Evaluation of Effluent Quality Trends Before and After Filtration Through the Composite Filter from Shirere Wastewater Treatment Plant to River Isiukhu in Kakamega County, Kenya

Philip Otenyo Makonjio[1]
Edward Masibayi[2]
K'Owino Isaac O.[3]
Samuel S. China[4]

[1]otenyo.philip@gmail.com
[2]enamusasi@mmust.ac.ke
[3]ikowino@mmust.ac.ke,
[4]schina@mmust.ac.ke

[1]https://orcid.org/0000-0003-1088-4711
[4]https://orcid.org/0000-0003-0136-209X

[1,2,3,4]Masinde Muliro University of Science and Technology, Kenya

ABSTRACT

The current stabilization ponds as wastewater treatment practices in urban areas have proven insufficient with continued discharge of untreated wastes into water bodies. Their challenge comes from inappropriate system selection and maintenance, improper design, construction mistakes, physical damage and hydraulic overload. Appropriate infrastructural technologies for waste removal that can be adopted in the drainage channels of effluents into water bodies are scarce. This study incorporates a reactor based composite filter of pumice and sand as an innovative approach for removing residual waste in effluents discharged from Shirere Wastewater Treatment Plant into River Isiukhu, Kakamega Municipality. The objective of the study was to evaluate the trend of effluent quality from Shirere wastewater treatment plant upto river Isiukhu before and after installation of composite granular filter. Effluents, drinking water from Shirere WWTP, Shikoye stream, River Isiukhu and protected spring along Shikoye stream, were collected using presterilized 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. Research design was experimental. 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% in September to November and 11.6±7% in 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 at 31.9±2.7% followed by 20.6±4.8% for September to November and 20.0 ±4.3% for March to May. Specifically, for the first season of March – May 2021 at 200 mm filtration depth were carried out at effluent flow rate of $0.0032 m^3/s$ and volume, $0.234\ m^3$. Concentrations of most parameters were above NEMA standards, like COD was 322mg/l yet maximum should be 100 mg/l. Therefore, it was concluded that silica pumice composite filter performance was achieved by big variations in the concentrations of COD, BOD, TSS, Phosphates and Nitrates at Shirere WWTP after filtration which was attributed to effective removing capacity. The effluent concentrations from sampling sites S1-S3 and S5-S7 were found to be above the NEEMA standards implying the high risk of using Isiukhu water and catchment area. Thus, this study recommended that, the composite filter reduced concentrations of all the parameters (COD, BOD, TSS, PO_3, NO_3) significantly from Shirere WWTP along Shikoye stream up to 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.

Keywords: Composite Granular Filter, Effluent Quality, Filter Depth, Retention Time, Wastewater Treatment

I. INTRODUCTION

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, & Rosa, 2019). A number of parameters such as pH, 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). 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 8696 m3/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 electro chemical 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. 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.

The 2019 population census of Kenya, 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 et al., 2019). These Urban areas have faced challenges emanating from inadequate resources, poor infrastructure and defective cleanup technologies (Koop, & Leeuwe., 2017). Other challenges included lack of effluent quality monitoring procedures at wastewater treatment plants. 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 urban areas are insufficient (Wang et al., 2014).Septic tank and soak pit waste management are examples of onsite wastewater treatments (Willingham et al., 2010).

The simplicity and low cost of stabilization ponds have made them an attractive proposition in both developed and developing countries. However, some of the problems of stabilization ponds are poor design, poor maintenance and overloading of ponds hence producing poor quality of effluents. Poor design emanates from either omission of an aerobic pond or non-alignment of facultative, aerobic or maturation ponds in series. The omission of aerobic ponds results into release of BOD and COD. Poor maintenance includes non-replacement of concrete side and bed slabs, removal of sludge from embankments and screen repairs that often leads to side and underground seepage. Hydraulic overloading caused by excess flow from the sewer piping system due to over population and open manholes (Mara,1987). Additionally, they all lack affordable infrastructure that can be adopted to effectively lower concentrations of effluent discharged from the treatment ponds into water bodies.

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 filtration infrastructure was adopted. The orientation was such that the effluent flowed into two reactors from top to bottom. One reactor had pumice granules and the other with scoria granules. They found that pumice removal of BOD was more efficient than scoria and vice versa to COD. However, this was not a field-based activity. In another laboratory-based study by El Hanandeh et al. (2017) a vertical composite filter comprising of biochar and sand in a column of 150mm high as filter media was adopted. The removal efficiency ranged between 50.6% to 87.5% depending on the experimental parameter under investigation. The flow of effluent was from top to bottom with high hydraulic transient. Similarly, De Rozari et al. (2021) used a vertical column of filters composed of sand and pumice for removal of phosphates under top to bottom flow by gravity. However, both natural flow of wastewater discharges and the infrastructural orientation of wastewater course-way into streams hamper the adoption of vertical filtration technologies.

The current study adopted and incorporated a horizontal flow-based reactor of pumice and sand composite filter in the exit of the maturation pond at Shirere Wastewater Treatment Plant. This was to mitigate on the inadequate removal of waste from effluents. The filter materials consisted of granular sand and pumice stone at depths of 200 mm, 400 mm and 600 mm. These depths were identified using a scientific criterion (French, 2012). These depths were using granular filter media bed depth (L) to grain size (D) ratio, optimum range of 1000-1200 (French, 2012). 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 passed through the filter.

II. LITERATURE REVIEW

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 1 below.

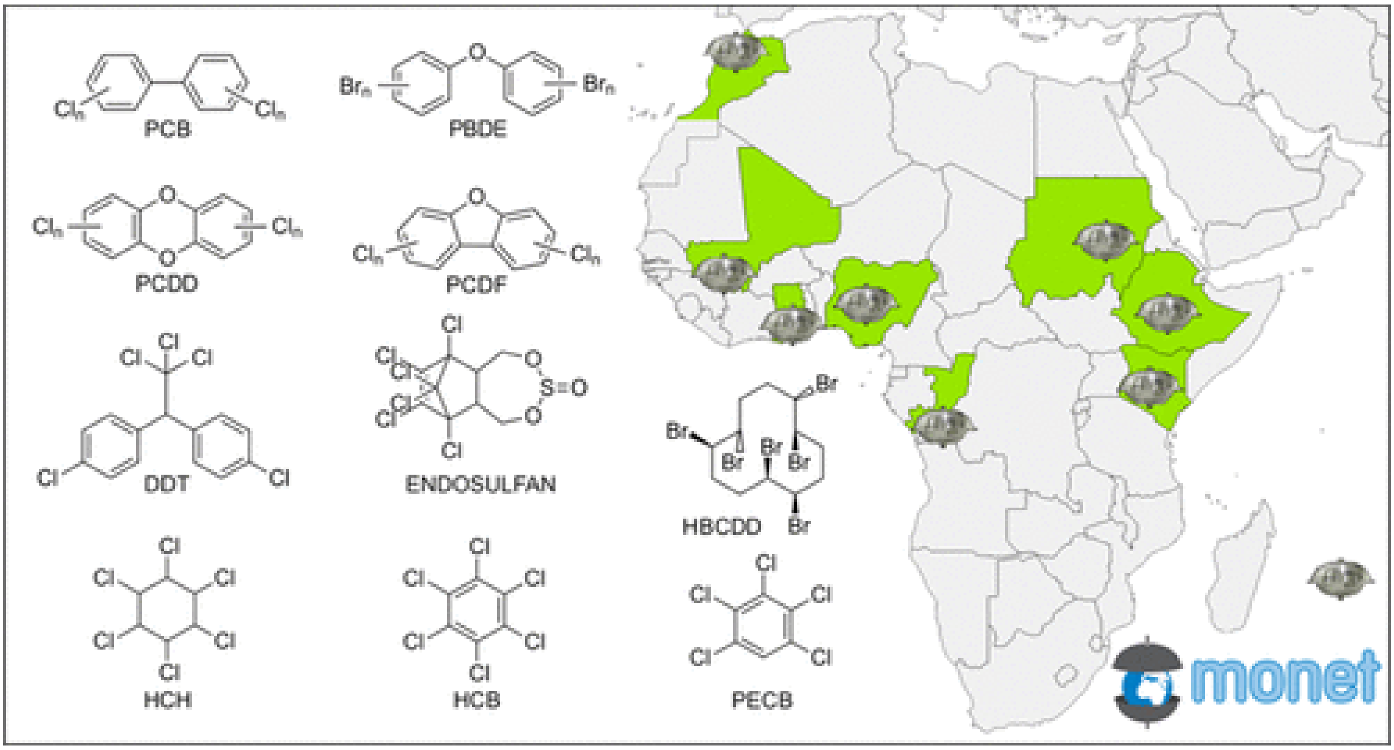

Figure 1
Persistent Organic Pollutants Commonly Found in Africa
Source : Liao et al. (2021)

These compounds which include pesticides, pharmaceuticals and personal care products (PPCPs) amongst other industrial and domestic wastes have the ability to bio accumulate 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 al., 2022). 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. Consequently, discharge of poorly treated effluent into rivers like River Isiukhu could result in contamination of its waters.

Filters for wastewater 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. 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 and wastewater consultants, 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 Blšt'áková 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 & El-Shafai (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 (Rahman 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.

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 (Khelladi 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.

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., 2003). Similarly, volcanic rocks of pumice and scoria have been used in lowering concentrations of BOD, COD, TSS, nitrates, phosphates, ammonia, sulphates and chromium (Aregu et al., 2018). Furthermore, El Hanandeh 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 Philliphi et al (2021) sing a vertical column filter of sand and pumice at 550mm depth.

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 and Mottier (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 (Baumann & 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 et al., (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 and Mottier (1971) 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 7.4×10^{-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.

2.1 Methodologies in Effluent Parameters Analysis

2.1.1 Biochemical Oxygen Demand (BOD)

BOD is currently measured using a standardized method known as the closed bottle, developed by (Jouanneau 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) (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.

2.1.2 Chemical Oxygen Demand (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).

2.1.3 Total Suspended Solids (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).

2.1.4 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 (Bedwell et al., 1995).

2.1.5 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).

2.2 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 previous literature, 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.

III. METHODOLOGY

Sampling was done at Shirere WWTP, Shikoye stream and river Isiukhu. Shikoye stream receives wastewater discharged from Shirere WWTP. 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.

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.

3.1 Installed Composite Granular Filter in the Reactor

The reactor was filled with composite granular filter made of heterogenous mixture of sand and pumice stone at levels 200 mm, 400 mm and 600 mm. 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 2 below. In related study (Aregu, 2018) schematic diagram showed a vertical orientation of effluent flow into the reactors from the top.

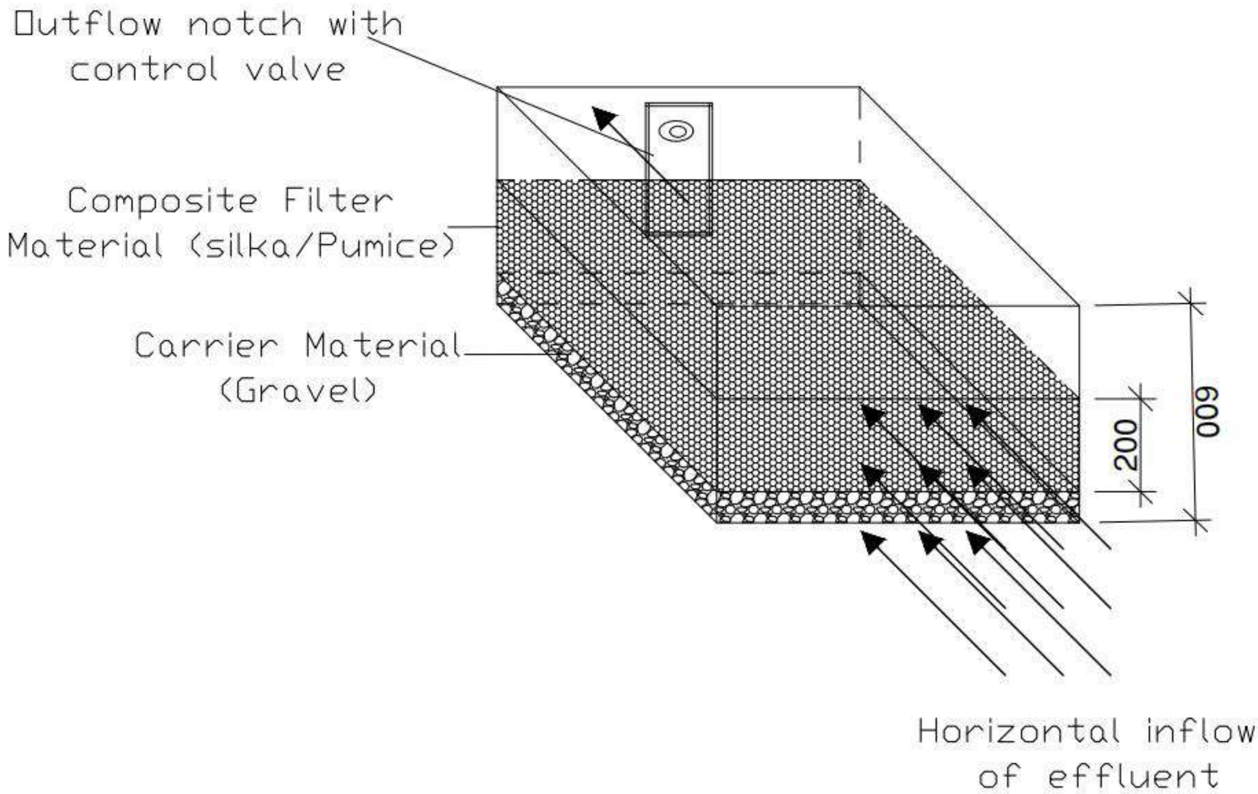

Figure 2
Installed Composite Granular Filter in the Reactor with Horizontal Inflow and Outflow of the Effluent

3.2 Effect of Filter Depth Variation on the Concentration of Five Parameters

The comparison of plots of depths against the concentrations of *BOD, COD, PO_3, NO_3 and TSS* were carried out for the seasons namely March - May, June – August, and September – November 2021.

IV. FINDINGS & DISCUSSION

The effect of the composite filter in reducing levels of wastes discharged from Shirere WWTP upto River Isiukhu via the Shikoye stream was evaluated. COD, BOD, TSS, PO_3 and NO_3 were used as dependent variables whose concentration was measured before and after installation of the composite filter at all sampling site's locations (in meters) in all seasons at varying filter depths (in millimeters) as independent variables.

4.1 Evaluation of Chemical Oxygen Demand quality

Szabolcs (2014), proposed that the biodegradable COD in the influent wastewater consisted of two fractions which were readily (Ss) and slowly biodegradable COD (Xs). Figure 3 shows variation of the concentration of the COD with distance from the composite filter to River Isiukhu.

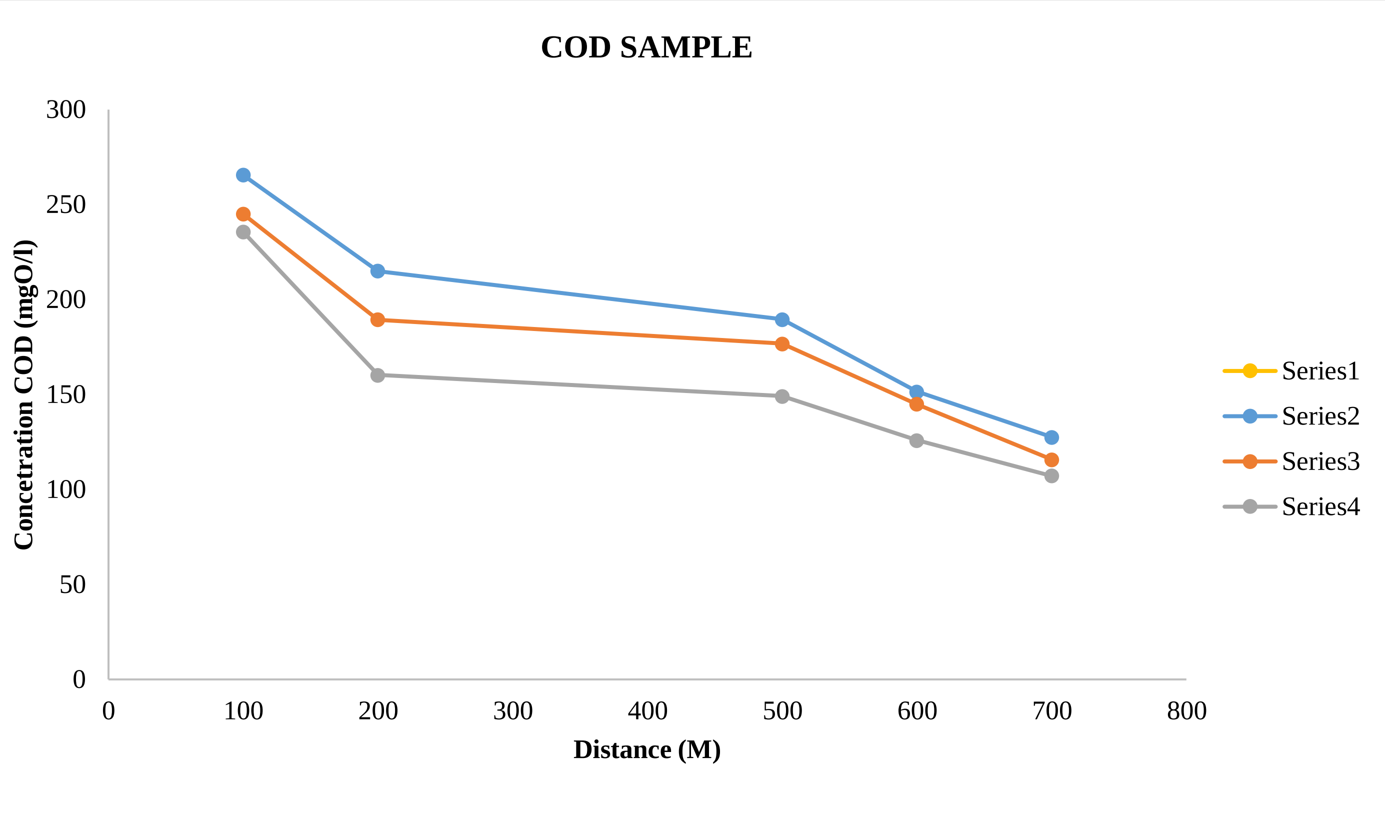

Figure 3

Variation of the Concentration of the COD with Distance from the Composite Filter to River Isiukhu at Filter Depths of 200 mm, 400 mm.600 mm and before Filtration.

As shown in the figure above, chemical oxygen level before filter installation was 347.8 mgO/l at the outlet of the maturation pond to 172.5 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 137.64mgO/l downstream. At 400 mm depth of the filter at the outlet was 244.97 mgO/l up to 115.4 mgO/l and 235.57 mgO/l at the outlet at 600 mm 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. Thus, this confirms that the composite filter installation had significant effect at 5% level 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 (100 mgO/l) which possess a very high risk of 267.47 mgO/l to the community, animals and plants around the river. This implies that when high COD and BOD levels are dumped into a river, it accelerates bacterial growth and depletes oxygen levels in the river. Most fish and many aquatic insects perish if oxygen levels drop to dangerous levels.

4.2 Evaluation of Biochemical Oxygen Demand 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 & Stigliani, 1996).

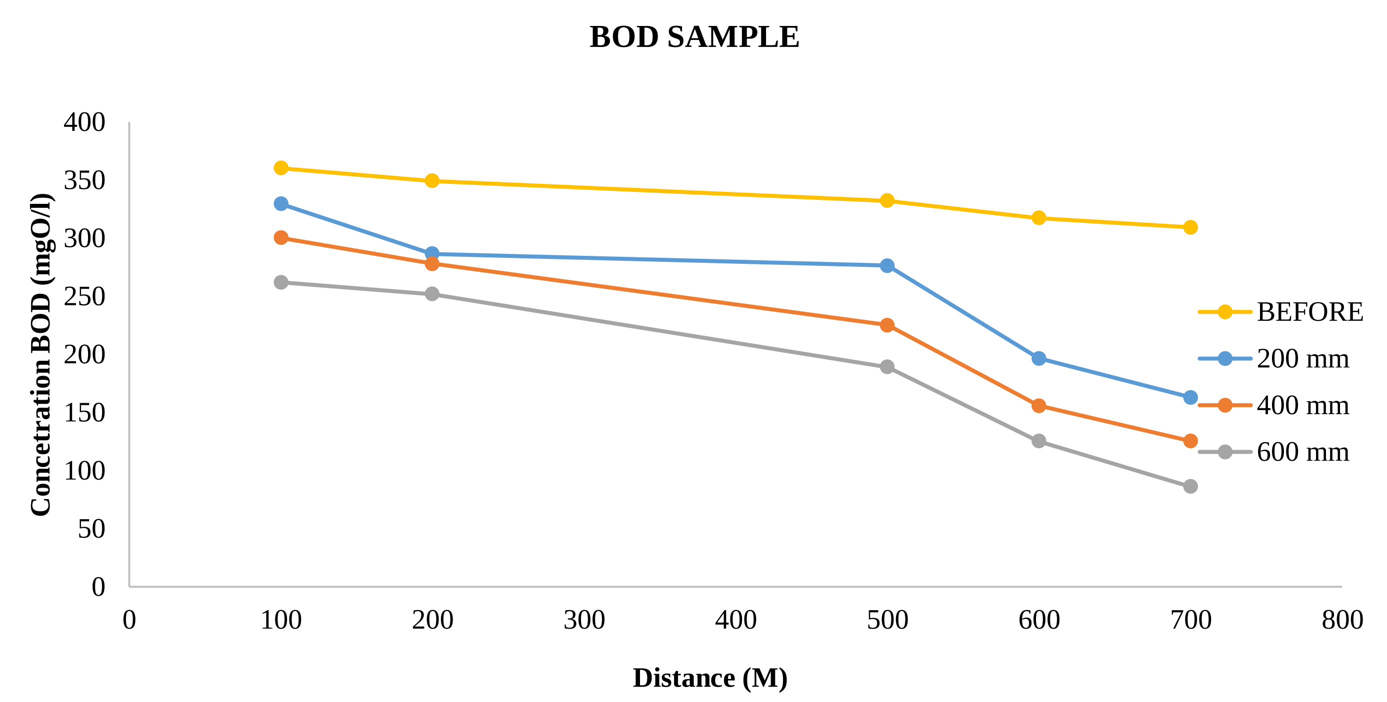

Figure 4
Variation of the Concentration of the BOD with distance from the Composite Filter to River Isiukhu at Filter Depths of 200 mm, 400 mm.600 mm and before Filtration.

As shown in figure 4 biochemical oxygen demand before the filter was installed was 360.5 MgO/l at the outlet up to 289.3 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 183.16 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 600 mm depth. These results show that wastewater depth influenced treatment efficiency of the pond because of two factors, namely increase of: volume of wastewater in contact with the composite filter with depth; and microbial activities with depth as their population increased with wastewater volume.

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.

4.3 Evaluation of Total Suspended Solids

The mass loadings per capita of BOD-5 and TSS are likely to remain stable when water efficiency increases, except in specific cases of grey water reuse that include on site treatment, and when regulations limit the use of garbage disposals to save water (Cook et al., 2017). The trend of quality of TSS was presented.

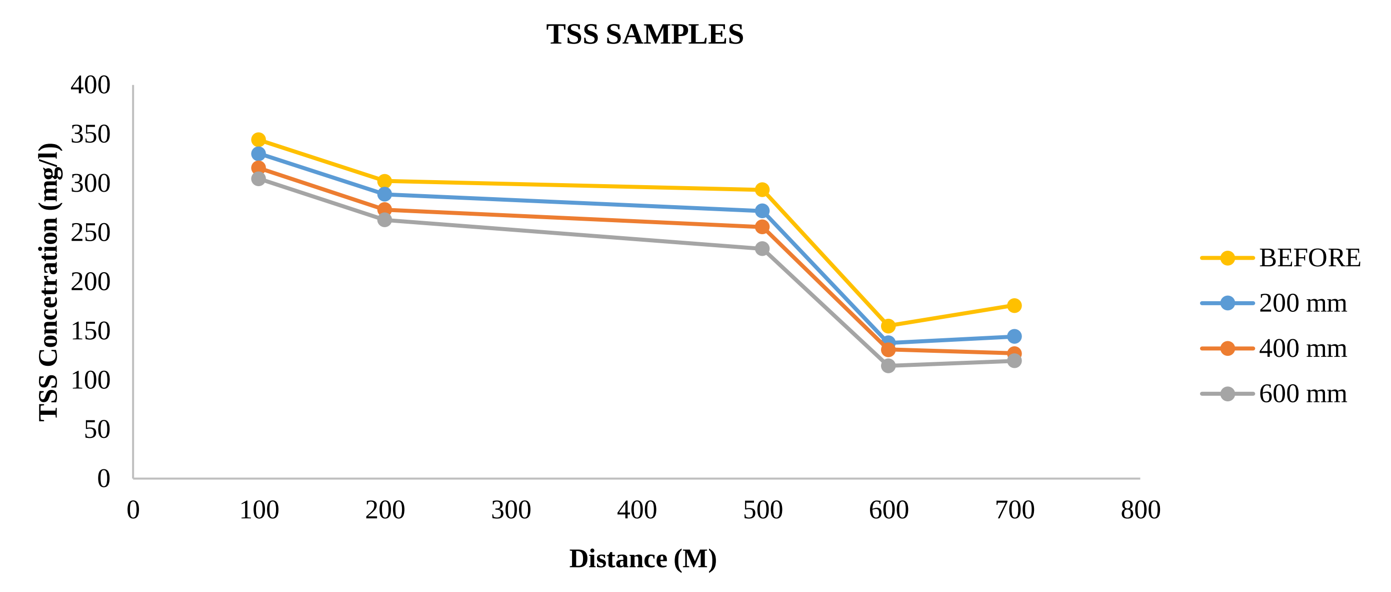

Figure 5
Variation of the Concentration of the TSS with Distance from the Composite Filter to River Isiukhu at Filter Depths of 200 mm, 400 mm.600 mm and before Filtration.

At 200 mm the total suspended solids (TSS) for effluent at the outlet after filtration was 350.33 mgO/l and reduced gradually to 160.36 mgO/l downstream while at confluence the concentration 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 Evaluation of Phosphates

The trend of quality of Phosphates was presented.

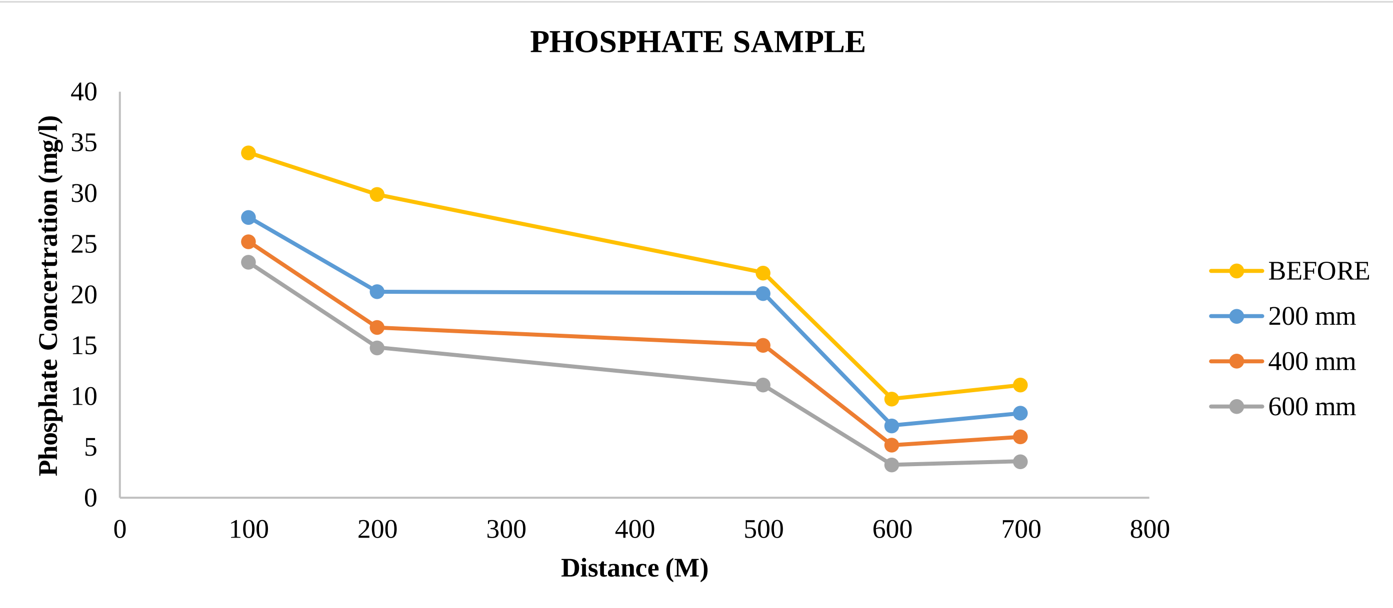

Figure 6
variation of the Concentration of the Phosphate with Distance from the Composite Filter to River Isiukhu at Filter Depths of 200 mm, 400 mm.600 mm and before Filtration.

As shown in figure 6 above, the phosphate reduced at the outlet before installation of the filter was 34.27 mg/l up to 13.20 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 400 mm it was 25.24 mg/l down to 5.991mg/l downstream. At 600 mm depth, the level was 23.19 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, it was confirmed that composite filter installation had significant effect at 5% level on the trend of quality of the effluent discharged from Shirere WWTP into river Isiukhu. This also confirmed that Shirere wastewater plant is discharging highly concentrated effluents into River Isiukhu, which is too risky to aquatic life and population downstream.

4.5 Evaluation of Nitrates

The trend of quality of Nitrates was presented in Figure 7 below.

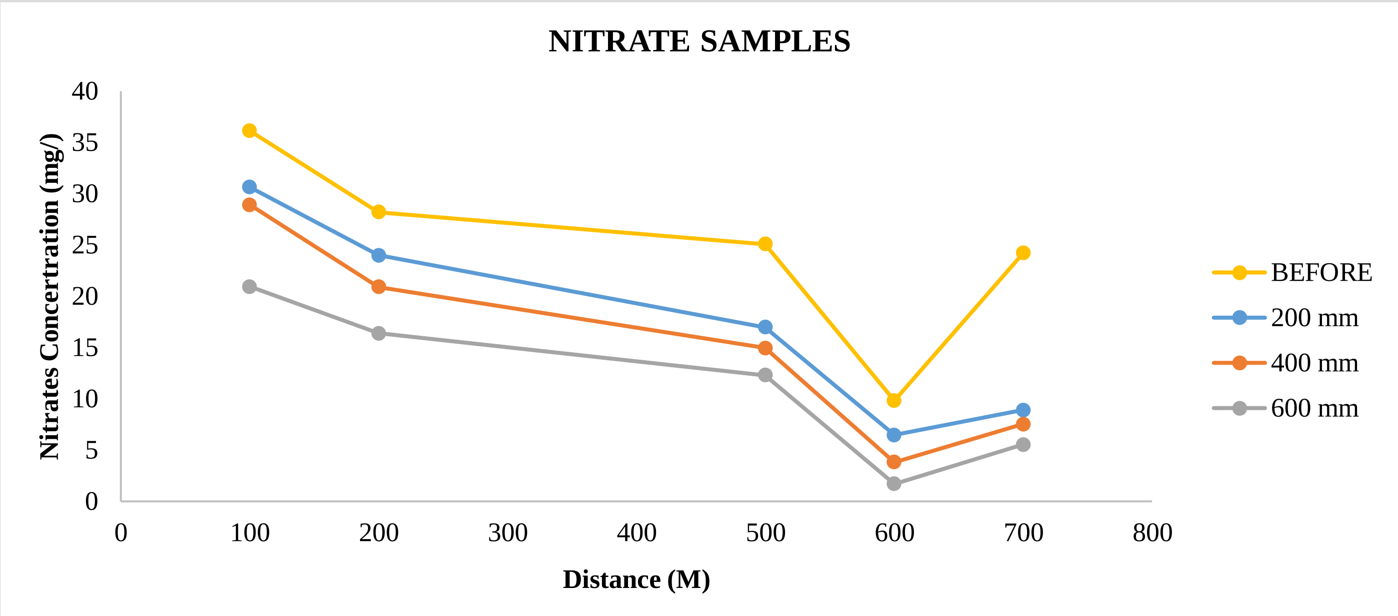

Figure 7

Variation of the Concentration of the Nitrates with Distance from the Composite Filter to River Isiukhu at Filter Depths of 200 mm, 400 mm.600 mm and before Filtration.

As shown in figure 7, 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 32.35 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 Isiukhu. At depth of 600 mm filter depth the level of Nitrate was 22.52 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 revealed that at 5% level, the composite filter installation had significant effect on the trend of quality of the effluent discharged from Shirere WWTP into river Isiukhu.

V. CONCLUSIONS & RECOMMENDATIONS

5.1 Conclusions

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.

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.

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 & Stiglain, 1996. 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.

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.

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.

Nitrates build up due to farming activities. Nitrates are rarely found in wastewater 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 (Camargo & Mara, 2010). 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.

5.2 Recommendations

The composite filter performance was 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. Therefore, the study recommended that, the composite filter reduced concentrations of all the parameters (COD, BOD, TSS, PO_3, NO_3) significantly from Shirere WWTP along Shikoye stream up to 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.

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