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Pilot Scale Investigation on the Removal of Pollutants from Secondary Effluent to Meet Botswana Irrigation Standards Using Roughing and Slow Sand Filters

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Abstract**—**Botswana is an arid country that needs to start reusing wastewater as part of its water security plan. Pilot scale slow sand filtration in combination with roughing filter was investigated for the treatment of effluent from Botswana International University of Science and Technology to meet Botswana irrigation standards. The system was operated at hydraulic loading rates of 0.04 m/hr and 0.12 m/hr. The results show that the system was able to reduce turbidity from 262 Nephelometric Turbidity Units to a range between 18 and 0 Nephelometric Turbidity Units which was below 30 Nephelometric Turbidity Units threshold limit. The overall efficacy ranged between 61% and 100%. Suspended solids, Biochemical Oxygen Demand, and Chemical Oxygen Demand removal efficiency averaged 42.6%, 45.5%, and 77% respectively and all within irrigation standards. Other physio-chemical parameters were within irrigation standards except for bicarbonate ion which averaged 297.7±44 mg L^{-1} in the influent and 196.22±50 mg L^{-1} in the effluent which was above the limit of 92 mg L^{-1}, therefore averaging a reduction of 34.1% by the system. Total coliforms, fecal coliforms, and *Escherichia coli* in the effluent were initially averaging 1.1 log counts, 0.5 log counts, and 1.3 log counts respectively compared to corresponding influent log counts of 3.4, 2.7 and 4.1, respectively. As time passed, it was observed that only roughing filter was able to reach reductions of 97.5%, 86% and 100% respectively for faecal coliforms, *Escherichia coli*, and total coliforms. These organism numbers were observed to have increased in slow sand filter effluent suggesting multiplication in the tank. Water quality index value of 22.79 for the physio-chemical parameters suggests that the effluent is of excellent quality and can be used for irrigation purposes. However, the water quality index value for the microbial parameters (1820) renders the quality unsuitable for irrigation. It is concluded that slow sand filtration in combination with roughing filter is a viable option for the treatment of secondary effluent for reuse purposes. However, further studies should be conducted especially for the removal of microbial parameters using the system.

Keywords**—**Irrigation, roughing filter, slow sand filter, turbidity, water quality index.

I. INTRODUCTION

REUSE of treated effluents is emerging as a renewable resource which increases with increase in water use [1]. The use of wastewater for irrigation is reported to be more widely applied as it has the benefit of considerable nutrient content [2]. However, wastewater is associated with the problem of undesirable levels of salinity and heavy metals as a result of insufficient treatment or lack of treatment. The challenge of using wastewater is due to pathogenic load from human and animal excreta [2]. Such pathogens can contaminate crops, pose health risks for agricultural workers, consumers and anybody who handles such crops. Several studies have shown that pathogenic microorganisms, biochemical oxygen demand, and total suspended solids can be removed by systems such as aerated lagoons, down flow hanging sponge, rotating biological contactors, trickling filters, and biological aerated filters [3]. However, the authors report that these technologies require high energy and huge capital cost and high operation and maintenance costs. In addition, the effluent from these technologies does not meet the set thresholds for disposal. More studies have been conducted on the use of filtration systems for the removal of pollutants from drinking water [4]. Such studies have proven that these systems have the ability to remove suspended solids, turbidity, and organics. In addition, [3] argued that slow sand filtration system has the advantage of high cost efficacy, high effluent quality, and operation simplicity hence best option for post treatment. Recent studies have focused on the use of the technology for wastewater treatment [4]. Reference [5] conducted a study on the treatment of wastewater using constructed soil filters, and results revealed an increase in dissolved oxygen levels, reduction of chemical oxygen demand from 352 mg L^{-1} to 20 mg L^{-1}. Biochemical oxygen demand was reduced from 211 mg L^{-1} to 7.0 mg L^{-1}. Some media have been tried on their efficacy for removal of faecal indicators such as *Escherichia coli* from wastewater. For instance, [6] used copper-zeolite as a filter material for the removal of *Escherichia coli* from storm water. Incorporating copper zeolite into the bio filters was reported to have improved *E. coli* log removal rate by 53%. In a study conducted by [3] for post treatment of up flow anaerobic sludge blanket effluent, it was reported that laboratory scale slow sand filtration removed 91.6% turbidity, 89.1% suspended solids, 77% chemical oxygen demand, 85% biochemical oxygen demand, 99.95% total and faecal coliforms and 99.99% faecal streptococci.

Even though many studies have been conducted on slow

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sand filters as an option for tertiary treatment for secondary effluents, there are few studies that have incorporated roughing filters as pre-treatment options. Furthermore, such studies have not been conducted in Botswana using some local available filter media to try to treat effluents to a level that meets irrigation standards of the country. Therefore, the objective of this study was to investigate the performance of a combination of roughing and slow sand filters as post treatment technology for polishing effluent from waste stabilisation ponds to meet Botswana irrigation standards. The study was conducted through pilot scale columns.

II. MATERIALS AND METHODS

A. Site Description

The study site was at Botswana International University of Science and Technology wastewater treatment system near maturation ponds. These works are located at the north-western end of the campus, and treat sewage from an initial population of 600 people though expansion of the facility is currently underway. The treatment works have been in operation since 2014 for the treatment of a design flow of 446 m^3d^{-1}.

B. Experimental Set up

The experimental rig consists of 1000 litres plastic tank placed on 2.5-meter stand. This tank feeds an acrylic roughing filter of cross sectional area 0.36 m^2 by 1.0 m depth acrylic on 1.5 m stand, which in turn feeds a slow sand filter of similar and same size on a 0.5 m stand (Fig. 1).

Fig. 1 Experimental setup for this study

C. Filter Bed Material

1. Roughing Filter

The filter bed is composed of different local materials of different layers and sizes placed in order of sizes with the smallest on top and larger at the bottom. The flow was in a downward direction. Gravel was collected from local quarry and coal clinker ash from BCL LTD mine in Selibe Phikwe, 150 km from study area. The media sizes and depths were as shown below (Table I) making a total depth of 0.52 m.

TABLE I
MEDIA SIZE AND DEPTH FOR ROUGHING FILTER

Media size (mm)	Depth (mm)
	Gravel
19	0-100
13	100-250
10	250-350
7	350-420
Coal ash clinker	
4	420-430
2.36	430-480
1.8	480-520
Total media depth	**520**

The media was washed with distilled water to remove organic matter and other contaminants and air dried in the laboratory. The drying process lasted for two weeks after which the materials were mechanically sieved through BS 410:1986. Under drainage system consisted of four 20 mm diameter plastic pipes of lengths 0.5 m with holes on top and connected in the centre by a circular plastic pipe draining to the outlet at the bottom. The four pipes were capped at the ends so that water drained to the centre. A plastic (polymer mesh) was placed on top of the drainage pipes to trap any fine particles that could block the outlet.

Media was placed into the column starting with the largest (19 mm), and each layer was gently compacted before placing the next layer. The procedure was repeated until the last layer consisting of 1.8 mm material was placed.

2. Slow Sand Filter

TABLE II
MEDIA SIZE AND DEPTH FOR SLOW SAND FILTER

Media size (mm)	Depth (mm)
	Gravel
19	0-100
13	100-250
10	250-360
Slag	
7- 4	360 - 470
Sand	
3.75 – 0.8	470 - 620
0.8 – 0.15	620 - 760
Total media depth	**760**

Media for slow sand filter was placed into the filter in the same manner as for roughing filter. The materials used were gravel collected from local quarry, slag sourced from BCL LTD mine, and river sand purchased from a local supplier. The sand was sieved through a stack of sieves to determine particle size distribution. The important parameters were determined which were the effective size (D_{10}) which is the diameter in the particle size distribution curve corresponding to 10% finer, the uniformity coefficient, (Cu) which is $\frac{D60}{D10}$, where D_{60} is the diameter corresponding to 60% finer in the particle size distribution. The media sizes and depths were as per the table below (Table II) with the overall bed depth of 760 mm.

The same procedure that was used for placing media into the tank was similar to that used for roughing filter with media washed with distilled water and dried. The same sizes of drainage system and polymer mesh were placed at the bottom of the column for the same purpose as for the roughing filter. Slag was chosen in order to find out whether it could remove phosphate ions from wastewater.

3.Pipe Connections

Pipes of sizes 20 and 15 mm were used for connecting the tanks. The pipe from the feed or storage tank into the roughing filter was 20 mm in diameter and that from the roughing filter into the slow sand filter was 15 mm in diameter. Pipe connections were from the bottom of each tank arranged in such a way that wastewater is gravitated from one tank to another. The storage tank was filled by a pump from the last maturation pond. Sampling points were placed along the outlet pipe of each tank. In addition, there were valves from the outlet of each tank to control the flow rates or hydraulic loading rates.

4. Covers

Cover nets in the form of polythene nets were placed on top of the filters to prevent birds, insects, leaves and other materials finding their way into the tanks. The walls of the tanks were covered with the nets to minimise sunlight contact which could promote excessive algal growth.

5. Experiments Procedure

Operation of the pilot facility started in October 2017 with hydraulic loading rates controlled at the outlet valves. During the first 28 days of the experiment, the hydraulic loading rate was adjusted to 0.04 m d^{-1} and thereafter to 0.12 m d^{-1}. A splash plate in the form of a stone was placed on the surface of media directly below the discharge hose to prevent media disturbance in both filters. The water level above the bed was kept at 10 cm for both filters with a free board of 15 cm. Periodic scrapping of the top layer of sand was carried out when it was found that there was an increase in headloss.

6. Sample Collection

Sampling was conducted in accordance with Botswana Bureau of Standards protocol, BOS ISO 5667-3 2003. Samples were collected from three samplings points from storage tank, roughing filter and slow sand filter tank. Sampling commenced after two weeks which was presumed to be the ripening period. Samples were collected into cleaned, rinsed and sterilised plastic or glass bottles depending on the parameters to be analysed. Bottles were then placed on cooler box containing ice to keep them at cool temperature during transportation to the laboratory. For metal analysis, samples were preserved by adding nitric acid.

7. Analytical Method

The physiochemical parameters such as pH, turbidity, electrical conductivity (EC), salinity, total dissolved solids (TDS), temperature, and dissolved oxygen (DO) were analysed on site. Turbidity was analysed using DR 900 multiparameter portable colorimeter, supplied by HACH, United States of America. Dissolved oxygen was analysed using Bench 2700 series meter supplied by Oakton Instruments, United States of America. The other parameters were analysed using portable multiparameter Testr^{TM} 35 series meter supplied by Thermo Fisher Scientific. Samples were also periodically quantified for total coliforms, faecal coliforms and *Escherichia coli* (*E. coli*) population as per Standard Methods (APPHA, 1998) through external laboratories.

D. Raw Effluent Quality

The study was conducted from October 2017 using secondary effluent from Botswana International University of Science and Technology (BIUST) wastewater treatment plant, which was a waste stabilisation system. The main wastewater characteristics of the site are summarised in Table III.

TABLE III
PHYSIO-CHEMICAL AND MICROBIAL ANALYSIS RESULTS FROM BIUST TREATMENT FACILITY

Parameter	BIUST Pond Inlet	BIUST Pond Outlet	BOS 463 2011 OR BOS 93: 2012 Wastewater Standard (Other Environments)
Nitrate, N	1.0	1.6	30
Chloride, Cl	27	30	350
Sodium, Na	50.8	57.5	230
Iron, Fe	0.07	0.11	5
Turbidity (*NTU)*	155	210	30
Electrical Conductivity µS/cm	1126	1006	3000
Total Dissolved Solids (TDS)	562	503	2000
Total Suspended Solids (TSS)	489	534	100 (drip irrigation)
Dissolved Oxygen (DO)	11	27.5	Min 60%
Chemical Oxygen Demand	50	120	Max. 150
Biochemical Oxygen Demand	50	70	Max. 30
pH	8.3	7.4	6.5 – 8.4
Zinc, Zn	0.020	0.073	2.0
Copper, Cu	0.005	0.090	0.2
Escherichia coli (count/100 ml)	240000000	1600	1000
Fecal coliforms (count/100 ml)	300000000	1700	1000
Total coliforms (count/100 ml)	420000000	2000	20000

E. Weighted Arithmetic Water Quality Index Method

The calculation of water quality index (WQI) was based on the weighted arithmetic water quality index method (AWQI) as described by [7]. The method classifies the water quality according to the degree of purity using commonly used parameters. 18 physiochemical parameters were used in the calculation and the standards used for the parameters were from Botswana Bureau of Standards (BOS 463: 2011). The following equation as described by [7] was used for the calculation:

$$WQI = \frac{\Sigma QiWi}{\Sigma Wi} \qquad (1)$$

The quality rating scale (Qi) for each parameter was calculated from the equation:

$$Qi = 100[(\frac{Vi-V0}{Si-V0})] \qquad (2)$$

where Vi is the concentration of analysed parameter in the analysed water, V_0 is the ideal value of the parameter in pure water and it is 0 except for pH which is 7.0 and dissolved oxygen which is 14.6 mg L^{-1}, si is the recommended standard value of the parameter. The unit weight (Wi) for each water quality parameter was calculated from the equation:

$$Wi = \frac{K}{Si} \qquad (3)$$

where K = proportionality constant and can be calculated from:

$$K = \frac{1}{\Sigma(\frac{1}{Si})} \qquad (4)$$

Water quality index rating as per [7] is described in Table IV and was used for classifying the water as per water quality index value.

TABLE IV
ARITHMETIC MEAN WATER QUALITY INDEX RATING [7]

WQI Value	Rating of water quality	Grading
0-25	Excellent water quality	A
26-50	Good water quality	B
51-75	Poor water quality	C
76-100	Very poor water quality	D
Above 100	Unstable for drinking purposes	E

III. RESULTS AND DISCUSSION

A. Particle Size Distribution

The particle size distribution of the sand is shown in Fig. 2. The effective grain size d_{10} is 0.45 mm, d_{60} is 1.1 mm and the uniformity coefficient d_{60}/d_{10} is 2.4. The D_{30} value of the sand was 0.69 mm; hence the coefficient of degradation is 0.96.

The recommended range of effective size of sand used in slow sand filtration is 0.15 – 0.35 mm and uniformity coefficient is 1.5 – 3. Other authors have reported effective grain sizes of 0.3-0.45 mm, 0.15 -0.3 mm [8]. The effective size of the sand used in this study was on the upper limit of the recommended range (0.45 mm), but uniformity coefficient (C_u) value (2.5) is within range. The higher Cu value implies that the range of particle sizes in the sand was larger. This might affect filter performance at higher hydraulic loading rates as small particles may fill interstices between large particles and may result in reduced hydraulic conductivity and block the filter media [8]. Other studies [9] have suggested effective size of the sands for slow sand filters to range between 0.3 and 1.5 mm, which implies that the sand used in this study would be in the range. Studies have reported that removal of bacteria, turbidity and colour are not very sensitive to sand size of up to 0.45 mm when flow rate is kept constant at 0.1 m h^{-1}. However, some authors such as [10] have reported that typical recommendations for slow sand filter grain size to be 0.15 mm < d10 < 0.4 mm. This range suggests that the effective grain size used in this study was slightly larger. They further report that the recommended Cu is < 5, filter bed depth > 50 cm and hydraulic loading rate of 0.05 to 0.4 m hr^{-1}. The hydraulic loading rate in this pilot study was varied between 0.04 and 0.12 m hr^{-1} suggesting that a better efficacy for bacteria, turbidity and colour removal could be achieved.

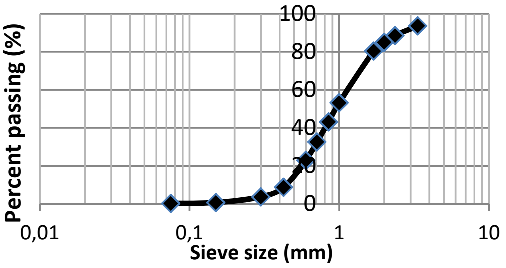

Fig. 2 Particle size distribution curve of the sand used in slow sand filter

B. Turbidity

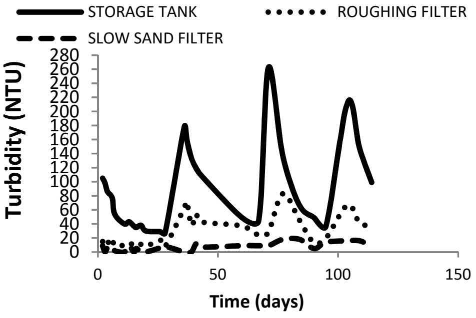

Fig. 3 Reduction of turbidity in storage tank, roughing and slow sand filters

Turbidity has been reported as one of the most important parameters for monitoring the performance of a filter [3]. Turbidity can carry nutrient and pathogens which can lead to biological activity. Fig. 3 shows effluent turbidity concentrations from the three tanks. The high peaks shown on storage correspond to concentration ns of feed water immediately after being pumped from maturation pond to the holding or storage tank.

The recommended limit of turbidity for disposal into water courses and other environments as per Botswana Standards is 30 Nephelometric Turbidity Units (NTU), and no limit has been recommended for irrigation purposes. Turbidity decreased through the system with effluent from slow sand filter ranging between 0 and 18 NTU and averaging 4.0±3.81 NTU. Feed turbidity from the storage tank ranged between 105 and 262 NTU. The storage tank was able to reduce turbidity to as low as 27 NTU with mean turbidity of settled wastewater in the tank being 83±27.8 NTU. The removal efficiency by the storage tank averaged 16.86±17.39% with minimum and maximum efficiencies of 3.3% and 55.04% achieved respectively. These results indicate that the storage tank was able to pre-treat the wastewater before treatment through the roughing filter. This suggests that some suspensions and colloidal particles were able to be reduced in the tank. This could have minimised clogging in the roughing filter hence increased its run time. Turbidity values from roughing filter effluent averaged 11.4±4 NTU with minimum and maximum values of 8 and 20 were observed. The removal efficiency averaged 75.0±12.4%, with 91.8% and 24.5% maximum and minimum efficiencies was observed, respectively. The use of multi grades of filter media in roughing filters has been reported to promote penetration of particles through the filter bed [11]. The roughing filter in this study consisted of different media sizes increasing downward. This could have improved efficiency of the filter in turbidity removal. In the case of slow sand filter, minimum and maximum values were 0 and 18 NTU respectively, and the average value in the effluent was 4 ± 3.8 NTU with removal efficacy ranging between 36% and 100% and the average efficiency being 70.7±26.6%. Increasing the hydraulic loading rate from 0.04 m/day to 0.12 m/day did not have much effect on the reduction of turbidity. The average effluent turbidity concentrations were 4.0 ±3.8 NTU and 5.6 ±4.87 NTU respectively for hydraulic loading rates of 0.04 m/day and 0.12 m/day. Reference [12] reported that an increase from short to long retention time can be expected to increase turbidity removal by 3.85%and decreased effluent turbidity by 0.40 NTU. The finding is similar to this study where reducing retention time decreased percentage removal by 0.5 percent and increased effluent turbidity by 1.85 NTU. The contribution by both storage tank and roughing filter in reducing the turbidity of the wastewater before passing through the slow sand filter is paramount. The use of multimedia beds in both roughing and slow sand filter could have contributed to high turbidity removal. Particle straining was enhanced due to the formation of biological active layer on the filter surface (Schumutzdecke) which was observed on both roughing and sand filters. The same was reported by [13] who conducted a study on surface and groundwater treatment using biosand filter. Turbidity removal in slow sand filters has been reported to be directly related to sand depth [14]. Since the wastewater during this study passed through roughing filter (520 mm) and then through slow sand filter (760 mm) that made up of 1280 mm depth, this depth increased the reduction of turbidly in the wastewater. At times 100% efficiency was achieved. It has been reported by [15] that increasing the number of filter layers reduces or resists the effect of increased hydraulic loading rate, therefore giving a robust filter performance. Since both roughing and slow sand filters were composed of multilayers of different particles, this contributed to high turbidity removal even when HLR was increased from 0.04 m d^{-1} to 0.12 md^{-1} as 100% efficiency could be observed at times.

C. Performance on Physiochemical Removal

Concentrations or loads of different pollutants from outlets of storage tank, roughing and slow sand filters are shown in Table V. The table shows maximum, minimum and average concentrations as observed from the three tanks.

TABLE V
MAXIMUM, MINIMUM AND MEAN CONCENTRATIONS OF PHYSIOCHEMICAL PARAMETERS FROM STORAGE, ROUGHING AND SLOW SAND FILTERS

Parameter	**Storage tank**			**Roughing filter**			**Slow sand filter**			
	Max	Min	Mean	max	Min	Mean	Max	Min	Mean	BOS 463:2011
TDS (mg L^{-1})	686	341	555±92	666	349	494±76	581	213	428±76	2000
Electrical conductivity (μS/cm)	931	747	837±79	856	623	734±79	671	599	642.5±17.8	3000
Salinity (mg L^{-1})	470	362	417.9±79	471	324	367.6±4	402	305	320±28	
SAR	3.2	3.0	3.08±0.1	3.40	3.25	3.31±0.08	3.85	3.60	3.72±0.12	8
SO4 (mg L^{-1})	65	28	43.31±20.7	60	36	47±16	63	35	48±18.5	200
BOD (mg L^{-1})	8	5	5.5±0.7	6	3	5±1.4	4	2	3±1.4	-
Nitrates (mg L^{-1})	20.5	0.08	7.74±10.8	15.9	0.035	6.47±9.1	12.9	0.14	5.05±6.9	30
COD (mg L^{-1})	223	58.95	130.8±84	60	31.5	44.15±17.9	40	25	30.4±8.0	-
pH	7.87	7.36	7.56±0.2	8.53	7.65	7.61±0.25	9.36	7.81	8.6±0.4	6.5-8.4
Suspended solids (mg L^{-1})	58	11	27±26.85	31	15	22±12	21	8	15.75±7	100
Phosphate (mg L^{-1})	12.74	6	8.96±5.3	7.54	5	6.1±2.1	2.88	2.0	2.29±0.8	-
Bicarbonate (mg L^{-1})	347.7	264.7	297.7±44	280.65	187.88	233.44±46	249.5	148.84	196.22±50.6	92
Sodium (mg L^{-1})	92	58	73±17	96	64	78±16	100	70	83±15	230
Iron (mg L^{-1})	0.61	0.11	0.28±0.28	0.26	0.07	0.23±0.1	0.19	0.03	0.09±0.09	5.0
Manganese (mg L^{-1})	0.26	0.08	0.19±0.09	0.17	0.03	0.13±0.09	0.1	0.03	0.07±0.038	0.2
Turbidity (NTU)	262	27	83.6±27.8	83	8	11.4±4.0	18	0	4.0±3.8	30
Dissolved oxygen(mg L^{-1})	8.0	6.5	7.3±0.54	9.0	8.5	8.75±0.21	10	8.5	9.25±0.65	7.25
Calcium (mg L^{-1})	49	31	42±6.0	45	36	30±5	37	33	32±3.2	
Magnesium (mg L^{-1})	20.35	17.35	18.85±1.29	19.0	16.5	16.5±4.0	20	14	16±2.1	

D. Total Dissolved Solids

Total dissolved solids (TDS) concentrations were observed to be decreasing as the wastewater passed from storage tank to roughing and slow sand filters. This was supported by maximum, minimum and mean concentrations from the three tanks. Effluent from storage tank had high concentrations of TDS followed by that from roughing filter and then slow sand filter. Mean concentrations from these tanks were 555±92, 494±76 and 428±76 respectively, indicating a reduction in concentration as the wastewater passed through each tank. All the concentrations were below the irrigation threshold in Botswana which is 2000 mg L^{-1}. The highest percent removal in roughing and slow sand filters were 21 and 23 percent respectively (not shown). It was also observed that, in some instances, the concentrations of TDS from roughing filter were higher than that from storage tank and that from slow sand filter being higher than that from roughing filter. This could have been as a result of media in these tanks ionising and hence increasing salt concentrations in the effluent of the tanks. Such increases were not concerned as the concentrations from slow sand filter were always much lower than the threshold limit. It has been reported by [16] that irrigation water with TDS less than 450 mg L^{-1} is considered good and that value greater than 2000 mg L^{-1} is unsuitable for irrigation purpose. As observed in this study, the maximum concentration observed was 686 mg L^{-1}, lower than the 2000 mg L^{-1} threshold. High concentration of TDS in irrigation effluent may result in soil salinity build up in the root zone there by increasing the osmotic pressure of the soil solution which can reduce water uptake by plants [17] . It is interesting to note that TDS results have revealed (not shown) that these parameter concentrations were reduced as wastewater passed through each tank. Similar results were reported by [18] who reported efficacy of 94% of roughing filters in removal of TDS from wastewater. The contribution of each component in the system cannot be ignored.

E. Bicarbonate Ion

From Table V, it is observed that all the other parameters except bicarbonate were lower than the prescribed limits. The average concentrations of bicarbonate ion in the effluent from storage tank, roughing filter and slow sand filter were 297.7±44, 233.44±46 and 196.22±50, respectively. Though this was a reduction in concentration as the wastewater passed through the system, the resulting values in the final effluent were greater than the recommended limit of 92 mg L^{-1}. The high concentration of bicarbonate ion in the effluent can lead to increased concentration of the ion in the soil water. This could lead to calcium and magnesium precipitating as insoluble salts. The reduction of these ions can lead to increased sodium absorption ratio and increase sodium hazard [19]. The likely source of bicarbonate ion is carbon dioxide (CO_2) in the atmosphere which dissolved and became hydrated to form carbonic acid (H_2CO_3) and then underwent two stages of dissociation producing HCO_3^- and CO_3^{2-} ions. Lime soda ash softening can be used to precipitate the carbonate ion in order to avoid hardness of the resulting effluent which can corrode irrigation equipment [19]. The bicarbonate ion can also lead to high levels of pH rise which will make water unsuitable for irrigation purposes. Dosing by an acid such as sulphuric acid can lower the pH of the effluent before irrigation. The pH rise was at times observed in the final effluent from slow sand filter where values greater than 8.6 units were observed which could have been a result of high bicarbonate ion concentration.

F. Electrical Conductivity

The electrical conductivity values detected from the effluent were lower than the permissible limit as the maximum value was 931 µS cm^{-1} lower than the maximum threshold of 3000 µS/cm (Table V). Average concentrations in the effluent from storage, roughing and slow sand filters were 837±79 µS cm^{-1}, 734±79 µS cm^{-1}, 642.5±17.8 µS cm^{-1}, respectively. Though the concentration of electrical conductivity was low, over time this can lead to accumulation of salts in the soil, resulting in reduced osmotic potential and soil fertility [20]. Plants will have less available water [21]. Reduction of electrical conductivity has been reported to be due to adsorption of cations on the negatively charged colloids [9]. The same authors report that another removal process is due to ionic absorption after migration through the column. It is evident from the results in Table V that electrical conductivity values from samples analysed were suitable for irrigation purposes. It is therefore necessary to monitor soil conditions periodically so that remedial measures can be taken earlier if the effluent is used for irrigation.

G. Salinity

Average salinity values detected from storage, roughing filter and slow sand filter tanks were 417.9±79 mgL^{-1}, 367.6±4 mgL^{-1} and 320±28 mgL^{-1} respectively (Table V). The corresponding maximum values were 470 mg L^{-1}, 471 mg L^{-1} and 402 mg L^{-1} indicating that concentrations in the roughing filter were higher than in the storage tank. This was a suggestion that some of the media in the tank were dissolving, hence increasing the salinity of wastewater in the filters. Though it has been reported that salts are not removed during wastewater treatment [22], these results show otherwise.

H. Other Physiochemical Parameters

The same trend was observed in the reduction of other parameters such as suspended solids (SS), BOD and COD (Table V). On average, percent removals of SS by roughing filter and slow sand filter were 18.5% and 28.41% respectively, and the overall average efficiency of the system was 42.6%. The removal of BOD by roughing and slow sand filter averaged 9% and 40% respectively with the observed overall average efficiency of 45.5%. The corresponding removal of COD was 66% and 31% respectively by roughing and slow sand filter, and the system average efficiency was 76.76%. Though the removal of suspended solids was minimal, the average effluent concentration (15.75±7 mg L^{-1}) was far less than the recommended limit of 100 mg L^{-1} hence within the required regulation. This low removal could be due to large effective grain size used (0.45 mm), increasing bed depth might result in higher efficiency. The BOD removal is comparable to the findings of [10] who reported a removal in the range of 34 to 66% whose effective size ranged between 0.25 mm and 0.82 mm and bed depth of 50 cm. In this study, the effective sand bed depth of 14 cm comprised of media grain size between 0.15 and 0.8 mm which was way below 50 cm used by [10]. COD removal was also comparable to the findings of the same authors who reported an efficiency of 14% to 43%. As for metals, it was observed that the removal of iron and manganese was achieved through both roughing and slow sand filters. The same was reported by [23] who studied the removal of the two ions from wastewater using biological roughing up flow filtration technology. The success of the technology was attributed to both biotic and abiotic mechanisms. The pH of the wastewater was observed to be high in the slow sand filter effluent than the effluent coming from the roughing filter and storage tank. Average pH values from storage tank, roughing and slow sand filters were 7.56±0.2, 7.61±0.25, and 8.6±0.4 units respectively. The corresponding maximum values were 7.87, 8.53, and 9.36 respectively showing an increase as water passed through the two filters. This could have been due to calcium oxide which was detected in both coal ash clinker and slag hence making the effluents from the two filters alkaline in nature. Dissolved oxygen concentrations from the three tanks were larger than the minimum value limit of 7.25 mg L^{-1}. Average concentrations in the effluent from storage, roughing and slow sand tanks were 7.3±0.54, 8.75±0.21 and 9.25±0.65 mg L^{-1} respectively. These results show that the water was aerated in all the tanks hence minimal possibilities of anaerobic digestions. Oxygen from the atmosphere dissolved into the water and since the tanks had free board provision this helped dissolution of oxygen. Low BOD in all effluents from the tanks meant that there was low depletion of DO in the system. Some of the parameters such as calcium and magnesium have no discharge limits to compare. But, these parameters play an important role in irrigation water. For instance, these ions will precipitate carbonate ions to form calcium carbonate or magnesium carbonate which will make infiltration of water into the soil difficult. In general, physio-chemical parameters did not pose any danger if the effluent was to be used for irrigation purposes except bicarbonate ion.

I. Faecal Indicator Bacterial Removal

The concentrations of bacteriological indicators from the three tanks are shown in Table VI. On average, the faecal coliforms concentrations in the effluent from storage tank, roughing filter and slow sand filter were 88728±183347, 2257±4213 and 13221±35434 coliform forming units per 100 ml of sample respectively. The results reveal that on average, roughing filter was able to remove 4.9 log counts of faecal coliform, which was 97.5% efficiency, but then the faecal coliforms in slow sand filter increased by 4.0 log counts, a 486% increase. The corresponding *E. coli* average concentrations from the same tanks were 634±1067, 88±229 and 330±526 coliform forming units per 100 ml, respectively. This was a reduction by 2.74 log counts which was 86% removal in the roughing filter and then an increase of 2.38 log counts or 275% increment in slow sand filter. Respective analysed total coliforms average concentrations were 320036±606096, 159340±227556, and 244483±376338 coliform forming units per 100 ml of sample. Roughing filter removed total coliforms by 5.20 log units (50%) and there was an increase by 4.93 log units (53%) in slow sand filter. The same results were reported by [24] who observed an increase of concentrations of standard plate count and coliform bacteria results in the effluent of slow sand filter. The fact that effluent concentrations exceeded influent concentrations was reported to be due to synthesis of attached bacteria on sand media. The other reason reported was that the internal biological population of the sand bed metabolises convected microorganisms until its capacity is exceeded and at that stage some of the influent organisms pass through the filter. Since the filter was loaded from concentrated sewage, the capacity of the base level of bacterial to metabolise was overwhelmed [24].

TABLE VI
BACTERIOLOGICAL INDICATOR CONCENTRATIONS FROM THE THREE TANKS

Parameter	Storage tank			Roughing filter			Slow sand filter			
	Max	Min	Mean	max	Min	Mean	Max	Min	Mean	BOS 463:2011
Faecal coliforms (CFU/100 ml)	500000	1700	88728±183347	200	0	2257±4213	30000	0	13221±35434	1000
E. coli (CFU/100 ml)	1600	0	634±1067	610	0	88±229	1450	0	330±526	1000
Total coliforms	68000	180	320036±606096	20000	2700	159340±227556	60000	2400	244483±376338	20000

Despite this, total coliforms, fecal coliforms and Escherichia coli in the effluent were at times as low as 1.1 log counts, 0.5 log counts and 1.3 log counts respectively compared to corresponding influent log counts of 3.4, 2.7 and 4.1 respectively. There were instances where faecal and *E. coli* were not detected in the effluent suggesting that all were removed by the filters. It has been reported that straining and adsorption are responsible for retaining pathogens in porous media [25]. For straining to be successful, pores of media should be smaller than the bacteria. Hence, it is evident that grain size and bacterial size are factors that would influence straining. In this study, the effective grain size of sand media in slow sand filter was 0.45 mm in diameter which could have been bigger than bacteria hence poor straining. This could be achievable for soils such as silt, clay and fine sand as they have pore sizes closer to most bacteria [25]. It has been reported that cells with lengths less than 1 μm are transported easily through porous media. Reference [26] reported that there are particles in surface water that are much smaller than pore size of media for example bacteria, viruses and colloidal particles which penetrate deeper into the bed. These particles are likely to be flushed out if there is no biofilm formation on media which will restrict their penetration. Reference [27] have reported that bed depth have no significance in bacteriological removal as depths of 0.5 m, 0.7 m and 1.0 m were observed to have no variation in reduction of coliforms. But, the authors have reported that bacteriological removal efficiency becomes sensitive to bed depth with larger sand sizes because of reduced surface area on media with larger grain sizes. Since effective grain size used in this study was 0.45 mm compared to recommended size of 0.15 mm, this could have contributed to lower removal efficiency observed at some instances.

In general, poor removal efficiency of the microorganisms by slow sand filter was noted, and the concentration in the effluent was higher than that from roughing filter. The particle size of the filter sand could have a played an impact on removal efficiency as the sand used was 0.45 mm in diameter compared to 0.15 mm used in other studies.

J. Irrigation Water Quality Index (Physiochemical)

Irrigation water quality index (IWQI) for this study as determined from various physio-chemical parameters is presented in Table VII. The observed values for the threshold as per Botswana Bureau of Standards- water quality for irrigation 2011 are shown. Unit weights and quality rating of the parameters are shown in the table. The irrigation water quality index calculated from these parameters give a value of 22.79 and since the value is between 0 and 25, it indicates excellent water quality [28]. Such water can be used for domestic, irrigation and industrial purpose. The results indicate that for the monitored physio-chemical parameters, the effluent from the treatment facility is good for use to irrigate plants. The variations of the observed values of the analysed parameters with time during the monitoring period were not high and values were always within the permissible BOS 463: 2011 limits. Only bicarbonate ion exceeded the limits very high, 196 mg L^{-1} compared to 92 mg L^{-1}. The effluent pH was also found to exceed the limit at times though not much.

K. Water Quality Index Based on Microbiology

Water quality index in terms of bacteriological analysis indicate that the water is not fit for irrigation (Table VIII) as the index is above 100. It will need additional treatment before reuse such as Ultra violet disinfection or chlorination.

TABLE VII
CALCULATED IRRIGATION WATER QUALITY INDEX OF PHYSIOCHEMICAL PARAMETERS FROM SSF

Parameter	Observed values (vi)	Standard values (si)	1/Si	Wi = K/Si	Quality rating (qi)	wiqi
pH	8.6	6-8.4	0.119	0.045	114.29	5.14
Electrical conductivity	642.5	3000	0.00033	0.000125	21.42	0.00268
Total dissolved solids	428	2000	0.0005	0.000189	21.4	0.00404
Turbidity	4	30	0.033	0.0125	13.3	0.166
Salinity	320	1000	0.001	0.000375	32	0.012
Sulphates	48	200	0.005	0.00188	24	0.045
Bicarbonate	196	92	0.0109	0.0041	213	0.873
Iron	0.09	5.0	0.2	0.075	1.8	0.0135
Suspended Solids	15.8	100	0.01	0.00375	15.8	0.059
SAR	3.72	8	0.125	0.0469	46.5	2.18
BOD	3	70	0.0143	0.00536	4.28	0.023
COD	30	150	0.0083	0.0025	20	0.05
Manganese	0.07	0.5	2	0.75	14	10.5
Sodium	101	230	0.004	0.00163	43.9	0.0716
Chlorine	33	350	0.003	0.00107	9.43	0.010
Dissolved oxygen	9.25	7.25	0.138	0.05	72.79	3.64
Σsi			**2.67**	**1.00**		**22.79**
WQI						**22.79**
K			**0.375**			

TABLE VIII
MICROBIOLOGICAL WATER QUALITY INDEX RESULTS

Parameter	Observed values (vi)	Standard values (si)	1/Si	Wi = K/Si	Quality rating (qi)	wiqi
Faecal coliforms	6570	1000	0.001	0.488	657	321
E. coli	325	1000	0.001	0.488	325	159
Total coliforms	54936	20000	0.00005	0.0244	54936	1340
Σsi			**0.00205**	**1.00**		**1820**
WQI						**1820**
K			**488**			

Before any optional disinfection is tried, further investigations will be carried out by using sand media with effective grain size close to 0.15 mm and also increasing bed depth for both media. Decrease in d_{10} has been reported by

[10] to reduce *E. coli* concentrations in the effluent. They also reported that an increase in uniformity coefficient resulted in *E. coli* reduction. So finer and homogeneous sand material results in higher *E. coli* reduction. The removal of these organisms is usually through attachment on media and grazing by other organisms such as protozoa [10].

IV. CONCLUSION

The use of slow sand filtration with incorporated roughing filter for the treatment of secondary effluent to meet Botswana irrigation standard has been investigated. The system was able to remove turbidity to satisfactory standards. Physio-chemical parameters were also very low in the final effluent except bicarbonate ion which was found to be way above the limit. Roughing filters were able to reduce bacteriological counts but it was observed that at times these increased in slow sand filter effluent. The calculated water quality index for physio-chemical parameters revealed good quality water which could be used for irrigation purposes, but bacteriological index suggested very poor quality. Further investigations such as using finer media and increasing bed depth need to be investigated.

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