potassium iodide and acetic acid solutions were prepared by adding 20 g and 100 millilitres respectively into 100milliters of distilled water and used as required.

High range digestion solution was made by adding 5g of potassium dichromate into 250milliters of distilled water, 85millilters ml of concentrated sulphuric acid added, and 16.5 g mercury sulphate ($HgSO_4$). The solution was allowed to cool at room temperature and diluted further to 1000mls. Low range digestion solution was similarly prepared using 0.5 g potassium dichromate. Sulphuric acid reagent was prepared by adding silver sulphate (Ag_2SO4) to concentrated H_2SO_4 at the rate of 2.5 grams of

Ag_2SO_4 per kg of H_2SO_4, distilled and mixed. Potassium hydrogen phthalate (KHP) was prepared by crushing 213 g of the salt and dissolving it in 1000 millilitres distilled water.

3.6.3 Instrumental Analysis

The optimum absorption wavelength referred as Lambda mark for phosphate ions was determined in the range between 500 nanometers (nm) to 950 nanometers (nm) wavelength (Targhat, 2015). Unless stated otherwise, the concentration of the phosphates was determined from triplicate measurements of wavelength value of 752 nanometers (nm).

3.6.4 Composite filter material data

The composite filter material was made of silica (sand) and pumice stone granules of different rations. The latter were ground into particles at the soil mechanics laboratory in MMUST by a mallet and sieved using granular sieves of different pore sizes. The granular sieves used consisted of 0.6 mm, 0.9 mm, 1.18 mm, 2.75 mm and 3.25 mm.



Plate 3.1: Several sizes of pumice stone aggregates

3.6.5 Composite filter Parameter optimization

The size of particle affects porosity of the filter. Porosity is the ratio of volume of space in between the mineral particles and total volume of the media ((Pepper, I. L., & Brusseau, M. L., 2019). Granular filter media bed depth (L) to grain size (D) ratio is

optimum between the range of 1000-1200 (French, 2012). For plants using conventional clarification Pretreatment, a common dual filter uses 600mm depth of sand having 0.9mm particles size and anthracite depth of 300m having 0.5mm particle size leading to L/D ratio of 1267. At Shirere WWTP the depth of maturation pond outlet was 800mm. Depth varied from 200mm, 400mm, and 600mm. The respective granular sizes calculated from the L/D ratios are represented in Table 3.4 below.

Table 3.4. Depth, Particles Size Ratio Optimal Values

		Ratio (L/D)					
		1000	1050	1100	1150	1200	1250
1	L		200	400	600	800	1000
	D		0.19	0.364	0.522	0.667	0.8
2	L	1000		200	400	600	800
	D	1		0.182	0.348	0.5	0.64
3	L	800	1000		200	400	600
	D	0.8	0.952		0.174	0.333	0.48
4	L	600	800	1000		200	400
	D	0.6	0.64	0.909		0.1667	0.32
5	L	400	600	800	1000		200
	D	0.4	0.571	0.727	0.87		0.16
6	L	200	400	600	800	1000	
	D	0.2	0.380	0.5454	0.7	0.833	

Source; Author, (2021)

From the Table 3.4, granular size ranges from 0.16mm to 1mm and depth from 200mm to 1000mm. However, the available standard sieves are given Table 3.5. The researcher chose to use 0.6mm, 0.9mm and 1.18mm as shown Table 3.5. granular size of 1.18 is of approximate size to 1mm. Particle size preparation was undertaken by mechanical sieving. Mechanical sieving is more efficient (Liao, W., & Thomas, S. C., 2019). In the British standard, sieving test procedure, a BS 410 standard sieves were used. The sieve numbers are from 4 to 270. The sieve numbers and their particle sizes are provided in the Table 3.5.

Table 3.5: Sieve Sizes Chart

No	Sieve number	Opening size (mm)
1	4	4.750
2	6	3.350
3	8	2.360
4	12	1.680
5	16	1.180
6	20	0.900
7	30	0.600
8	40	0.425
9	50	0.300
10	60	0.250
11	80	0.180
12	100	0.150
13	140	0.106
14	200	0.075
15	270	0.053

Source; Author, (2021)

Sand and pumice stones were availed at MMUST Civil Engineering lab. The sand was clean sharp river sand and pumice stone was 50mm rock that was reduced by a market on clean surface to sievable sizes. The sieves were cleaned by a brush. The granular materials were dried for 3-4 minutes in order to expel moisture. The sieves were arranged in order as shown in Table 3.5 and plate 3.2.



Plate 3.2. Process of sieving materials at MMUST civil engineering Laboratory
Source; (Author 2021)

3.6.5.1 Optimum pumice-sand ratio

Using sand of granular size of 1.18 mm and sand of 0.6 mm the ratios of sand: pumice mixture was varied from 100%, 75%, 50%, 25%, and 0% of sand while maintain the total weight of the two at 100%. The mixture was mixed uniformly and put in a vertical cylindrical glass of 400 mm length and 30 mm in diameter. It was filled with the mixture up to 300 mm and 25 ppm standard phosphate solution eluted down the column. Amount of phosphates adsorbed was determined by recording the absorbance values.

3.6.5.2 Optimum granular size

The above experiment was repeated under same conditions while maintaining sand: pumice ratio at 50%and sand granular size of 1.18 mm. Pumice granular sizes were varied from 0.6 mm, 0.9 mm, 1.18, 2.75 and 3.25 mm respectively.

3.6.5.3 Adsorption time determination for the composite filter

Using the optimal developed filter, batch experiments were carried using samples collected at S1. These were incubated between a period of 0.5, 1.0, 2, 4, 8, 16 and 64 hours at room temperature in the laboratory. Variation of absorbance with time was measured at Lambda mark wavelength.

3.6.5.4 Reactor Design, fabrication and Filter material installation

The waste water filtration instrument was designed to fit the outlet S1 of the maturation pond as described in Figure 3.2, 3.3 above. Its dimensions were as follows: length of 1170mm; width1000mm; and height 600mm (**see Figure 3.4)**. This reactor was made of stainless steel with an inlet screen and adjustable outlet notch for control. This was

to be installed in maturation pond exit manhole to create S1, reactor and S2 sampling points.

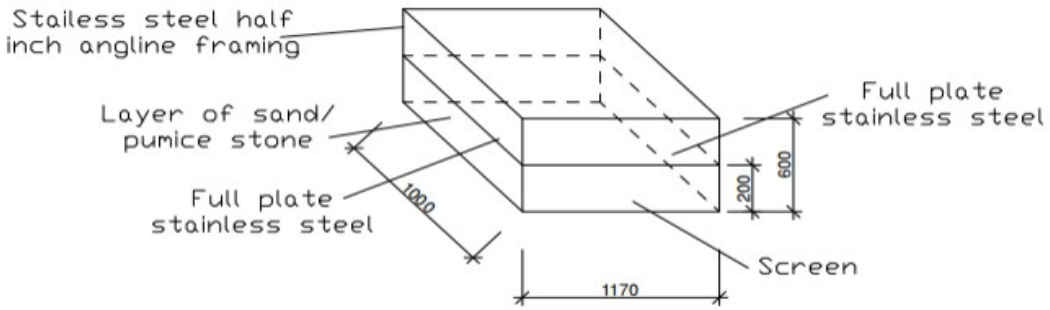


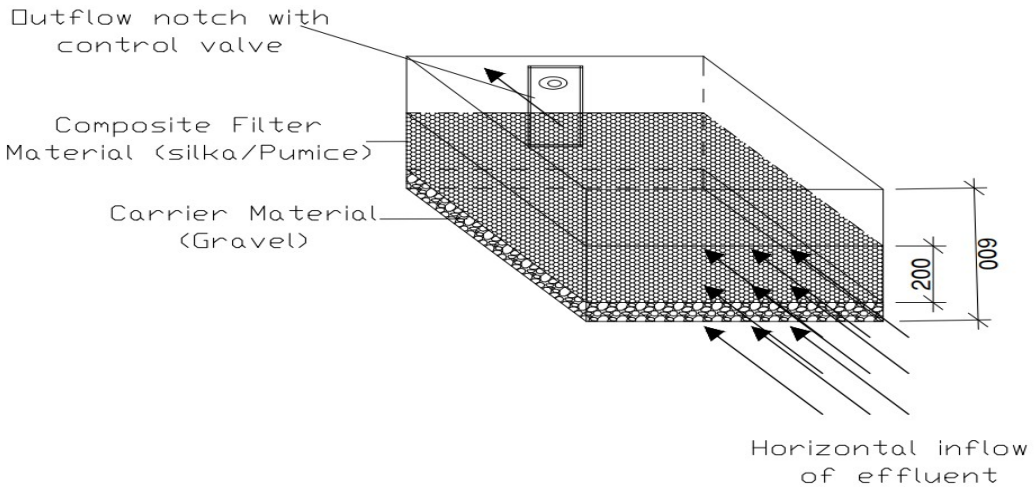
Figure 3.4: Design of Reactor/wastewater filtration instrument

Source; Author, (2021)

Granular Sizes of Silica is frequently used as a filtration medium because of its capacity to hold onto particles, (Putri L.D et al 2020). Granulated Pumice stone's porous nature, improves filtration when combined with silica, (Ünal S. et al, 2016). Glass columns are often used in lab settings for filtration investigations and other controlled experiments, (Orhan F.S et al, 2016). This vertical cylindrical glass column has a diameter of 30 mm and a length of 400 mm. Standard Phosphate Solution at 25 ppm were employed for testing and calibration in water quality studies, (APHA, 2005). UV-VIS spectrophotometers are essential for measuring absorbance in chemical analyses, which includes detecting phosphate content, (Baran A. 2022).

The reactor was filled with composite granular filter made of heterogenous mixture of sand and pumice stone at levels 200mm, 400mm and 600mm. The composite filtration unit (CFU) or reactor was installed at the exit manhole of maturation pond for filtration process where effluent entered through front screen plate by gravity, through the filter onto outlet notch as shown in figure 3.5 below. In related study (Aregu, MB, 2018),

schematic diagram showed a vertical orientation of effluent flow into the reactors from the top to the bottom



Source; Author, (2021)

3.6.6 Field experiments Using Composite Filter in Reactor at maturation pond

Triplicate samples were collected at sites $S1_2$, S2- S7 during the seasons of March to May, June to August and September to November (Simpson 2013). The samples were collected in labelled 500 milliliters bottles sterilized by HNO_2 acid and stored under controlled container conditions before being transported to the laboratories. Three bottles per site were collected to enable sufficient analysis in the MMUST chemical laboratories. The field samples were filtered through 0.4-µm pore membrane filters and kept at 4^0C until analysis. An aliquot of 50 milliliters of these used were digested with 20milliliters of HCl acid at 80^0C until the solution became transparent (APHA, 2005).

3.6.8 Measurement of Chemical Oxygen Demand (COD)

The oxidant in the COD test was potassium dichromate. Digestion was carried out on samples containing a specific amount of oxidants, sulphuric acid, and heated at 150°C. The digestion process took two hours and the COD results were recorded. The reagents used were Sulphuric acid, high range digestion solution and low range digestion solution.

3.6.9 Measurement of Biological Oxygen Demand (BOD)

For every site, a sample of 500millitres of waste water from controlled conditions, clean calibrated thermometer was installed for measurement of temperature. The temperature chamber was controlled constantly in the DO instrument for 30 minutes before calibration.

The water was aerated and diluted before adding nutrient solutions. The solution was diluted up to one litre and one millilitre each of ferric chloride, calcium chloride, magnesium sulphate and potassium phosphate added to it. The container of the solution was shaken for one minute to saturate it with oxygen at maintained temperature of 20^0c.

The initial and final DO tests of water was determined and recorded as follows: - air diffusion stone was inserted into the warming container and aerated the sample for 15 minutes. Three 50 millilitres of sub-sample were thoroughly mixed by inverting them 20 times. Each sub-sample was poured into clean BOD bottle, topped by agitated dilution water. Other three blanks of dilute water were prepared for quality control. The initial DO concentration (D1) of each sample and dilute blank was measured in calibrated DO instrument, and final DO concentration, (D2) of each sample in air incubator at the end of 5 days was measured in calibrated DO instrument and D2 recorded as BOD.

3.6.10 Measurement of Nitrates

500 milliliters waste water portions that were collected were used in this experiment. In this case, 3.5 milliliters of filtrate were transferred into 100 millimeters volumetric flask, diluted with distilled water to the marked line, and shaken until homogeneously mixed (dilution factor 28.5 liters) (Neddy et al, 2018).

This was filtered through 0.45µm membrane filters to remove turbidity and sealed with paraffin paper. 10 milliliters of solution were transferred into 100 milliliters volumetric flask, added 0.1 grams of zinc powder, added 1 milliliter of hydrochloric Acid, allowed to stand for 10 minutes, 2.5 milliliters of Sulphuric acid added, shaken and left to react for 5 minutes. More 2.5 milliliters of Ethylenediamine Dihydrochloride solution were added and shaken with distilled water to the marked line. (Neddy et al, 2018)

The amount of nitrates in the solution was determined by measuring the absorbance at 220 nm and 275nm wavelength after allowing to reach the operating time. Each treatment was repeated 6 times. Levels of nitrate in the sample was calculated by multiplication with conversion factor, volume and dilution factor and divided by weight and recorded accordingly.

3.6.11 Measurement of Phosphates

An analogous point was reached when all excess dichromate reacts. This indicates that the amount of ferrous ammonium sulphate used was equivalent to the excess dichromate. This endpoint was likewise be signalled by a colour indicator; however, the process was paired with a potentiometric indicator. (Like an electrode). Tools used in the measurement were UV-VI, spectrophotometer at 752 nanometre wavelength, 100m/s beaker, 200milliliter flask, 25milliliters measuring pipettes and 10milliliters

graduated cylinder. Reagents used in the measurement were distilled water, ammonium heptamolybdate tetrahydrate and potassium among titrate trihydrate.

3.6.12 Measurement of Total Suspended Solids

TSS analysis was performed by collecting the total solids potion on a filter. Typically, for the analysis, a what man934-AH glass micro-fiber or its equivalent with a nominal pore size of 1.5 mm was used, and a pre-determined volume, typically 0.1 liter, was passed through the filter. The filter was weighed both before and after the sample was filtered, and it was commonly dried at 103-1050 degrees Fahrenheit. The filtration method was ideal for samples containing 200mg/L of clay-size material. Tools used in the measurement of this use drying over, filtration apparatus, analytic balance, glass fibre filter and watch glass. The reagent used was pure water.

3.6.13 Socio-economic data collection

For socio economic survey the selected respondents for the study were sampled through stratified random and simple random sampling. The community were stratified based on household requirements provide for each stratum. Members in each stratum were sampled by simple random sampling using lottery method. The slips were named and container mixed. Blindfold selection was done until sample size was achieved.

As shown in table 3.4, total for two categories of population, the sample size was 84 persons. The following procedure was used in determining the sample size for each population displayed in table 3.4. Following Shen, Y., & Fisher, L. (1999) formula for determining representative sample size, a scale factor of 0.1(10%) was applied for both KACWASCO and community. Data collected from KACWASCO shows that there are 40 workers for sewerage at Shirere WWTP and 2019 national census indicated a population of 800 in the Shirere waste water treatment area and Isiukhu catchment. A

good maximum sample size is usually 10% of population as long as it doesn't exceed 1000, Shen, Y., & Fisher, L. (1999).

Table 3.6: Study Sample Sizes

Respondents	**Population**	**10%**
Sample		
Community members	800	80
KACWASCO workers	40	4
TOTAL	840	84

Source; Author, (2021)

3.7 **Quality control, Validity and reliability of data collection instruments**

3.7.1 Validity of data collection instruments

3.7.1.1 Questionnaires

Socio-economic survey data collection tools were taken under same conditions (Sharma, et al 2011). The questionnaire and the interviews were pretested through a pilot study to ascertain their reliability. This pre-test was at the other WWTP at Nabongo. The Pearson coefficient (r) was used to compute the correlation coefficient between the two test scores, (Wilson, et al 2011).

3.7.2 Reliability of data collection Instruments

The reliability is the stability and consistency with which the instrument measures concept and helps to assess the goodness of a measure (Sekaran, U., and Bougie, R., 2010). It also indicates the extent to which it is without bias and hence ensures consistent measurement across time and across various items.

For scientific, the experiments of absorbance versus concentration were carried out at Lambda wavelength. The reliability of the phosphate data was used for calibration and

ascertained by a plot concentration versus absorbance for standards (Slater,et al 2010) . This was done to precede each of the samples analysed.

For socio-economic, reliability test was administered by use test- retest method. A code book was prepared and scores of the first test correlated with scores of the second test, and Pearson product moment of correlation was computed using SPSS software version 21.0.

3.8 Data analysis

According to Springmeyer et al (1992), the scientific data analysis can be decomposed as shown Figure 3.6.

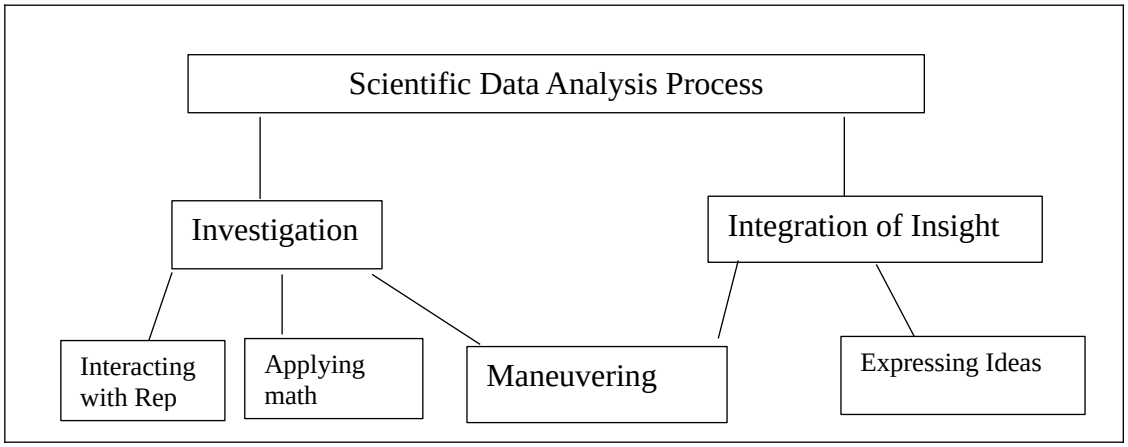


Figure 3.6: Categories of process elements

Source; Author, (2021)

In this study, since the research design was multiple design approach. Each objective was handled separately. The detailed analysis of each objective with the help of Figure 3.5 given in subsections 3.9.1 – 3.9.4.

3.8.1 Development of the silica-pumice composite filter
Standard Phosphate calibration curve

In determination of optimal filter material, standard calibration curve was used. The standard calibration curve was developed by determination of maximum wavelength known as lambda mark which was fixed on UV-VIS spectrophotometer. The lambda

mark was got by varying wavelength between 500nm to 950nm with respective mean absorbance of filtrate (potassium dihydrogen phosphate).

Before estimating standard phosphate calibration curve, Lambda mark was determined. A stock solution of 0.01mole of potassium dihydrogen phosphate was prepared by dissolved 1.36gram in 500millilitres of distilled water. Three trials of absorbance were measured according Targhat (2015) varying wavelength from 550nm to 950nm every wavelength (**see Table 4.4)**. In the year 2015, Tarighat in his research using the same ratios and materials he found lambda mark as and Kumar,et al. (2007) at which compares well with our results.

Here, the experiments were carried out to determine the lambda mark and standard phosphate calibration curve. In this study, Gaussian model was used to establish the relationship between the wavelength, and Absorbance, as follows.

(3.2)

where is amplitude, is the mean, and is the standard deviation. These parameters were determined by non-linear curve fitting using Matlab software. From Figure 3.7, Lambda mark, corresponds to .

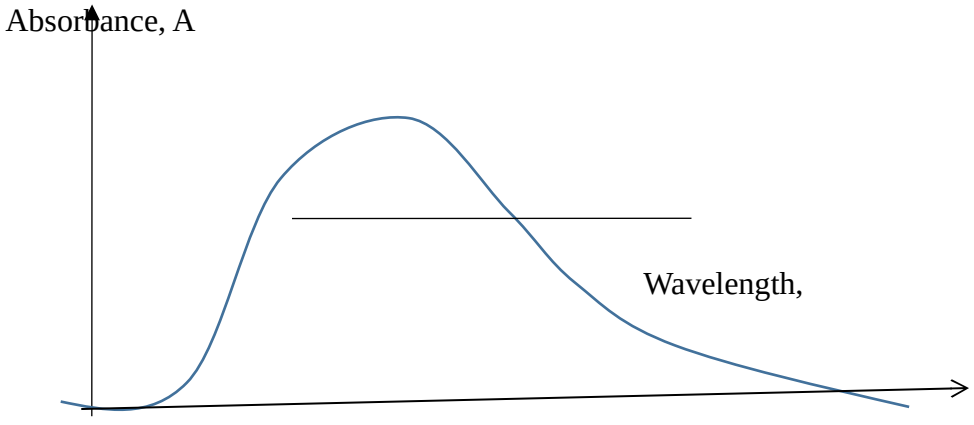


Figure 3.7: *A plot of Wavelength versus Absorbance*

Source; Author, (2021)

Determination of calibration curve requires Lambda mark which was optimized by use of differential calculus. This was calculated by maximizing Eq. (3.2), and solving the resulting equation for to obtain:

(3.3)

Having obtained Lambda mark of , UV-VIS spectrophotometer was fixed at it. The stock solution of 5ppm, 10ppm, 15ppm, 20ppm, 25ppm, and 30ppm were used to read the corresponding absorbance. The measurements were carried in three trails, and the mean absorbance were tabulated. The plot of concentration versus absorbance resulted into a linear relationship. The linear relationship between concentration and absorbance is known as calibration curve. Determination of particle size for the effective filter, and the best pumice stone-sand ratio also used Gaussian model.

Two-term exponential model was used to the determination the relationship between absorbance variance, and time, as follows.

(3.4)

where and are the parameters that were determined using Matlab software.

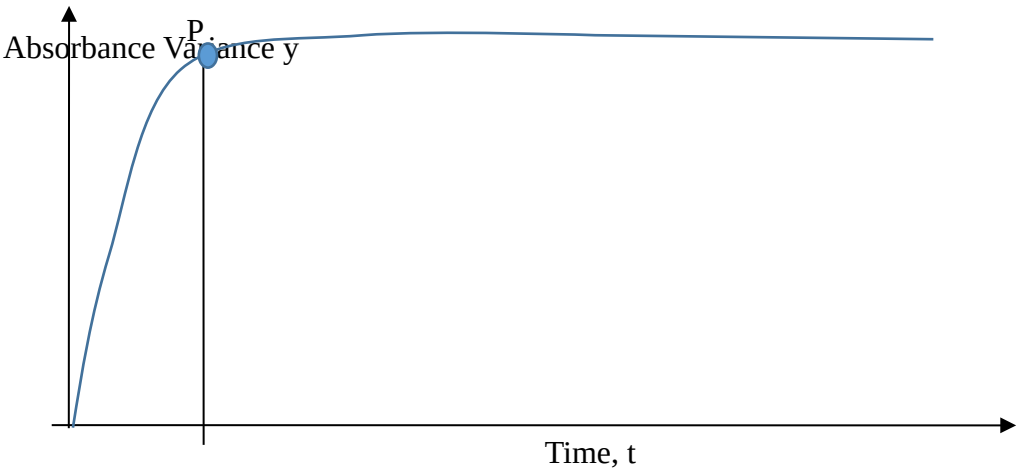


Figure 3.8: Time versus absorbance Variance

Source; Author, (2021)

From Figure 3.8, time, is the adsorption time. Point is the point of inflection. For point of inflection, = 0. Solving for t, we obtain Eq. (3.5).

(3.5)

Model evaluation for Eqs. (3.2) and (3.4) was made using coefficient of determination, .

(3.6)

where: total of observations

independent variable

dependent variable

The most common interpretation of the coefficient of determination is how well the regression model fits the observed data. varies from 0 to 1.

3.8.2 Development of the mathematical model

3.8.2.1 Model Assumptions

The mass-balance analysis is the most basic method for determining the changes that occur when a reaction occurs in a container (reactor) or in a defined area of a body of liquid (Metcalf, L., Eddy, H. P., & Tchobanoglous, G., 1991). Figure 3.9 depicts the mass balance for a single reactor in this research.

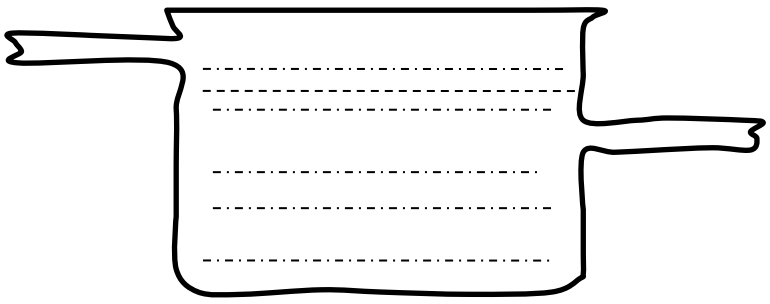


Figure 3.9: The system representation of WWTP using a composite filter

Source; Author, (2021)

The system is displayed in Fig.3.9 where and are the volumetric flow rate into and out of the reactor. = concentration of effluent into the reactor, and = concentration of effluent out of the reactor.

To apply a mass-balance analysis to the liquid contents of the reactor shown in Figure 3.9, the following assumptions were made:

(1) the volumetric flow rate of effluent out of the reactor is equal to the volumetric flow rate of effluent into the reactor, = = ,

(2) the liquid within the reactor is not subject to evaporation (isothermal conditions), and

(3) No reactions in the process of filtration.

3.8.2.2 Model Description

For the stated assumptions, the materials mass balance can be formulated as follows:

(3.6)

Rewriting and simplifying, Eq. (3.1) yields

(3.7)

Eq. (3.7) is a first order ordinary differential equation with variables separable which can be easily integrated as follows. Integrating between the limits of and and and , gives

(3.8)

which, when solved, yields

(3.9)

where is ponding time.

The solution of mass balance equations, such as those given by Eq. (3.7), can be simplified in most applications in the field of wastewater treatment by noting that the

long term (so-called steady-state) is of primary significance. If only the steady-state effluent concentration is sought, Eq. (3.1) can be simplified by noting that the rate accumulation is zero under steady-state conditions (). From Eq. (3.7), steady-state is given as

= (3.10)

Figure 3.3 is the graphical representation of Eq. (3.10).

The graph of Eq. (3.10) is given as shown in Figure 3.10.

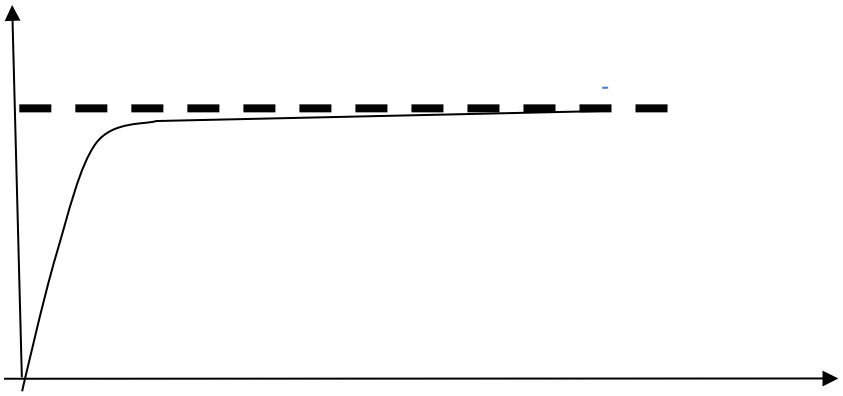


Figure 3.10: Graphical representation of time, t versus concentration, C

Source; Author, (2021)

In this study, the parameters and were replaced with , , , , and , , , , and respectively. Equation (3.7) can be written as

(3.11)

For steady-state, Eq. (3.11) becomes

(3.12)

Applying Eq. (3.9), the concentration of the five parameters at any time are as follows.

(3.13)

In summary, the model involves 3 state variables and 15 parameters. In this study, the model equations given by Eq. (3.13) were calibrated by taking several samples of the concentrations of**,,,,** and at the entrance and the outlet of filter**.** These concentrations values were optimized**.** The application of the model to the WWTP is presented into the Chapter four.

Other models developed were; Kinetic parameters for first-order models and Multiple regression model.

3.8.3 Effect of filter depth variation on the concentration of five parameters

The comparison of plots of depths against the concentrations of , , , , and were carried out for the seasons namely March - May, June – August, and September – November 2021.

3.8.4 Knowledge, Attitude and Perception of Shirere community towards wastewater treatment plant

Analysis of Variance (ANOVA) was used. In this study, hypotheses of ANOVA were

Hypotheses:

Perception and wastewater treatment

Perception of the residents have no influence on wastewater treatment

The ANOVA table can be given as follows

Table 3.7: ANOVA

Source	SS	df	MS	F
Regression	SSR			
Residual	SSE			
Total	SST			

where:

Source; Author, (2021)

The source (of variability) column tells us of Squares (sum of squared deviations):

- SST measures variation of the data around the overall mean
- SSR measures variation of the group means around the overall mean
- SSE measures the variation of each observation around its group mean

Degrees of freedom:

for SSR, since it measures the variation of the k group means about the overall mean.

for SSE, since it measures the variation of the n observations about k group means

for SST, since it measures the variation of all n observations about the overall mean

= Mean Square = / :

The statistic = : If the null hypothesis is true, the F statistic has an F distribution with and degrees of freedom in the numerator/denominator respectively. If the alternate hypothesis is true, then tends to be large. We reject in favor of if the statistic is sufficiently large. Statistical Package for Social Sciences (SPSS) software version 17 was used to calculate statistic.

3.9 Ethical Considerations

All elements of academic writing necessitate adherence to proper researcher behaviour during the conduct and presentation of research findings, necessitating the use of ethically sound research methods (Akaranga, S. I., & Makau, B. K., 2016).

Before beginning the data collection operations, permission was requested from MMUST. After obtaining the necessary approvals, a research permit from the National Commission for Science, Technology, and Innovation (NACOSTI) was requested. Three research assistants were trained in research ethics during the investigation. The investigation includes collecting procedural data from ten sites ranging from S1 to S7.

3.10 Limitation of the study

The limitations in the field while collecting data included;

- The effluent was not wholly filtered through the equipment due inadequate sealing into the channel.
- The information collected on matters on pollution from the interviews were not exact because the respondents did not have sufficient data on the effects of the sewerage plant on the community.

3.11 Delimitations of the study

The limitations of the study were solved by;

- Incorporating more silica pumice material on its external sides.
- Triangulation method was applied to achieve the reliable and accurate information on pollution matters and sewerage effect on treatment plant.

3.12 Assumption of the study

The following assumptions were made regarding the study;

1. Assumed that there was already a sand filter at Shirere Waste Water Treatment Plant.
2. Assumed that Shirere Wastewater Treatment Plant had acceptable detention period

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Introduction

The chapter presented the findings of the study and their discussions in subsections. It also included the analyses of factors affecting the performance of the composite filter in laboratory and field tests; real life application of composite filter in removal of pollutants from effluents; and seasonal variability of pollutant removal from effluents. Similarly, presented were regression and correlation analyses, hypothesis testing models and inferences drawn from the analyses.

4.2 Factors affecting Performance of the composite filter

In order to determine the effective silica-pumice composite filter performance, various parameters were investigated under both laboratory and field filtration experiments. The findings are enumerated under subsections below.

4.2.1 Laboratory filtration experiments

Laboratory experiment filtrations involved particle size determination, composite filter composition and adsorption time determinations.

4.2.1.1 Particle size determination

The particle sizes were obtained after passing ground pumice stone and sand through various molecular sieves as shown in table 4.1 below. Briefly, the 0.60 mm sieve retained all particles sizes that were ≥ 0.60 mm while allowing particles that were <

0.60 mm sizes to pass. Similarly, particles of sizes < 0.9 mm, < 1.18 mm, < 2.75 mm and < 3.25 mm were obtained and used in preparation of the composite filter.

Table 4.1: Particle Size Sieving Order.

No.	Granular Sieve Size (mm)	Retained sizes (mm)	Size obtained (mm)
1		≥0.60	< 0.60
2	0.60	≥0.90	<0.90
3	0.90	≥1.18	<1.18
4	1.18		
5	2.75	≥2.75	<2.75
	3.25	≥3.25	<3.25

Source; Author, (2021)

By use of UV-VIS spectrophotometer, determination of Lambda mark was used for calibration curve development. The results of maximum wavelength determination by measuring mean absorbance against several wavelength as shown in table 4.2 below.

Table 4.2: maximum wavelength determination

No	Wave Length (nm)	Mean Absorbance
1	500	0.198
2	550	0.275
3	600	0.354
4	650	0.499
5	700	0.587
6	750	0.625
7	800	0.665
8	850	0.586
9	900	0345
10	950	0.223

Source; Author, (2021)

The parameters of Gaussian function, were determined by non-linear curve fitting in R-programming and their optimal values were found as follows:,, and . Therefore, the model for this study was found to be and with coefficient of determination, of

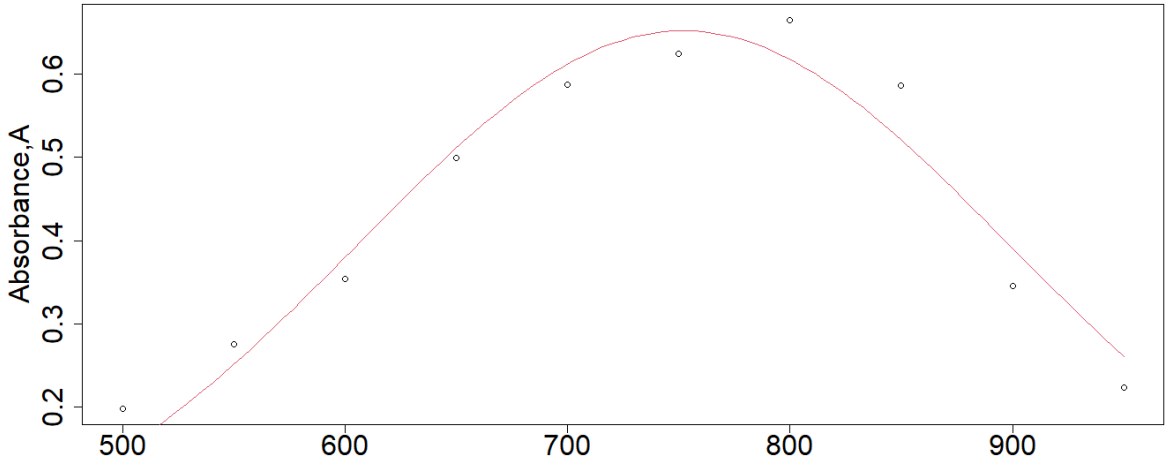


Figure 4. 1: Plot of wavelength versus absorbance for the determination of optimum wavelength, (lambda () mark)

Source; Author, (2021)

From this graph, at maximum absorbance, using differential calculus, the lambda mark was found to be . At fixed lambda mark the filtrate was concentrated at 5,10,15,20, and 25 ppm and absorbance used for development of standard calibration curve. Amount of phosphate removed was obtained using the calibration curve in figure 4.2 below.

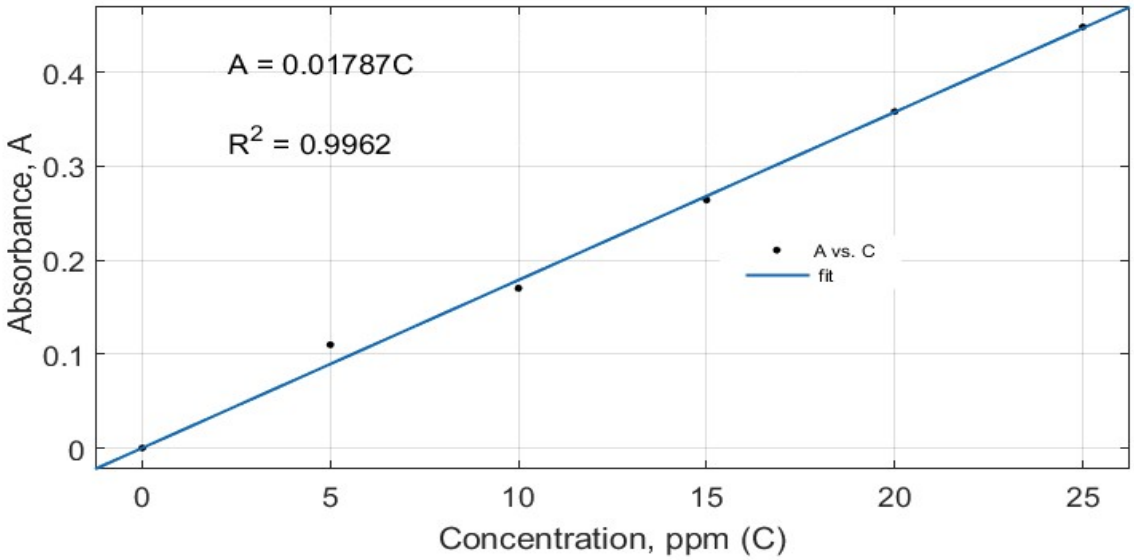


Figure 4. 2: Calibration curve showing a plot of concentration in ppm against absorbance of 0.01M potassium dihydrogen phosphate in distilled water.

Source; Author, (2021)

Once the calibration curve was developed, filtrate concentrates of 5,10,15,20 and 25 absorbance were measured before and after filtering several mixes of granular composites filter for optimal particle size determination.In this case, the residual amount of phosphorus determined by measuring absorbance at lambda mark, and the exact concentration obtained from the calibration curve shown in Figure 4.2.

More phosphates were adsorbed in the order; 0.6mm > 0.9mm > 1.18mm > 2.75mm and > 3.25mm as illustrated in figure 4.3. This finding was consistent with earlier works of (Xie etal.,2013); Farizoglu et al, (2013) showing that filtration efficiency often increased as the particle size decreased. Similarly, French, (2012) revealed a range of 0.5mm of sand to 0.9mm which is within the range of this study.

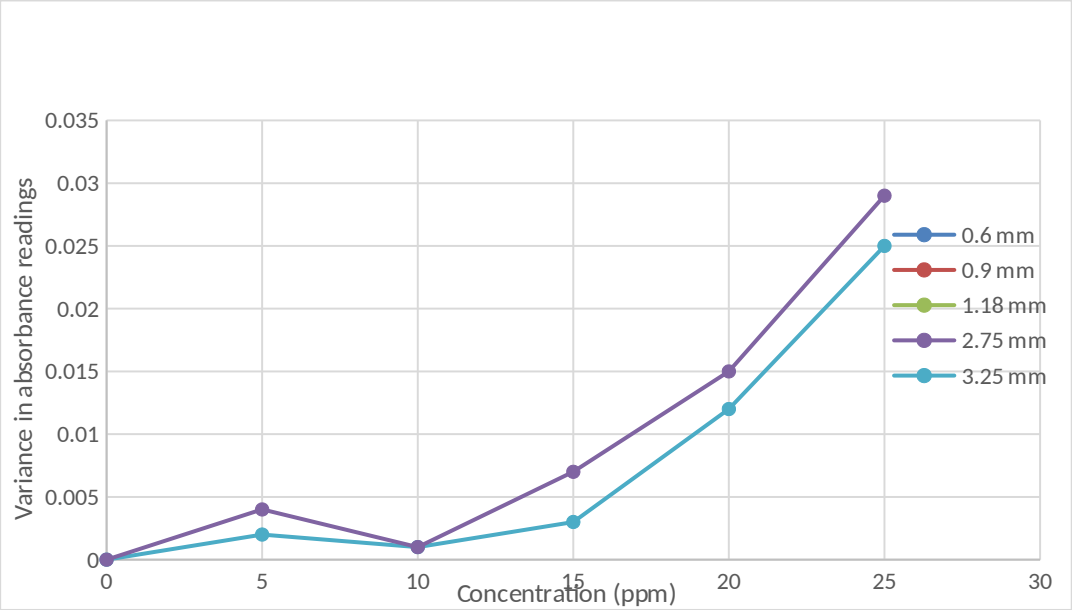


Figure 4. 3: Variation of absorbance with particle sizes (Composite ratios used was 50% 1.18

mm sand and 50% pumice granular sizes).

Source; Author, (2021)

As depicted in the graph, the maximum retention capacity of the pumice sand mixture was obtained at granular particle size of 0.60mm pumice and 1.18 mm sand.

Similar results were obtained using the Gaussian and R- programming function. In this case the granular sizes were varied against residual absorbance using phosphate concentration set at 25 ppm. The results were as shown in figure 4.4 below.

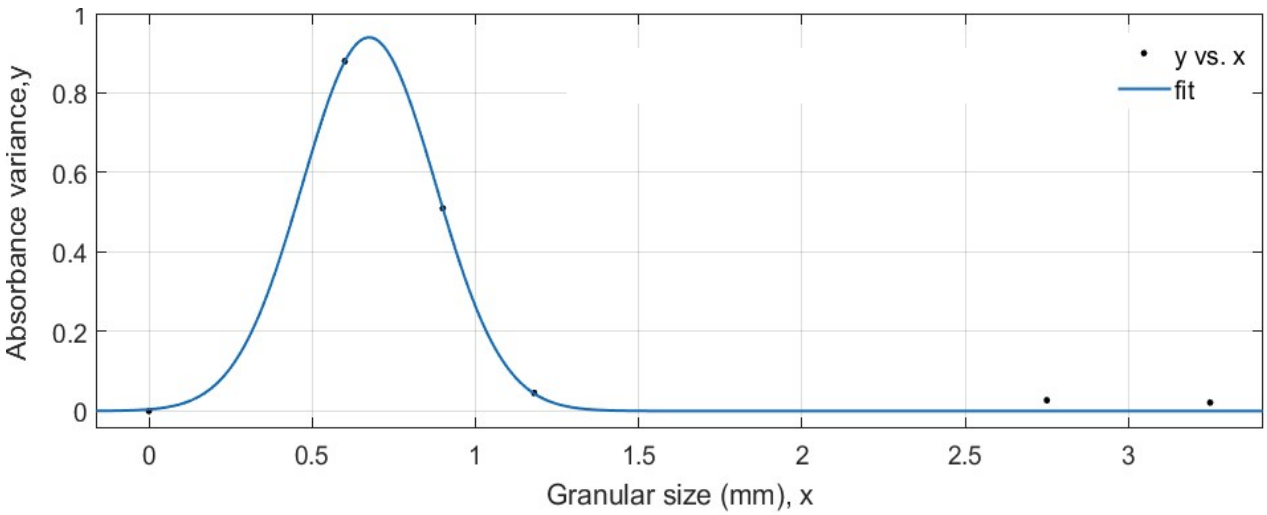


Figure 4. 4: Granular Size versus absorbance obtained from Gaussian and r-programming function with best fit.

Source; Author, (2021)

4.2.1.2 Pumice stone and sand ratio

The optimal composite ratio was established at 50% of 1.18mm sand and 50% 0.6mm pumice granules. These details are shown in figure 4.5. Data on ratios of 100% sand, 75% sand, 25% sand and 0% sand with respective complementary ratio of 0.6 mm pumice stone ratio were lower than the 50% composite ratio (Figure 4.4A and Figure 4.4 B). This is consistent with earlier study in by Farizoglu *et al*., (2013) which 0.2 mm -1 mm were established as effective sludge particle sizes for removal of nutrients in waste effluents. Arguably, pumice particles < 0.6 mm may have formed pores of sizes less < 0.45 um thus promoting clogging of the composite filter (Shulkin .et al, *2022).* Similarly, particles > 0.6 may have formed pore sizes > 45 um thereby allowing more of the effluents to pass through.

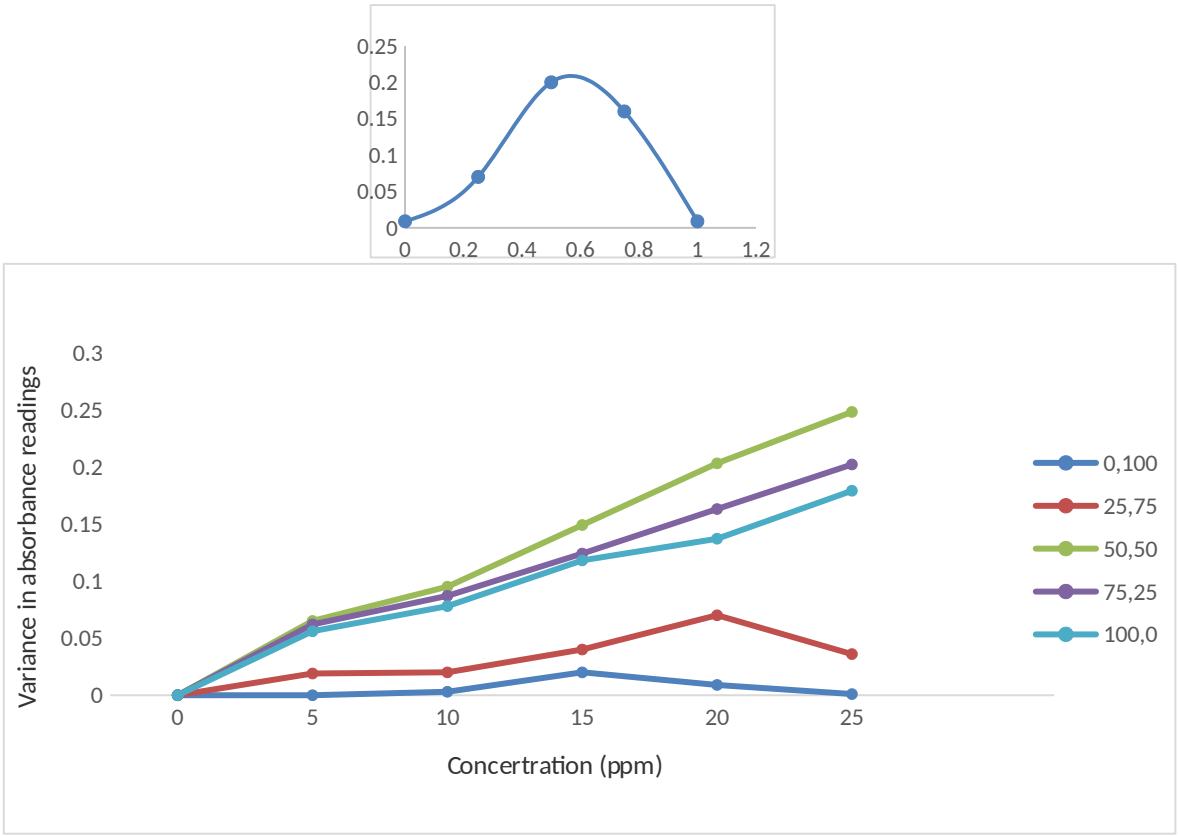


Figure 4. 5: Variance in absorbance readings against concentration

Source; Author, (2021)

Figure 4.5 shows the variance in absorbance with concentration of the composite filter. The ratio of pumice 100% and sand 0% gave a variance of 0.02 while that of 75%pumice and sand 25% gave 0.20 for the same phosphorous concentration. Further, as shown in the inset of Figure 4.5, the maximum variation in absorbance of 0.202 was obtained at 50% sand composition. These findings are in agreement with the works of (French ,(2012); Burhanettin *et al*., (2019); Bulentr *et al*.,(2019). Therefore, optimum composite filter performance was selected at the ratio of 50% both sand 1.18mm and pumice 0.6mm composite filter and used in field reactor experiments. Hence the researcher rejected the null hypothesis which stated that varying conditions of the composite filter does not significantly affect its performance on waste removal from effluent, in favor of alternative hypothesis.

4.2.1.3 Adsorption time

The optimum composite filter was used in adsorption time experiment where, wastewater collected from Site 1, was used in batch experiment at MMUST chemistry laboratories. Figure 4.6 shows the variation in phosphorous absorbance against incubation time in batch experimental conditions.

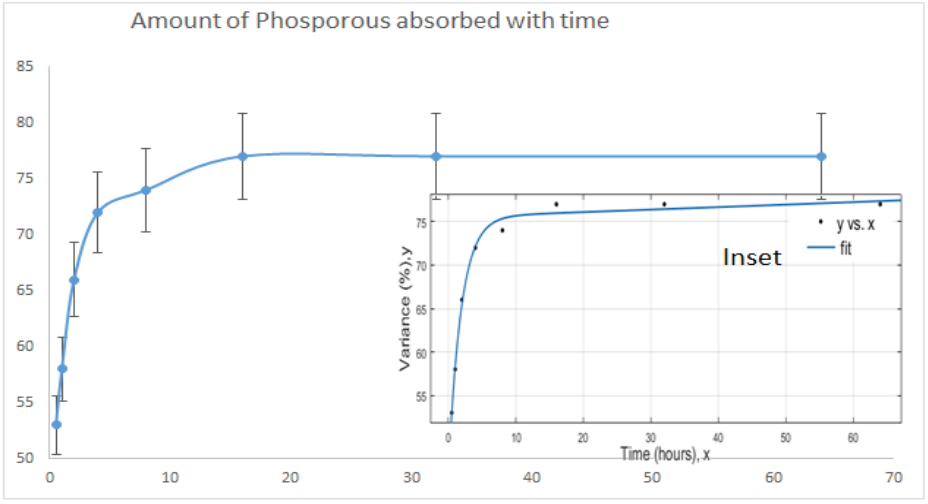


Figure 4. 6: Plot of time versus absorbance variance (%)

Source; Author, (2021)

From figure 4.6 above, it is shown that, the phosphate removal efficiencies were 53%, 58%, 66%, 72%, 74% and 77% for contact time of a half an hour, 1, 2, 4, 8, 16, 32 and 64 hours respectively. The rate of phosphates removed under these conditions increased sharply up to 8 hours and gradually reached equilibrium after 16 hours reaction time. Thus, the equilibrium 77% adsorption of phosphates by the composite filter reached was attained after 16 hours beyond which minimum was observed. Inset is an adsorption model for the same composite filter developed for the same experimental conditions. This still showed 77% asymptotically success for phosphate removal.

This becomes an ideal highest efficiency in terms of performance when it will be installed at the exit manhole of maturation pond of Shirere Wastewater treatment plant (WWTP).

The chemical composition of the pumice is shown in Table 4.2 as reckoned by, (Feryal ,2005).

Table 4.3: Chemical composition of pumice stone

Chemical	Composition (%):
SiO_2	70.35
Al_2O_3	14.60
Fe_20_3	1.05
Na_20	3.60
K_20	4.40
MgO	0.10
CaO	0.80
TiO_2	0.15
Uniformity coefficient [D_{60}/D_{10})	1.35
Effective grain size D_{10} [mm)	0.59
Porosity (%)	69.24
Density (0.5-1.0 mm grain size) [g/cm^3)	0.69

Source; Adopted (Feryal ,2005)

Studies have shown that sorption kinetics by pumice are largely dependent on the physical and/or chemical characteristics of the sorbent materials (Kamal *et al*., 2013).

As shown in table 4.3, pumice contains Al^{3+}, Na^{+}, Ca^{2+} and Mg^{2+} cations and the O^{2-} anion that played a key role in controlling the rate of removal of pollutants. The removal of waste by adsorption on the composite was found to be rapid at the initial period of contact time. This was caused by strong attractive forces between the chemical waste molecules and the cations/anions on the sorbent surface that caused fast diffusion onto the porous surface of the filter. However, it was followed by fast saturation of the pores by solutes in the wastewater matrix to attain rapid equilibrium thereby causing the leveling of the graph (Figure 4.6). Thus, it yielded an exponential model in which there was linearity at small distances near the origin. It then rose more steeply and flattened out gradually after 10 hours**.** The obtained results showed that the adsorption forces followed a decaying experimental equation of with a correlation coefficient of 0.994.

4.2.2 Field Experimental Investigations

Field measurements were carried out before and after filtration on samples from S1 and S2 sampling points to establish the efficiency of the filter. The findings included seasonal variability of COD, BOD, TSS, Nitrates and Phosphates and variation of composite filter depth as discussed in the sub-sections below.

4.2.2.1 Seasonal Variability of COD and BOD

It is common knowledge that COD is higher during the rainy seasons and BOD in dry seasons, (Iheukwumere et al.,2021). However, the findings of this study show that the performance of the composite filter was affected by the hydraulic transient conditions in each season.

Table 4.4a shows the average reduction of COD was high in mid-season of June to August with a record of 42.2 ±4.66%. This was followed by September to November season at 39±15% which showed similar reduction rate to the period March to May at 37 ±11%. It was envisaged that these seasonal variations in rate of reduction of COD were correlated to variations in rainfall patterns as depicted in data obtained from Kakamega metrological station (**Appendix I**). In this case lower rainfall volumes of 188.33 ± 34.43 mm were recorded in the period between June-August. On the other hand, an average rain volume of 217.9 ± 109.82 mm recorded in September to November was similar to that of 216.33 ± 93.11 mm recorded in March to May respectively. Thus, the season of June to August was a period of low rainfall, a factor that contributed to reduced effluent inflow rates (Iheukwumere et al.,2021). The reduced inflow rates were caused by increased retention time for wastes because of low volumes of water in the treatment ponds. The net result reduced hydraulic transient conditions that favored increased adsorption (Farizoglu et al, 2013)

Comparatively, the months of March to May and September to November had high rainfall. This resulted in increased effluent inflow rates thereby causing high hydraulic transient and reduced retention time. As a consequence, there was less resident time in the filter and therefore low efficiency.

As shown in table 4.4a, as depth was increased from 200mm, 400mm and 600mm, COD reduction improved from 40.7% to 41.0% to 45.34%, respectively for the June to August season. The same trend was evident in the other two seasons due to increased retention period and reduced hydraulic transient. In retrospect, the performance of the filter in the month of September to November was in between the long rain season and relatively dry season. In a similar experiment (Markonen *et al*. 2018) using only pumice filter media, it was observed that reduced COD efficiency was at 27%. relative

to over 40% achievement in this study. Thus, the composite filter used in research performed better than the pumice media filter by Markonen *et al*. 2018.

Concomitantly the BOD followed the same trend as the COD (Table 4.4b). This was depicted by filter performance of June to August, 19.6±7% followed by 15.6 ±9.5% for September to November and 19±2.5% for March to May of BOD that was nearly the same to that of September to November period. The reduced rainfall in the June to August season was responsible for low effluent flow rates as already explained under discussions on COD. From the foregoing, the levels of BOD and COD reflected reduced pollution This was a major achievement in terms of pollution control in our rivers. The performance of the filter for the month of September to November was between the other two seasons. Tables showing Effect of Seasonal Variability of pollutants removal on varying depths of the composite filter in the year 2021.

Table 4.4a: COD (mg O_2/l) in percentages

Depth	**200**	**400**	**600**	**Trend**	**Explanations**
March – May	14.0	5.8	11.4	Negative	Negative reduction of 8.2% between 200mm and 400mm and further
June – August	10.2	10.16	13.57	Negative	Reduced pollutant removal by 0.04% between 200mm and 400mm and reduced by 3.41% between 400mm to 600mm. Reduced removal of pollutants due to reduced affinity between BOD and filter materials.
September – November	12.3	15.46	17.4	Positive	Pollutants removal increased by 3.16 % from 200mm to 400mm and 1.9% from 400mm to 600mm.

Table 4.4b: BOD (mg O_2/l) in percentages

Depth	200	400	600	Trend	Explanation
March – May	36.4	35.15	42.0	Positive	Pollutants removal increased by 4% from 200 mm to 400mm and 7% from 400mm to 600 mm
June – August	40.7	41.0	45.34	Positive	Pollutants removal increased by 0.3% from 200mm to 400mm and 4% from 400mm to 600mm.
September – November	31.6	37.5	41.6	Positive	Pollutants removal increased by 5.9 % from 200mm to 400mm and 4.1% from 400mm to 600mm.

4.2.2.2 Seasonal variability of TSS

As shown in table 4.4c, the average rate of TSS removal in June to August was 19.3±4.5% followed by 16.6±3.8% of September to November and 11.6±7% of March to May. This is in agreement with study by (Markonen *et a*l.,2018) in which 68% removal of TSS was achieved using pumice single filter. Comparatively, the composite filter used in this work had maximum a removal rate of 19.3% TSS in the field under real life situation. The low rate of removal in the field was due to continued inflow of raw effluent at different concentrations into the samples being collected. This emanated from seepage of the effluent on the sides of the filter into the effluent discharged thus increasing levels of suspended solids. Thus, under the prevailing circumstances the 19.3% is a fair indicator the composite filter would have performed better in the absence of the leakages.

Table 4.4c TSS (Mg/l) in percentages

Depth	200	400	600	Trend	Explanation
March – May	10.04	9.55	11.76	Positive	Pollutants removal reduced by 0.85% from 200mm to 400mm and increased by 2.21% from 400mm to 600mm.
June – August	19.3	10.4	11.1	Positive	Pollutants removal decreased by 9.32% from 200mm to 400mm and increased by 0.7% from 400mm to 600mm.
September – November	13.16	15.6	16.6	Positive	Pollutants removal increased by 2.44% from 200mm to 400mm and 1% from 400mm to 600mm.

4.2.2.3 Seasonal variability of Nitrates and Phosphates

The average rate of Nitrate removal in June to August was 41.8±7.6% followed by 30.0±2.8% for March to May and 25.0±8.6% for September to November. Briefly, the season of June to August was a period of low rainfall. The reduced rainfall led to reduced effluent inflow rates into the filter as earlier discussed. This resulted in reduced hydraulic pore pressure and consequently increased adsorption on to composite filter particles. Therefore, more of nitrates were retained by the filter during this season, a factor that increased efficiency of filter as indicated by 41.8±7.6%. In the same vein. the season of March to May followed by 30.0±2.8% and was trailed by the season of September to November of 25.0±8.6%. This low removal rates are attributed to lower adsorptions of nitrates on to particles of composite filter as a result of increased effluent inflow rates during higher precipitation at these times.

Comparatively more Nitrates were removed than the phosphates in all the three seasons. Notable is the fact that waste removal percentage often increase with

increasing of the mass of adsorbent, the contact time and the initial solute concentration (Kamal *et al*. 2013).

Table 4.4d: NO_3 (Mg_2/l) in percentage

Depth	200	400	600	Trend	Explanation
March – May	16	17	26	Positive	Pollutants removal increased by 1% from 200mm to 400mm and 5% from 400mm to 600mm.
June – August	20.6	36.7	38.5	Positive	Pollutants removal increased by 16.1% from 200mm to 400mm and 2.1% from 400mm to 600mm.
September – November	16.6	20.6	24.5	Positive	Pollutants removal increased by 4% from 200mm to 400mm and 4.4% from 400mm to 600mm.

In retrospect, phosphate adsorption trends process was similar to those of nitrates. Phosphates had an average rate of removal in September to November as 23.8±4.8% followed by17.67±6.7% for June to August and 8.2 ±10% for March to May.

Table 4.4e: PO_3 (Mg_2/l) in percentage

Depth(mm)	200	400	600	Trend	Explanation
March – May	4.0	9.0	13.0	Positive	Pollutants removal increased by 4% from 200mm to 400mm and 4% from 400mm to 600mm.
June – August	14.0	18.0	21.0	Positive	Pollutants removal increased by 4.0% from 200mm to 400mm and 3% from 400mm to 600mm.
September – November	17.0	25.6	28.8	Positive	Pollutants removal increased by 8.6% from 200mm to 400mm and 3.2% from 400mm to 600mm.

This explains the increase in amount of COD, TSS, nitrates and phosphorus removed by the filter as the depth increased. Arguably, increase in depth amounted to increased initial concentration of the wastes. As shown in Table 4.3 physical characteristics, the cationic and anionic nature arising from the presence of cations such as Ca^{2+}, Al^{3+}, Na^{+}, K^{+} and the O^{2-} anion within the composite contributed immensely the removal of these chemicals through adhesion and ionic interactions (Kamal *et al*.,2013).

4.2.2.4 Comparative analysis of percentage removal of pollutants in current research with other documented studies

Table 4.4f. Season 1 March – May 2021 Rainy

Parameter	**Current Research composite filter of pumice and sand**			**Markonen et al (2018) Ethopia**		**Philipi et al (2019) Fundongen**	**Ali et al. (2019) Jordan**
Sample	200mm Filter depth	400mm Filter depth	600mm Filter depth	Pumice 150mm depth	Sand 150 mm depth	Pumice Augmented Sand	Sand + Biochar
TSS (mg/l)	15	17	22	65	75	93	-
COD (mgo2/l)	32	36	43	27	48	60	-
BOD (mgo2/l)	35	10	12	56	52	65	-
NO3 (mg/l)	20	28	42	40	40	73	-
PO4 (mg/l)	16	17	26	41	57	85	75

Table 4.4.g. Season 2 June – August 2021 dry season

Parameter	Current Research			Markonen et al (2018) Ethopia		Philipi et al (2019) Indonesia	Ali et al. (2019) Jordan
Sample	20mm Filter depth	40mm Filter depth	600mm Filter depth	Pumice 150 mm depth	Sand 150 mm depth	Pumice Augmented Sand	Sand + Biochar
TSS (mg/l)	19.7	17.6	21.2	68	75	93	-
COD (mgo2/l)	40.7	34.6	38.24	27	48	60	-
BOD (mgo2/l)	20.6	21.7	13.66	56	52	65	-
NO_3 (mg/l)	29.4	50.4	43.7	40	40	73	-
PO_4 (mg/l)	20.6	36.7	38.5	41	57	85	75

Table 4.4h. Season 3 September – November 2021 Short Rain

Parameter	Current Research			Markonen et al (2018) Ethopia		Philipi et al (2019) Fundongen	Ali et al. (2019) Jordan
Sample	20mm Filter depth	40mm Filter depth	600mm Filter depth	Pumice 150 mm depth	Sand 150 mm depth	Pumice Augmented Sand	Sand + Biochar
TSS (mg/l)	15.1	15.9	18.9	68	75	93	-
COD (mgO_2/l)	31.6	45.3	36.0	27	48	60	-
BOD (mgO_2/l)	10.6	16.7	20.1	56	52	65	-
NO_3 (mg/l)	20.6	25.6	28.8	40	40	73	-
PO4 (mg/l)	16.6	20.6	20.0	41	57	85	75

From Table 4.4f-h, TSS removal levels in the first season is indicated by percentage removal of 15% at 200 mm depth, 17% at 400 mm and 22% at 600 mm 65% for pumice and 75% for sand conducted by Markonnen et al (2018) at 150 mm. Assuming that environmental conditions affecting the flow rate, namely wind speed, rainfall amount and temperature are nearly the same 150 mm and 200 mm, the filter adopted by Markonnen et al (2018) performed better. Same trend in filter performance is noted in seasons 2 and 3. However, it is worth noting that works by Markonnen et al (2018) and Philipi et al (2019) were not field. This implies that these laboratory studies had minimal disruptions from environmental conditions compared to this field study.

The removal levels of nitrates in the first season is indicated by percentage removal of 20% at 200 mm depth, 28 at 400 mm and 42% at 600 mmcompared to 40% reduction rate obtained by Markonnen et al (2018) at 150 mm using sand and pumice separately. It changed to 29.4%, 50.5% and 43.7% in season 2 and 20.6%, 25.6% and 28.8% in season 3 while the work by Markonnen et al (2018) maintained 40% in the two seasons. This implies that composite filter performed better than the work by

Markonnen et al (2018) in season 2 in removing NO_3 than season 1 and 3. The best rate of removal of phosphates was recorded in season 2 as 20.6% at 200 mm, 36.7% at 400 mm and 38.5% at 600 mm rates of removal of phosphates was below 30% at all depths in all the other seasons. The study by Markonnen et al (2018) recorded 41% for pumice and 57% for sand. Either way, the filters adopted by Markonnen et al (2018) were more efficient in removing phosphates.

COD removal levels in the first season is indicated by percentage removal of 32% at 200mm depth, 36% at 400mm and 43% at 600mm. In comparison work by Markonen et al (2018) recorded 27% for pumice and 48% for sand. Work by Philipi et al (2019) recorded 60% removal efficiency of COD. As such, the pumice-sand composite filteris more efficient in COD removal than those adopted in works of Markonen et al (2018) but less efficient than that adopted by Philipi et al (2019) under laboratory conditions. The trend in season 1 was nearly replicated in seasons 2 and 3. Since COD and BOD followed the same trend (Table 4.4f-h), it is believed that BOD performance tallied with that COD even in comparative performance with the works of Markonen et al (2018).

4.3 Development of Mathematical Model

4.3.1 The mass balance model

The mass balance model was given as

(4.1)

These equations were integrated using the fourth-order Runga Kutta (RK) method. The initial values of , (), and for the method are given in Tables 4.5 – 4.13. The analytical solution for the same system of equations is given by Eq. 4.2 as shown below.

Which translates to specific model as shown below:

(4.2)

The parameter (flow rate) was determined using Arcostic Doppler Velocimeter (ADV), while volume (V), was obtained by multiplying the depth of the filter and the reactor area. Using the values obtained by RK, non-linear least square method was applied to estimate the parameters of the above system of equations.

The mass balance equations for each season, flow rate, and depth were integrated via the use of the fourth-order Runga Kutta (RK) method for systems of equations given by Eq. (4.2). The results and discussions are given in the subsections 4.3.1 – 4.3.9.

4.3.1. 1 March – May 2021 at 200mm filter depth

March – May 2021 at 200mm filtration depth were carried out at effluent flow rate of 0.0032 and volume, 0.234 Tables 4.31 provided and as starting values for numerical integration of Eq. (4.1)

Table 4.5 Concentrations of and filtration for March – May season at 200mm and 0.0032

Filtration	Concentration ()		COD	BOD	TSS
Before	0.0241	0.0199	0.3002	0.2813	0.3252
After	0.0220	0.0161	0.1909	0.2726	0.2913

Source; Author, (2021)

The results of the integrations are shown in Figure 4.7. The corresponding equations of the graphs of Figure 4.6 are given by table 4.6

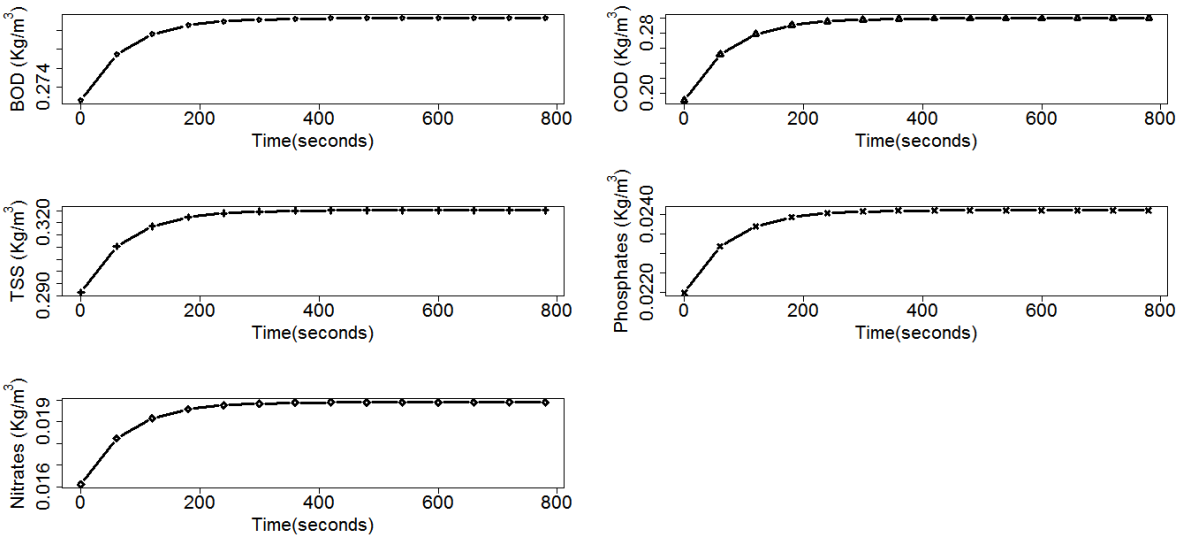


Figure 4. 7: Concentrations of,, , and versus time with filter at depth of , of volume, and input discharge of for March-May season

Source; Author, (2021)

Table 4.6: Result Summary, season 1, at 200mm

Seasons	Depth (mm)	Parameters	C_{in}	Q ()	V (	V/Q= (Detention time, sec)	Q/V(t_0)	Concentration (C) at t_0)
March-may	200	COD	0.3002	0.0032	0.234		0.0137	0.1891
		BOD	0.2813	0.0032	0.234		0.0137	0.1772
		TSS	0.3252	0.0032	0.234		0.0137	0.2049
		NO_3	0.0199	0.0032	0.234		0.0137	0.0125
		PO_3	0.0241	0.0032	0.234		0.0137	0.01518

Source; Author, (2021)

From eq. 4.2, the concentration of each of the parameters increased until it reached steady-state. The steady-states of the graphs of Figure 4.7 given by Eqs. 4.2 were obtained by differentiating these equations, equating to zero, and the resulting concentrations were determined as shown in table 4.6. From the table, the model is predicting well the COD concentration at S2 sampling point which has very minimal variance. Measured COD was 0.1909 and the model predicted COD was 0.1891**.** The Measured Phosphates was, 0.0220 kg/m^3 while the model predicted phosphates was 0.0152 kg/m^3 this indicates a minimal variance of 0.0078 kg/m^3 implying that the model is accurate. This implies that the model could perfectly predict the parameters displaying a minimal variance. Therefore, the null hypothesis was rejected since it stated that development of the mathematical model for the composite filter does not significantly depict its efficiency while the alternative hypothesis was accepted.

4.3.1.2March – May 2021 at 400mm filtration depth

March – May 2021 400mm filtration depth were determined at effluent flow rate of 0.0036 and 0.468 of volume. The concentrations, before and after for ,, , and represented in Table 4.6.

Table 4.7: Concentrations of and filtration for Season March – May at 400mm depth.

Filtration	Concentration ()		COD	BOD	TSS
Before	0.0291	0.0328	0.3559	0.3002	0.3654
After	0.0255	0.0272	0.2311	0.2827	0.3305

Source; Author, (2021)

These provided the initial values for the Runga Kutta (RK) method. The integration of the system of Eq. (4.1) using fourth-order Runga Kutta (RK) method for systems of equations gave the graphs shown Figure 4.18. Eqs. 4.6 – 4.10.

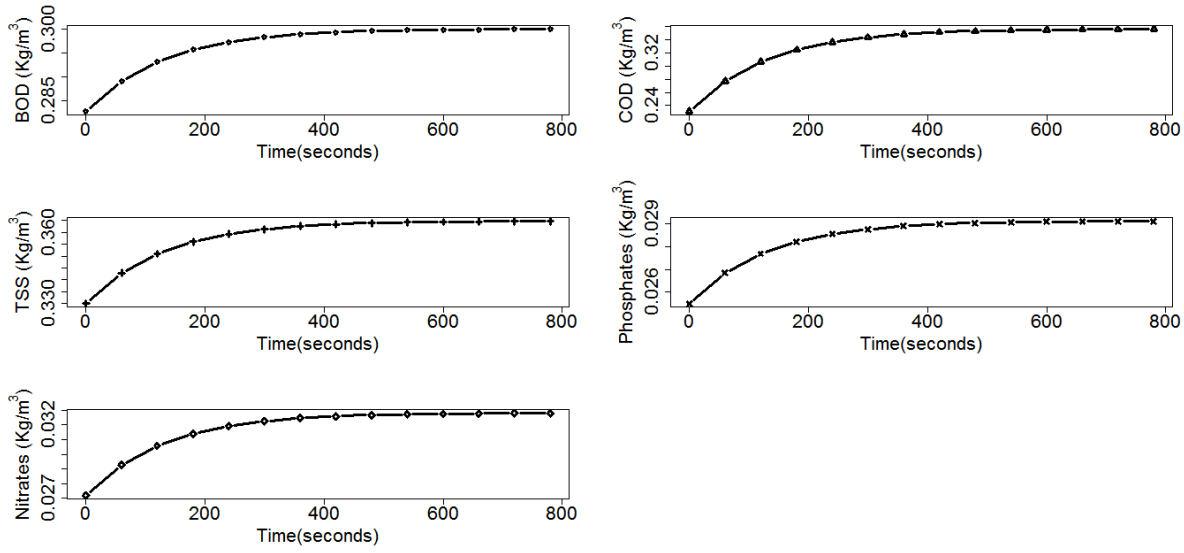


Figure 4. 8: Concentrations of,, , and versus time with filter at depth of , of volume, and input discharge of for March-May season.

Source; Author, (2021)

Table 4.8: Result Summary for season 1, at 400mm

Seasons	**Depth**	**Paramete**	**C_{in})**	**Q=(**	**V(**	**V/**	**Q/V(t_0)**	**Concent**

	(mm)	rs				Q=(Detention time, sec)		ration (C) at t_0)
March-may	400	COD	0.3559	0.0036	0.468	130	0.00769	0.2242
		BOD	0.3002	0.0036	0.468	130	0.00769	0.1891
		TSS	0.3654	0.0036	0.468	130	0.00769	0.2302
		NO_3	0.3278	0.0036	0.468	130	0.00769	0.2065
		PO_3	0.0291	0.0036	0.468	130	0.00769	0.0183

Source; Author, (2021)

From Eqs. 4.2, the concentration of each of ,, , and increased until it reached steady-state. For steady-state, concentrations were as follows: ,, , and detention time, seconds. From table 4.8 the model was predicting well the COD concentration at S2 which had very minimal variance. Measured COD was 0.2311 and the model COD was 0.2242**.** In addition, the measured PO^3 was 0.0255 kg/m^3, and the model predicted PO^3 0.0183 kg/m^3. This also displays a minimum variance of 0.0072 kg/m^3, which implies that the model is accurate in predicting the parameters. In this case, null hypothesis was also rejected while alternative hypothesis was accepted

4.3.1.3 March – May 2021 at 600 mm filter depth

March – May 2021 at 600mm filter depth corresponded to 0.702 of the filter and effluent flow rate of 0.0045 **.** The values of the concentration of and before, and after, are given Table 4.9.

Table 4.9: Concentrations of and filtration for March – May season at 600mm

Filtration	Concentration ()			COD	BOD	TSS
Before		0.0278	0.0319	0.2967	0.3220	0.3416
After		0.0221	26.783	0.1694	0.2853	0.3010

Source; Author, (2021)

The , and were the starting initial values of the system of differential equations given by Eq. (4.1). The integration of the system of Eq. (4.1) using fourth-order Runga Kutta (RK) method for systems of equations and the results are depicted in Figures 4.9.

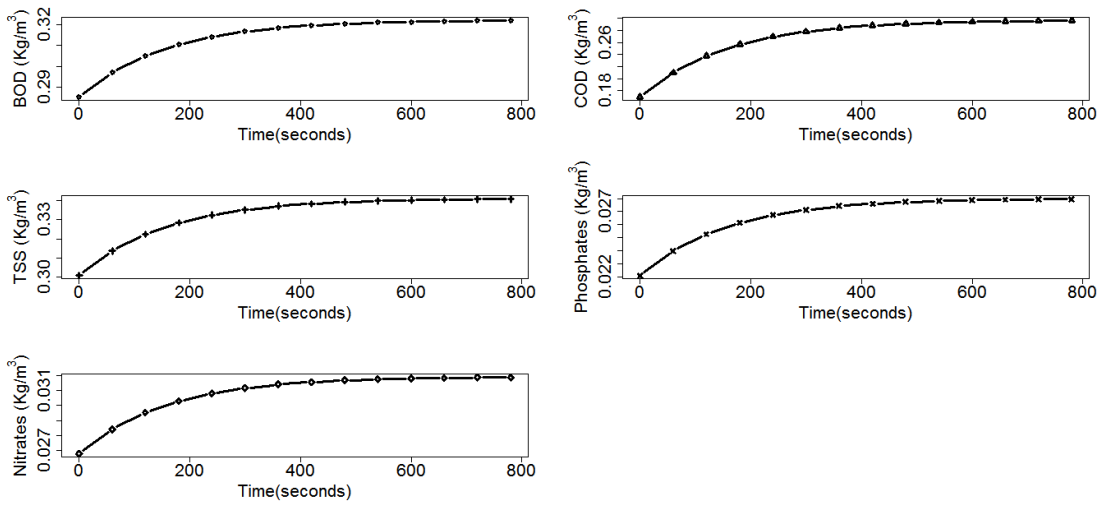


Figure 4. 9: Concentrations of, , , and versus time with filter at depth of, of volume, and input discharge of for March-May season.

Source; Author, (2021)

Table 4.10: Result Summary, season 1, at 600mm

Seasons	Depth (mm)	Parameters	C_{in})	Q=(	V(	V/ Q=(Detention time, sec)	$Q/V(t_0)$	Concentration (C) at t_0)
March-may	600	COD	0.2967	0.0045	0.7020	156	0.0064	0.1869
		BOD	0.3220	0.0045	0.7020	156	0.0064	0.2029
		TSS	0.3416	0.0045	0.7020	156	0.0064	0.2152
		NO_3	0.0319	0.0045	0.7020	156	0.0064	0.0201
		PO_3	0.0278	0.0045	0.7020	156	0.0064	0.0175

Source; Author, (2021)

From Eqs. 4.2, the concentration of each of the and increases until it reaches maximum. For steady-state, concentrations are as follows: ,,, and detention time, seconds. The model in table 4.10 was predicting accurately the COD concentration at S2 which had very minimal variance. Measured COD was 0.1694 and the model COD was 0.1869**.** The measured PO^3 was 0.0221 kg/m^3 while the model predicted 0.0175 kg/m^3, which has a negligible variance.

The for three different depths, 200mm, 400mm, 600mm corresponding to volume: , ,, gave the following detention times; seconds, seconds and seconds. This is an indication that the detention time increases with the increase in volume of the filter. Additionally, it was noted that under the first season, the developed mathematical model, predicted well all the parameters understudy, with negligible variances hence acceptance of alternative hypothesis which states that development of mathematical model for the composite filter significantly depict its efficiency.

4.3.1.4 June – August at 200mm filter depth

June – August season effluent flow rate of 0.0039 and volume, 0.234 . The concentrations of concentrations of and for , , , and before,

and after are represented in Table 4.8.

Table 4.11: Concentrations of, , , and for March – May season at 200mm depth

Filtration	Concentration ()			COD	BOD	TSS
Before		0.0221	0.0179	0.2702	0.2813	0.3002
After		0.0200	0.0141	0.1609	0.2526	0.2613

Source; Author, (2021)

The values in the Table 4.11 were used as the starting initial values of RK method for Eq. (4.1). Integration of the system of differential equation, Eq. (4.1) yielded

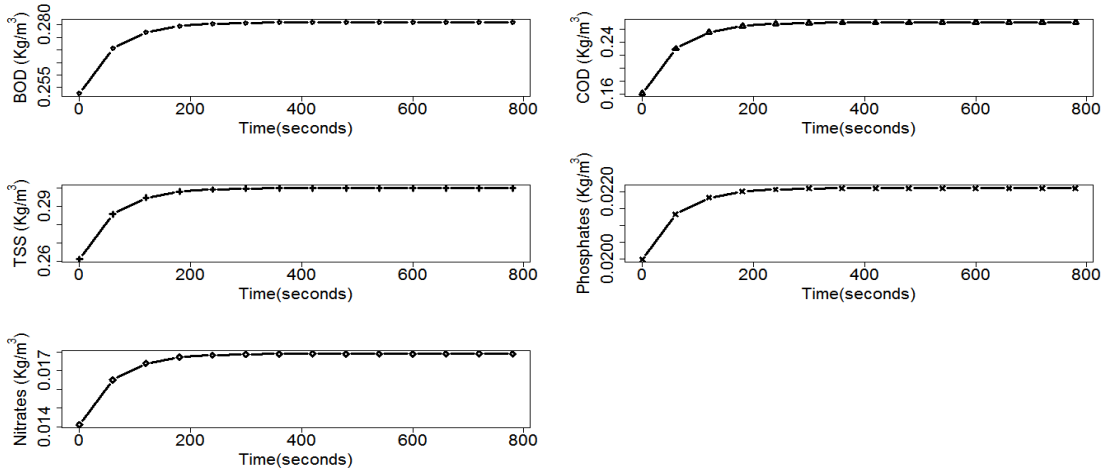


Figure 4. 10: Concentrations of, , , and versus time with filter at depth of, of volume, and input discharge of for June-August season.

Source; Author, (2021)

Table 4.12: Result Summary, season 2, at 200mm

Seasons	**Depth (mm)**	**Parameters**	**C_{in})**	**Q=(**	**V(**	**V/ Q=(Detention time, sec)**	**Q/ V(t_0)**	**Concentration (C) at t_0)**

June-August	200	COD	0.2702	0.0039	0.234	60	0.0167	0.1702
		BOD	0.2813	0.0039	0.234	60	0.0167	0.1772
		TSS	0.3002	0.0039	0.234	60	0.0167	0.1891
		NO_3	0.0179	0.0039	0.234	60	0.0167	0.0113
		PO_3	0.0221	0.0039	0.234	60	0.0167	0.0139

Source; Author, (2021)

From Eqs. 4.2, the concentration of each of the variables (, increased until it reached maximum. Differentiating these equations and equating zero, the resulting concentrations were ,, , and detention time, seconds. The model prediction in table 4.12 was accurately performing for the COD concentration at S2 which had very minimal variance. Measured COD was 0.1609 and the model COD was 0.1702**.** Additionally, the measured PO3 was 0.0020 kg/m^3, while the prediction of the model was 0.0139 kg/m^3. This suggests that the variance between the measured and predicted values in all parameters were so small, confirming the perfectness of the developed model in predicting the filter parameters. Hence under this season, alternative hypothesis was accepted.

4.3.1.5 June – August at 400mm filter depth

The experiment was carried out at effluent flow rate of 0.0042 and 0.468.

Table 4.13: Concentration values before and after filtration for June – August season at 400mm and 0.0042

Filtration	Concentration ()			COD	BOD	TSS
Before		0.0212	0.0228	0.3209	0.2702	0.3254

After	0.0204	0.0173	0.2111	0.2427	0.3155

Source; Author, (2021)

Table 4.13 provided the initial concentration values for system of differential equations. The integration of the system of Eq. (4.1) using fourth-order Runga Kutta (RK) method for systems of equations and the results are as follows.

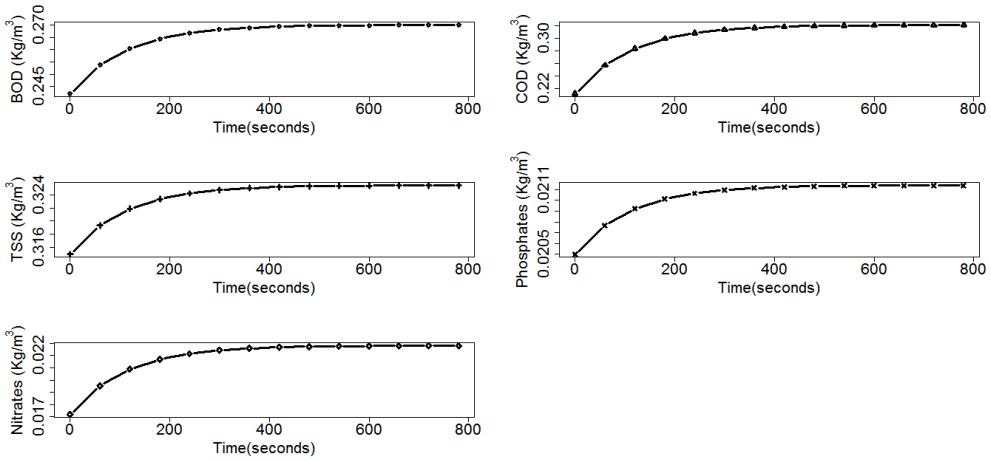


Figure 4. 11: Concentrations of and versus time with filter at depth of of volume, and input discharge of for June-August season.

Source; Author, (2021)

Table 4.14: Result Summary, season 2, at 400mm

Seasons	Depth (mm)	Parameters	C_{in})	Q=(	V(	V/ Q=(Detention time, sec)	Q/V(t_0)	Concentration (C) at t_0)
June-August	400	COD	0.3209	0.0042	0.468	111	0.0090	0.2021
		BOD	0.2702	0.0042	0.468	111	0.0090	0.1702
		TSS	0.3254	0.0042	0.468	111	0.0090	0.2050
		NO_3	0.0218	0.0042	0.468	111	0.0090	0.0137
		PO_3	0.0212	0.0042	0.468	111	0.0090	0.0134

Source; Author, (2021)

From Eqs. 4.2, the concentration of each of the variables (, increased until it reached maximum. Differentiating these equations and equating zero, the resulting concentrations were ,, , , and detention time, seconds. The model in table 4.14 was predicting accurately the COD concentration at S2 which had very minimal variance. Measured COD was 0.2111 and the model COD was 0.2021**.** Also, the measured PO3, was 0.0204 and the predicted model was 0.0134 kg/m^3, which is a minimal variance confirming the accuracy rate of the developed model.

4.3.1.6 June – August season at the filter depth of 600mm

June – August filtration experiments were determined using effluent flow rate of 0.0045, and volume .

Table 4.15: Concentrations of, , , and before and after filtration for June – August season at 600mm and 0.0045

Filtration	Concentration ()			COD	BOD	TSS
Before		0.0256	0.0318	0.2567	0.3313	0.3812
After	C	0.0221	0.0228	0.1619	0.2856	0.3413

Source; Author, (2021)

Table 4.15 provided the initial parameter values and the state constants for following system of differential equations. The integration of the system of Eq. (4.1) results to the following

Eqs. 4.2 and their plots are given in Figure 4.12.

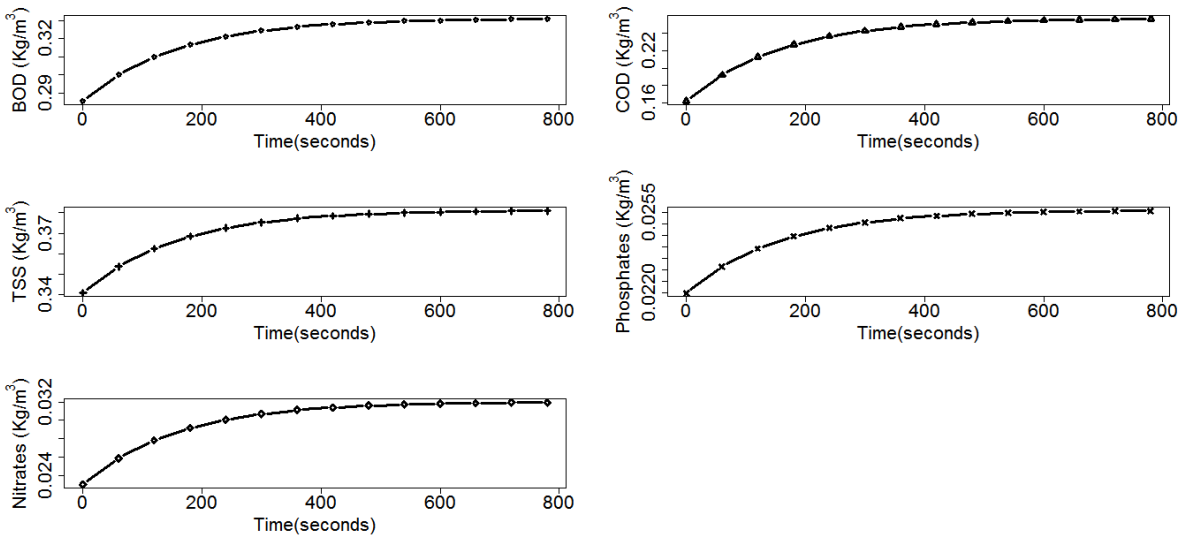


Figure 4. 12: Concentrations of, , , and versus time with filter at depth of, of volume, and input discharge of for June -August season.

Source; Author, (2021)

Table 4.16: Result Summary, season 2, at 600mm

Seasons	Depth (mm)	Parameters	C_{in}	Q=(	V(	V/ Q=(Detention time, sec)	Q/ V(t_0)	Concentration (C) at t_0)
June-August	600	COD	0.2567	0.0045	0.702	156	0.0064	0.1617
		BOD	0.3313	0.0045	0.702	156	0.0064	0.2087
		TSS	0.3812	0.0045	0.702	156	0.0064	0.2402
		NO_3	0.0318	0.0045	0.702	156	0.0064	0.0200
		PO_3	0.0256	0.0045	0.702	156	0.0064	0.0161

Source; Author, (2021)

From Eqs. 4.2, the concentration of each of the variables (, increased until it reached maximum. Differentiating these equations and equating zero, the resulting concentrations were ,, , , and detention time, seconds. The model in table 4.16 was predicting accurately the COD concentration at S2 which had very minimal variance. Measured COD was 0.1619 and the model COD was 0.1617The measured PO3 was 0.021 kg/m^3, while the prediction from the model was, 0.0161 kg/m^3 showing a small variance.

Therefore, for June – August season, the three different depths, 200mm, 400mm, 600mm corresponding to volume: , ,, gave the following detention times; seconds, seconds and seconds. This is an indication that the detention time increases with the increasing rate of volume of the filter. The findings display a high sensitivity of the model developed since the difference between the measured and the predicted values was minimal.

4.3.1.7 September – November season at the filter depth of 200mm

The experiment was performed at effluent flow rate, 0.0039 and 0.234 of volume of the filter.

Table 4.17: Concentrations of, , , and before and after filtration for September – November season at 200mm and 0.0039

Filtration	Concentration ()			COD	BOD	TSS
Before		0.0313	0.0251	0.3450	0.3071	0.3356
After		0.0290	0.0221	0.2360	0.2973	0.2984

Source; Author, (2021)

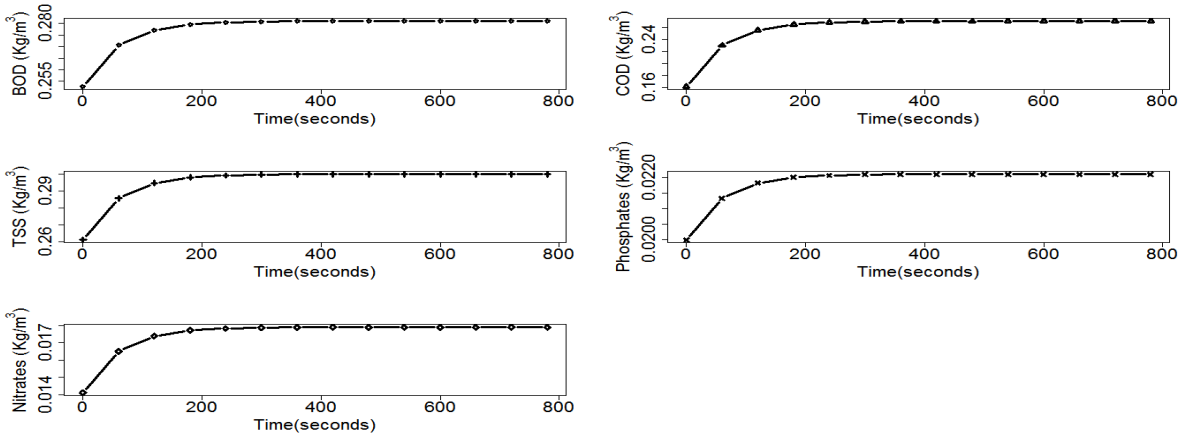


Figure 4. 13: Concentrations of, , , and versus time with filter at depth of , of volume, and input discharge of for June-August season.

Source; Author, (2021)

Table 4.18: Result Summary, season 3, at 200mm

Seasons	**Depth (mm)**	**Parameters**	**C_{in})**	**Q=(**	**V(**	**V/ Q=(Detention time, sec)**	**Q/ V(t_0)**	**Concentration (C) at t_0)**
Sept-Nov	200	COD	0.3450	0.0039	0.234	60	0.0167	0.2174

	BOD	0.3071	0.0039	0.234	60	0.0167	0.1935
	TSS	0.3356	0.0039	0.234	60	0.0167	0.2114
	NO_3	0.0251	0.0039	0.234	60	0.0167	0.0158
	PO_3	0.0313	0.0039	0.234	60	0.0167	0.0197

Source; Author, (2021)

From Eqs. 4.2, the concentration of each of the variables (, increased until it reached maximum. Differentiating these equations and equating zero, the resulting concentrations were ,, , , and detention time, seconds. The model in table 4.18 was predicting accurately the COD concentration at S2 which had very minimal variance. Measured COD was 0.2360 and the model COD was 0.2174**.** The prediction from the model showed PO3 of 0.0197 kg/m^3 , while the measured PO3 was 0.0290 kg/m^3

4.3.1.8 September – November season at the filter depth of 400mm

September – November season at the filter depth of 400mm corresponded to of volume and effluent flow rate of 0.0042.

Table 4.19: Concentrations of, , , and before and after filtration for September – November season at 400mm and 0.0036

Filtration	Concentration ()		COD	BOD	TSS
Before	0.0367	0.0461	0.2650	0.3010	0.3803
After	0.0325	0.0385	0.1458	0.2902	0.3302

Source; Author, (2021)

Table 4.19 provided the initial parameter values and the state constants for following system of differential equations. The integration of the system of Eq. (4.1) using fourth-order Runga Kutta (RK) method for systems of equations and the results are as follows.

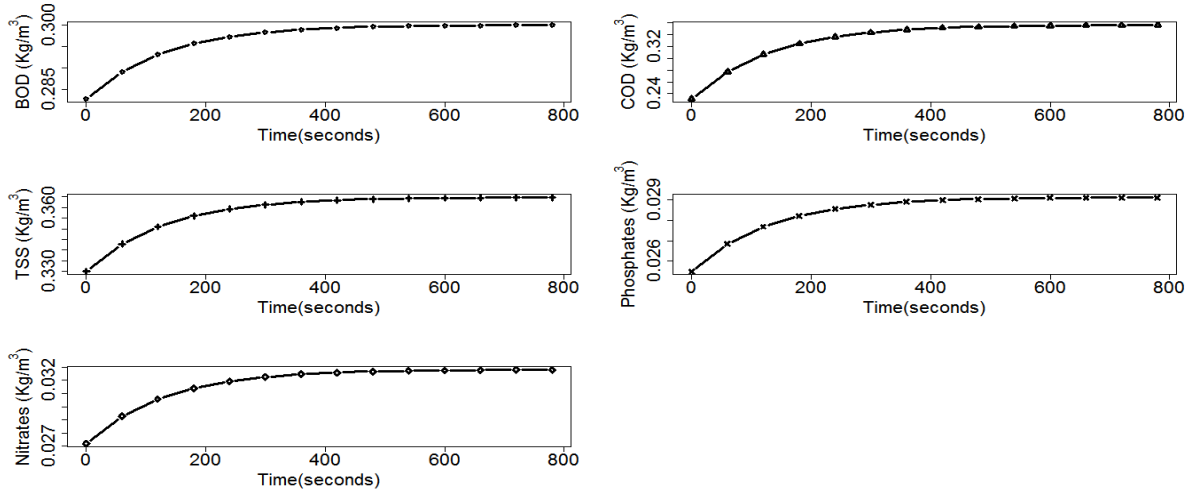


Figure 4. 14: Concentrations of,, , and versus time with filter at depth of, of volume, and input discharge of for March-May season.

Source; Author, (2021)

where Eqs. 4.2 are the equations for graphs shown in Figure 4.14.

Table 4.20: Result Summary, season 3, at 400mm

Seasons	**Depth (mm)**	**Parameters**	**C_{in})**	**Q=(**	**V(**	**V/ Q=(Detention time, sec)**	**$Q/V(t_0)$**	**Concentration (C) at t_0)**
Sept-Nov	400	COD	0.2650	0.0036	0.468	130	0.0077	0.1670
		BOD	0.3010	0.0036	0.468	130	0.0077	0.1896
		TSS	0.3803	0.0036	0.468	130	0.0077	0.2396
		NO_3	0.0461	0.0036	0.468	130	0.0077	0.0290
		PO_3	0.0367	0.0036	0.468	130	0.0077	0.0231

Source; Author, (2021)

From Eqs. 4.2, the concentration of each of the parameters increased until it reached maximum. Differentiating these equations and equating zero, the resulting concentrations were ,, , , and detention time, seconds. The model in table 4.20 was predicting accurately the COD concentration at S2 which had very minimal variance. Measured COD was 0.1458 and the model COD was 0.1670**.** The measured TSS was 0.3302 kg/m^3 and the prediction from the model was 0.2396 kg/m^3 which is equally a minimal variance.

4.3.1.9 September – November 600mm filter depth

September - November 600mm filter depth, corresponded filter volume of 0.702 and effluent flow rate of 0.0045. Table 4.21 represents the concentration values of variables, and

Table 4.21: Concentrations of, , , and before and after filtration for September – November season at 600mm

Filtration	Concentration ()	COD	BOD	TSS

Before	0.0222	0.0278	0.2834	0.3172	0.3692
After	0.0183	0.0214	0.1820	0.2676	0.3286

Source; Author, (2021)

Table 4.21 provided the initial concentration values for the system of differential equations, Eq. (4.1). The integration of the system of Eq. (4.1) resulted to Eqs. 4.2 and their plots are given in Figure 4.15.

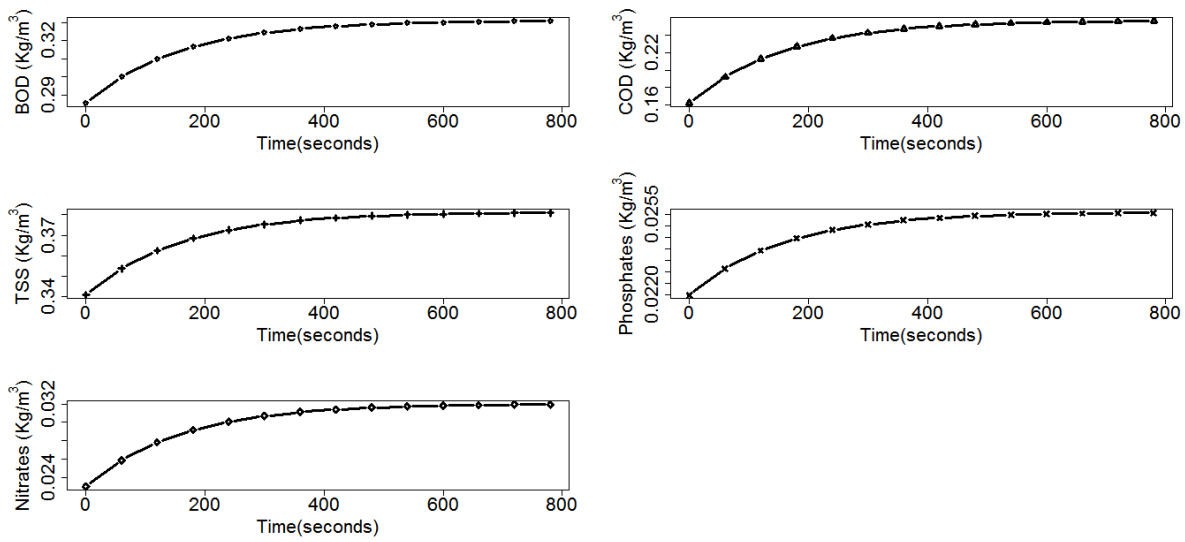


Figure 4. 15: Concentrations of, , , and versus time with filter at depth of, of volume, and input discharge of for September - November season.

Source; Author, (2021)

Table 4.22: Result Summary, season 3, at 600mm

Seasons	**Depth (mm)**	**Parameters**	**C_{in})**	**Q=(**	**V(**	**V/ Q=(Detention time,**	**$Q/V(t_0)$**	**Concentration (C) at t_0)**

						sec)		
Sept-Nov	600	COD	0.2834	0.0045	0.702	156	0.0064	0.1785
		BOD	0.3172	0.0045	0.702	156	0.0064	0.1998
		TSS	0.3692	0.0045	0.702	156	0.0064	0.2326
		NO_3	0.0278	0.0045	0.702	156	0.0064	0.0175
		PO_3	0.0222	0.0045	0.702	156	0.0064	0.0140

Source; Author, (2021)

From Eqs. 4.2, the concentration of each of the variables increased until it reached maximum. Differentiating these equations and equating zero, the resulting concentrations were ,,,, and detention time, seconds. The model in table 4.22 was predicting accurately the COD concentration at S2 which had very minimal variance. Measured COD was 0.1820 and the model COD was 0.1785**.** While the measured PO_3 was 0.0183 kg/m^3 and the model predicted PO_3 of 0.0140 kg/m^3 which implies that the model is more accurate since the variance is minimal. Also noted, for the September – November season, the three different depths, 200mm, 400mm, 600mm corresponding to volume: , ,, gave the following detention times; seconds, seconds and seconds. This is an indication that as the volume of the filter increase, the detention time increases as well.

Additionally, the variance between the measured and predicted results, was minimal, positing the accuracy of the developed model. These findings in all the seasons shows that the model developed was statistically significant on depiction of composite filter efficiency, hence rejection of null hypothesis.

4.3.2 First-Order Kinetic Models

Another model to back up mass-balance model was first order kinetic models. These models were used to model the removal kinetics of each measured contaminant for each season and for each stage, composite filter unit (CFU). The resulting models are summarized in Tables 4.23a to table 4.23c. These models assume that outlet contaminant values are proportional to inlet values and exponentially related to the hydraulic retention time (HRT). The kinetic parameters are important for evaluating the performance of the modelled process, as an average value of the inlet load, and values are interpreted as decay rate constants () and are indicative of the removal efficiency. Here, depth is a linear function of volume of the filter. The higher the depth, the higher the volume. Also, the seasons were compared. Higher values represent better removal, and higher volumes are thus required in treatment units to accomplish sufficient wastewater treatment.

March – May 2021 at 200mm filter depth

The March- May season at a depth of 200mm, 400mm, and 600mm, goodness of fit of the models developed for the composite granular filter (CGF) were found to be good for BOD, TSS, and with values equal or greater than 0.90. and a fit was obtained for COD, and having values of 0.8547, and 0.8136 respectively.

June – August 2021 at 400mm filtration depth

The goodness of fit of the models developed for the composite granular filter (CGF) was good for BOD, TSS, , and , and ranged from at depth 400 and March- May season was found to be good for BOD, TSS, and with values equal or greater than 0.90. A decent fit was obtained for COD, and having values of 0.8547, and 0.8136 respectively.

Only for the cases of TSS with R^2 of 0.87; however, the p-values for all the parameters were below 0.05, except for NO3. The best of fit obtained for TSS is advantageous, since a reduction in this parameter at this stage is a priority, (Fernández et al, 2020). In the case of the UAF, a good fit was obtained for BOD5 and COD with R2 values equal to 0.81 and 0.85, respectively; in addition, the p-values of and for BOD5, COD, TSS, NO2−, and NO3− were below 0.05.

Table 4.23a: Kinetic parameters for first-order models for March – May (MAM) at 200mm, 400mm depth

		(composite Granular Filter) CGF		
	Depth(mm)			
BOD	200	279.60	-0.02926	0.9743
COD		250.02	-0.02187	0.8547
TSS		331.60	-0.04057	0.9535
		29.32	-0.03920	0.9596
		29.12	-0.05475	0.8136
BOD	400	321.97	-0.05352	0.7861
COD		355.50	-0.10340	0.3034
TSS		325.15	-0.03900	0.8418
		32.77	-0.06876	0.7696
		29.13	-0.07506	0.8979
BOD	600	321.97	-0.06651	0.9192
COD		220.45	-0.09271	0.5747
TSS		341.20	-0.05558	0.8726
		31.89	-0.06365	0.7250
		27.92	-0.07089	0.5098

Source**; Author, 2021)**

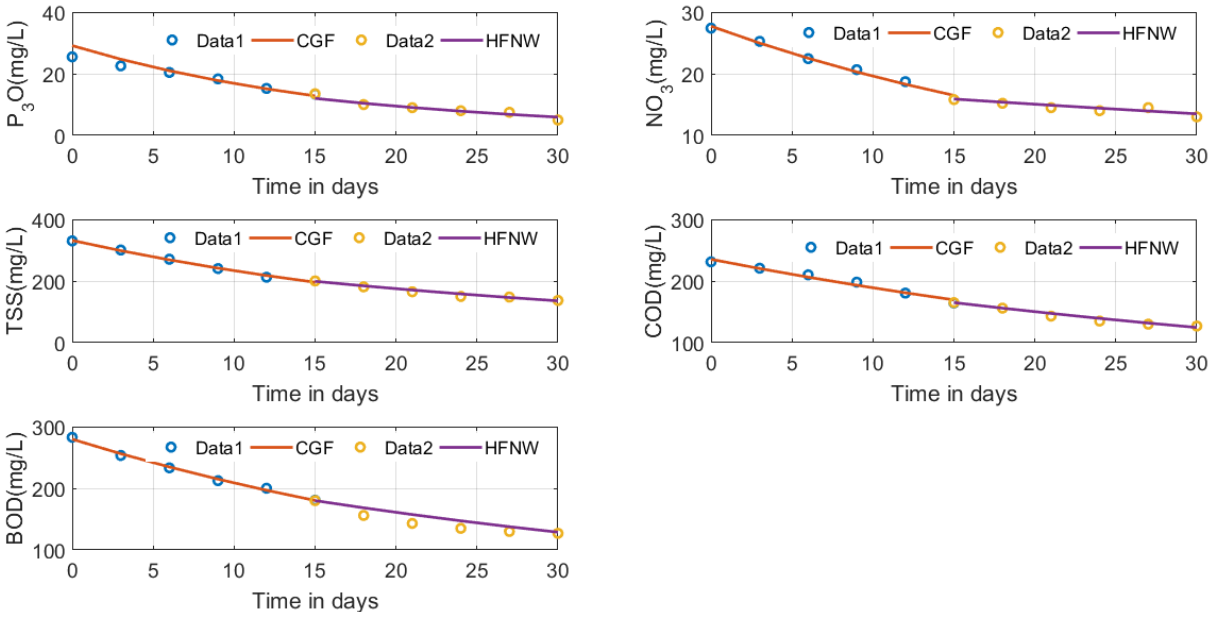


Figure 4. 16: Experimental data and first order Kinetic model for the composite granular filter and at 200mm March- May 2021.

Source; Author, (2021)

Table 4.23b Kinetic parameters for first-order models for June – August (JJA) at 200mm, 400mm and 600mm depth

		CGF		
	Depth (mm)			
BOD	200	281.32	-0.0719	0.9301
COD		250.18	-0.1079	0.7002
TSS		325.5	-0.06523	0.5524
		17.89	-0.07937	0.6786
		22.082	-0.03901	0.8121
BOD	400	270.16	-0.05978	0.876
COD		220.55	-0.03216	0.9673
TSS		325.4	-0.01876	0.9672
		20.77	-0.05428	0.3816
		21.39	-0.02648	0.9456
BOD	600	331.3	-0.03425	0.1646
COD		200.23	-0.04641	0.273
TSS		381.2	-0.04296	0.5743
		25.54	-0.03808	0.4859
		25.62	-0.04921	0.6956

Source; Author, (2021)

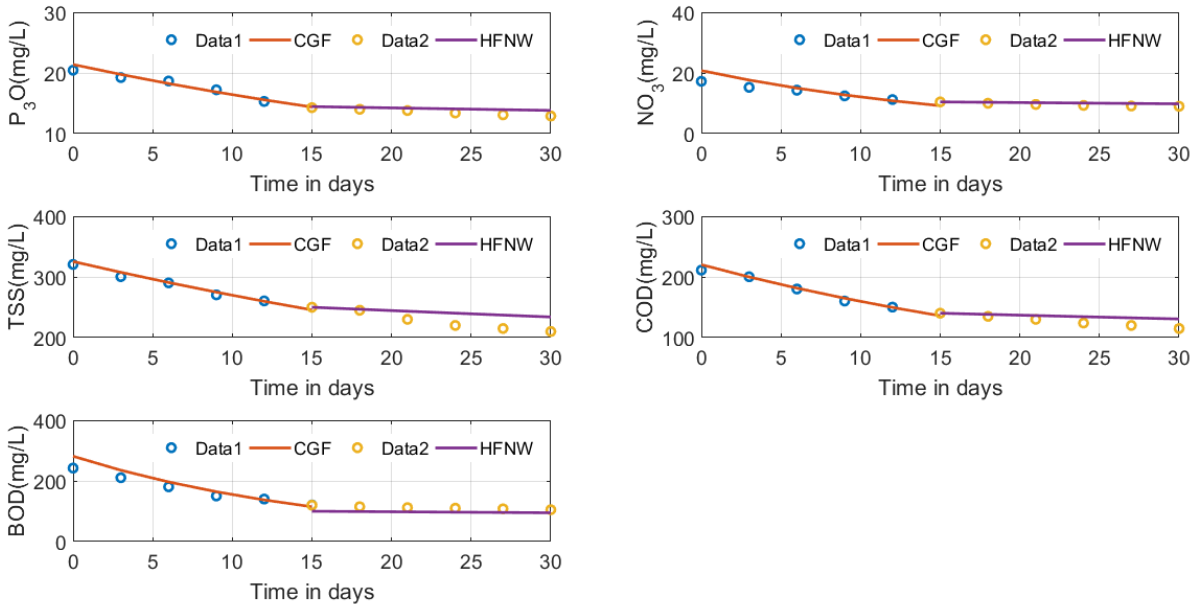


Figure 4. 17: Experimental data and first order Kinetic model for the composite granular filter at 400mm July- August 2021.

Source; Author, (2021)

Table 4.23c Kinetic parameters for first-order models for September – November (SON) at 200mm, 400mm and 600mm depth.

		CGF		
	Depth (mm)			
BOD	200	307.10	-0.02068	0.9411
COD		308.1	-0.01811	0.8476
TSS		335.55	-0.03	0.1384
		25.2	-0.03932	0.4413
		31.3	-0.02876	0.8691
BOD	400	330.9	-0.03304	0.5064
COD		200.45	-0.07391	0.4471
TSS		380.25	-0.04503	0.566
		46.35	-0.03577	0.7774
		36.65	-0.03233	0.2691
BOD	600	300.13	-0.02762	0.2205
COD		200.12	-0.01676	0.3441
TSS		369.50	-0.02842	0.3987
		24.12	-0.02788	0.1071
		22.15	-0.04616	0.7656

Source; Author, (2021)

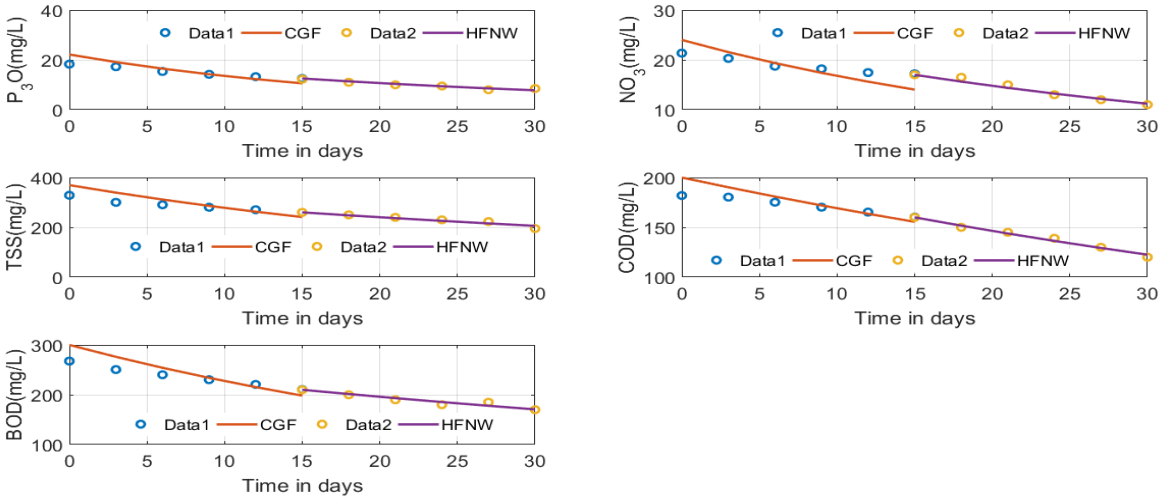


Figure 4. 18: Experimental data and first order Kinetic model for the composite granular filter at 600mm September- November 2021.

Source; Author, (2021)

4.3.3 Multiple regression model

Linear regression Models allow prediction of other parameter concentration based on those that are easy to measure. Correlation of COD for complete treatment system, measurement of nitrates and DO is done. Three models were found with these characteristics and are marked in table 4a, 4b and 4c. Models were considered to be relevant when R^2 was found to be less than 0.99 and *p*-values of predictor variables were found to be less than 0.05.

Table 4.24a: Multiple regression models at 200mm depth for the MAM season, 2021

Model	= 1.8479 - 2.0230+3.3708	
		0.9673
		0.0024
p-values		**0.0175**
		0.0196
Model	= -0.3869+ 0.1214	
		0.9439
		0.0024
p-values		**0.0062**
Model	= 0.8585-7.6306+ 5.0950	
		0.9969
		0.0004
p-values		**0.0052**
		0.0019
Model	= 0.7729-6.9526+ 15.1120	
	0.9908	
		0.0004
p-values		**0.0010**
		0.0055
Model	= -0.0392+0.4855+0.377	
		0.9826
		0.0004
p-values		**0.0014**
		0.0104
Model	= -0.2684+0.2444+2.0577	
	0.9675	
		0.0004
p-values		**0.0043**
		0.0194

Source; Author, (2021)

, , , , and are the measured concentrations outlet at , and , , , , and are corresponding values of concentrations at . **Bold**: Significant p-values ($p < 0.05$).

Table 4.24b: Multiple regression models at 400mm depth for the JJA season.

Model	= -0.01865+ 0.76269	
		0.9838
		0.000658
p-values		**0.0009542**
Model	**= 0.09284+ 0.05513**	
		0.9694
		0.000658
p-values		**0.002488**
Model	**= -0.09691+6.22440**	
		0.9008
		0.006807
p-values		**0.01452**
Model	**= -0.9015+22.1955**	
	0.9013	
		0.006807
p-values		**0.01442**
Model	**= -0.2242+ 0.4800**	
		0.9842
		0.006807
p-values		**0.0009242**
Model	**= -0.2701+ 1.5198**	
	0.9655	
		0.006807
p-values		**0.002972**

Source; Author, (2021)

, , , , and are the measured concentrations outlet at , and , , , , and are corresponding values of concentrations at . **Bold**: Significant p-values ($p < 0.05$).

Table 4.24c: Multiple regression models at 600mm depth for the S-O-N season.

Model	= -4.978 + 4.923+ 1.974	
		0.9543
		0.001335
p-values		**0.008167**
		0.0273
Model	= 0.61470 +0.06322 -0.08435	
		0.958
		0.001335
p-values		**0.01376**
		0.02512
Model	= 0.6326+12.8447 -14.6853	
		0.8462
		0.007535
p-values		**0.03862**
		0.009082
Model	= 0.8308 -13.2101 + 9.6339	
	0.8558	
		0.007535
p-values		**0.05014**
		0.008525
Model	= -1.2954 + 2.5625	
		0.913
		0.007535
p-values		**0.01192**

Model	= -0.4275-0.1278+ 2.3485	
	0.9386	
		0.007535
p-values		**0.01136**
		0.03662

Source; Author, (2021)

, , , , and are the measured concentrations outlet at , and , , , , and are corresponding values of concentrations at . **Bold**: Significant p-values ($p < 0.05$). This implies that the model developed was fit, stable and significant since the all p-values<0.05 the threshold level.

4.4 **Evaluation of the trend of effluent quality before and after installation of composite granular filter from Shirere WWTP up to river Isiukhu.**

The effect of the composite filter in reducing levels of wastes discharged from Shirere WWTP upto River Isikhu via the Shikoye stream was evaluated. Concentration of COD, BOD, TSS, PO_3 and NO_3 was measured before and after installation of the composite filter at all sampling sites in all seasons at varying filter depths.

4.4.1 Evaluation of COD quality

Figure 4.19 shows variation of the concentration of the COD with distance from the composite filter to River Isiukhu.

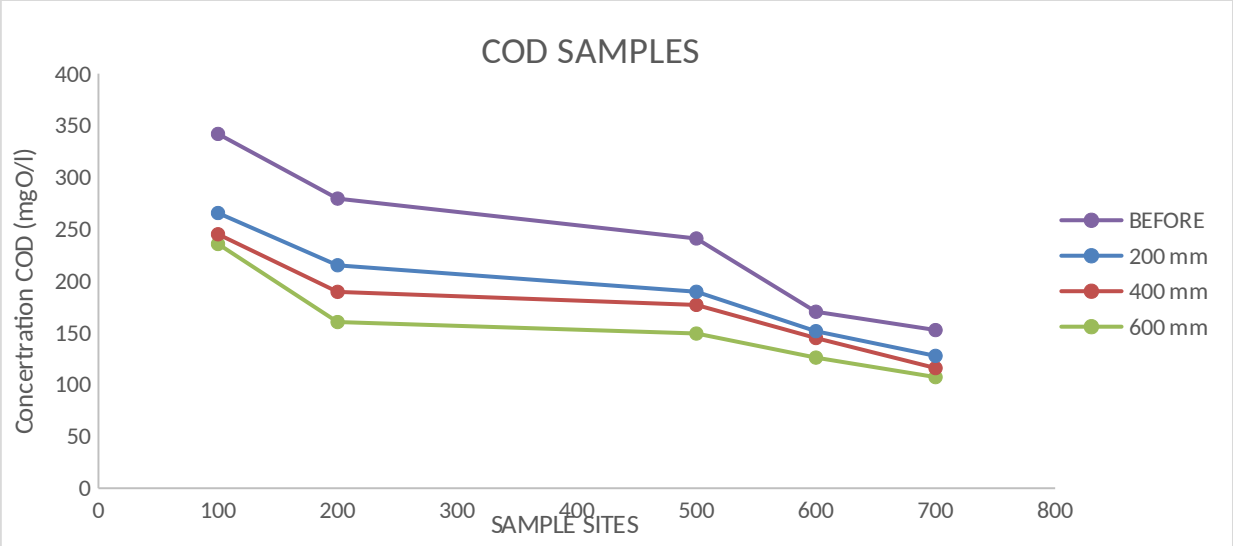


Figure 4. 19: Variation of the concentration of the COD with distance from the composite filter to River Isiukhu at filter depths of 200mm, 400mm.600mm and before filtration.

Source; Author, (2021)

As shown in the graph above, chemical oxygen level before filter installation was 341.8 mgO/l at the outlet of the maturation pond to 152.5 mgO/l downstream of river Isiukhu. When the filter was installed at depth of 200 mm, the COD at outlet after filtration was 265.47 mgO/l up to 127.635mgO/l downstream. At 400mm depth of the filter at the outlet was 244.9668 mgO/l up to 115.4 mgO/l and 235.57 mgO/l at the outlet at 600mm depth of the filter up to 107.16 mgO/l downstream. The filter at 600 mm depth reduced the COD level to almost NEMA standard of 100mgO/l. Thus, the study revealed that the filter had significant effect on COD reduction leading to rejection of null hypothesis which stated that, the composite filter installation had no significant effect on the trend of quality of the effluent discharged from Shirere WWTP into river Isiukhu

These results also confirmed that the discharge of effluent into Shikoye stream being well above the recommended level by NEMA which possess a very high risk to the community, animals and plants around the river. The reduced COD downstream is as a result of a recharge from the swampy area towards River Isiukhu which dilutes the concentration especially during rainy season. However, it is also possible for concentrations to be retained in the dry season. Also, the reduction of COD might be because of self-cleansing by the Shikoye stream.

4.4.2 Evaluation of BOD quality

BOD was measured to determine the rate at which a biochemical reaction would occur in a stream where a contaminant effluent had been released, (Spiro and Stigliani., 2003).

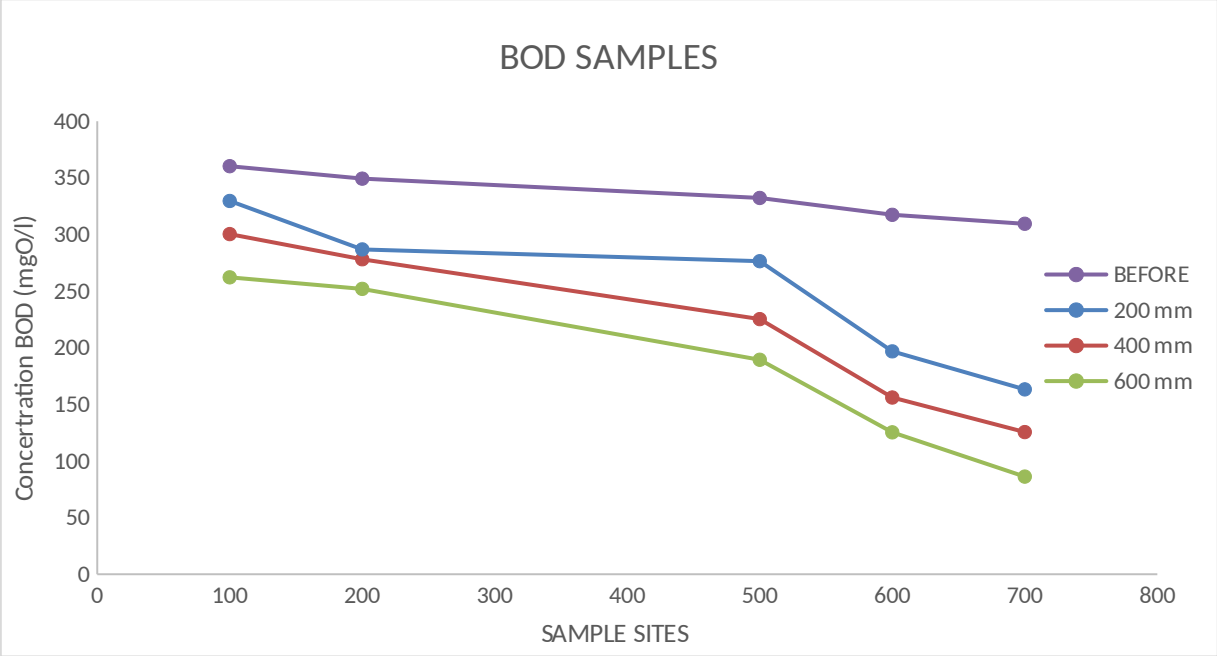


Figure 4. 20: Variation of the concentration of the BOD with distance from the composite filter to River Isiukhu at filter depths of 200mm, 400mm.600mm and before filtration.

Source; Author, (2021)

As shown in figure 4.20 biochemical oxygen demand before the filter was installed was 330.5 MgO/l at the outlet up to 189.3 MgO/l downstream at river Isiukhu. When the filter was installed at 200 mm depth, the outlet level was 329.52 MgO/l up to 163.16 MgO/l downstream. At 400 mm depth 300.27 MgO/l to 125.46 MgO/l downstream and 262.1 MgO/l at the outlet to 82.98mgO/l downstream at 600mm depth. These results show that wastewater depth influenced treatment efficiency of the pond because of two factors, namely increase of:

(i) volume of wastewater in contact with the composite filter with depth; and

(ii) microbial activities with depth as their population increased with wastewater volume, (James et al., 2014)

The reduction in BOD levels by 43 mgO_2/l is a major achievement in this study. It demonstrates the filter has over 57% capabilities of reducing contaminants associated with BOD. Furthermore, reduction of BOD with the depth of filter into filter chamber demonstrates capability of filter response to varying depths. Nonetheless, it is unclear whether these results are due only to the higher hydraulic retention time (HRT) of the deeper system or increase in microbial population as the volume of wastewater increased. Even then, the downstream levels of BOD after installation were close to NEMA standards recommendation of 100mgO/l, especially at 600 mm filter depth determined as 82.98 MgO/l.

4.4.3 Evaluation of TSS

The trend of quality of TSS was presented.

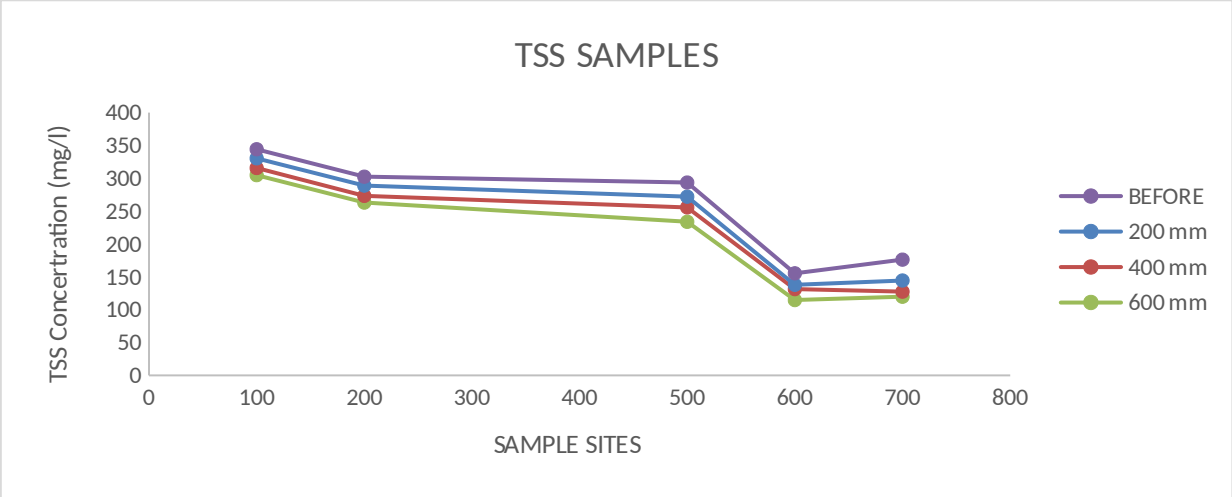


Figure 4.21: variation of the concentration of the TSS with distance from the composite filter to River Isiukhu at filter depths of 200mm, 400mm.600mm and before filtration.

Source; Author, (2021)

At 200 mm the total suspended solids (TSS) for effluent at the outlet after filtration was 330.33 mgO/L and reduced gradually to 144.36 mgO/l downstream. At confluence was 270.8 mgO/l

At 400 mm, effluent at outlet after filtration was 315.566 mgO/l and reduced gradually to 127.36 mgO/l at the confluence and reduced to 133 mgO/l downstream.

At 600 mm depth, effluent at outlet after filtration was 304.75 mgO/l and reduced gradually at the confluence to 127.36 mgO/l and reduced to 119.667 mgO/l downstream. Ali, (2018), found that removal of turbidity was relatively high in higher depths than in shallow depth. Percentage of turbidity was in the range 59 to 90%.

4.4.4 Evaluation of Phosphates

The trend of quality of Phosphates was presented.

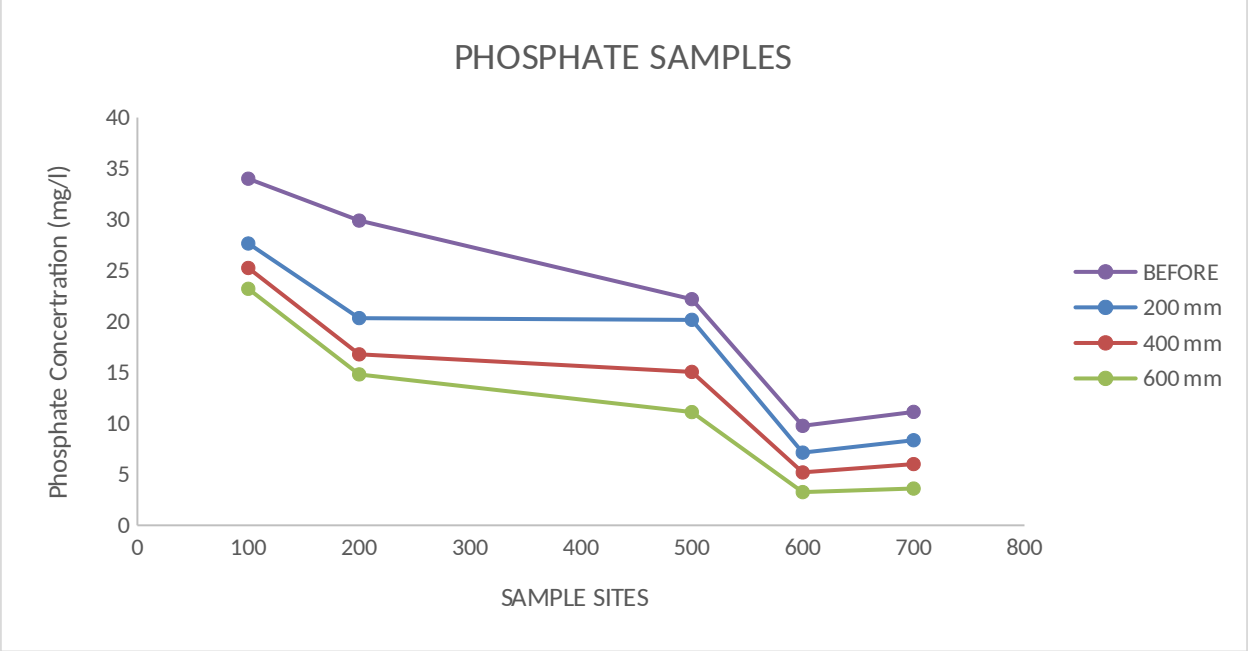


Figure 4.22: variation of the concentration of the phosphate with distance from the composite filter to River Isiukhu at filter depths of 200 mm, 400 mm.600 mm and before filtration.

Source; Author, (2021)

As shown in figure 4.22 above, the phosphate reduced at the outlet before installation of the filter was 35.27 mg/l up to 11.2 mg/l downstream. After installation of the filter at a depth of 200 mm, the level of phosphate was 27.64 mg/l at the outlet and down to 8.34 mg/l downstream to the river. At depth of 400mm it was 25.24 mg/l down to 5.991mg/l downstream. At 600 mm depth, the level was 23.199 mg/l at the outlet down to 3.59 mg/l downstream a river Isiukhu. The installation of the filter had high impact of phosphate reduction in effluent discharged into river Isiukhu. Thus, the researcher rejected the null hypothesis in favor of alternative hypothesis which stated that

composite filter installation had significant effect on the trend of quality of the effluent discharged from Shirere WWTP into river Isiukhu. This therefore confirms our fears that indeed Shirere wastewater plant is actually discharging effluent into River Isiukhu which is highly concentrated and is risky to aquatic life and population downstream.

4.4.5 Evaluation of Nitrates

The trend of quality of Nitrates was presented

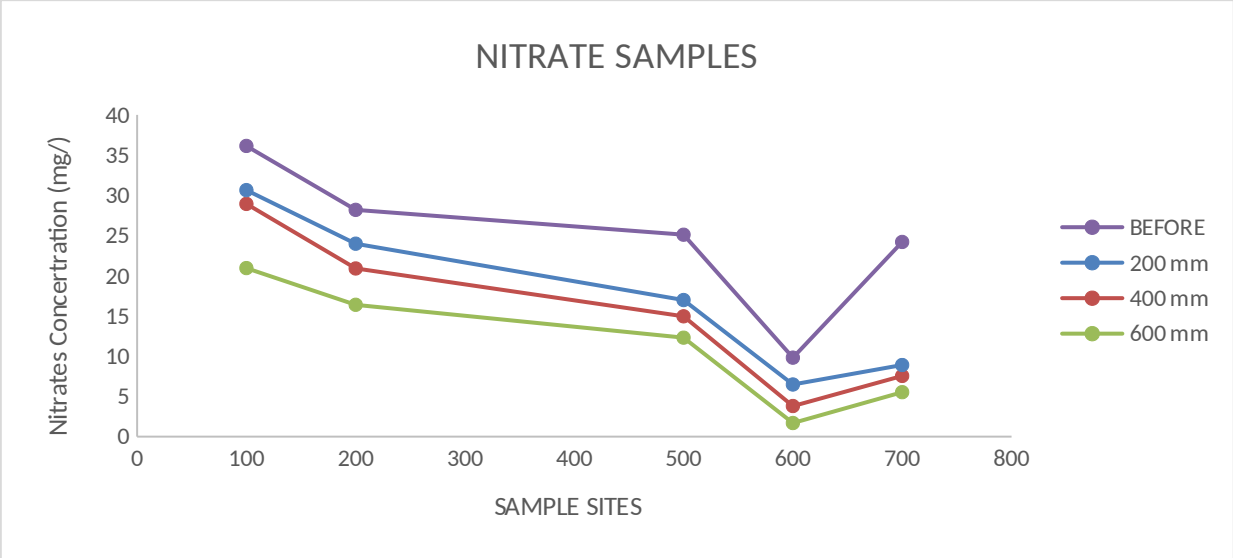


Figure 4.23: variation of the concentration of the Nitrates with distance from the composite filter to River Isiukhu at filter depths of 200mm, 400mm.600mm and before filtration.

Source; Author, (2021)

As shown in figure 4.23 above, the concentration of nitrate before installation of the filter was 36.13 mg/l at the out let to 24.2 mg/l downstream in river Isiukhu. When the filter was installed at 200 mm depth the level of Nitrate was 20.95 mg/l outlet up to 8.93 mg/l downstream at river Isiukhu. At 400 mm 28.93mg/l at outlet to 7.54 mg/l downstream river Iisiukhu. At depth of 600 mm filter depth the level of Nitrate was 25.12 mg/l at the outlet and 5.36 mg/l downstream. Overall, the concentration of

Nitrates was lower than NEMA approved levels of 50 mg/l and proved that the filter had reduced concentration of Nitrates by 76.4 %. Comparatively George et al., 2019, in simultaneous Nitrification and denitrification in slow sand filters with rates of filtration in the range of 0.15 to 0.38 m^3/hr., filter depth of 0.5 to 1.5m^3 of sand size 0.3 to 06 mm found nitrogen concentration to be inversely proportional to the square root of the filter depths. Ali, (2018), found that the cause of high removal efficiency of nitrates was due to higher biomass density supported by higher specific surface area and concluded nitrogen removal was less dependent on the sand depth. Therefore, this finding leads to rejection of null hypothesis which stated that composite filter installation has no significant effect on the trend of quality of the effluent discharged from Shirere WWTP into river Isiukhu.

4.5 Assessment of community knowledge, attitude and perception towards effluent quality discharged from Shirere wastewater treatment plant upto river Isukhu.

The researcher and his assistants set out 84 questionnaires for the community and KACUWASCO workers to ascertain their knowledge, attitude and perception of Shirere WWTP performance.

4.5.1 Reliability and Validity tests

4.5.1.1 Reliability

The consistency of an instrument in measuring what it is supposed to measure was established by first verifying internal consistency and then conducting a pilot study. If the Cronbach's Alpha coefficient is more than 0.70, a questionnaire is considered credible (De Groot, et al 2008). The dependability of the independent variables and the dependent variable was tested using SPSS, and the findings are displayed in Table 4.25

All of the variables obtained had Cronbach's Alpha greater than 0.7, indicating that they met the necessary 0.7 for data internal consistency (Mugenda, A. G., & Mugenda, A., 2008).

Table 4.25: Reliability test

Variable	Cronbach alpha
Water quality risk factors	.769
Waste water effluent quality	.886

Source: (Author, 2021)

4.5.1.2 Validity

The extent to which a measure what it purports to measure is known as data validity (Porter, 2010). Validity is defined by Mugenda and Mugenda, (2008) as the degree to which research findings derived from data analysis accurately reflect the topic under

investigation. According to Table 4.15, the Kaiser–Meyer–Olkin sampling measure showed a KMO value of larger than 0.5, indicating that the sample size was sufficient to treat the data collected as distributed normally. The null hypothesis "item to item correlation matrix based on the replies gathered from respondents for all the effective variables was an identity matrix" was tested using Bartlett's test sphericity. The Bartlett's test was examined using the chi-square test, which revealed that all of the variables were significant at the 0.000 level of significance, rejecting the null hypothesis while the alternative hypothesis stating that parameters were statistically significant, was accepted.

Table 4.26: Test for validity **Extraction Method**: Principal Component Analysis.

Factors	**KMO test**	**Barlett's test of sphericity**		
		Chi-Square	Df	Sig.
Water quality risk factors	0.799	178.02	1	0.000
Waste water effluent quality	0.893	160.15	1	0.002

Source: (Author, 2021)

4.5.2 Response Rate

Only 82 of the 84 questionnaires provided to the sampled respondents (KACWASCO employees and community members) were filled out and returned in this study. As a result, 82 were correctly filled, and these were the only ones utilized in the analysis, resulting in a response rate of 97.6%. as shown in table 4.27.

Table 4.27: Questionnaire Return Rate

		Frequency	Percent
Valid	Returned	82	97.6
	Not Returned	2	2.4
	Total	84	100.0

Source: (Author, 2021)

The high response rate was ascribed to the researcher's use of numerous strategic tactics, according to the report. For instance, the researcher hired a research assistant to handle the distribution and collection of questionnaires while the researcher conducted interviews with the key informants.

4.5.3 Knowledge

The study used the parameters where: 1= Extremely dissatisfied (ED), 2 = Dissatisfied (D), 3 = Neutral (Ne), 4 = Satisfied (S) and 5 = Extremely Satisfied (ES). A summary of the findings is as shown in Table 4.28.

Table 4.28: Responses on knowledge of Shirere Community towards waste water

		ED (%)	**D (%)**	**N**	**S (%)**	**ES (%)**	**Mean**	**Std. Dev.**	**Max**	**Min**
Effluent from Shirere WWTP polluting River Isiukhu	82	2 (2.4)	10 (12.2)	18 (21.9)	34 (41.6)	18 (21.9)	4.24	1.204	5	1
Poor filtration has led to discharge of effluent pollutant	82	8 (10.0)	10 (12.2)	22 (26.8)	28 (34.0)	14 (17.0)	4.02	1.059	5	1
There is visual pollution in river and effluent channel stream	82	10 (12.2)	12 (14.6)	22 (26.8)	29 (35.4)	9 (11.0)	3.91	1.183	5	1
The pitch catchment area is not monitored	82	8 (9.3)	11 (13.5)	23 (28.0)	29 (35.3)	11 (13.8)	4.14	1.309	5	1
A lot of disease	82	9 (11.1)	9 (10.7)	15 (18.0	23 (28.4)	26 (31.8)	4.15	1.147	5	1

outbreak in the catchment area is due to pollution from effluent	)

Source: Author, (2021)

Hypothesis 1: Knowledge and wastewater treatment.

H_{O1} .The level of community knowledge towards effluent quality discharged from Shirere Wastewater Treatment Plant had no significant effect on the effluent pollution into River Isiukhu.

Table 4.29: Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.510[a]	.429	.827	1.70112

Source: Author, (2021)

From the study findings in Table 4.29, the value of R-square is 0.429. This implies that, 42.9% of variation of wastewater treatment was explained by negative knowledge of the residents.

Table 4.30 ANOVA test

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	1149.030	1	1149.030	397.067	.002[b]
	Residual	237.291	81	2.894		
	Total	1386.321	82			

a. Dependent Variable: waste water treatment, b. Predictors: (Constant), knowledge of the residents

Source: Author (2021)

From the findings in Table 4.30, at 0.05 level of significance the ANOVA test indicated that in this model the independent variable namely; knowledge of the residents is

important in predicting of waste water treatment as indicated by significance value=0.002 which is less than 0.05 level of significance (p=0.002 < 0.05).

Table 4.31: Coefficients Model

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	4.476	.712		6.285	.000
	Perception of the residents	.510	.026	.910	19.927	.002

a. Dependent Variable: waste water treatment

Source: Author (2021)

From Table 4.28 to 4.31 the study findings revealed that knowledge of the residents had significant influence on Shirere Waste Water Treatment Plant in Kakamega County. In table 4.31 the statistics output was t-statistic=19.927, p-value=0.002< 0.05. These results confirms that null hypothesis was rejected at a 5% level of significance, in favor of alternative hypothesis, showing that citizens' knowledge of the Shirere Waste Water Treatment Plant in Kakamega County was significant. Thus, for every unit increase in knowledge of the residents in Shirere there was a corresponding increase on waste water treatment by 0.510.

4.5.4 Attitude and Perception

The study used the parameters where: 1= Strongly Disagree (SD), 2 = Disagree (D), 3=Neutral (Ne), 4 = Agree (A) and 5= Strongly Agree (SA). A summary of the findings is as shown in Table 4.21

Table 4.32: Responses on attitude and perception

	N	SD (%)	D (%)	Ne (%)	A (%)	SA (%)	Mean	Std. Dev.	Max	Min
River Isiukhu is of benefit to all	82	2 (2.1)	10 (12.1)	18 (21.8)	34 (41.9)	18 (22.1)	4.24	1.204	5	1
River Isiukhu is polluted by Shirere WWTP	82	8 (10.0)	11 (12.8)	22 (26.6)	28 (33.9)	13 (16.6)	4.02	1.059	5	1
Fish from River Isiukhu is fit for consumption	82	10 (11.8)	10 (12.5)	22 (26.6)	29 (35.6)	11 (13.5)	3.91	1.183	5	1
Pollution is cause for a lot of diseases	82	8 (9.3)	11 (13.5)	23 (28.0)	29 (35.3)	11 (13.8)	4.14	1.309	5	1
Water from Shikoye Stream around Shirere WWTP is fit for consumption	82	9 (11.1)	9 (10.7)	15 (18.0)	23 (28.4)	26 (31.8)	4.15	1.147	5	1

Source: Author (2021)

Hypothesis 2: Attitude and perception and wastewater treatment

H_{O2}. The level of community attitude and perception towards effluent quality discharged from Shirere Wastewater Treatment Plant has no significant effect on the effluent pollution into River Isiukhu.

Table 4.33: Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.226[a]	.045	.040	2.675

Source: Researcher (2021)

From findings in Table 4.32, the value of R-Square is 0.045. This implies that, 4.5% of variation of Wastewater Treatment Plant in Shirere was explained by attitude and perception of the residents within the area. Therefore, the study rejected the null hypothesis that states that attitude and perception have no significant effect on wastewater treatment in Shirere in favor of alternative hypothesis.

Table 4.34 ANOVA test

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	1232.942	1	1232.942	659.160	.045[b]
	Residual	153.379	81	1.870		
	Total	1386.321	82			

a. Predictors: (Constant), attitude

b. Dependent Variable: wastewater treatment

Source: Author, (2021)

From the findings in table 4.33, at 0.05 level of significance the ANOVA test indicated that in this model the independent variable namely; attitude and perceptions of the residents in Shirere, is important in predicting of wastewater management in

Shirere as indicated by significance value=0.045 which is less than 0.05 level of significance ($p=0.045<0.05$).

Table 4.35 Coefficients for the model

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	4.406	.557		7.913	.567
	Attitude	.628	.024	.943	25.674	.045

a. Dependent Variable: Wastewater treatment

Source: Researcher (2021)

From Table 4.34, the study revealed that attitude and perception of the residents in Shirere had a significant influence on wastewater treatment at Shirere in Kakamega County (t statistic = 25.674, p-value =). Hence, for every unit increase in attitude and perception of the residents there was a corresponding increase in waste water treatment at Shirere in Kakamega County by 0.628. Therefore, at 5% level of significance the null hypothesis was rejected, as alternative hypothesis was confirmed, indicating that attitude and perception had a positive influence on waste water treatment at Shirere in Kakamega County.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Overview

This section gives a summary of the study's findings. The findings led to conclusions and, finally, recommendations that can be used in the formulation of policies that will intervene in the management of wastewater treatment processes.

5.2 Summary

After data analysis and discussion, conclusions were based on collected data and experiments.

5.2.1 Effect of the silica pumice composite filter performance efficiency at its optimal conditions.

The performance of composite filter was based on measurements of five parameters namely COD, BOD, TSS, , and at varying effluent flow rate into the filter and its depth. These was carried out by taking 6, 500millitres of effluent samples to MMUST chemistry laboratories from sampling sites S1 to S7. In total were 18 trials for three seasons (March – May, June – August, and September – November) 2021. In all the seasons, the filter performance was measured by evaluating the differences between samples at site one and samples at site two. The varying conditions were composite filter depth and effluent flow rate. The depth of the filter varied from 200mm to 600mm at an interval of 200mm.

5.2.1.1 Effect of varying filter depth on phosphates

In the season of March to May, phosphates after filtration varied from 24.082g/ml to 21.9g/ml which is 4.0% at depth 200mm, varied from 29.12g/ml to 25.476g/ml which is 9% at 400mm and varied at 27.67g/ml to 22.097 mg/l which is 13% at 600ml.

June to August season 2021, phosphates after filtration varied from 22.002ml/l to 19.99g/ml which is 14% at depth 200mm, varied from 25.16g/ml to 22.07g/ml which is 18% at 400mm and varied at 31.37mg/l to 29 mg/l which is 21% at 600ml.

For September to November, phosphates after filtration varied from 31.35mg/l to 29mg/l which is 17% at depth 200mm, varied from 36.68mg/l to 32.5mg/l which is 25.6% at 400mm and varied at 22.15mg/l to 18.285 mg/l which is 28.8% at 600ml. From the results, the 600mm depth is showing high efficiency than 400mm and 200mm by difference of 13% in the mid-season. This implies that increased mass leads to increased filtration efficiency.

5.2.1.2 Effect of varying filter depth on Nitrates

In the season of March to May, Nitrates after filtration varied from 19.87mg/l to 16.08g/ml which is 16% at depth 200mm, varied from 32.776mg/l to 27.236mg/l which is 17.0% at 400mm and varied at 31.89mg/l to 26.783 mg/l which is 26% at 600mm.

June to August season 2021, Nitrates after filtration varied from 17.87mg/l to 14.08mg/ml which is 20.60% at depth 200mm, varied from 22.76mg/l to 17.22mg/l which is 36.7% at 400mm and varied at 31.7mg/l to 22.983 mg/l which is 38.5% at 600mm.

For September to November, Nitrates after filtration varied from 25.12mg/l to 22.56mg/l which is 10.24% at depth 200mm, varied from 46.135mg/l to 38.155mg/l

which is 20.6% at 400mm and varied at 27.85g/l to 21.135 mg/l which is 24.5% at 600ml. Based on the results, the 600mm depth shows high efficiency of 38.5% in the middle season and 24.5% in the last season caused by volumetric increment.

5.2.1.3 Effect of varying filter depth on COD

In the season of march to May, COD after filtration varied from 300.9mg/l to 190.88g/ml which is 36.4% at depth 200mm, varied from 355.58mg/l to 231.13mg/l which is 35.15% at 400mm and varied at 296.71mg/l to 169.35 mg/l which is 42.0% at 600ml.

June to August season 2021, COD after filtration varied from 270.18mg/l to 160.85mg/l which is 40.7% at depth 200mm, varied from 320.88mg/l to 251.13mg/l which is 41.0% at 400mm and varied at 256.75mg/l to 161.55 mg/l which is 45.34% at 600ml.

For September to November, COD after filtration varied from 345mg/l to 236.95mg/l which is 31.6% at depth 200mm, varied from 265mg/l to 145.8mg/l which is 37.5% at 400mm and varied at 283.35mg/l to 181.95 mg/l which is 41.6% at 600mm. From the findings, the 600mm depth reveals high efficiency of 45.34% due to higher retention time caused by increased volume. This is the best performance of the composite filter in the field and can still go higher if the challenges are addressed.

5.2.1.4 Effect of varying filter depth on BOD

In the season of march to May, BOD after filtration varied from 281.5mg/l to 242.6mg/l which is 14% at depth 200mm, varied from 300.16mg/l to 282.7mg/l which is 5.8% at 400mm and varied at 321.97mg/l to 285.25 mg/l which is 11.45% at 600mm.

June to August season 2021, BOD after filtration varied from 281.32mg/l to 252.6mg/l which is 10.2% at depth 200mm, varied from 270.16mg/l to 24.7mg/l which is 10.16% at 400mm and varied at 331.3mg/l to 285.64 mg/l which is 13.56% at 600ml.

For September to November, BOD after filtration varied from 307mg/l to 297.25mg/l which is 12.3% at depth 200mm, varied from 330.95mg/l to 290.2mg/l which is 15.46% at 400mm and varied at 317.2mg/l to 267.6 mg/l which is 16.4% at 600mm. From the results, the highest waste reduction was 16.4% at 600mm depth. This implies that when you increase the depth of the composite filter, efficiency increases. As per these findings, the null hypothesis stated that, varying conditions of the composite filter does not significantly affect its performance on waste removal from effluent. Therefore, the null hypothesis was rejected in favor of alternative hypothesis.

5.2.1.5 Effect of varying filter depth on TSS

In the season of march to May, TSS after filtration varied from 325.15mg/l to 291.3g/ml which is 10.4% at depth 200mm, varied from 365.4mg/l to 330.5mg/l which is 9.55% at 400mm and varied at 341.2mg/l to 301.5 mg/l which is 11.76% at 600ml.

June to August season 2021, TSS after filtration varied from 325.5mg/l to 261.3mg/l which is 19.72% at depth 200mm, varied from 325.4mg/l to 320.5mg/l which is 10.4% at 400mm and varied at 381.26mg/l to 341.25 mg/l which is 11.1% at 600mm.

For September to November, TSS after filtration varied from 335.55mg/l to 298.25mg/l which is 13.16% at depth 200mm, varied from 380.25mg/l to 330.2mg/l which is 15.6% at 400mm and varied at 369.15mg/l to 328.6 mg/l which is 16.4% at 600ml. This shows that, the part of filter material inhibits adequate reduction of the TSS when the volume is increased. Therefore, the more volume the poor the filter performance. This led to rejection of null hypothesis which stated that the varying conditions of the

composite filter does not significantly affect its performance on waste removal from effluent. The alternative hypothesis was confirmed.

5.3. Mathematical Models

The results of Mass balance model, First-order Kinetic Model and multiple regression model are summarized in the following equations per season.

The mass balance equations for each season, flow rate, and depth were integrated via the use of the fourth-order Runga Kutta, (RK) method for systems of equations given by Eq. (4.1).

5.3.1. March – May 2021 at 200mm filter depth

March – May 2021 at 200mm filtration depth, effluent flow rate of 0.0032 and volume, 0.234 , model equations are given as below;

For the steady-states, the resulting concentrations are determined as follows. ,,and detention time, = seconds.

5.3.2 March – May 2021 at 400mm filtration depth

March – May 2021 400mm filtration depth, effluent flow rate of 0.0036 and 0.468 of volume. The model equations are given below.

For steady-state, concentrations are as follows: ,, , and detention time, seconds.

5.3.3 March – May 2021 at 600 mm filter depth

March – May 2021 at 600mm filter depth corresponded to 0.702 of the filter and effluent flow rate of 0.0045**,** and model equations are given as follows.

For steady-state, concentrations are as follows: ,,, and detention time, seconds.

The for three different depths, 200mm, 400mm, 600mm corresponding to volume: , ,, gave the following detention times; seconds, seconds and seconds. This is an indication that the detention time increases with the volume of the filter.

5.3.4 June – August at 200mm filter depth

June – August season effluent flow rate of 0.0039 and volume, 0.234 .

From Equations above, the concentration of each of the variables (, increases until it reaches maximum. Differentiating these equations and equating zero, the resulting concentrations were ,, , and detention time, seconds.

5.3.5 June – August at 400mm filter depth

The experiment was carried out at effluent flow rate of 0.0042 and 0.468.

The final equations are therefore,

From Equations above, the concentration of each of the variables (, increases until it reaches maximum. Differentiating these equations and equating zero, the resulting concentrations were ,, , , and detention time, seconds.

5.3.6 June – August season at the filter depth of 600mm

The mass balance model equations of June – August season effluent flow rate, 0.0045, and volume corresponding to 600mm depth are as follows.

From these equations, the concentration of each of the variables (, increases until it reaches maximum. Differentiating these equations and equating to zero, the resulting concentrations are ,, , , and detention time, seconds.

June – August season, the three different depths, 200mm, 400mm, 600mm corresponding to volume: , ,, gave the following detention times; seconds, seconds and seconds. This is an indication that the detention time increases with the volume of the filter.

5.3.7 September – November season at the filter depth of 200mm

Applying the effluent flow rate of 0.0039 and volume, 0.234 , resulted to the following mass balance model equations.

From Equations above, the concentration of each of the variables (, increases until it reaches maximum. Differentiating these equations and equating to zero, the resulting concentrations were ,, , , and detention time, seconds.

5.3.8 September – November season at the filter depth of 400mm

For the volume, and effluent flow rate, 0.0036, the model equations are as follows.

From Equations above, the concentration of each of the parameters increases until it reaches maximum. Differentiating these equations and equating zero, the resulting concentrations were ,, , , and detention time, seconds.

5.3.9 September – November 600mm filter depth

September - November 600mm filter depth, corresponded filter volume of 0.702 and effluent flow rate of 0.0045. The model equations are given as

From Equations above, the concentration of each of the variables increased until it reached maximum. Differentiating these equations and equating zero, the resulting concentrations were ,,,, and detention time, seconds.

September – November season, the three different depths, 200mm, 400mm, 600mm corresponding to volume: , ,, gave the following detention times; seconds, seconds and seconds. This is an indication that the detention time increases with the volume of the filter.

5.4 Evaluation of the trend of effluent quality before and after installation of composite granular filter from Shirere WWTP up to river Isiukhu

The quality of effluent was measured from the Sampling Site one to Sampling Site seven (S1 to S7) to establish the trend of COD, BOD, TSS, phosphates and nitrates concentration and compare to the standard laid by national environmental management authority (NEMA). The reference standards, risks of different usage of effluent are taken into consideration.

5.4.1 COD

The quality of COD measured from the data was found to be between 270 mgO2/l to 12 mgO2/l as shown by the trend. The NEMA standard recommended concentration is 100 mgO2/l. For all the sampling sites from S1 to S7 the COD concentration is reducing. The sample discharged by the Shirere WWTP without filtration is above 100 mgO2/l. The composite filter reduced concentration significantly but the required standard was realized at S3. This confirms the discharge of effluent that is highly concentrated is being released by Shirere WWTP into River Isiukhu. It is therefore important to incorporate composite filter to the waste water discharged into the environment from the plant in order to remove associated health risks.

5.4.2 BOD

BOD data was originally intended to be used to assess the rate at which a biochemical reaction would occur in a stream into which contaminating effluent had been discharged (Spiro and Stiglain, 2003). From the date measured the BOD concentrations from the treatment plant is very high at 240 mgO2/l and reduces continuously until is released to River Isiukhu. The effluent discharge is way above the NEMA recommended concentration of 100mgO2/l but the filter reduces the concentration.

5.4.3.TSS

High concentration of TSS effluent water affects high penetration thus interferes with aquatic life. The ranges from 178mg/l to 10mg/l. the standard recommended is 1,200mg/l, therefore the filtration reduces the TSS but also as the effluent moves downstream, the quantity of TSS increases as at S5 up to S6 where there is confluence of Shikoye River and River Isiukhu. But later the TSS reduced moderately up to 20mg/l. As per the NEMA standards, the TSS in all seasons and different varying depths of the filter was within the recommended range, hence low risk.

5.4.4 Phosphates

Excessive algal development is likely when phosphates are present in natural waterways in high concentrations. The mechanism of phosphate removal happens in the water stabilization pond system. The phosphates data measured shows a reduction from 100mg/l to 2mg/l from the plant all the way to River Isiukhu. Phosphates released poses minimum risk to the water users for the maximum expected standard is 100mg/l of which the ones released were below it.

5.4.5 Nitrates

Nitrates build up due to farming activities. Nitrates are rarely found in waste water due to hydrolyzation of nitrates to ammonia which is very volatile. The principal channel for nitrogen removal appears to be ammonia volatization, which occurred at extremely low rates in aerobic ponds, (Soares et, al. 1969). This is embraced by the data acquired which shows the highest quality to be 58mg/l and reduced systematically up to River Isiukhu at 1.03mg/l. Nitrates posed minimum risk to the water users for the maximum expected standard is 100mg/l of which the ones released were below it.

5.5 Knowledge, perception and attitude of KACUWASCO workers and community

5.5.1 Perception

From the study findings in Table 4.18, the value of R-square is 0.429. This implies that, 42.9% of variation of waste water treatment was explained by negative perception of the residents.

From the findings in Table 4.19, at 0.05 level of significance the ANOVA test indicated that in this model the independent variable namely; perception of the residents is

important in predicting of waste water treatment as indicated by significance value=0.002 which is less than 0.05 level of significance (p-v 0.002 < 0.05).

From Table 4.20, the study findings revealed that perception of the residents had significant influence on Shirere Waste Water Treatment Plant in Kakamega County (t-statistic=19.927, p-value=0.002< 0.05). Therefore at 5% level of significance the null hypothesis was rejected, indicating that perceptions of the residents have significance relationship with Shirere Waste Water Treatment Plant in Kakamega County. Thus, for every unit increase in perception of the residents in Shirere there was a corresponding increase on waste water treatment by 0.510.

5.5.2 Attitude

From findings in Table 4.14, the value of R-Square is 0.045. This implies that, 4.5% of variation of Waste Water Treatment Plant in Shirere was explained by attitude of the residents within the area. From the findings in table 4.15, at 0.05 level of significance the ANOVA test indicated that in this model the independent variable namely; attitude of the residents in Shirere, is important in predicting of wastewater management in Shirere as indicated by significance value=0.045 which is less than 0.05 level of significance (p-value= 0.045 < 0.05).

From Table 4.16 the study revealed that attitude of the residents in Shirere had a significant influence on wastewater treatment at Shirere in Kakamega County (t-statistic=25.674, p-value = 0.045 < 0.05). Therefore, at 5% level of significance the null hypothesis was rejected, indicating that attitude had a positive influence on waste water treatment at Shirere in Kakamega County. Likewise, for every unit increase in attitude of the residents there was a corresponding increase in waste water treatment at Shirere in Kakamega County by 0.628.

5.6 Conclusions

The study arrived at the following conclusions as per objectives:

5.6.1 To determine the silica pumice composite filter performance efficiency at its optimal conditions.

The silica pumice composite filter performance is evidenced by big variations in the concentrations of COD, BOD, TSS, Phosphates and Nitrates at Shirere WWTP after filtrations. This is attributed to effective filtering capacity of the composite filter that had been installed. From the results, its noted that the filter is most effective on COD throughout the seasons by 36.4% to 35.05% to 42.24% to 40.24% to 37% to 45% and 35% efficiency. This is followed by BOD at 14% to 5.8% to 11.4% to 10.2% to 10.16% to 13.57% to 12.3% and 15.46%. The reduction of the concentrations had an impact on the discharged effluent into river Isiukhu. Changes in TSS concentrations changed from 10.4% to 9.55% to 11.76% to 19.72% to 10.4% to 11.1% to 13.16% and 15.6%. this shows that as you increase the depth of the filter the efficiency of the filter increases up to 15.6% in removal of the TSS. Phosphates removal changed from 4% to 9% to 3% to 14% to 7.3% to 11% and 17%. This also indicates an increase in efficiency as you increase depth of the filter, for our case from 4% to 17%.

Increased housing and infrastructure construction activities within the plant's catchment area may also be to blame for the high quantities of settleable solids. The construction site waste and loose soils found their way to the treatment facility. Increased farming activities, such as tilling soil near sewer lines, could also have contributed to higher TDS and settleable solids levels in the final effluent. The high COD and BOD levels indicated that there was more organic substance in the sewage from the treatment plant's service region. The temperature and pH levels in the study sites did not differ

significantly. It was also reported that the nitrate concentration in this investigation was 0.737 mg/l, which was within acceptable limits. It's also worth noting that none of the parameters were examined at the plant: TSS, Dissolved Oxygen, Phosphates, Color, Turbidity, Conductivity

The use of filters in wastewater treatment reduced the organic matter intake, resulting in oxygen levels that were within natural values. Despite the fact that BOD measurements showed that the system effectively removed the majority of the organic matters from the wastewater, the treated wastewater had a substantial impact on the water quality and biogeochemistry of the River Isiukhu. The fact that the WWTP was a constant supply added to the problem. Given that secondary treatment proved insufficient, additional effective environmental management measures, such as wastewater tertiary treatment with the goal of eliminating nutrients from the effluent, would be required. Another option is to use a different water body for effluent dilution, one that is larger and capable of self-purification.

5.6.2 To develop a mathematical model for prediction of removal of waste from effluent by composite granular filter at wastewater treatment plant.

The mathematical model for wastewater treatment plant for managing the quality of effluent into Isiukhu River is given as follows.

From the model above, the concentrations can be arrived at by substituting time since other parameters are known. The initial concentrations, volume of the filter, effluent flow rate into the filter, and filter depth and time specifically for prediction. This situation eventually approaches the steady state levels in the reactors when the time is

long or infinite. This will enable the design engineer to design the system that will still maintain the desired output but vary volumes and inflow rates of effluent into reactors.

The first-order kinetic model, and multiple regression model, developed can be used for prediction of parameters from the known parameters.

5.6.3 To evaluate the trend of effluent quality before and after installation of composite granular filter from Shirere WWTP up to river Isiukhu.

The quality of effluent concentration was measured from the sampling site one to sampling site seven (S1 to S7) to establish the trend of COD, BOD, TSS, phosphates and nitrates concentration and compare to the standard laid by national environmental management authority (NEMA). The reference standards, risks of different usage of effluent were taken into consideration.

COD

For all the sampling sites from S1 to S7 the COD concentration reduced. The sample discharged by the Shirere WWTP without filtration is above 100 mgO2/l which is the recommended maximum centration by NEMA. The composite filter reduced concentration significantly but the required standard was realized at S3. This confirms the discharge of effluent that is highly concentrated is being released by Shirere WWTP into River Isiukhu.

BOD

BOD data was originally intended to be used to assess the rate at which a biochemical reaction would occur in a stream into which contaminating effluent had been discharged (Spiro and Stiglain, 2003). From the samples analyzed, the BOD concentrations from the treatment plant were very high at 240 mgO2/l and reduced continuously until is released to River Isiukhu. In conclusion, the effluent discharged

was way above the recommended concentration of 100mgO2/l. by NEMA indicating a high level of pollution.

TSS

High concentration of TSS effluent water affects high penetration thus interferes with aquatic life. The ranges from 178mg/l to 10mg/l. the standard recommended is 1,200mg/l, therefore it was concluded that the filtration reduces the TSS but also as the effluent moves downstream, the quantity of TSS increases as at S5 up to S6 where there is influence of Shikoye River and River Isiukhu. But later the TSS reduced moderately up to 20mg/l. The TSS level in the water poses no risk as it is within the recommended range.

Phosphates

In general, when phosphate levels in natural waters are high, excessive algae growth is likely. In water stabilization pond system, the mechanism of phosphates elimination occurs. The phosphates data measured showed a reduction from 100mg/l to 2mg/l from the plant all the way to River Isiukhu. In conclusion, Phosphates released poses a minimum risk to the water users for the maximum expected standard is 100mg/l of which the ones released were below it.

Nitrates

Nitrates build up due to farming activities. Nitrates are rarely found in waste water due to hydrolyzation of nitrates to ammonia which is very volatile. Volatization for ammonia seems to be the main pathway for nitrogen removal, being regarded as very low rates in aerobic ponds (Soares *et, al*. 1969). This is embraced by the data acquired which shows the highest quality to be 58mg/l and reduced systematically up to River

Isiukhu at 1.03mg/l. Thus, Nitrates posed no risk in the water as most of it escaped as ammonia which is highly volatile.

5.6.4 To assess community knowledge, attitude and perception towards effluent quality discharged from Shirere wastewater treatment plant upto river Isukhu

The level of knowledge of the community around Shirere Waste Water Treatment Plant has no bearing on the effluent pollution into River Isiukhu. Finally, an evaluation of the community members from the social investigation data showed negative attitude due to the pollution exhibited by the Shirere WWTP.

From the findings in table 4.33, at 0.05 level of significance the ANOVA test indicated that in this model the independent variable namely; attitude of the residents in Shirere, is important in predicting of wastewater management in Shirere as indicated by significance value=0.045 which is less than 0.05 level of significance (). From Table 4.34 the study revealed that attitude of the residents in Shirere had a significant influence on wastewater treatment at Shirere in Kakamega County (t-statistic=25.674, p-value=0.045< 0.05). Therefore, at 5% level of significance the null hypothesis was rejected, indicating that community knowledge, perception and attitude had a positive influence on waste water treatment at Shirere in Kakamega County. Likewise, for every unit increase in attitude of the residents there was a corresponding increase in waste water treatment at Shirere in Kakamega County by 0.628.

5.7 Recommendations

The following are the recommendations made from the study; The silica pumice composite filter performance is evidenced by big variations in the concentrations of COD, BOD, TSS, Phosphates and Nitrates at Shirere WWTP after filtrations. The

effective filtering capacity of the composite filter that had been installed showed a positive impact on the effluent filtration.

i. From the results, its therefore recommended that the composite filter technology is applied to non-compliant sewerage treatment plants.

ii. The mathematical model (mass balance) for wastewater treatment plant for managing the quality of effluent is recommended for prediction any of the parameters by substituting the values for time. This will enable the design engineer to design the system that will still maintain the desired output but vary volumes and flow rates of the reactors.

iii. The composite filter reduced concentrations of all the parameters (COD, BOD, TSS, ,) significantly from Shirere WWTP along Shikoye stream upto the confluence of river Isiukhu. Most of the parameters after filtration were ranging within the required standards of NEMA. The requisite measure of adopting new technology of composite filtration should be sustained.

iv. The level of knowledge of the community around Shirere Waste Water Treatment Plant with regards to pollution of river Isiukhu by the pollutants under this study was low. Therefore, there is need for the community sensitization within river Isiukhu catchment area. This is to increase more pollution awareness and development of community best mitigation measures.

5.8 Areas for Further Studies

Future studies can major on;

- Replication of this model was majorly on Shirere wastewater treatment plant, therefore, future studies can be conducted in other treatment plants to ascertain

the level of parameter concentrations in order to mitigate on adverse effects and add scientific and physical knowledge.

- Future researchers can conduct studies on lower communities on the knowledge on mitigation measures on pollution matters.
- More studies should be carried out on other types of materials to be used in the composite filter to enhance performance.

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APPENDICES

Appendix I. Monthly Rainfall Mean from Kakamega Meteorological station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2021	109	140	112	291	246	161	177	227	341	130	182.7	53.4	2170.1

Appendix II. STANDARD FORMS

This appendix provides examples of the forms which operators are encouraged to use to standardize sampling and reporting.

Those included are:

- First schedule quality standards for source of domestic water
- Second schedule water quality monitoring for sources of domestic water
- Guidelines values for discharge into public water (The Environmental Management and Coordination Regulatory, 2006)
- A sample analysis report form;
- Effluent sampling monitoring sheet
- A dilution scheme for BOD
- Laboratory sheet for biochemical oxygen demand (BOD_5).

Table 4.13 Shirere Waste Water Treatment Plant – Components and Present Status

Shirere Waste Water Treatment Plant – Components and Present Status		
COMPONENTS	**EVALUATION**	**REMARKS/ REHABILITATION WORKS**
I) Shirere Waste Water Treatment Plant Type – Waste Stabilization Pond System Components: 1nr Primary Facultative Pond, 200m x 86m x 1.72m deep 1nr Secondary Facultative Pond, 84m x 67m x 1.72m deep 1nr Maturation Pond, 116m x 84m x 1.72m deep	Design Capacity assessed and found to be 525m^3/d (Dry Weather Flow) No screening arrangement provided No laboratory equipment is available for analysis of treated and raw effluent to enable monitoring of efficiency of wastewater systems Present sewage flow into the treatment works measured to be approximately 2000m^3/d, which is 4 times the capacity of the Works	Construct new inlet works with screens and grit chamber Desludge ponds and rehabilitate inlets, outlets and embankments Construct and equip new laboratory at the site Provide new operation and maintenance equipment for the Treatment Works. Expand Sewerage System and Sewage Treatment Works to handle increased flows.

Table 4.14 First Schedule Quality Standards for Source of Domestic Water

Parameter	Guide value (max allowable)
PH	6.5-8.5
Suspended solids	30 (mg/L)
Nitrate – NO_3	10 (mg/L)
Ammonia – NH_3	0.5 (mg/L)
Nitrite – NO_3	3 (mg/L)
Total dissolved solids	1200 (mg/L)
Scientific name (E.coli)	Nil/100ml
Fluoride	1.5(mg/L)
Phenol	Nil (mg/L)
Arsenic	0.01 (mg/L)
Cadmium	0.01 (mg/L)
Lead	0.05 (mg/L)
Selenium	0.01 (mg/L)
Copper	0.05 (mg/L)
Zinc	1.5 (mg/L)
Alkyl benzyl sulphonates	0.5 (mg/L)
Permanganate value (PV)	1.0 (mg/L)

Nil means less than limit of detection using prescribed sampling and analytical methods and equipment as determined by the authority.

Table 4.15 Second Schedule Water Quality Monitoring for Sources of Domestic Water

Name of water source:

Sample no-

Description of sample (untreated)-

Date and time sample received in the lab-

Date and time sample was examined-

PARAMETERS	**RESULTS**	
	Observed value	**Guide value (mac allowable)**
pH		6.5-8.5
Suspended solids		30(mg/L)
Nitrate – NO_3		10 (mg/L)
Ammonia – NH_3		0.5 (mg/L)
Nitrite – NO_2		3 (mg/L)
Total dissolved solids		1200 (mg/L)
(e coli)		Nil/ 100 ml
Fluoride		1.5 (mg/L)
Phenol		Nil (mg/L)
Arsenic		0.01 (mg/L)
Cadmium		0.01 (mg/L)
Lead		0.05 (mg/L)
Selenium		0.01 (mg/L)

Copper		0.005(mg/L)
Zink		1.5 (mg/L)
Alkyl benzyl sulphonate Permanganate value		0.5 (mg/L) 1.0 (mg/L)

Table 4.16 Guidelines values for discharge into public water (The environmental management and coordination regulatory, 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, NO3 compounds and NO2 compounds	mg/l	100
Arsenic	mg/l	0.02
Arsenic and its compounds	mg/l	0.1
Benzene	mg/l	0.1
P^H	P^H	6.5-8.5
BOD (5 days at 20C) max	mgO_2/l	30
COD, max	mgO_2/l	50
Temperature, max	^OC	$+3^oC$ of ambient temperature 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
Fluoride	mg/l	1.5
Fluoride 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 and vegetable fats)	mg/l	30
Oil and grease	mg/l	0.1
Phenols	mg/l	0.1
Selenium	mg/l	0.06
Selenium and its compounds	mg/l	30
Hexavalent Chromium VI compounds	mg/l	ND
Sulphide	mg/l	0.3
Total Suspended Solids	mg/l	1200
Tetrachloroethylene	mg/l	15
Thiobencarb	mg/l	Nil
Thiram	mg/l	0.006
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

Secondary data on quality of effluent discharged into river Isiukhu from Shirere WWTP will be obtained from Water Service provider i.e., Kakamega County Water Service Company and Kakamega WARMA

Table 4.18 First schedule Quality standards for sources of domestic water

Parameter	**Guide value (max allowable)**
pH	6.5-8.5
Suspended solids	30 (mg/L)
Nitrate – NO_3	10 (mg/L)
Ammonia – NH_3	0.5 (mg/L)
Nitrite – NO_3	3 (mg/L)
Total dissolved solids	1200 (mg/L)
Scientific name (E.coli)	Nil/100ml
Fluoride	1.5(mg/L)
Phenol	Nil (mg/L)
Arsenic	0.01 (mg/L)
Cadmium	0.01 (mg/L)
Lead	0.05 (mg/L)
Selenium	0.01 (mg/L)
Copper	0.05 (mg/L)
Zinc	1.5 (mg/L)
Alkyl benzyl sulphonates	0.5 (mg/L)
Permanganate value (PV)	1.0 (mg/L)

Nil means less than limit of detection using prescribed sampling and analytical methods and **equipment as determined by the authority.**

Table 4.19 Second schedule Water quality monitoring for sources of domestic water

Name of water source -

Sample no-

Description of sample (untreated)-

Date and time sample received in the lab-

Date and time sample was examined-

PARAMETERS	**RESULTS**	
	Observed value	**Guide value (mac allowable)**
Ph		6.5-8.5
Suspended solids		30 (mg/L)
Nitrate – NO_3		10 (mg/L)
Ammonia – NH_3		0.5 (mg/L)
Nitrite – NO_2		3 (mg/L)
Total dissolved solids		1200 (mg/L)
(e coli)		Nil/ 100 ml
Fluoride		1.5 (mg/L)
Phenol		Nil (mg/L)
Arsenic		0.01 (mg/L)
Cadmium		0.01 (mg/L)
Lead		0.05 (mg/L)
Selenium		0.01 (mg/L)
Copper		0.005(mg/L)
Zink		1.5 (mg/L)
Alkyl benzyl sulphonates Permanganate value		0.5 (mg/L) 1.0 (mg/L)

Table 4.20 Guidelines values for discharge into public water (The environmental management and coordination regulatory, 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, NO3 compounds and NO2 compounds	mg/l	100
Arsenic	mg/l	0.02
Arsenic and its compounds	mg/l	0.1
Benzene	mg/l	0.1
P^H	P^H	6.5-8.5
BOD (5 days at 20C) max	mgO_2/l	30
COD, max	mgO_2/l	50
Temperature, max	℃	+3ºC of ambient temperature 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
Fluoride	mg/l	1.5
Fluoride 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 and vegetable fats)	mg/l	30
Oil and grease	mg/l	0.1
Phenols	mg/l	0.1
Selenium	mg/l	0.06
Selenium and its compounds	mg/l	30
Hexavalent Chromium VI compounds	mg/l	ND
Sulphide	mg/l	0.3
Total Suspended Solids	mg/l	1200
Tetrachloroethylene	mg/l	15
Thiobencarb	mg/l	Nil
Thiram	mg/l	0.006
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

Source: WASREB (schedule 7)

Table 4.24 Design parameters for ponds

Parameter	**Table 3.2 Research design for the study**	**Aerobic** [2]	**Facultative** [3]	**Anaerobic** [4]
Detention, Time, days	Specific objectives	5 – 40	5 – 30	20 – 50
Pond Size, acres	i)To determine changes in the concentration of BOD, COD, TSS, Nitrates and Phosphates in water, sediment and effluent discharged into River Isiukhu.	2 – 10	2 – 10	0.5 – 2
Depth, feet	ii)To asses' changes in human health risks of studied BOD, COD, TSS, Nitrates and Phosphates associated water and effluent at Shirere Waste Water Treatment Plant. .	3 – 5	4 – 8	8 – 16
pH	Graphs	6.5 - 10.5	6.5 - 9.5	6.5 - 7.2
Temperature Range, °C	Equations	0 – 30	0 – 50	6 – 50

Optimum Range, °C	iii) To determine changes in ecological risks to environment associated with effluent discharged into River Isiukhu	20	20	30
BOD, Loading (lb/ac/day)	Graphs	60 – 120	50 – 180	200 – 500

Table 4.32 Historical data of SWWTP to River Isiukhu from the year 2010 to 2020

Source of Sample		**Date Sampled**	**pH**	**BOD (mgO2/l)**	**COD (mgO2/l)**	**Total Suspended solids (mg/l)**	**Lead (mg/l)**	**Cadmium (mg/l)**	**Nitrate (mg/l)**
Shirere WWTP	**FE**	**19/04/2010**		**50**					
Shirere WWTP	**FE**	**17/06/2010**		**20**					
Shirere WWTP	**FE**	**26/07/2010**		**427**					
Shirere WWTP	**FE**	**18/01/2011**		**50**					
Shirere WWTP	**FE**	**17/08/2011**		**40**					
Shirere WWTP	**FE**	**15/10/2011**	**8.57**	**35**	**41.2**	**30**			
Shirere WWTP	**FE**	**06/11/2012**	**8.67**	**44**	**75**	**125**			
Shirere WWTP	**FE**	**26/02/2013**	**6.56**	**50**	**192**	**60**			
Shirere WWTP	**FE**	**16/6/2014**	**8.17**	**120**		**60**			**0.88**

Shirere WWTP	**FE**	**11/08/2015**					**9.684**		
Shirere WWTP	**FE**	**10/09/2015**					**0.197**		
Shirere WWTP	**FE**	**09/10/2015**					**0.197**		
Shirere WWTP	**FE**	**03/03/2017**	**7.27**	**140**	**416**	**160**			
Shirere WWTP	**FE**	**08/05/2019**	**7.90**	**40**	**80**	**142**			
Shirere WWTP	**FE**	**25/07/2019**	**7.50**	**90**	**560**	**68**			**6.852**
Shirere WWTP	**FE**	**29/07/2020**	**9.0**	**5**	**266.7**	**29**			

Source. WARMA

FE - Final Effluent

Table 4.33 Historical data of drainage up to river Isiukhu from the year 2010 to 2020

Source of Sample		Date Sampled	pH	BOD (mgO2/l)	COD (mgO2/l)	Total Suspended solids (mg/l)	Lead (mg/l)	Cadmium (mg/l)	Nitrate (mg/l)
R. Shikoye U/S Shirere ETP	U/S	26/07/2010		12					
R. Shikoye U/S Shirere ETP	U/S	18/01/2011		0					
R. Shikoye U/S Shirere ETP	U/S	17/08/2011	6.29	6					
R. Shikoye U/S Shirere ETP	U/S	15/10/2011	5.96	5	62	1			
R. Shikoye U/S Shirere ETP	U/S	06/11/2012	6.61	2	74	40			
R. Shikoye U/S Shirere ETP	U/S	26/02/2013	5.90	1	32				13.3
R. Shikoye U/S Shirere ETP	U/S	16/06/2014	5.23	4	32				1.99
R. Shikoye U/S Shirere ETP	U/S	09/10/2015					7.95		
R. Shikoye U/S Shirere ETP	U/S	30/05/2016	5.30		429		0.717	1.029	
R. Shikoye U/S Shirere ETP	U/S	30/05/2016	5.71		163.5		7.053	4.037	

R. Shikoye U/S Shirere ETP	**U/S**	**03/03/2017**	**6.94**	**5**	**192**	**40**			
R. Shikoye U/S Shirere ETP	**U/S**	**08/05/2019**	**5.90**	**1**	**32**	**100**			
R. Shikoye U/S Shirere ETP	**U/S**	**25/07/2019**	**6.10**	**1**	**16**	**11.3**			**9.776**
R. Shikoye U/S Shirere ETP	**U/S**	**29/07/2020**	**7.40**	**0**	**64**	**8**			

Source. WARMA

Appendix III. INDUSTRIAL DISCHARGES

Parameters other than C.B.O.D, Total Phosphorus, Total Nitrogen, pH, and Ammonia which may be present in an industrial discharge and which may affect the operation of secondary treatment plant.

RENDERING OF ANIMAL BY-PRODUCTS

Oils, Fats and Grease, Mineral Oil (Interceptor)

MANUFACTURE OF FISH MEAL AND FISH OIL

Oils, Fats and Grease Mineral Oil (Interceptor)

BREWING, DISTILLING AND MALTING

Oils, Fats and Grease Mineral Oil (Interceptor)

MANUFACTURE OF DAIRY PRODUCTS

Oils, Fats and Grease, Mineral Oil (Interceptor), Mineral Oil (Biological Treatment)

MANUFACTURE OF COATING MATERIALS

Oil Organ halogens Zinc, Chromium VI, Total Chromium, EC list 1 (76/464/EEC)

TREATMENT OR PROTECTION OF WOOD WITH PRESERVATIVES

EC list 1 (76/464/EEC)

Chromium VI, Total Chromium, Organ halogens, Phenols, Arsenic, Mineral Oil, (Interceptor), Mineral Oil (Biological Treatment), Oils, Fats and Grease

ROASTING, SINTERING OR CALCINING OF METALLIC ORES (PRINCIPALLY LEAD, ZINC, IRON ORE)

Cadmium, Mineral oil, Mercury, Lead, Zinc, Copper, Nickel, Chromium VI, Total Chromium

PRODUCTION, RECOVERY OR PROCESSING OF NON-FERROUS METALS, THEIR COMPOUNDS OR OTHER ALLOYS

Mineral oil, Cadmium, Mercury, EC list 1 (76/464/EEC), Nickel, Silver, Lead, Chromium VI Total Chromium, Tin, Zinc, Copper

METAL MINING AND MINERAL QUARRYING

Oils, Fats and Grease, Mineral Oil (Interceptor), Mineral Oil (Effluent), Thallium

OPERATIONS INVOLVING COATING WITH ORGANO-TIN COMPOUNDS

EC List 1 (76/464/EEC), Organic-Tin, Copper, Mineral Oil Metals

COARSE CERAMICS INCLUDING REFRACTORY BRICKS, STONEWARE PIPES, FACING AND FLOOR BRICKS AND ROOF TILES

Mineral Oil, Sulphide, Fluoride

MELTING OR PRODUCTION OF IRON OR STEEL

Mineral Oil, Cadmium, Mercury, EC List 1(76/464/EEC), Lead, Zinc, Chromium VI, Total Chromium, Nickel

PRODUCTION, RECOVERY, PROCESSING OR USE OF FERROUS METALS IN FOUNDRIES

Mineral Oil, Phenols, Cadmium, Mercury, EC List 1(76/464/EEC) Other parameters depending on Resins and Binders

MANUFACTURE OF CHEMICALS (INCLUDING OLEFINS AND THEIR DERIVATIVES, ORGANIC OR ORGANO- METALLIC, INORGANIC, FERTILISERS, PESTICIDES, PHARMACEUTICAL, VETERINARY, INTERMEDIATES, GLUES, BONDING AGENTS, VITAMINS INVOLVING HEAVY METALS)

Oils, Fats, and Grease, Organohalogens Phenols, Cyanide, Mercury Tin, Lead, Chromium VI, Total Chromium, Cadmium, Zinc, Copper Mineral Oil (Interceptor) Mineral Oil (Biological treatment) EC List 1 (76/464/EEC) Benzene, Toluene and Xylene Genetically Modified Organisms (S.I. No. 345 of 1994)

FELLMONGERING OF HIDES AND TANNING OF LEATHER

Oils, Fats and Grease Mineral Oil (Interceptor) EC List 1 (76/464/EEC) Chromium VI, Total Chromium, Sulphide Phenols

DYEING, TREATMENT OR FINISHING OF FIBRES OR TEXTILES

Oils, Fats and Grease, Organohalogens, Phenols, Mercury, Nickel, Cobalt, Lead, EC List 1 (76/464/EEC) Chromium VI, Total Chromium, Arsenic, Cadmium, Zinc, Copper, Mineral Oil (Interceptors), Mineral Oil (Biological treatment), Organochionne

pesticides, Benzene, Toluene and Xylene, Mothproofing agents (as Cl), Organophosphorus pesticides, Aldrin, Dieldrin, Endrin, Isodrin, Sulphide

SLAUGHTERING

Oils, Fats and Grease, Mineral Oil (Interceptor)

MANUFACTURE OF SYNTHETIC FIBRES

Oils, Fats and Grease, Mineral Oil (Interceptor), Phenols, Cyanide, Mineral Oil (Biological treatment)

PROCESSING OF ASBESTOS OR MANUFACTURE OR PROCESSING OF ASBESTOS BASED PRODUCTS MANUFACTURE OF GLASS FIBRE OR MINERAL FIBRES, AND PRODUCTION OF GLASS

Mineral Oil (Biological treatment), Phenols, Lead, Arsenic, Fluoride, EC List 1 (761464/EEC)

MANUFACTURE OF INTEGRATED CIRCUITS AND PRINTED CIRCUIT BOARDS

Oils, Fats and Grease, Mineral Oil (Interceptor), Chromium VI, Total Chromium, Arsenic, Fluoride, Copper, Tin, Lead

ELECTROPLATING

Oils, Fats and Grease, Mineral Oil (Interceptor), Mineral Oil (Effluent treatment), Organohalogens, Phenols, Mercury, Nickel, Silver, Lead, Chromium VI, Total Chromium, Cadmium, Tin, Zinc, Copper, EC List 1 (76/464/EEC), Cyanide

MANUFACTURE OF VEGETABLE AND ANIMAL OILS AND FATS

Oils, Fats and Grease, Mineral Oil (Interceptor), Mineral Oil (Biological treatment)

PROCESSING OF IRON AND STEEL IN FORGES, DRAWING PLANTS AND ROLLING MILLS

Oils, Fats and Grease, Lead, Nickel, Zinc, Chromium VI, Total Chromium, Copper, Mineral Oil

Appendix IV :Results

Masinde Muliro University of Science and Technology (MMUST)

Department of Pure & Applied Chemistry

MARCH -MAY 2021

A) RESULTS FOR ANALYSIS AT FILTER DEPTH OF 200MM, 3.9L/S FLOWRATe

CODE	SAMPLE IDENDITY
S1	Outlet of maturation pond
S2	After filtration
S3	Shikoye stream 1 (location one)
S4	Shikoye water spring
S5	Shikoye stream meets river Isiukhu confluence of Isiukhu
S6	Lower Isiukhu river point
S7	Upper Isiukhu river point

Table 4.2.3

SAMPLE		PH	PHOSPHATES Mg/l	NITRATES Mg/l	COD MgO_2/l	BOD MgO_2/l	TSS Mg/l
S1	A	8.6	24.038	19.10	300.6	279.56	324.3
	B	8.6	24.126	20.64	303.0	283.08	326.0
AVERAGE		**8.6**	**24.082**	**19.87**	**300.18**	**281.32**	**325.15**
S2	A	8.6	21.917	16.07	191.7	272.50	289.5
	B	8.5	22.074	16.09	190.0	272.71	293.1
AVERAGE		**8.55**	**21.99**	**16.08**	**190.85**	**272.60**	**291.3**
S3	A	6.3	18.650	13.719	189.3	255.08	283.0
	B	6.3	14.549	15.004	189.5	257.86	278.7
AVERAGE		**6.3**	**16.6**	**14.36**	**189.4**	**256.47**	**280.85**
S4	A	8.5	1.056	0.315	0.01	0.18	0.007
	B	8.5	0.979	0.400	0.01	0.21	0.004
AVERAGE		**8.5**	**2.01**	**0.36**	**0.01**	**0.195**	**0.0055**
S5	A	7.8	5.291	10.450	175.3	228.91	263.9
	B	7.8	5.384	9.731	174.5	228.70	263.0
AVERAGE		**7.8**	**5.338**	**10.009**	**174.9**	**228.80**	**263.45**
S6	A	7.6	2.311	1.240	121.8	135.75	124.9
	B	7.6	2.308	1.837	119.5	138.39	125.7
AVERAGE		**7.6**	**2.309**	**1.538**	**120.65**	**137.07**	**125.3**

S7	7.7	4.40	10.04	132.5	169.4	143.9
	7.7	4.41	10.00	132.5	169.2	148 3
AVERAGE	**7.7**	**4.405**	**10.02**	**132.5**	**169.3**	**146.1**

B) 400MM DEPTH, 4.2L/S FLOWRATE

CODE	**SAMPLE IDENDITY**
S1	Outlet of maturation pond
S2	After filtration
S3	Shikoye stream 1 (location one)
S4	Shikoye water spring
S5	Shikoye stream meets river Isiukhu confluence of Isiukhu
S6	Lower Isiukhu river point
S7	Upper Isiukhu river point

SAMPLE		**PH**	**PHOSPHATES**	**NITRATES**	**COD**	**BOD**	**TSS**
			Mg/l	**Mg/l**	**MgO_2/l**	**MgO_2/l**	**Mg/l**
S1	A	8.1	29.140	32.780	356.1	300.32	364.8
	B	8.1	29.139	32.772	355.6	300.00	366.0
AVERAGE		**8.1**	**29.139**	**32.776**	**355.85**	**300.16**	**365.4**
S2	A	8.0	25.483	27.084	231.40	282.10	329.7
	B	8.1	25.470	27.392	230.86	283.30	331.3
AVERAGE		**8.05**	**25.476**	**27.238**	**231.13**	**282.70**	**330.5**

S3	A	6.6	1.00	0.04	0.01	0.01	0.010
	B	6.6	1.00	0.04	0.01	0.01	0.010
AVERAGE		**6.6**	**1.00**	**0.04**	**0.01**	**0.01**	**0.010**
S4	A	7.4	19.24	15.31	263.4	270.4	281.7
	B	7.4	19.24	15.58	263.4	270.4	281.7
AVERAGE		**7.4**	**19.24**	**15.44**	**263.4**	**270.4**	**281.7**
S5	A	7.4	18.73	13.74	260.1	228.71	273.9
	B	7.4	18.73	13.70	261.4	228.71	273.0
AVERAGE		**7.3**	**18.73**	**13.72**	**261.05**	**228.71**	**273.45**
S6	A	7.3	12.16	9.49	168.2	127.7	153.8
	B	7.3	12.10	9.63	168.2	127.7	153.8
AVERAGE		**7.3**	**12.13**	**9.56**	**168.2**	127.7	**153.8**
S7	A	7.3	2.31	2.19	152.4	89.5	136.5
	B	7.3	2.31	2.47	151.9	89.5	136.5
AVERAGE		**7.3**	**2.31**	**2.33**	**152.25**	**89.5**	**136.5**

C) 600MM DEPTH, 4.5L/S FLOWRATE

CODE	SAMPLE IDENDITY
S1	Outlet of maturation pond
S2	After filtration
S3	Shikoye stream 1 (location one)
S4	Shikoye water spring
S5	Shikoye stream meets river Isiukhu confluence of Isiukhu
S6	Lower Isiukhu river point
S7	Upper Isiukhu river point

SAMPLE		PH	PHOSPHATES Mg/l	NITRATES Mg/l	COD MgO_2/l	BOD MgO_2/l	TSS Mg/l
S1	A	7.4	27.947	31.808	297.058	321.80	341.6
	B	7.4	27.993	31.983	296.379	322.15	340.8
AVERAGE		**7.4**	**27.970**	**31.890**	**296.71**	**321.97**	**341.2**
S2	A	7.4	22.100	26.987	169.0	285.90	300.74
	B	7.4	22.094	26.580	169.7	284.68	301.35
AVERAGE		**7.4**	**22.097**	**26.783**	**169.35**	**285.29**	**301.045**
S3	A	6.7	1.01	0.01	0.01	0.07	0.010
	B	6.7	1.01	0.00	0.01	0.10	0.030
AVERAGE		**6.7**	**1.01**	**0.005**	**0.01**	**0.085**	**0.02**
S4	A	7.3	4.09	17.81	148.1	270.3	292.7

	B	7.3	4.09	17.81	148.1	270.3	292.7
AVERAGE		**7.3**	**4.09**	**17.81**	**148.1**	**270.3**	**292.7**
S5	A	7.3	2.98	12.54	140.4	238.76	283.0
	B	7.3	2.98	12.54	140.4	238.76	283.0
AVERAGE		**7.3**	**2.98**	**12.54**	**140.4**	**238.76**	**283.0**
S6	A	7.3	2.14	4.67	126.9	126.9	122.4
	B	7.3	2.14	4.67	126.9	126.9	122.4
AVERAGE		**7.3**	**2.14**	**4.67**	**126.9**	**126.9**	**143.95**
S7	A	7.3	4.54	1.14	132.6	77.6	120.6
	B	7.3	4.54	1.14	132.6	77.5	120.6
AVERAGE		**7.3**	**4.54**	**1.14**	**132.6**	**77.55**	**120.6**

Masinde Muliro University of Science and Technology (MMUST)

Department of Pure & Applied Chemistry

JUNE-AUGUST 2021

A) RESULTS FOR ANALYSIS AT FILTER DEPTH OF 200MM, 3.9L/S FLOWRATE

CODE	SAMPLE IDENDITY
S1	Outlet of maturation pond
S2	After filtration
S3	Shikoye stream 1 (location one)
S4	Shikoye water spring
S5	Shikoye stream meets river Isiukhu confluence of Isiukhu
S6	Lower Isiukhu river point
S7	Upper Isiukhu river point

Table 4.2.3

SAMPLE		PH	PHOSPHATES Mg/l	NITRATES Mg/l	COD MgO_2/l	BOD MgO_2/l	TSS Mg/l
S1	A	8.37	22.093	17.00	270.25	280.61	325.1
	B	8.43	22.071	18.74	270.11	281.96	325.9
AVERAGE		**8.4**	**22.082**	**17.87**	**270.18**	**251.32**	**300.15**
S2	A	8.45	20.07	14.04	160.8	252.0	261.3
	B	8.25	19.91	14.12	160.9	252.6	261.3
AVERAGE		**8.35**	**19.99**	**14.08**	**160.85**	**252.60**	**261.3**
S3	A	5.3	14.05	12.30	159.2	236.30	260.95
	B	5.3	14.07	12.42	159.6	236.64	260.55
AVERAGE		**5.3**	**14.6**	**12.36**	**159.4**	**236.47**	**260.85**
S4	A	6.5	1.01	0.12	0.01	0.155	0.0055
	B	6.5	1.01	0.04	0.01	0.155	0.0055
AVERAGE		**6.5**	**1.01**	**0.08**	**0.01**	**0.155**	**0.0055**
S5	A	6.8	4.32	7.01	154.01	208.7	233.5
	B	6.8	4.36	7.01	154.17	208.9	233.4
AVERAGE		**6.8**	**4.34**	**7.01**	**154.9**	**208.80**	**233.45**
S6	A	6.6	2.10	1.3	112.33	107.09	110.4
	B	6.6	2.08	1.3	112.97	107.05	110.2
AVERAGE		**6.6**	**2.09**	**1.3**	**112.65**	**107.07**	**110.3**

S7	A	7.1	2.00	5.02	108.4	152.8	200.9
	B	7.1	2.02	5.22	108.4	152.2	200.3
AVERAGE		**7.1**	**2.01**	**5.12**	**108.2**	**152.5**	**200.6**

B) 400MM DEPTH, 4.2L/S FLOWRATE

CODE	**SAMPLE IDENDITY**
S1	Outlet of maturation pond
S2	After filtration
S3	Shikoye stream 1 (location one)
S4	Shikoye water spring
S5	Shikoye stream meets river Isiukhu confluence of Isiukhu
S6	Lower Isiukhu river point
S7	Upper Isiukhu river point

SAMPLE		PH	PHOSPHATES Mg/l	NITRATES Mg/l	COD MgO_2/l	BOD MgO_2/l	TSS Mg/l
S1	A	7.1	21.145	22.976	320.105	270.05	325.8
	B	7.1	21.133	22.576	320.65	270.27	325.0
AVERAGE		**7.1**	**21.139**	**22.776**	**320.85**	**270.16**	**325.4**
S2	A	7.05	20.379	17.242	211.15	242.60	310.7
	B	7.05	20.573	17.234	211.11	242.80	320.3
AVERAGE		**7.05**	**20.476**	**17.238**	**211.13**	**242.70**	**320.5**
S3	A	5.6	1.00	0.04	0.01	0.01	0.010
	B	5.6	1.00	0.04	0.01	0.01	0.010
AVERAGE		**5.6**	**1.00**	**0.04**	**0.01**	**0.01**	**0.010**
S4	A	6.4	12.28	11.35	233.5	240.12	271.9
	B	6.4	12.20	11.53	233.3	240.68	271.5
AVERAGE		**6.4**	**12.24**	**11.44**	**233.4**	**240.4**	**271.7**
S5	A	6.3	11.73	12.72	221.05	218.81	243.65
	B	6.3	11.73	12.72	221.05	218.61	243.25
AVERAGE		**6.3**	**11.73**	**12.72**	**221.05**	**218.71**	**243.45**
S6	A	6.3	8.13	6.56	138.3	107.7	123.8
	B	6.3	8.13	6.56	138.1	107.7	123.8
AVERAGE		**6.3**	**8.13**	**6.56**	**138.2**	**107.7**	**123.8**

S7	A	6.3	1.20	1.45	112.3	79.7	116.2
	B	6.3	1.42	1.21	111.2	79.3	116.3
AVERAGE		**6.3**	**1.31**	**1.33**	**112.25**	**79.5**	**116.5**

C) 600MM DEPTH, 4.5L/S FLOWRATE

CODE	**SAMPLE IDENDITY**
S1	Outlet of maturation pond
S2	After filtration
S3	Shikoye stream 1 (location one)
S4	Shikoye water spring
S5	Shikoye stream meets river Isiukhu confluence of Isiukhu
S6	Lower Isiukhu river point
S7	Upper Isiukhu river point

SAMPLE		PH	PHOSPHATES Mg/l	NITRATES Mg/l	COD MgO_2/l	BOD MgO_2/l	TSS Mg/l
S1	A	7.7	25.240	31.808	257.058	330.80	381.6
	B	7.7	25.993	31.983	256.379	331.80	380.8
AVERAGE		**7.7**	**25.6165**	**31.7855**	**256.7185**	**331.30**	**381.2**
S2	A	7.6	22.100	22.987	162.0	285.90	341.2
	B	7.7	22.094	22.580	161.7	285.38	341.3
AVERAGE		**7.65**	**22.097**	**22.7835**	**161.85**	**285.64**	**341.25**
S3	A	6.7	1.11	0.02	0.03	0.08	0.010
	B	6.7	1.11	0.00	0.02	0.10	0.020
AVERAGE		**6.7**	**1.11**	**0.001**	**0.025**	**0.09**	**0.0015**
S4	A	7.7	19.09	24.83	160.1	280.3	340.0
	B	7.7	19.20	24.74	160.3	280.1	340.2
AVERAGE		**7.7**	**19.145**	**24.785**	**160.2**	**280.2**	**340.1**
S5	A	7.5	18.5	10.44	120.4	278.76	338.0
	B	7.5	17.9	10.24	120.4	278.80	337.8
AVERAGE		**7.5**	**18.2**	**10.34**	**120.4**	**278.78**	**337.9**
S6	A	7.5	2.23	4.77	116.9	120.8	112.4
	B	7.35	2.14	4.68	116.9	121.7	112.2
AVERAGE		**7.425**	**2.185**	**4.725**	**116.9**	**121.25**	**112.3**

S7	A	7.6	4.31	1.04	132.6	66.6	129.7
	B	7.36	4.30	1.04	132.6	66.5	130.1
AVERAGE		**7.48**	**4.305**	**1.04**	**132.6**	**66.55**	**129.9**

Masinde Muliro University of Science and Technology (MMUST)

Department of Pure & Applied Chemistry

SEPTEMBER-NOVEMBER 2021

A) RESULTS FOR ANALYSIS AT FILTER DEPTH OF 200MM, 3.9L/S FLOWRATE

CODE	**SAMPLE IDENDITY**
S1	Outlet of maturation pond
S2	After filtration
S3	Shikoye stream 1 (location one)
S4	Shikoye water spring
S5	Shikoye stream meets river Isiukhu confluence of Isiukhu
S6	Lower Isiukhu river point
S7	Upper Isiukhu river point

Table 4.2.3

SAMPLE		PH	PHOSPHATES Mg/l	NITRATES Mg/l	COD MgO_2/l	BOD MgO_2/l	TSS Mg/l
S1	A	7.8	31.31	25.01	345.1	307.12	335.9
	B	7.7	31.30	25.23	344.9	307.08	335.2
AVERAGE		**7.75**	**31.305**	**25.12**	**345.0**	**307.10**	**335.55**
S2	A	7.5	29.30	22.04	237.0	296.8	298.2
	B	7.6	28.70	22.14	236.9	297.7	298.5
AVERAGE		**7.55**	**29.0**	**22.09**	**236.95**	**297.25**	**298.35**
S3	A	6.9	25.20	22.30	234.7	295.4	284.8
	B	6.9	25.27	22.61	238.1	294.8	285.1
AVERAGE		**6.9**	**25.235**	**22.455**	**236.4**	**295.1**	**284.95**
S4	A	7.1	1.00	0.100	0.001	0.06	0.001
	B	7.1	1.00	0.100	0.001	0.04	0.001
AVERAGE		**7.1**	**1.00**	**0.10**	**0.001**	**0.05**	**0.001**
S5	A	7.6	23.7	19.79	233.4	274.2	275.4
	B	7.6	23.8	19.99	233.3	274.8	275.4
AVERAGE		**7.6**	**23.75**	**29.89**	**233.35**	**274.5**	**275.4**
S6	A	7.5	5.342	2.240	138.1	142.35	120.8
	B	7.5	5.348	2.237	138.3	142.71	120.7
AVERAGE		**7.5**	**5.345**	**2.2385**	**138.2**	**142.53**	**120.75**

S7	A	7.1	20.36	10.89	105.4	122.80	134.8
		6.9	20.40	10.89	105.0	122.90	135.0
AVERAGE		**7.0**	**20.38**	**10.89**	**105.2**	**122.85**	**134.9**

B) 400MM DEPTH, 4.2L/S FLOWRATE

CODE	**SAMPLE IDENDITY**
S1	Outlet of maturation pond
S2	After filtration
S3	Shikoye stream 1 (location one)
S4	Shikoye water spring
S5	Shikoye stream meets river Isiukhu confluence of Isiukhu
S6	Lower Isiukhu river point
S7	Upper Isiukhu river point

SAMPLE		PH	PHOSPHATES Mg/l	NITRATES Mg/l	COD MgO_2/l	BOD MgO_2/l	TSS Mg/l
S1	A	8.0	37.0	46.00	264.8	331.3	380.4
	B	8.1	36.3	46.27	265.2	330.6	380.1
AVERAGE		**8.05**	**36.65**	**46.135**	**265.0**	**330.95**	**380.25**
S2	A	8.1	32.5	38.49	145.9	290.00	330.9
	B	8.0	32.4	38.54	145.7	291.40	330.3
AVERAGE		**8.05**	**32.45**	**38.515**	**145.8**	**290.2**	**330.2**
S3	A	6.1	1.00	0.001	0.010	0.001	0.009
	B	6.0	1.00	0.001	0.014	0.001	0.008
AVERAGE		**6.05**	**1.00**	**0.001**	**0.012**	**0.001**	**0.0085**
S4	A	6.9	30.50	36.99	141.6	289.7	328.0
	B	7.1	30.48	36.80	141.9	289.2	328.9
AVERAGE		**7.0**	**30.49**	**36.895**	**141.75**	**289.45**	**328.45**
S5	A	7.8	27.2	34.30	140.3	288.1	323.3
	B	7.8	27.6	34.70	140.8	288.2	323.0
AVERAGE		**7.8**	**27.4**	**34.5**	**140.55**	**288.15**	**323.15**
S6	A	**7.6**	1.05	3.34	1.37	124.5	144.1
	B	**7.6**	1.18	3.31	1.35	124.7	144.3
AVERAGE		**7.6**	**1.115**	**3.325**	**1.36**	**124.6**	**144.2**

S7	A	**7.5**	17.6	15.22	137.4	189.7	256.0
	B	**7.5**	17.4	15.09	137.5	188.9	256.1
AVERAGE		**7.5**	**17.5**	**15.155**	**137.45**	**189.3**	**256.05**

C) 600MM DEPTH, 4.5L/S FLOWRATE

CODE	**SAMPLE IDENDITY**
S1	Outlet of maturation pond
S2	After filtration
S3	Shikoye stream 1 (location one)
S4	Shikoye water spring
S5	Shikoye stream meets river Isiukhu confluence of Isiukhu
S6	Lower Isiukhu river point
S7	Upper Isiukhu river point

SAMPLE		PH	PHOSPHATES Mg/l	NITRATES Mg/l	COD MgO_2/l	BOD MgO_2/l	TSS Mg/l
S1	A	8.1	22.3	27.7	283.5	317.4	369.1
	B	8.1	22.0	27.9	283.2	317.0	369.2
AVERAGE		**8.1**	**22.15**	**27.8**	**283.35**	**317.2**	**369.15**
S2	A	7.9	18.30	21.3	182.0	267.8	328.4
	B	7.9	18.27	21.4	181.9	267.4	328.8
AVERAGE		**7.9**	**18.285**	**21.35**	**181.95**	**267.6**	**328.6**
S3	A	6.7	1.00	0.01	0.001	0.001	0.003
	B	6.7	1.00	0.01	0.001	0.001	0.003
AVERAGE		**6.7**	**1.00**	**0.01**	**0.001**	**0.001**	**0.003**
S4	A	7.7	18.07	22.27	180.0	266.8	326.7
	B	7.7	18.06	22.24	180.1	266.6	326.9
AVERAGE		**7.7**	**18.065**	**22.255**	**180.05**	**266.7**	**326.8**
S5	A	7.7	17.92	22.00	178.7	266.0	326.3
	B	7.7	17.96	22.00	178.6	266.1	326.6
AVERAGE		**7.7**	**17.94**	**22.00**	**178.65**	**266.05**	**326.45**
S6	A	7.3	1.00	2.03	136.0	140.9	137.4
	B	7.3	1.00	2.01	135.9	141.3	137.1
AVERAGE		**7.3**	**1.00**	**2.02**	**135.95**	**140.65**	**137.25**

S7	A	7.5	18.0	20.45	147.6	156.6	179.7
	B	7.5	18.3	20.47	146.7	157.3	176.8
AVERAGE		**7.5**	**18.15**	**20.46**	**147.15**	**156.95**	**178.25**

Appendix V. NACOSTI PERMIT

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RESEARCH



This is to Certify that Mr.. Philip Makoniio Otenyo of Masinde Muliro University of Science conduct research in Kakamega on the topic: IMPACT OF COMPOSITE FILTER EFFLUENT AT SHIRERE WASTE WATER TREATMENT PLANT IN KAKAMEGA 2/ 202

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