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Low Cost Filtration of Domestic Wastewater for Irrigation Purpose

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Abstract

Water scarcity in developing countries has forced farmers to use sewage as an alternative source of irrigation water. However, the usage of sewage for vegetable production has been known to cause excessive and often-unbalanced addition of nutrients hence posing a threat to food safety. The objective of this study was to determine the efficacy of slow sand filter and wetland plant in domestic wastewater treatment. To achieve this objective, samples were collected from the domestic wastewater collection pond within Jomo Kenyatta University of Agriculture and Technology (JKUAT). Laboratory tests were conducted on the collected samples and they revealed the presence of BOD, DO, pH, TDS, Sulfates, Chloride, Turbidity, Salinity, Conductivity, Alkalinity and Coliform; whose values varied when compared with that of the parameters for standard irrigation water. This gave insight to the kind of treatments and filtration medium that were required to transform domestic wastewater into water fit for irrigation. A slow sand filter bed was designed and constructed using precisely six samples materials; sand, sand and wetland plants, gravel, gravel and wetland plants, mixture of gravel and sand, mixture of gravel and sand with wetland plants. These materials were used to identify the chemical and biological changes in domestic wastewater within a seven-day period. The water collected from the slow sand filter was tested, results showed that, of all six samples, slow sand filter using the mixture of gravel, sand with wetland plants had an average percentage efficient of 90% in removing all impurities from domestic wastewater thereby turning it into water suitable for irrigation. It is hoped that this study will provide a safe, easy, eco-friendly and cheap method of wastewater treatment while ensuring the sustainability of wastewater for irrigation and the expansion of green spaces in urban and peri-urban areas.

Keywords

Domestic Wastewater, Irrigation Water, Slow Sand Filter

1. Introduction

1.1. Background of the Study

Wastewater according to Tchobanoglous and Burton (1995) is the combination of liquid waste or water-carried waste from households, institutions, commercial and industrial establishments, as well as groundwater, surface water and storm water. Domestic wastewater comprises 50% - 80% of residential wastewater. These come from households and assimilated persons such as hotels and business centers. They are a mixture of sewage and domestic wastewater. These waters represent at least 2/3 of the daily water consumption of each inhabitant, hostels and business centers. The majority of these wastewaters are managed by autonomous sanitation or discharged into the open-air canals. Although this used water may contain grease, food particles, hair, and any number of other impurities, it may still be suitable for reuse. Reusing domestic wastewater serves two purposes: it reduces the amount of freshwater needed to supply a household, and it reduces the amount of wastewater entering sewer or septic systems [1].

Wastewater reuse is proving to be one of the answers to water scarcity and the failure to satisfy the food demand that accompanies it. Reduction of relative dependence on portable water usage is becoming a necessary facet of good water management. In fact, agriculture is hampered by the scarcity of water and the problem of built land. Water stress in arid and semi-arid countries has encouraged farmers to use sewage as a source of irrigation. These types of practices are not without consequences on the environment and public health. The application of raw sewage is often implicated in the microbiological, physical and chemical contamination of vegetable, water bodies and soil. The use of raw wastewater poses real public health problems. There is an apparent necessity of sewage treatment before any usage of the water. Thus, many new or modified treatment processes are being investigated in attempt to solve the serious water supply and wastewater disposal problems of the growing population and its industries. Even with the application of the water-reducing scheme, a large amount of water is still required and eventually, reuse of water may have to be practice. Therefore, several possible reuses of water schemes such as distillation and membrane techniques for complete reuse and biological oxidation, filtration and disinfection schemes for partial reuse have been considered [2].

1.2. Statement of the Problem

In arid and semi-arid countries, freshwater for domestically industrial and agricultural use is generally unavailable. It is common for urban farmers in city to use untreated wastewater for irrigation. It was suggested that domestic wastewater from kitchen sink and dish washer should not be reused as these can contain heavy loads of organic materials, fats and caustic additives in high concentrations that are not readily broken down by soil organisms [3]. Soaps and detergents are components in domestic wastewater that could adversely affect plants the most. There is still much to be done in improving wastewater quality before reuse.

1.3. Objective of Study

Domestic wastewater, in the developing countries, is either allowed to flow either in open streets channels (gutter) or through sewers connected to a natural river. The objective of this study is to determine the potential of slow sand filter and wetland plant to treat domestic wastewater to meet up to the standard of the characteristics of irrigation water.

1.4. Scope of Study

The findings of this study rebound to the benefit of farmers using domestic wastewater as an important source of water in urban and peri-urban agriculture. The greater demand of water for agriculture and the increase of environment and public health problems due to wastewater use justify the need for more effective engineering approach. The study is to help uncover the critical area in wastewater treatment process that many researchers are looking to improve.

2. Materials

2.1. Characteristics of Domestic Wastewater

Analysis of water and wastewater is aimed at determination of the level of impurity and the type of treatment required for an effective purification before intended use. The analysis involves determining the physical, chemical and biological characteristics of wastewater [4]. Different types of waste materials are discharged into a variety of plumbing fixtures that are used at different times of the day and week. The characteristics of household wastewater change according to the composition, amount of food and water intake [5]. Discussed domestic wastewater from Jomo Kenyatta University of agriculture and Technology (JKUAT) were sampled once a week during one month. BOD, DO, pH, TDS, Sulphates, Chloride, Turbidity, Salinity, Conductivity, and Alkalinity tests were measured based on the standard method book, the results were given in Table 1.

2.2. Standard Characteristics for Irrigation Water

Table 2 presents the standard of irrigation water according to the world Food Organization. Therefore, there is a need to conform our water quality through lab tests.

1) ds/m = decisiemen/metre in S.I. units (equivalent to 1 mmho/cm = 1

Table 1. General characterization of the domestic wastewater used for treatment and collected within JKUAT.

Parameters	Range of value			Mean value	Standard of irrigation	Units
Resistivity	1.440	1.757	2.275	1.569	-	KΩ
Temperature	22.67	23.93	23.45	23.22	25	˚C
Ph	8.082	8.215	9.377	8.610	≤9	
BOD5	25.35	27.95	29.75	17.73	≤30	mg/L
DO	3.177	4.703	6.44	4.224	≤10	mg/L
TDS	283.0	340.3	303.8	318.0	≤2000	Ppm
Conductivity	567	676.3	712	631.5	≤3000	µS
Turbidity	5.133	5.8	6.45	5.528	≤30	NTU
Chloride	0.4263	1.1020	1.874	0.6891	35	Ppm
Sulphates	15.61	18.80	24.56	17.54	96	Ppm
Alkalinity	176.7	267.5	227.6	232.1	≤200	mg/L
Salinity	0.2133	0.2967	0.338	0.2561	≤10	Psu
TSS	3.96	4.19	4.25	4.13	≤30	mg/L
E. coli	146	192	251	196	≤800	CFU/100ml

Table 2. Laboratory determinations needed to evaluate common ırrigation water quality.

Water parameter	Symbol	Unit1	Usual range in irrigation water	
		Salinity		
Salt Content				
Electrical Conductivity	ECw	dS/m	0 - 3	dS/m
Total suspended Solids	TSS	mg/l	0 - 2000	mg/l
		Cations and Anions		
Calcium	Ca^{++}	me/l	0 - 20	me/l
Magnesium	Mg^{++}	me/l	0 - 5	me/l
Sodium	Na^{+}	me/l	0 - 40	me/l
Carbonate	CO_3^{-}	me/l	0 - 10	me/l
Bicarbonate	HCO_3^{-}	me/l	0 - 20	me/l
Chloride	Cl^{-}	me/l	0 - 30	me/l
Sulphate	SO_4^{-}	me/l	0 - 20	me/l
		NUTRIENTS2		
Nitrate-Nitrogen	NO_3-N	mg/l	0 - 10	mg/l
Ammonium-Nitrogen	NH_4-N	mg/l	0 - 5	mg/l
Phosphate-Phosphorus	PO_4-P	mg/l	0 - 2	mg/l

Continued

Potassium	K^+	mg/l	0 - 2	mg/l
		MISCELLANEOUS		
Boron	B	mg/l	0 - 2	mg/l
Acid/Basicity	Ph	1 - 14	6.0 - 8.5	
Sodium Adsorption Ratio (SAR) 3	SAR	(me/l) 1, 2	0 - 15	
Coliform		Cu/100ml	0 - 5000	Cu/100ml

millimmho/centi-metre) mg/l = milligram per litre ≈ parts per million (ppm). me/l = milliequivalent per litre (mg/l ÷ equivalent weight = me/l); in SI units, 1 me/l = 1 millimol/litre adjusted for electron charge.

2) NO_3-N means the laboratory analyses for NO_3 but reports the NO_3 in terms of chemically equivalent nitrogen. Similarly, for NH_4-N, the laboratory analyses for NH_4 but reports in terms of chemically equivalent elemental nitrogen. The total nitrogen available to the plant is the sum of the equivalent elemental nitrogen. The same reporting method is used for phosphorus.

3) SAR is calculated from the Na, Ca and Mg reported in me/l.

2.3. Laboratory Filter Dimensions

Thirty-six filters made of circular plastic containers whose capacity is 70 liters, the depth of the containers is 65 cm and the diameter is 45 cm. Six different arrangements of slow sand filter, replicated three times, were considered:

Slow sand filter composed of a 10 cm thick gravel layer of 25 mm grain size, a 10 cm thick gravel layer of 10 mm grain size and a 30 cm thick gravel layer of 5 mm grain size. Each layer was separate by a porous tissue material. This arrangement was coded as FG and represented by **Figure 1**:

Slow sand filter composed of a 10 cm thick sand layer of 0.15 mm grain size, a 10 cm thick sand layer of 0.60 mm grain size and a 30 cm thick sand layer of 0.35 mm grain size. Each layer was separate by a porous tissue material. This arrangement was represented by **Figure 2** and coded as FS:

Figure 3 shows the slow sand filter composed of a 10 cm thick gravel layer of 25 mm grain size, a 10 cm thick gravel layer of 10 mm grain size and a 30 cm thick gravel layer of 5 mm grain size. Each layer was separate by a porous tissue material. This arrangement was coded as FGP:

Slow sand filter composed of a 10 cm thick sand layer of 0.15 mm grain size, a 10 cm thick sand layer of 0.60 mm grain size and a 30 cm thick sand layer of 0.35 mm grain size with wetland plants is presented in **Figure 4**. Each layer was separate by a porous tissue material. This arrangement was coded as FSP:

Figure 5 is a representation of the slow sand filter composed of a 10 cm thick sand layer of 0.35 mm grain size, a 10 cm thick sand layer of 0.60 mm grain size, a 10 cm thick sand layer of 0.15 mm grain size, a 10 cm thick gravel layer of 5 mm grain size, and 10 cm thick gravel layer of 10 mm grain size. Each layer was separate by a porous tissue material. This arrangement was coded as FSG:

Slow sand filter composed of a 10 cm thick sand layer of 0.35 mm grain size, a 10 cm thick sand layer of 0.60 mm grain size, a 10cm thick sand layer of 0.15 mm grain size, a 10 cm thick gravel layer of 5 mm grain size, and 10 cm thick gravel layer of 10 mm grain size with wetland plants. Each layer was separate by a porous tissue material. Figure 6 represents this arrangement, which was coded as FSGP:

The main constituent materials of this study were natural coarse aggregates, natural river sand, and domestic wastewater. They are all locally available in Kenya, and the research was conducted at the Structural and Materials Laboratory of Jomo Kenyatta University of agriculture and Technology (JKUAT).

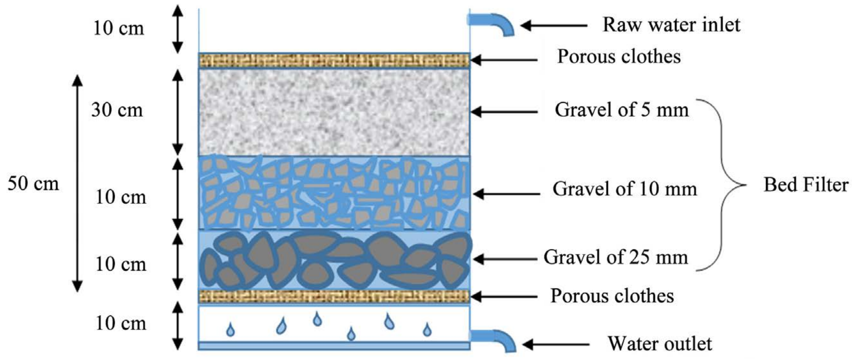

Figure 1. Slow sand filter (FG).

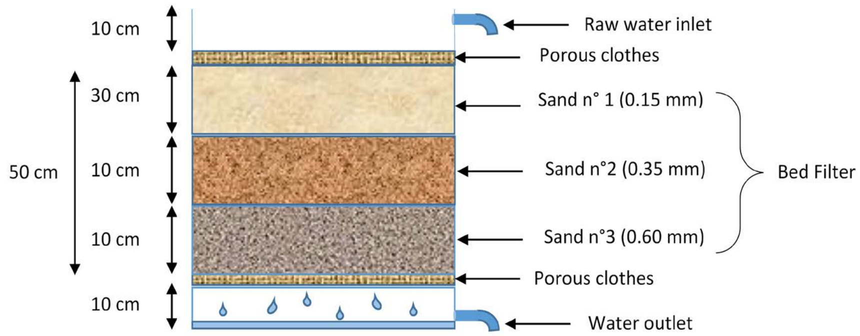

Figure 2. Slow sand filter (FS).

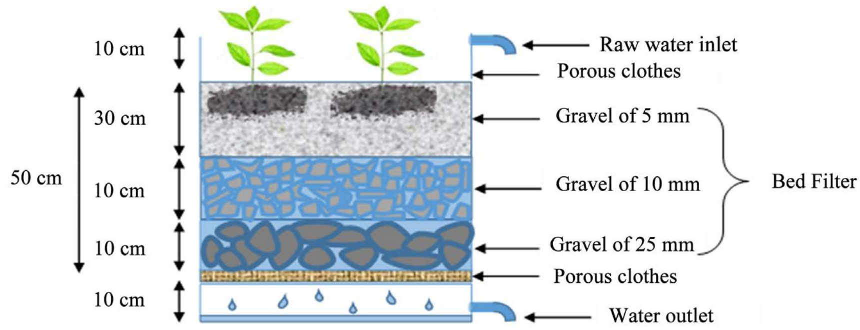

Figure 3. Slow sand filter with wetland plants (FGP).

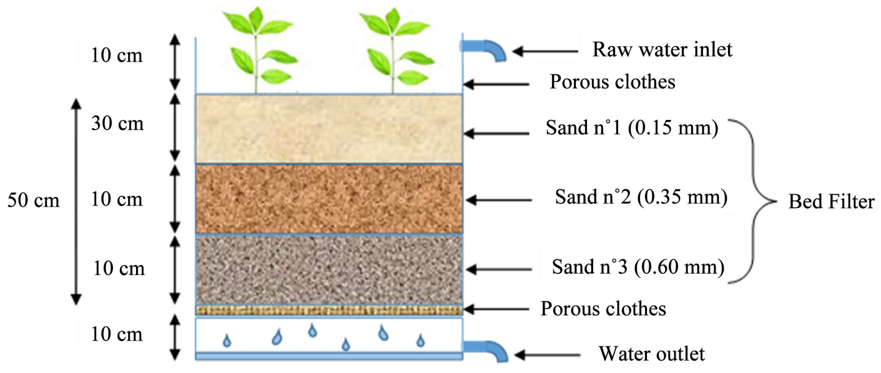

Figure 4. Slow sand filter with wetland plants (FSP).

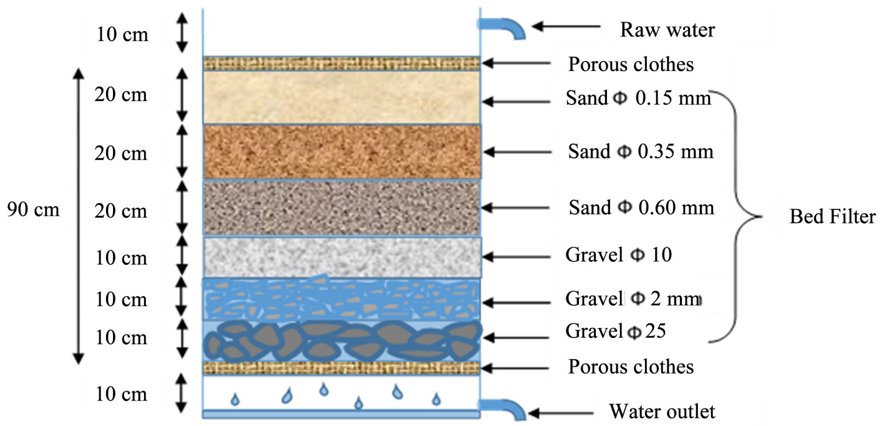

Figure 5. Slow sand filter with mix aggregates (FSG).

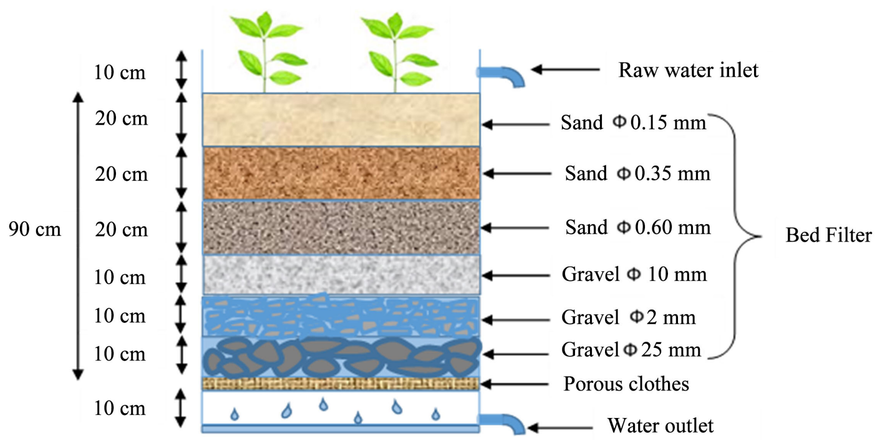

Figure 6. Slow sand filter with wetland plants (FSGP).

2.4. Natural River Sand

The sample sand used in this study was from Meru River in Kenya. This sand has a fineness modulus of 2.32 with particles sizes between 0 - 4.75 mm. The sand equivalent value and silt content value have been found respectively as 94.87% and 5.44%. Uniformity coefficient, specific density and porosity of the sand are 1.82, 1.48 and 0.42, respectively. The particle size distribution has been determined as shown in Table 3. Other physical properties of the sand such as bulk density (in SSD condition), apparent and absolute densities (in Oven-dry condition) and water absorption are summarized in Table 4. The sand used was found suitable to be used as a slow sand filter bed filter.

2.5. Natural Coarse Aggregates

Local coarse aggregate from Mlolongo quarries (Kenya) was used. The coarse aggregates have a maximum particle size of 25 mm with a finesse modulus of 5.85. The cleanliness of the coarse aggregate known in French as "Propreté des granulats" is 2.95%, which is below the limit 5% according to NF P 18-597. The physical properties of the coarse aggregate are reported to Table 4 whereas the particles size distribution is highlighted in Table 3. The properties make them suitable for use in slow sand filter.

2.6. Domestic Wastewater

The domestic wastewater to be treated in the study was obtained from the JKUAT university wastewater pond.

3. Experimental Program

Domestic wastewater is characterized according to the origin, which defines the specific treatment that can be implemented to purify the wastewater for

Table 3. Particle size distribution of sand and coarse aggregates.

Sieve size (mm)	Percentage of passing	
	Sand	Coarse
25	-	100
19	-	99.92
12.5	-	90.01
9.52	-	35.35
4.75	100	5.23
2.36	97.12	0.46
1.18	84.22	0.14
0.6	49.9	0.14
0.3	28.05	0.14
0.15	3.2	0.14

Table 4. Aggregates size distribution.

Aggregates	Loose bulk density (kg/m^3)	Rodded bulk density (kg/m^3)	Apparent density (kg/m^3)	Absolute density (kg/m^3)	Water absorption (%)
Sand	1465	1602	1480	2651	1.7
Coarse	1243.6	1179.11	1350	2516	4.6

non-potable uses such as irrigation. This work is divided into two parts: A first part that focuses into the cleaning of the slow sand filters aggregates, the characterization of the aggregates and the determination of the porosity. A second part is dedicated to the study of slow sand filter for the treatment of domestic wastewater. In this part, laboratory test to measure the physicochemical parameters like BOD, DO, pH, TDS, Sulphates, Chloride, Turbidity, Salinity, Conductivity, and Alkalinity. Survival studied of microorganisms like as E. coli was also investigated.

3.1. Aggregate Characterization

Two types of aggregates were used in the manufacturing of the filter media:

- The first is a natural river sand from Meru River in Kenya;
- The second is a natural coarse aggregate from Mlolongo quarries (Kenya).

Because the aggregates contain organic particles, a preparation was needed before it could be used. The sand was washed to remove all the fine clay and organic particles. It was then placed in an oven at 100˚C for 24 hours before undergoing sieving. Sieving was then performed using a series of sieves with opening size ranging from 1.5 mm to 200 µm for the sand and 25 mm to 5 mm. The tests sieves were arranged in a stack with the largest mesh openings at the top of the stack. The aggregates are placed on the top sieve. After sieving, all particles passing through the sieves with 200 µm and 5 mm opening were rejected. It should be noted that after removal of much finer grains, the aggregates used were heterogeneous.

The size distribution is represented by the uniformity coefficient, which enables us to see how well graded our sample is (that is, whether there is a completely different range of sizes, or whether most of the sample is only one size). This is calculated by taking the d_{60} and dividing by the d_{10}. The average particle size, *i.e.* the average equivalent diameter denoted dg is obtained by calculation of arithmetic mean. d_{10} and d_{60} represent the grain diameter in µm, for which, 10%, and 60% of the sample respectively, are finer than. **Figure 7** and **Figure 8** represented respectively the coarse aggregates and sand sizes distribution curves. For slow sand filtration, some degree of uniformity is desirable in order to ensure that the pore sizes between the grains are reasonably regular and that there is sufficient porosity.

Porosity of the three types of filter system was determined after packing a column, prior to experiments. The wetland plants within the filter system were not considered. Porosity was then calculated by measuring the volume of the solid phase needed to pack a column of a known total volume and was found to respectively for the sand and the coarse aggregates as presented in **Table 5**.

3.2. Slow Sand Filter and Experimental Method

The experiment was carried out at laboratory scale process using a slow sand filter to treat domestic wastewater for irrigation purpose. The above six different

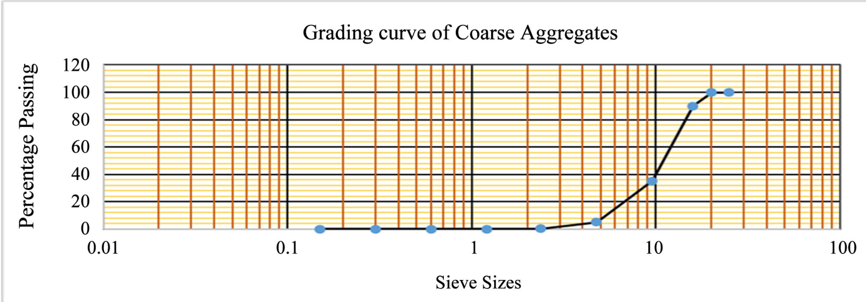

Figure 7. Coarse particles size distribution curve.

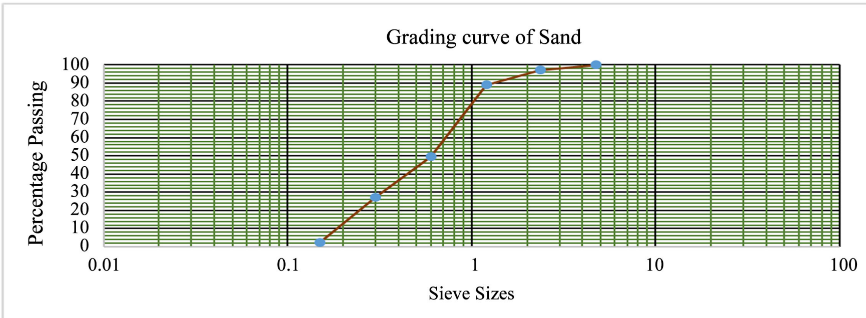

Figure 8. Sand particle size distribution curve.

Table 5. Porosity of the different types of filters.

Filters types	Water volume (ml)			Column sample volume (ml)			Porosity (%)			Mean porosity (%)
FS	165	175	170	400	400	400	41.25	43.75	42.5	42.5
FG	275	270	280	600	600	600	45.83	45.00	46.68	45.83
FGS	170	185	165	500	500	500	34.00	37.00	33.00	34.68

arrangements of slow sand filters, replicated three times, were used. The filters were made of circular plastic containers whose capacity is 70 liters, the depth of the containers is 65 cm and the diameter is 45 cm. The filter media was made of at least three medium which are fine or/and coarse gravel, both filling the entire 50 cm. The experimental set up was placed adjacent to the raw domestic wastewater storage tank at ambient temperature.

The filter operation was simple. First, close the outlet valve and open the inlet valve for the wastewater to enter into the filter and remain there for a 7 days to form the biological layer on its surface. Then, open the outlet valve to sample and collect the raw wastewater from the top inlet for laboratory analysis. Filtration worked from February to March 2018.

3.3. Sample Preparation and Laboratory Testing

1) Sample collection

Samples were collected mainly at two stages. First, samples were collected before the operation of filters. Secondly, samples were collected after the 7 days of filtration operation.

2) Preparation for Samples Collection

Before collecting samples from the filter system, some preparations were made. Bottles were washed and sterilized as follow:

a) For Physio-chemical test, 500 ml plastic bottles used for drinking water were used. Bottles were washed well and then were allowed to dry before sample collection.
b) For Biological test, 500 ml plastic bottles also were used. They were washed well with bleaching powder and then dried.

3) Samples before Filter operation

Sample were collected and tested before operation of the filter mainly to get general information about the quality of wastewater. For Physio-chemical Analysis, empty and washed bottles of mineral water were used. Samples were collected from JKUAT wastewater treatment ponds. The bottles were filled up to the top, so that oxygen from the air may not enter and mixed with the water, as it causes error in the test.

After sterilization was completed, samples for bacteriological testing were taken from the pond by filling water up to half in the bottles and lids were kept tight for easy transportation to the laboratory. Collected samples were placed in a cooler to provide favorable environment. The samples were then tested at laboratory.

4) Samples after Filter operation

Samples were tested after the operation of filter, as to see the performance of filter and its suitability for domestic wastewater treatment. Same procedure was adopted for Physio-chemical and Bacteriological tests as in above paragraph. Wastewater samples for Physio-chemical and Bacteriological analysis were collected from installed filters after passing through filter media in the same way as mentioned earlier.

5) Laboratory analysis

The parameters measured at within the JKUAT Environmental Engineering Laboratory, include the physico-chemical parameters such as pH, conductivity, Total dissolved Solids (TDS), Dissolved Oxygen (DO), Turbidity and Temperature. The chemical parameters measured include Chloride, Sulphates and BOD while the bacteriological parameter measured was fecal coliform. The above parameters were selected based on their importance in wastewater treatment and reuse for irrigation.

Temperature and pH which are among the physico-chemical parameters can help understand the operating conditions of the system while TDS, Conductivity and DO can provide the primary indication of the chemical constituents available in the wastewater. BOD was measured to help quantify the oxygen consumed by bacteria from the decomposition of organic matter. Fecal Coliform is used as an indicator for fecal pollution therefore it was used to portray a picture of the biological pollution loading.

The physico-chemical parameters were measured JKUAT Environmental Engineering Laboratory. DO, pH, TDS, Conductivity, salinity and Temperature were measured using the Multi-parameter Water Quality Meter (Benchtop 900). The turbidity was measured using an SGZ-B portable turbidity meter (SGZ-20B). The analysis of the BOD was done using ampero-metric determination of DO.

Fecal Coliform was analyzed using the broth culture technique. The appropriate samples treatments such as dilution using dilution water were done before incubating at temperature of 35˚C for 48 hours.

4. Results and Discussion

4.1. Physical Parameters

The samples obtained from each slow sand filter output were analyzed in triplicate. The results of the analysis of the input and output domestic wastewater from the university wastewater treatment pond were analyzed. The following bar charts show the variations of each parameter before and after filtration. The average values of each parameters of the input and output domestic wastewater are shown in **Table 6**.

4.2. Quality of Grey Water

The temperature recorded from the domestic wastewater varies from 21˚C to 21.5˚C. Temperatures recorded are below 35˚C, considered as a direct discharge limit in the receiving environment [6]. The pH oscillates between 7.34 and 8.15. Electrical conductivity shows a wide variation in the composition of effluents, it varies between 354 μS/cm and 490.3 μS/cm. The conductivity values recorded at the output exceed of 2 μS/cm. The primary effect of total salinity is to reduce crop growth and production. Total salinity is generally expressed by overall mineralization or electrical conductivity. The maximum chloride value recorded is 0.4217 mg/liter and the minimum value is 0.1140 mg/liter. The recorded concentrations is far low than the limit concentration of direct release into the receiving environment (50 mg/liter) [7]. The low chloride content is obviously due to the low use of common salts (sodium chloride) in food preparation. The maximum and minimum sulfite concentrations obtained at the output range respectively from 10.99 mg/liter to 15.73 mg/liter.

The presence of alkalinity is on the high side. This may be attributed to the kind of laundry powders and soaps use in cleaning by the university Staff.

4.3. Performance of Filter

Comparing the following bar charts, it was found that there was a significant reduction in the strength of the domestic wastewater and hence the quality of each parameters in the filtration process. The efficiency of the filter in the reduction of all the parameters was high due to their tangible nature which enable them to succumb surface forces of the filter media; among which are the Van

Table 6. Wastewater quality before and after filtration.

	before filtration		After filtration		
Parameters	Range value	Mean value	Range value	Mean value	Units
Resistivity	1.440 - 1.757	1.569	1.743 - 2.703	2.341	KΩ
Temperature	22.67 - 23.93	23.22	21 - 21.53	21.37	˚C
Ph	8.082 - 9.377	8.610	7.344 - 8.145	7.617	
BOD5	13.35 - 27.95	17.73	6.700 - 16.450	10.50	mg/L
DO	3.177 - 4.703	4.224	1.270 - 2.053	1.686	mg/L
TDS	283.0 - 340.3	318.0	187.9 - 255.3	225.9	ppm
Conductivity	567 - 676.3	631.5	354 - 490.3	423.9	µS
Turbidity	5.133 - 5.800	5.528	3.2 - 4.567	4	NTU
Chloride	0.4263 - 1.1020	0.6891	0.1140 - 0.4217	0.2679	ppm
Sulfite	15.61 - 18.80	17.54	10.99 - 15.73	13.75	ppm
Alkalinity	176.7 - 267.5	232.1	127.5 - 144.2	136.1	mg/L
Salinity	0.2133 - 0.2967	0.2561	0.1233 - 0.1833	0.1461	psu

Dar Waals forces that bind the particles to the surface even though, they may bear the same electrical charge as the filter grains. For this reason, even for highly turbid domestic wastewater, the output was so clear, that the bottom of the containing vessel can be seen (*i.e.* high reduction of turbidity). The relatively large surface area of the filter media or the interface in contact with the water and its impurities are also contributing factors [8].

1) Turbidity

Figure 9 shows that the turbidity of the domestic wastewater is virtually reduce by all the different types of slow sand filters since their operation, as high as the turbidity of the raw domestic wastewater.

The use of the wetland plants has a meaningful importance in the reduction of the turbidity. In fact, the different filters with wetland plants have a higher removal percentage compared to the filter without wetland plants. This is due to the whole network o roots that the wetland plants were able to create at the top of the filter. It has allow the retention of some particles.

The transport mechanisms of the wastewater within the filter best explain the change in the colour and turbidity of the water. The particles contained in the water are brought into contact with the sand according to the following processes:

- Screening or sieving: It consists of the retention of particles whose diameter is greater than the space left by the grains between them. This sieving is all the more extensive as the grains are small and angular in shape.
- Sedimentation: The sand layer also behaves as a sedimentation basin, with the sedimentation surface being the sum of the small upward grain areas.

2) Salinity

The Food and Agriculture Organization of the united Nation requires a limit of 3 dS/m. Compared to this standard our treated water fall in this range. Figure 10 shows the variation of the salinity within the different filter. The input water has a lower salt content because the university does not employ many chloride product unless for the cleaning service. The filters with gravel has the greatest removal percentage of the salinity followed the filter with sand. The wetland plants did not make a difference within the filter system. In contrary, the salinity may have affected the plants in their process of cleaning the wastewater.

3) Total Dissolved Solids (TDS)

The process of dissolved solid is a complex process involving biological and chemical reaction within the bed filter. The variation of the total dissolved solids concentration is represented by Figure 11. Under the influence of sunlight, algae grow and absorb the nutrients contained in raw water such as nitrates, carbon dioxide, phosphates by transforming them into cell walls and oxygen.

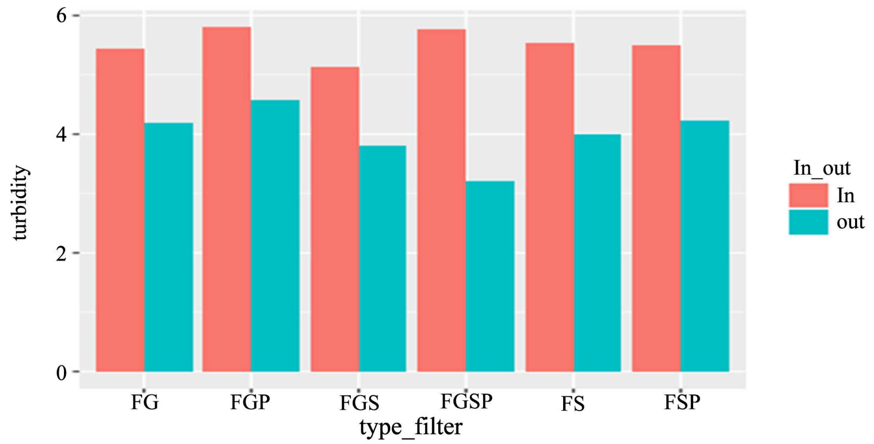

Figure 9. Turbidity.

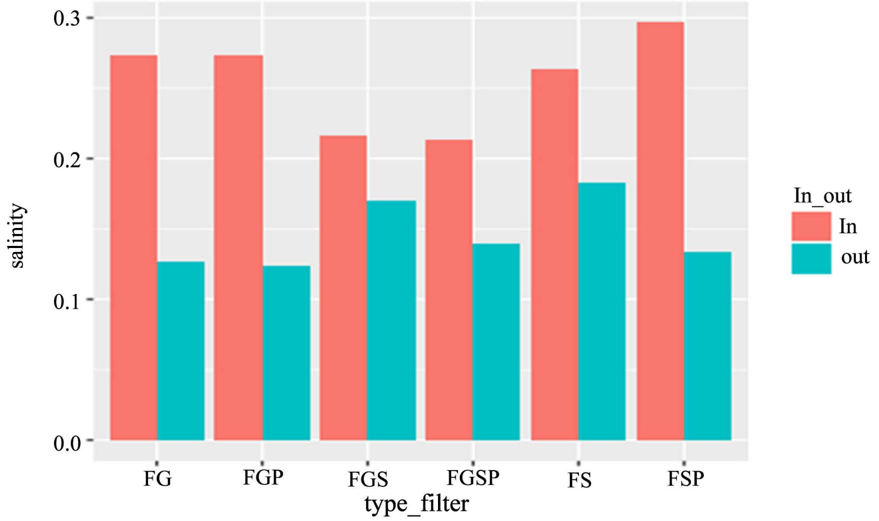

Figure 10. Salinity.

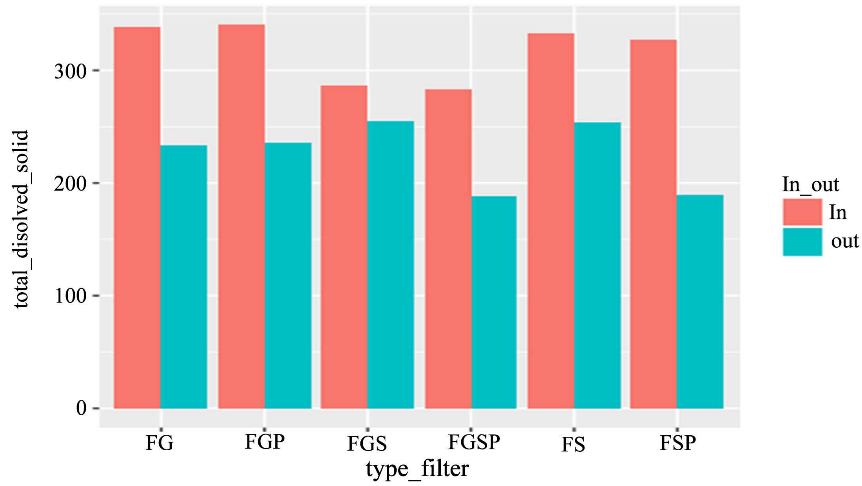

Figure 11. Total dissolved solids.

In this study, the total dissolved solid is not of high value as compared to the previous studies because the project was done during the raining season of Kenya. The lack of sunlight is a better explanation of these values. By observing **Figure 11** we can notice that the filter with sand aggregate have higher value of total dissolved solids than the gravel aggregates. This is due to the favorable condition offer by the sand in the formation of the biological membrane. The gravel is less favorable due to the size of the grain. Thus, less biological activity to transform the solids. Unlike the gravel, the filters with plants have a lower value of dissolved solids because the plants are using them to grow. The wetland plants are therefore efficient in the treatment of dissolved solids when incorporated in a slow sand filter.

4) Biochemical Oxygen Demand (BOD_5)

Figure 12 represents the variations in the BOD concentration of the collected and filtered wastewater for each type of filter. High BOD is an indication of poor water quality. Authorized BOD are 30 mg/l, respectively, for agriculture. Biochemical Oxygen Demand, BOD removal percentages are in line with what was finding in the literature reviews. Literature review suggested a 70% removal of the BOD with a height of 0.6 - 1.2 m while in our case we have a removal percentage of more 90% with a height of 40 cm. A filter with a depth of 35 cm works well to maintain dissolved oxygen stability in the filter.

Generally, biochemical oxygen demand (BOD) is used as an index for organic matter. In a high BOD environment, oxygen in water is consumed for decomposing organic matters to create an anaerobic state, and, during the process of decomposition, oxides in the soil such as Fe^{3+}, Mn^{5+}, and SO_4^{2-} consume oxygen to lower the oxidation-reduction potential. In the end, the generated iron, manganese, and sulfides along with organic acids can disrupt the paddy crop to absorb nutrients [8].

5) Alkalinity

An alkalinity test measures the level of bicarbonates, carbonates, and hydroxides in water and test results are generally expressed as "ppm of calcium carbonate ($CaCO_3$)". The desirable range for irrigation water is 0 to 100 ppm calcium carbonate. Levels between 30 and 60 ppm are considered optimum for most plants. Irrigation water tests should always include both pH and alkalinity tests. Figure 13 shows the alkalinity concentration of all the filters before and after filtration.

In our case, the Alkalinity is of higher value than the desirable range due to the use of bicarbonates substances used in the university. However, the slow sand filters were able to reduce the alkalinity up to 50%. The wetland plant has a little effect in the reduction of the alkalinity as derived from Figure 13.

6) Chloride

The chloride content is very low and obviously due to the general use of less common salts (sodium chloride) in cleaning. All the filters reacted positively in the reduction of the chloride. The filter with sand has the best removal percentage of chloride. This is due to a very good biological bed, which was able to reduce the chloride concentration. The chloride concentration of all the filters before and after filter is presented in Figure 14.

7) Sulphates

One of the adverse effects of sulphate in the environment is its conversion in a process known as bacterial sulphate reduction where sulphate/sulphure is converted to hydrogen sulphide:

$$SO_4^{2-} + 2CH_2O = H_2S + 2HCO_3^-$$

According to the EEC standard (1975), the limit concentration for the sulphates is 250 mg/L. In the case of this study, the concentration is far below the limits, which is in the order of 19 mg/L. Figure 15 is a best representation of the sulphates variation before and after filtration for all the filters. The filter with a mix of the aggregates has the higher removal percentage followed by the filters with gravel. The filter with sand has a lower removal percentage.

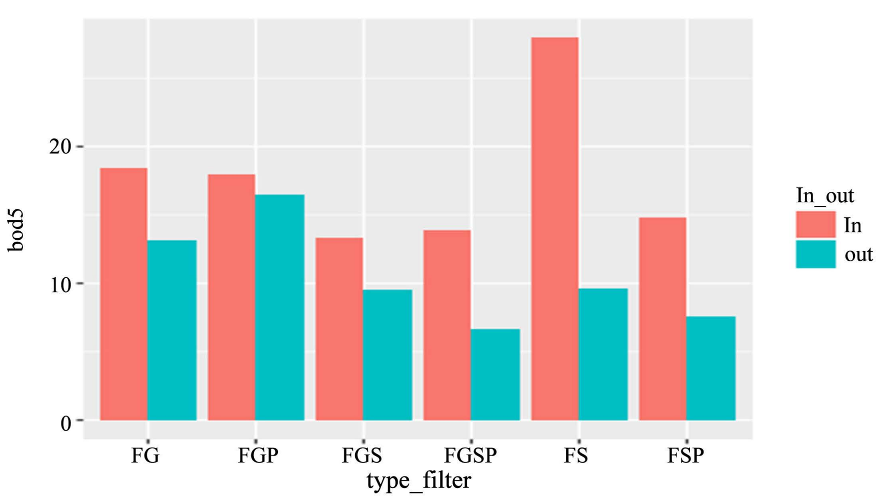

Figure 12. Biochemical oxygen demand (BOD_5).

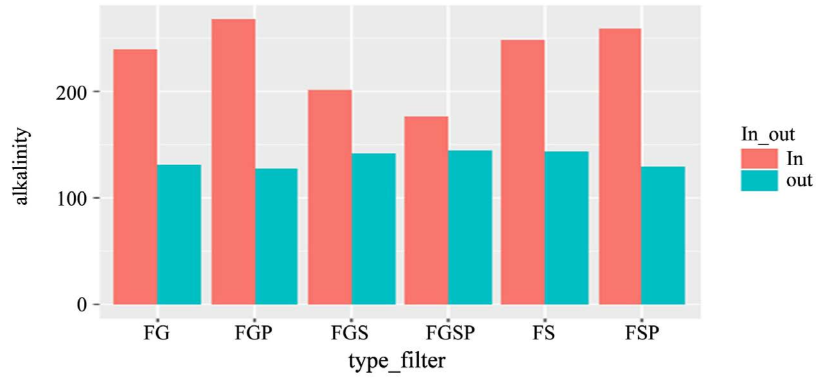

Figure 13. Alkalinity.

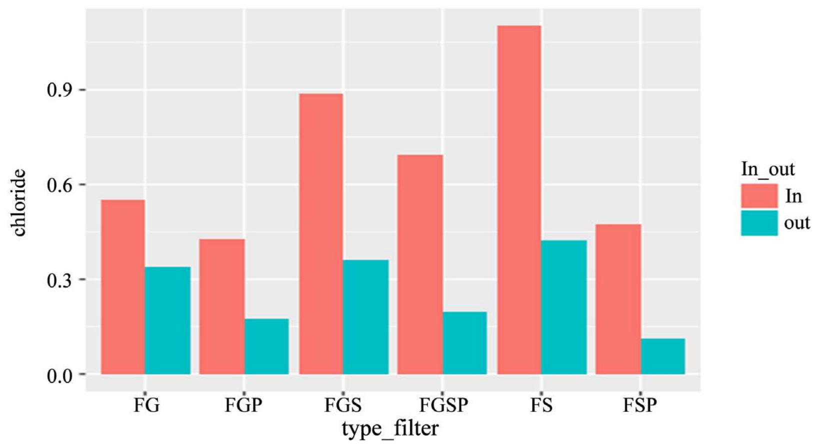

Figure 14. Chloride.

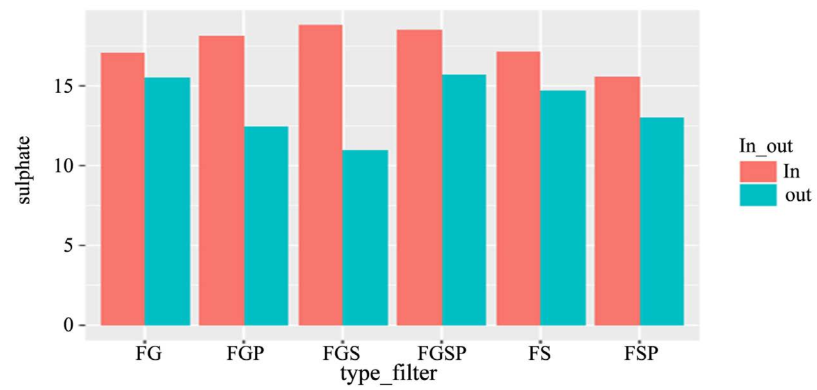

Figure 15. Sulphates.

5. Conclusion

The use of aggregates as filter media is proven to be effective. Indeed, it is required to have relatively large depth and surface area of natural aggregates for effective filter. This is therefore a major method of conservation of potable water for irrigation uses in the future most especially in arid and semi-arid areas. As regard to the results obtained from this investigation, some conclusions can be drawn: Authorized BOD is 30 mg/l, respectively, for agriculture. Thus, it can be concluded that the output of the filter is suitable for agricultural use in terms of BOD.

6. Recommendations

Some recommendations can be made as regard to the results obtained from the study.

Parameters such as heavy metals, sodium and nutrients are very important in agricultural water uses because they are the source of heavy metals of industrial wastewater. Although the discussed sewage is domestic wastewater, it is necessary to complete the research on the removal of such metals by slow sand filter system in future. More comprehensive research and experiments are necessary for the removal of sodium and nutrients.

In addition, the results obtained are opened to further research and improvement. The efficiency of these filters could be improved by varying the sizes, ranges, proportions and depth of the bed filter.

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References

[1] Agunwamba, J.C. (2001) Waste Engineering and Management Tools. Immaculate Publications Ltd., Enugu, Nigeria.

[2] Crook, J. (1991) Quality Criteria for Reclaimed Water. *Water Science and Technology*, **24**, 109-121. https://doi.org/10.2166/wst.1991.0241

[3] Estrey, O.M. and Morgan, P. (1991) Effects of Improved Water Supply and Sanitation on Ascaris Disarrhoea, Dracunculias and Trachoma. *Bulletin on WHO*, **69**, 609-621.

[4] Agunwamba, J.C. (2000) Water Engineering System. Immaculate Publications Limited, Enugu, Enugu State, Nigeria, 92-118.

[5] Agbogu, V.N., Umoh, V.J., Okuofu, C.A., Smith, S.I. and Ameh, J.B. (2005) Study of the Bacteriological and Physiochemical Indicators of Pollution of Surface Waters in Zaria; Nigeria. *African Journal of Biotechnology*, **5**, 732-737.

[6] Ministère de l'Environnement du Burkina Faso (2013) LOI N°006-2013/AN PORTANT CODE DE L'ENVIRONNEMENT AU BURKINA FASO.

[7] Ukpong, E.C. and Agunwamba, J.C. (2012) Grey Water Reuse for Irrigation. *International Journal of Applied Science and Technology*, **2**, 97-113.

[8] Asano, T., Burton, F.L., Leverenz, H., Tsuchihashi, R. and Tchobanoglous, G. (2007) Water Reuse: Issues, Technologies, and Applications. McGraw-Hill, New York.