

Performance Assessment of a Locally Constructed Wastewater Sludge Filter in the Tolon District of the Northern Region of Ghana

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ABSTRACT

Wastewater sludge has attracted global interest due to its source, volume, quality, treatment, disposal, and reuse. It impacts human life and ecosystems, especially in areas facing water scarcity caused by factors such as climate change, increasing global population, urbanisation, and water pollution. The study evaluated the performance of a locally constructed filter for treating wastewater sludge, aiming for potential reuse in irrigation and non-critical applications. The filter was constructed using materials like chippings and river sand with varying grain sizes, arranged in three layers. Parameters considered for evaluation included up-flow velocity, hydraulic retention time, flow rate, and filtration velocity. The porosity of the filter materials, such as crushed stones and river sand, was 44.7% and 5.9%, respectively. The pH of the wastewater sludge slightly increased from 6.20 before filtration to 6.61 after filtration. TDS levels decreased from 102.67 mg/L to below detection limits while turbidity reduced from 8198.67 to 19.0 NTU post-treatment. Salinity levels dropped significantly from 201 to 0.002 mg/L, indicating a 99.99% removal efficiency. Dissolved oxygen (DO) and other parameters also improved. The counts of total coliform, faecal coliform, and *E. coli* decreased markedly from 200 to 100 CFU/100 ml, 60 to 8 CFU/100 ml, and 25 to 4 CFU/100 ml, respectively. The designed filter effectively improved the quality of wastewater sludge post-treatment, bringing it within acceptable limits. Future research could examine the filtered and unfiltered wastewater sludge produced at the Savannah Agricultural Research Institute water treatment plant for irrigating various vegetables and monitoring their growth and yield.

Keywords: Wastewater sludge, filter design, filtration, wastewater quality, irrigation.

Introduction

Water scarcity is an escalating global crisis driven by climate change, rapid population growth, urbanization, and increasing pollution of freshwater sources (Chitonge *et al.*, 2020). In response, wastewater reuse has emerged as a viable strategy to supplement freshwater resources, particularly for agricultural irrigation.

Using wastewater for irrigation holds significant potential, especially in areas where water is scarce (Almukhtar *et al.*, 2018). Treated wastewater, when safely and effectively managed, offers considerable potential for enhancing water security, especially in water-stressed regions (Maryam and Büyükgüngör, 2019). According to Winpenny *et al.* (2010), the

reuse of wastewater can generate multifaceted benefits for urban populations, rural farmers, and ecosystems alike.

In sub-Saharan Africa, including Ghana, the seasonal and often unpredictable nature of water supply presents a critical challenge to sustainable agricultural production. The Northern Region of Ghana, including the Tolon District, experiences pronounced dry seasons and irregular rainfall patterns, making irrigation difficult to sustain using conventional freshwater sources. Despite the pressing need, most rural communities lack access to centralized wastewater treatment systems, and the reuse of treated wastewater remains limited due to infrastructural, technical, and policy constraints (Mugagga and Nabaasa, 2016).

Recent efforts at the Council for Scientific and Industrial Research – Savanna Agricultural Research Institute (CSIR–SARI) have led to the development of a locally constructed wastewater sludge filtration system intended to treat residual sludge generated during water purification. This sludge, produced during coagulation and flocculation using alum sulphide and subsequent disinfection with chlorine, is currently underutilized or disposed of without environmental safeguards. However, this by-product holds untapped potential for safe reuse in irrigation if properly treated (Bauer *et al.*, 2021).

Despite various global advancements in low-cost wastewater treatment technologies, little has been documented regarding context-specific, locally adapted sludge treatment systems suitable for resource-constrained settings like the Tolon District. The scientific and technical performance of such systems, particularly with respect to their filtration efficiency, operational sustainability, and agricultural suitability, remains an understudied area. This study therefore aims to evaluate the performance of a locally constructed wastewater sludge filter in the Tolon

District, with the goal of determining its viability for small-scale irrigation reuse.

The core objective was to assess the filtration efficiency of the system and its potential to produce water that meets quality standards for non-potable use, while also aligning with the broader goal of enhancing local water-use efficiency. The research addressed a clear knowledge gap concerning the treatment and reuse of sludge in semi-arid rural Ghana, and it sought to contribute evidence-based insights that can inform local water management strategies and policy frameworks. This study was particularly relevant to the achievement of the United Nations Sustainable Development Goals (SDGs), notably SDG 6 (Clean Water and Sanitation) and SDG 12 (Responsible Consumption and Production) (Jeong *et al.*, 2016). Wastewater reuse could support the UN's 2030 Sustainable Development Initiative, especially its sub-target to improve water quality by eliminating dumping, reducing contamination, and minimizing the share of untreated water by 2030. It could also significantly increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater, helping to address water scarcity and substantially reduce the number of people suffering from it. As a potential source of irrigation water, wastewater treatment offers various benefits, such as reliable water supply, a reduced need for chemical fertilizers, and enhanced soil conditioning that increases crop yield (Gao *et al.*, 2021).

By promoting the safe reuse of treated wastewater sludge, the study supported efforts to improve water quality, increase recycling and safe reuse, and reduce pollution. Additionally, the findings have the potential to support local livelihoods by enabling year-round irrigation, thereby contributing to food security and poverty reduction. This study was driven by the urgent need to find low-cost, scalable

wastewater treatment solutions tailored to rural communities in Ghana. It evaluated a practical intervention developed under local conditions and offers empirical data that could influence broader adoption, adaptation, and policy development around wastewater reuse in similar regions.

Materials and Methods

Study Area

The study was conducted at the Water Treatment Plant (WTP) of the Council for

Scientific and Industrial Research-Savannah Agricultural Research Institute (CSIR-SARI) in Nyankpala, Tolon District, Ghana (Figure 1). It is located at latitude 9.407532° N and longitude 0.9871° W. The area experiences both dry and wet seasons with unimodal rainfall of roughly 1026 mm from May to October with a peak period between August and September. The distribution of temperature is uniform with an average yearly temperature of 28.3°C (MoFA, 2000).

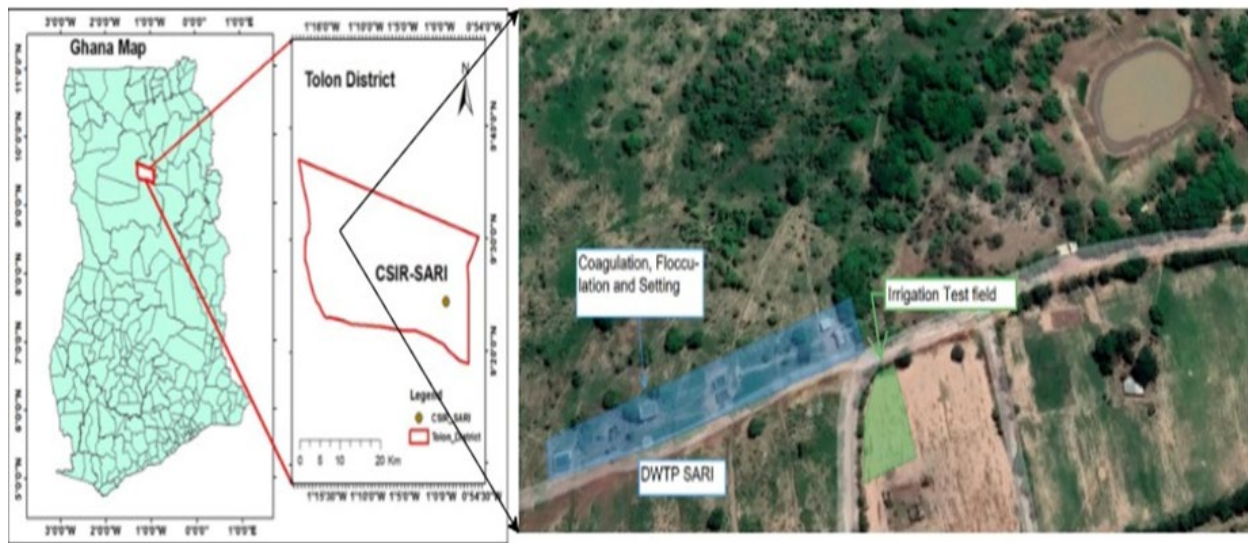


Figure 1: Map of Ghana showing Tolon District and CSIR-SARI

The drinking water treatment plant at the Council for Scientific and Industrial Research – Savannah Agricultural Research Institute (CSIR – SARI) in Tamale, Ghana, uses a standard treatment scheme to treat surface water from a constructed dugout for domestic use. The setup at CSIR-SARI includes two sedimentation tanks with capacities of between 45 and 53 m^3 , and two filtration tanks, each with an identical capacity of 23 m^3 . The final stage is the clear well tank, which has a capacity of 4.5 m^3 , before the clean water is sent to the distribution tank with a capacity of 91 m^3 .

Materials and Equipment Used for the Study

The river sand was obtained from Nyankpala town, the chipping stones were sourced at UDS Nyankpala at the Green People Project site, and the crushed stones were collected at Kukuo community under Sagnarigu Municipality. These materials were chosen because they are locally available and relatively inexpensive. The purpose of these materials was crucial in designing a roughing filter, as they enhance the physical and chemical properties of the wastewater sludge. The materials and equipment used for the study are presented in Tables 1-3 and Figure 2.

Table 1: Material for Sedimentation Tank

Item	Quantity	Size
Poly Tank	1	1800 L
PVC pipe	5	63 mm
Valves	2	110 mm
PVC T-joint	2	110 mm
PVC Elbow	6	63-110 mm
End cap	4	63 mm

Source: Adapted from Kreijen (2020)

Table 2: Materials for Filtration Tank

Item	Quantity	Size
Poly Tank	1	1800 L
PVC Elbow	4	63-110 mm
End Cap	6	63 mm
Valves	3	110 mm
PVC T-joint	1	110 mm
Reducing Bend	5	
PVC Glue	3	
Tape Measure	1	
Saw	1	
HDPE Pipes	1	100 m
Pump	1	35 m ³ /hr
PVC Cutter	1	
PVC Union	5	
Electric Flow Meter	1	
PVC Pipes	10	

Source: Adapted from Kreijen (2020)

Table 3: Characteristics of Bedding Materials for Filter Setup

Layer	Depth of the Layer (cm)	Filter Type	Size of Filter Material (mm)
1	40	Crushed stones	18 – 24
2	40	Chippings	12 - 18
3	40	River Sand	2 – 4

Source: Adapted from Kreijen (2020)

**a. River sand****b. Crushed Stones****c. Chippings****Figure 1: Materials for Roughing Filter Setup**

Setup of the Sedimentation Tank

There are several common types of sedimentation tanks, but this research focused on the vertical settling tank. The inlet valve was positioned at the bottom of the tank, while the outlet flow valve was situated at the top. This arrangement is because particles with higher velocity will settle more quickly. The vertical sedimentation tank was designed to have a low flow velocity, suitable for flocculants settling, which have lower efficiency for discrete settling compared to a horizontal flow tank.

To prevent rapid clogging of the filter, a sedimentation tank was installed to hold the wastewater sludge for pretreatment. The tank was positioned on an overhead metal stand measuring 1.88 m in length, 1.25 m in width, and 2.45 m in height. A 100 m HDPE pipe was connected to a 35 m³/hr gasoline pump to lift the wastewater sludge from a 100 m distance from the source to the tank. An L-shaped pipe network (60 x 40 cm), with the longest side measuring 60 cm and a height of 40 cm, is laid at the base of the tank (Figure 3). This design aims to prevent disturbance of the settled sludge during filtration. The flow of pretreated sludge relies on gravity to remove suspended solids (SS), such as flocs, sand, and clay. Sedimentation is based on the difference in density between suspended solids and water. The sludge can settle within 10 days to prevent clogging of the roughing filter before filtration begins. Due to stable, non-turbulent flow within the tank, heavier particles settle in the designated zone over this period. Subsequently, the accumulated sludge at the bottom moves through the outlet, and the pretreated wastewater is released into the roughing filter in the filtration tank. The up-flow velocity depends on the tank's dimensions and flow rate. The retention time (HRT) in the sedimentation tank is a critical factor; it was maintained within an hour to ensure optimal settling efficiency.

Design Parameters of Vertical Sedimentation Tank

The key parameters taken into consideration whilst designing the vertical sedimentation tank were:

1. Volume (V) of the tank (m³)
2. Height (h) of the tank (m)
3. Diameter (d) [m] / surface (A) of the tank (m²)
4. Inlet/outlet flow (m³/hr)
5. Up-flow velocity (m/h)
6. Hydraulic retention time (HRT) (hr)

Setup of Filtration Tank

After mounting the sedimentation tank, the filtration tank along with its drain system was connected inside the tank. The filtration tank was filled with local materials such as crushed stones, chippings, and river sand. These materials were arranged and filled into three uniform layers with different grain sizes. Each layer was 40 cm high, making the total bed height 120 cm. The roughing filter materials were arranged in the following order: crushed stones as the first layer at the bottom of the tank, with sizes ranging from 18-24 mm; chippings as the second layer, with sizes of 8-12 mm; and river sand as the third layer, with sizes of 4-8 mm. The pretreated wastewater was filtered into the filtration tank through the base of the roughing filter and collected at the top of the filter bed. Both tanks were connected, with the sedimentation tank linked to the main source. Each tank was fitted with a T-section valve on the water inflow pipe. This T-section joint had two valves; one for shutting off the water inlet and the other for releasing water through the outlet pipe.

A multiple PVC pipe distribution system, or drain, was designed and installed at the base of the filtration tank to distribute the inflowing pretreated wastewater. This PVC system was connected to control valves to regulate hydraulic energy. The outlet openings in the distribution pipes were no larger than the filter grain sizes to prevent media loss during back-washing. The

technical design of this system is shown in Figure 3.



Figure 3: PVC Pipe Distribution Network System

2.6 Design Parameters of a Roughing Filter

The design parameters of the roughing filter are presented in Table 4.

Table 4: Design Parameters of the Roughing Filter

1. The volume of the tank (m^3)	7. Up-flow velocity (m/hr)
2. Height of the tank (m)	8. Hydraulic retention time (hr)
3. Height of the filters bed (m)	9. Height of the layers (m)
4. Diameter of the tank (m)	10. Grain size layer (m)
5. The surface area of the Tank (m^2)	11. Filtration velocity (m/hr)
6. Inlet/outlet flow (m^3/hr)	

Formulae for Calculating the Necessary Parameters of the Sedimentation and Filtration Tanks

The formulae for estimating the parameters of sedimentation and filtration tanks are presented in Equations 1 to 7 as given by Kreijen (2020).

Volume of the tank, $[\text{m}^3] = 0.25 \times \pi \times D^2 \times h = A \times h$Equation 1

Area of the tank, $A = 0.25 \times \pi \times D^2$Equation 2

The up-flow velocity of the tank = Q/A Equation 3

Hydraulic Retention Time (HRT) of the Tank = $\frac{V}{t}$ Equation 4

The flow rate of the Tank, $\text{m}^3/\text{s} = \frac{V}{t}$Equation 5

Filtration Velocity of the Tank (m/hr) = $\frac{Q}{A}$Equation 6

Discharge of the Tank (Q) = AVEquation 7

Where; A – Surface area, D – Diameter, h – height, t – time, Q – discharge, and v – volume.

Washing of Filter Materials

The filter materials were thoroughly washed twice before being placed in the filtration tank. The crushed stone chips and river sand were cleaned to remove organic materials, silt, and clay particles. This was

necessary because biodegradables could decompose and affect the odour, and particles slowly passing through the filter might increase the turbidity of the treated water.

Determination of Physical Properties of Filter Media

The following methods were used to assess the physical properties of the filtering media and various microbial, chemical, and major nutrient parameters. The filter material consisted of crushed stones, chippings, and river sand. The bulk densities of the different filter materials were determined by measuring their volume with a graduated cylinder and recording the weight with a scale. The relationship between volume and weight, as described by Rühlmann *et al.* (2006), was utilised in calculating the bulk density using Equation 8:

$$\rho = \frac{m_{fm}}{V_{fm}} \times 100 \%$$

..... Equation 8

Where; ρ – bulk density (gcm^{-3}), V_{fm} – the volume of the filter media (cm^3), and m_{fm} – the mass of the dried filter media (g).

The mean filter media particle density was computed using the liquid immersion approach as elaborated by Ruhlmann *et al.* (2006). Particle density as given by Rühlmann *et al.* (2006) was determined using Equation 9:

$$\rho_p = \frac{m_{fm}}{V_{fp}} \times 100 \%$$

..... Equation 9

Where; ρ_p – the density of the particles (gcm^{-3}), V_{fp} – the volume of the filter media excluding pore space (cm^3), and m_{fm} – the mass of the dried filter (g).

The porosity of the filter media, as developed by Rühlmann *et al.* (2006) was calculated by finding the ratio between the

average particle density and bulk density of the different media used using Equation 10:

$$n = \frac{\rho_b}{\rho_p} \times 100 \%$$

..... Equation 10

Where: n – the porosity of the filter media (%), ρ_b – the bulk density (gcm^{-3}), and ρ_p – the density of the particles (gcm^{-3}).

Design and Installation of Roughing Filter for Sludge Filtration

Design of Roughing Filter

As illustrated in Figure 4, the sedimentation tank was designed and placed on an overhead metallic stand above the filtration tank. The overhead metallic stand has a height of 300 cm whilst the surface area of the platform of the overhead stand was $28,800 \text{ cm}^2$ (180 cm by 160 cm).

As shown in Figure 4, the holes where the metal stand poles were placed were reinforced with concrete to ensure they stayed firmly anchored to the ground. The filter tank was positioned on a concrete platform 40 cm above ground level. Both tanks were connected, with the sedimentation tank linked to the sludge source and the filtration tank connected to the outlet. The sedimentation tank features a non-return valve (NRV) inlet that allows wastewater sludge to flow in only one direction, preventing reverse flow when pressure conditions might cause such an issue. A flow meter was installed on a 1-inch pipe to measure the volume of wastewater sludge passing through the inlet into the sedimentation tank. PVC T-section connectors equipped with two control valves were installed on the water inflow pipes. One valve controls the inlet of wastewater sludge, while the other, a fast drainage valve, allows sludge to pass through the drainage pipe when open or during backwashing of the sedimentation tank.

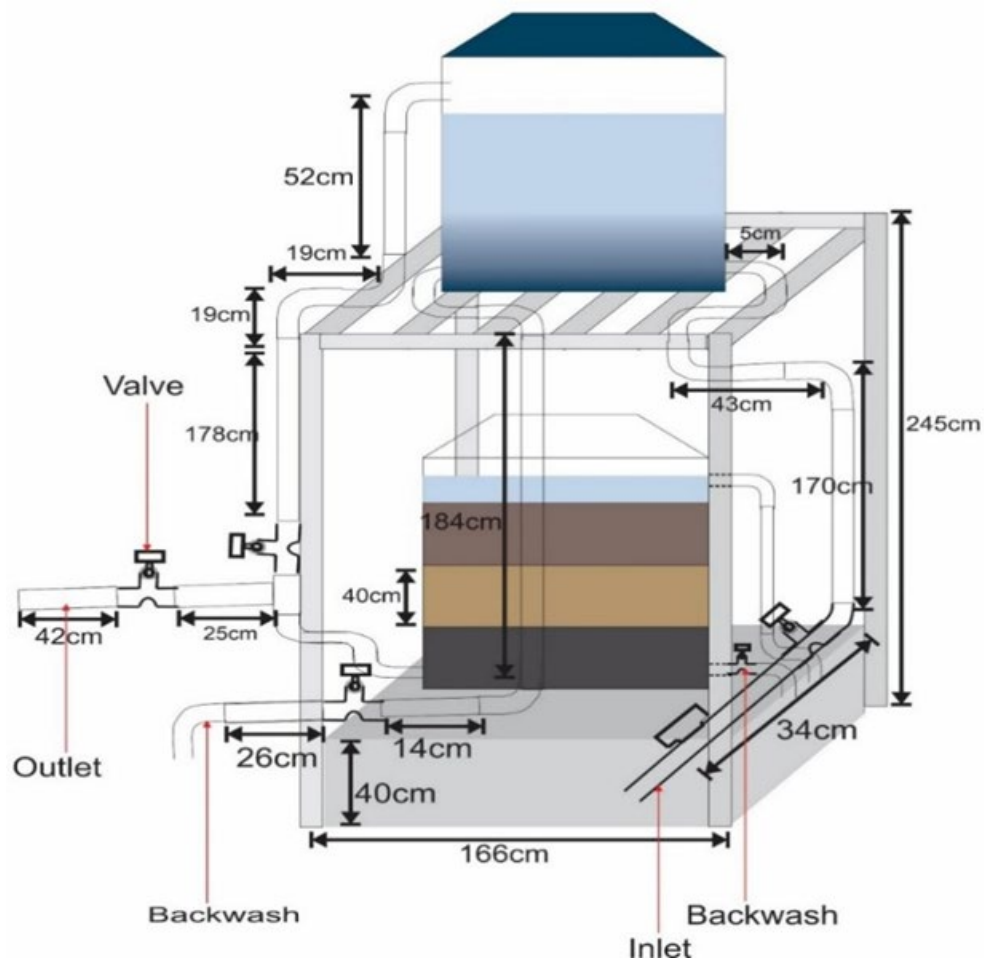


Figure 4: Design of a Filter System for Wastewater Sludge Treatment

(Author's Construction, 2022)

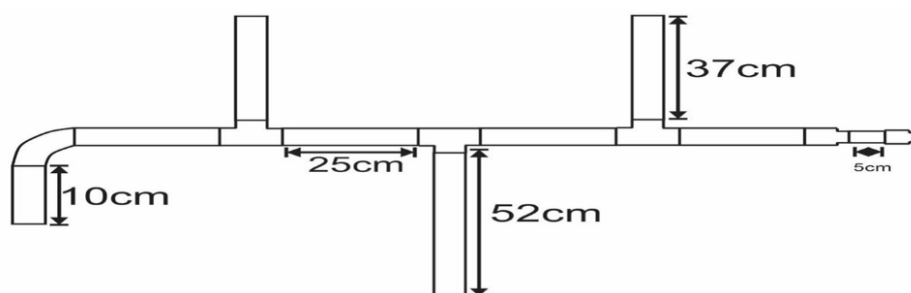


Figure 5: Design of a Filter Distribution and Drainage System Installed in the Filtration Tank

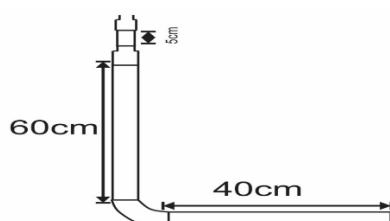


Figure 6: Design of Filter Inlet Flow Installed in the Sedimentation Tank

The inlet flow pipes for both the sedimentation and filtration tanks were positioned 5 cm above the tank bottoms. The wastewater sludge outflow pipe for the sedimentation tank was located 5 cm below the wastewater inlet level, while for the filtration tank, it was placed 20 cm above the filter bed's top, below the wastewater level of the inflow. Poly tank connectors, such as pipes measuring 50 mm and 25.4 mm, along with reducers, elbows, reunions, valves, and T-joints, were installed at appropriate positions. All connections were glued to prevent leaks.

The sedimentation tank was connected to an L-shaped inlet valve (60 cm x 40 cm), as shown in Figure 5, with the longer section positioned inside the bottom of the tank and the shorter section oriented vertically. This design prevents disturbance of the settled sludge and suspended particles at the tank's bottom whenever wastewater is pumped in. The wastewater sludge was allowed to settle for seven days in the sedimentation tank after pumping in, to ensure all suspended particles settle before moving on to filtration. Pre-treatment is crucial to maintain filter efficiency by preventing clogging. Therefore, wastewater must undergo a settling stage before filtration, and the L-shaped inlet valve helps prevent sludge from entering the filter tank during the filtration process.

Filter Tank

Pretreated wastewater in the sedimentation tank flowed out through the wastewater distribution system under gravity as the pump continued to lift wastewater sludge from the source to the sedimentation tank. The pretreated wastewater was distributed evenly over the filter surface to avoid

sourcing the filter media. The hydraulic energy of the pretreated wastewater was reduced by installing T-sections at the wastewater inflow with a length of 1m on multiple PVC pipes at the bottom of the filtration tank to divert the inflow. This T-section contains two valves: one for shutting off the inlet and the other as a drainage valve to allow wastewater to flow through the drain pipe when opened. The technical design of this system is shown in Figure 4 with its dimensions. The design ensures that the outlets in the distribution pipes are not larger than the filtering grains to prevent the filtered materials from being washed out during back-washing. It is placed 5 cm above the filter bottom in the filter bed. After back-washing, when the filter has been emptied of water, the drainage valve must be closed, and the inflow valve can be reopened.

Physical Properties of Filter Materials Used

Table 5 presents the physical properties of materials used in the construction of the roughing filter. The filter consists of three layers. The top layer is made of river sand with particle diameters ranging from 4 to 8 mm. The middle layer comprises chippings with particle diameters from 8 to 12 mm, while crushed stones with a particle diameter of 18 mm and above are used for the bottom layer. The dry bulk density of the river sand is the highest at 2.50 g/cm³, followed by chippings at 1.50 g/cm³, and crushed stones at 1.45 g/cm³. The particle densities for river sand, chippings, and crushed stones are 2.65 g/cm³, 2.57 g/cm³, and 2.62 g/cm³, respectively. Among the three filter materials, crushed stones are the most porous, with a porosity of 44.7%. Conversely, river sand is nearly non-porous, with a porosity of 5.9%.

Table 5: Physical Properties of Filter Materials used in Roughing Filter Layers

Filter material	Diameter (mm)	Dry Bulk Density (g/cm ³)	Particle Density (g/cm ³)	Porosity (%)
River sand	2-4	2.50	2.65	5.9
Chippings	8 - 12	1.50	2.57	41.6
Crushed stones	18 +	1.45	2.62	44.7

The particle diameter of various filter materials was considered due to the nature of wastewater sludge generated at the study site. Larger particle sizes allow more suspended particles to pass through during filtration and are subsequently trapped by smaller particles. Hatt et al. (2006) reported that smaller particle sizes tend to trap more suspended solids and/or contaminants. Some materials are more porous than others, which is a design consideration to ensure that while some particles escape from more porous layers, they are captured by less porous media layers. This is because different pore sizes result in varying efficiencies in removing suspended solids and/or contaminants from wastewater (Abagale, 2014).

Operation and Maintenance of the Filtration System

After testing the system, accumulated suspended solids in the filter bed were back-washed. This was achieved by closing the inlet valve and opening the drainage valve at the other end of the T-section joint valve. The wastewater in the sedimentation tank flowed out by gravity at a high velocity. Due to this high flow rate, sediments in both tanks were flushed out, and the sedimentation and filtration tanks were cleaned again. The valves were reset to their default settings, allowing the filtration system to operate again.

The filtration rate (FR) for this study was 1.5 m/h, meaning that it took the pre-filtered wastewater sludge contained in the filter tank one and a half hours to be collected as filtered water. The value obtained is similar to 0.3 m/h and 1.5 m/h. in a study by SKAT (1996).

The hydraulic retention time (HRT) of the pre-filtered wastewater sludge was held in the filtration tank for over an hour, aligning with the findings of other researchers such as Jeong et al. (2016). Jeong et al. (2016) indicated that if wastewater spends less than an hour passing through the filtration

process in the filter tank, it may not produce optimal results. The flow velocity (FV) of the system, where wastewater sludge is pumped from the source into the sedimentation tank, was 0.8 l/s.

Sample Collection and Laboratory Analysis of Wastewater Sludge Liquid Phase Parameters

Separate water samples were collected for both physico-chemical and microbiological/bacteriological analyses. All samples for physico-chemical analyses were collected directly into pre-cleaned 1000 ml plastic sample bottles from the wastewater sludge, pretreated, and filtered. For bacteriological assessment, samples were collected into sterilised 1000 ml sample bottles from the same sites. The samples were stored in an insulated box with ice and transported to the WRI water quality laboratory for analysis. A total of twelve (12) wastewater sludge samples were collected for analysis, including three (3) samples each of untreated water, sludge, pretreated water, and filtered water from the water treatment plant. Pretreated wastewater from the sedimentation tank, which was allowed to settle for 10 days, was collected for analysis. The physico-chemical and bacteriological analyses were conducted according to procedures specified in the Standard Methods for the Examination of Water and Wastewater, 23rd Edition (APHA, 2012).

Results and Discussion

Properties of Wastewater Sludge Liquid Phase Before and After Filtration

Table 5. presents the summary statistics of the physical and chemical properties, and nutrient and microbiological levels of wastewater sludge liquid phase from the Savannah Agriculture Research Institute (SARI) water treatment site. The levels of these properties were compared with the FAO, WHO, or EPA standard thresholds.

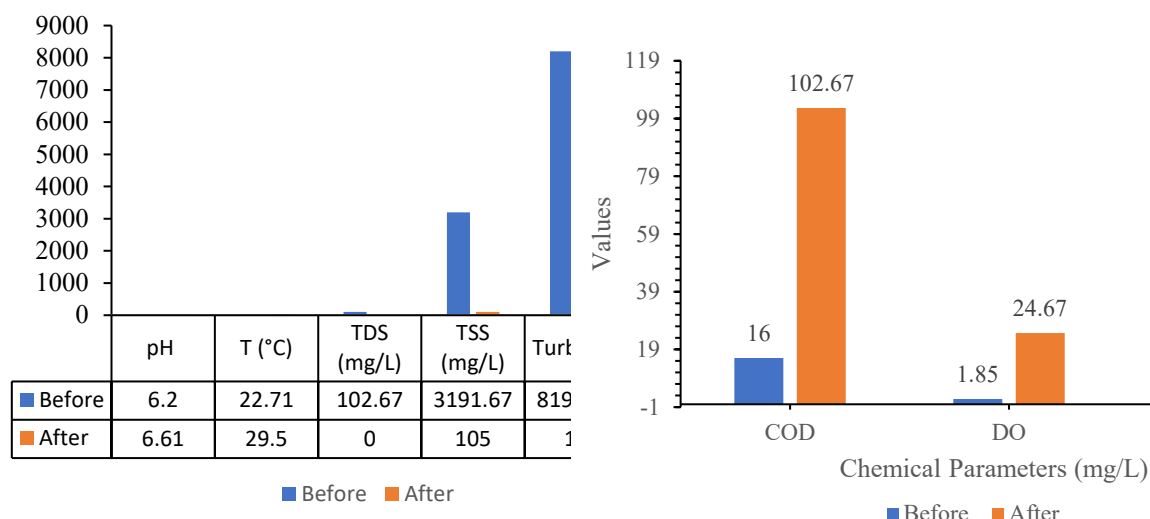
Table 6: Summary Statistics of Wastewater Sludge Liquid Phase Properties for Before and After Filtration

Parameter		Mean $\pm$ SD		% Increment or Removal	FAO 15 /WHO 2006/EPA 2008 Guideline
Name	Abbreviation	Before Filtration	After Filtration		
Physical					
Power of Hydrogen	pH	6.20 $\pm$ 0.26	6.61 $\pm$ 0.01	29.89	6.0 – 8.5 ^f
Temperature	T (°C)	22.71 $\pm$ 0.15	29.50 $\pm$ 0.10	23.02	< 30 ^f
Total Dissolved Solids	TDS (mg/L)	102.67 $\pm$ 4.93	0.00 $\pm$ 0.00	100	0 – 2000 ^f
Total Suspended Solids	TSS (mg/L)	3191.67 $\pm$ 541.30	105.00 $\pm$ 1.00	96.71	0 – 50.0 ^e
Turbidity	-	8198.67 $\pm$ 1123	19.00 $\pm$ 0.50	99.77	0 – 75 ^e
Salinity	Salinity (ppt)	201.00 $\pm$ 021	0.002 $\pm$ 0.00	99.99	0.7 – 3 ^f
Chemical					
Chemical Oxygen Demand	COD (mg/L)	16.00 $\pm$ 0.2	102.67 $\pm$ 4.93	98.2	0 – 1 ^e
Dissolved Oxygen	DO (mg/L)	1.85 $\pm$ 0.05	24.67 $\pm$ 13.58	54.19	0 – 250 ^e
Biological Oxygen Demand	BOD (mg/L)	0.95 $\pm$ 0.01	6.74 $\pm$ 3.75	85.91	0 – 50.0 ^e
Nutrient					
Nitrate Nitrogen	NO ₃ -N (mg/L)	1.03 $\pm$ 0.12	8.19 $\pm$ 0.00	87.42	0 – 10.0 ^f
Nitrite Nitrogen	NO ₂ -N (mg/L)	0E-7 $\pm$ 0E-8	-	-	0 – 5.0 ^f
Ammonium Nitrogen	NH ₄ -N (mg/L)	1.43 $\pm$ 0.098	0.74 $\pm$ 0.00	48.39	0 – 2.0 ^f
Phosphate Phosphorus	PO ₄ -N (mg/L)	0.096 $\pm$ 0.06	0.02 $\pm$ 0.00	77	0 – 1 ^f
Potassium	K ⁺ (mg/L)	0.47 $\pm$ 0.13	0.40 $\pm$ 0.01	14.89	
Microbiological					
Total Coliform	(cfu/100ml)	200 $\pm$ 0.00	100 $\pm$ 0.00	50	0-400 ^w
Faecal Coliform	(cfu/100ml)	60 $\pm$ 0.00	8 $\pm$ 0.00	86.67	0 – 10 ^w
E. coli	(cfu/100ml)	25 $\pm$ 0.00	4 $\pm$ 0.00	84	0 – 10 ^w
Salmonella spp	(cfu/100ml)	0 $\pm$ 0.00	0 $\pm$ 0.00	0	-

f - FAO Guidelines for Wastewater Quality Parameters for Irrigated Agriculture

w - WHO Guidelines for wastewater quality parameters

e EPA Guidelines for wastewater quality parameters



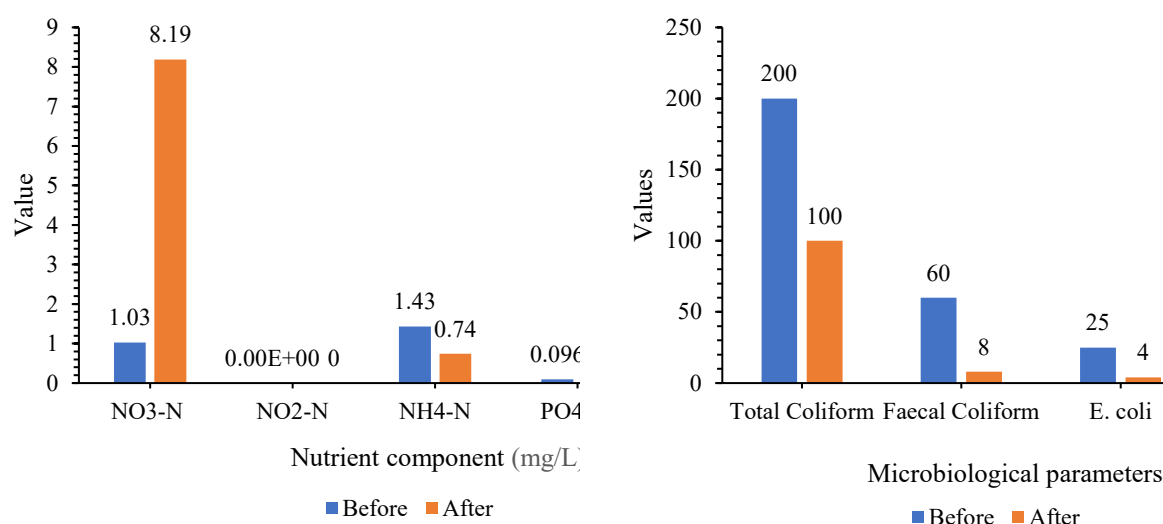


Figure 9: Graphical Representation of Wastewater Sludge Liquid Phase Properties for Before and After Filtration

Physical Properties of Wastewater Sludge Liquid Phase Before and After Filtration

The results indicated that the pH level of the wastewater sludge the liquid phase before and after filtration was 6.20 ± 0.26 and 6.61 ± 0.01 , respectively (Table 5 and Figure 9). The pH levels of the wastewater sludge the liquid phase, both before and after filtration, were compared to the FAO standard guideline limits of 6.0-8.5 for irrigated agriculture. The WHO (2006) report found that irrigation water with pH levels outside this range has a higher tendency to influence the mobility of heavy metals in soils, resulting in the mobile metals being absorbed by crops and further contaminating water sources or bodies during runoff. Nyiyongu *et al.* (2019) found that wastewater with an unfavourable pH concentration is difficult to treat biologically and that if the concentration is not changed before discharge, the wastewater effluent may change the concentration in natural waters.

As presented in Table 5, the average temperature levels for both the wastewater sludge the liquid phase liquid phase before and after filtration ranged from 22.71 to 29.5 °C, and the results were compared to

(EPA) standard guidelines for safe discharge. The mean electrical conductivity (EC), indicating the salinity levels in the wastewater sludge liquid phase before and after filtration, was 202.67 $\mu\text{S}/\text{cm}$ and 157 $\mu\text{S}/\text{cm}$, respectively. The values recorded for wastewater sludge liquid phase before and after filtration did not meet FAO or EPA standard guidelines, despite the reduction in EC levels following filtration. The mean Total Dissolved Solids (TDS) values of the wastewater sludge liquid phase before and after filtration ranged from 102.67 mg/L to 0 mg/L, falling within the FAO standard limit of 0-2000 mg/L for irrigation purposes. The mean Total Suspended Solids (TSS) levels for wastewater sludge liquid phase before and after filtration ranged from 3191.667 mg/L to 105 mg/L and were compared to FAO standard guidelines limits of 0 to 200 mg/L for irrigation use. This suggests that the filtered wastewater sludge liquid phase is meets the TSS quality criteria for irrigation purposes. Zaman *et al.* (2018) reported that high dissolved solids in water can harm crop yield when used for irrigation because the dissolved salts make it more difficult for plants to absorb water from the soil. The high value recorded in the wastewater sludge liquid phase before treatment could

be due to dissolved organic and inorganic substances accumulated in the sludge from the alum used during the flocculation and coagulation process of the raw water; hence, the necessity for the wastewater sludge liquid phase to undergo a filtration process to reduce dissolved solids levels in the wastewater sludge liquid phase. The best and most efficient method for removing TDS from water and its harmful effects is typically through a water filtration system (Chaukura *et al.*, 2020; Thibault *et al.*, 2021). It was also observed that, due to the multiple filter layers, the concentration of the total dissolved solids was reduced drastically to acceptable limits for reuse.

The average turbidity level of the wastewater sludge liquid phase before and after filtration ranged from 8198.67 to 19 NTU, indicating a 99.77% removal efficiency. The final turbidity level remains within the acceptable limits of the FAO standard of 0-75 NTU for irrigated agriculture. In evaluating the removal efficiency of different roughing filters, Adel *et al.* (2014) found that the filters can remove colloids and particles with efficiencies ranging from 73.33% to 87.88%. Although this range of values is lower than what was recorded in this study, it confirms the effectiveness of the designed system and the suitability of roughing filters to reduce the turbidity of the wastewater sludge liquid phase. However, Liu *et al.* (2018) achieved a higher removal efficiency (>99%).

As a metric for water quality, the more turbid the water is, the poorer its quality (Teh *et al.*, 2016). The change that occurs from turbid irrigation water is comparable to suspended solids and must thus, be measured and regulated (Jeong *et al.*, 2016). Kahle *et al.* (2021) stated that turbidity is an optical quality parameter that describes how clear or cloudy water is in

general. It has to do with color, although it is more about the loss of transparency caused by suspended particles and colloidal materials. These statistics, known as suspended solids, are utilised as an indicator of water quality.

The salinity levels before and after filtration were 201 mg/L and 0.002 mg/L, respectively. This indicates a filter removal efficiency of 99.99%. The salinity level after filtration falls within the FAO acceptable limits for water salinity (0.7 to 3 mg/L) in agricultural use. The reason for the wastewater sludge having higher salinity levels could be due to the presence of organic and inorganic pollutants originating from the water treatment station, where alum is applied to raw water to trap suspended particles at the bottom of the tank before filtration. As a result of the accumulated sludge solid phase, salinity increases. Therefore, it can be concluded that filtration improves water salinity. Sometimes, it could also be due to farming activities upstream of the dugout that wash contaminants into the water during the rainy season, increasing its salinity. Water that is too saline can significantly affect crop growth. Due to differences in osmotic pressure, crops struggle to absorb water, leading to stunted growth (Niu and Cabrera, 2010). According to Jeong *et al.* (2016), irrigation water with a salinity of less than 0.7 mg/L does not impact crop growth, while water with levels exceeding 3 mg/L causes considerable damage. This indicates that the saline content of the filtered water renders it suitable for crop production.

Chemical Properties of Wastewater

The chemical parameters considered are Dissolved Oxygen (DO), Chemical Oxygen Demand (COD), and Biological Oxygen Demand (BOD). The results for these parameters are presented in Figure 10.

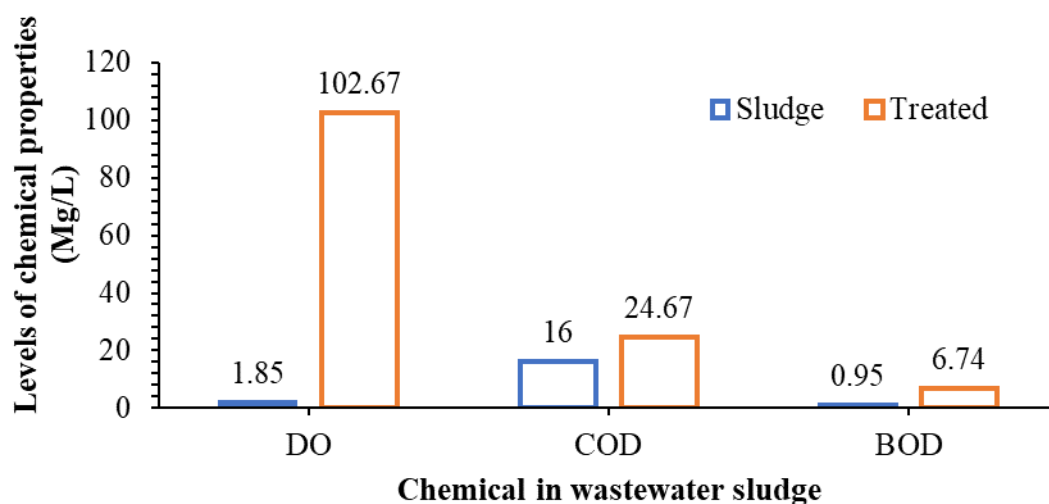


Figure 10: Averages of Chemical Properties of Wastewater Sludge Liquid Phase Before and After Filtration

The mean values recorded for the dissolved oxygen (DO) levels in the wastewater sludge liquid phase before and after filtration were 1.85 mg/L and 102.67 mg/L respectively. The dissolved oxygen level increased after filtration, indicating a DO improvement efficiency of 98.2%. A similar increase was observed in a study by Bali et al. (2011), who reported a 97% improvement in the DO of wastewater liquid phase after filtration with sand filters. The removal efficiency of a filter for a given parameter may vary depending on the effluent being filtered. Mensah (2017) recorded over 200% efficiency with his bio-sand filter-designed septic effluent. Although dissolved oxygen levels may not be considered crucial for irrigated agriculture, they are essential in aquaculture and environmental protection. The concentration of dissolved oxygen in wastewater determines its quality and its ability to support life, whether on farms or in aquatic environments (Kalbar et al., 2013). The increase in dissolved oxygen may be attributed to wastewater being exposed to the open environment after filtration, where the odour has been removed from the filtered wastewater.

The average levels of Chemical Oxygen Demand (COD) in wastewater sludge

liquid phase recorded were 16 mg/L before filtration and 32.33 mg/L after the wastewater sludge liquid phase underwent the filtration process. Essentially, the designed filter has a COD improvement efficiency of 54.19 %. Bali et al. (2011) achieved a better filter removal efficiency of 81 % for COD, and an 82.8 % efficiency was reported in the study by Adu-Ofori (2019). The mean value for Biological Oxygen Demand (bod) recorded was 0.95 mg/L before filtration, while the filtered wastewater sludge liquid phase recorded 6.74 mg/L. The recorded values for the filtered wastewater sludge liquid phase were within the limits of EPA standard guidelines for wastewater, as shown in Table 4.1. The improvement in BOD after filtration indicates a filter efficiency percentage of 85.91 %. Similar results were obtained by Manga et al. (2016) and Adu-Ofori (2019), who reported removal efficiencies of 85.6 % and 86.8 %, respectively. The BOD level in the filtered wastewater sludge liquid phase was used as a measure to estimate the amount of organic matter present. Conversely, the COD level indicates the total oxygen demand for digesting or decomposing both organic and inorganic matter in the filtered wastewater sludge. According to Kalbar et al., the decomposition of higher COD and BOD

levels results in depleted dissolved oxygen levels, leading to anaerobic conditions and more contaminated wastewater sludge.

Nutrient Concentration Levels

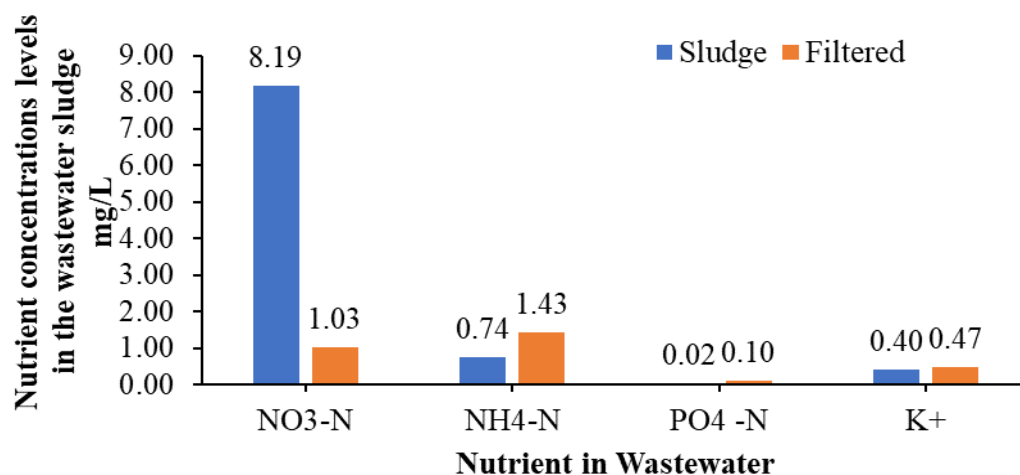


Figure 11: Averages of Nutrient Concentrations in Wastewater Sludge Liquid Phase Before and After Filtration

As shown in Figure 10, apart from Nitrate Nitrogen, all the mean values of the nutrients- ammonium nitrogen, phosphorus phosphate, and potassium- after filtration increased. For Nitrate Nitrogen (NO₃-N), the wastewater sludge liquid phase before filtration had a mean value of 8.19 mg/L, which decreased to 1.03 mg/l after the filtration process, indicating a removal percentage of 87.42 %. This contrasts with Bali et al.'s (2011) record of a 91.91 % increase in NO₃-N after filtration. The reduction in nitrate concentration may be linked to the lack of transformation of organic nitrogen into nitrate during the treatment process through oxidation reactions. The average values for Ammonium Nitrate (NH₄-N) before filtration were 0.74 mg/L, which rose to 1.43 mg/l after filtration, representing an increase of 48.39 %. This is contrary to Bali et al. (2011), who reported an 86.49 % removal. The mean value of phosphate Phosphorus (PO₄-N) in wastewater sludge liquid phase was 0.02 mg/L before filtration and increased to 0.10 mg/l after Filtration. PO₄- N levels rose by 77 % after filtration, while Bali et al. (2011) observed a decrease

of 64.61%. Similarly, Adu-Ofori (2019) recorded a removal efficiency of 58.7 %. The mean potassium concentration in wastewater sludge liquid phase was 0.40 mg/L before filtration and 0.47 mg/L after. Both unfiltered and filtered wastewater sludge liquid phase are shown in Figure 4.3, and the results fall within the acceptable limits of FAO standard guidelines.

According to Kumar et al. (2015), nitrogen and phosphorus are essential for plant growth, although other elements such as iron are needed only in trace amounts for biological development. It has been found that wastewater contains a variety of nutrients necessary for agricultural production (Chiu et al., 2015). While nutrient content in wastewater sludge liquid phase plays a vital role in plant growth, it can have negative effects if it exceeds recommended levels (Erel et al., 2019). Excessive nitrogen levels in wastewater can cause over-fertilisation, leading to rapid vegetative growth, delays or unevenness in crop maturity, and poor quality. According to An *et al.* (2016), wastewater can contain 5 to 50 mg/L of phosphorus. Organic phosphorus is biologically converted into

phosphate during wastewater pre-treatment.

Microbial Levels in Wastewater Sludge Liquid Phase Before and After Filtration

The microbial parameters determined during the laboratory analysis include; Total coliform, Faecal coliform, E. coli, and Salmonella spp, and the results are presented in Figure 4.7.

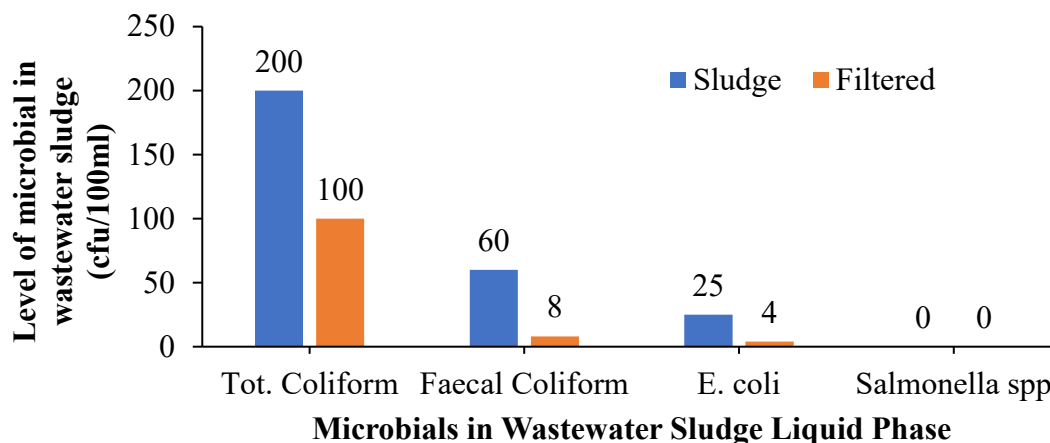


Figure 12: Levels of Microbial in Wastewater Sludge Liquid Phase

As shown in Figure 11, prior to the filtration of the wastewater sludge liquid phase, the total coliform level was 200 cfu/100ml. After filtration, this value decreased to 100 cfu/100ml, which falls within the acceptable range of the FAO standard guideline limits of 0-400 cfu/100ml for irrigation. The average faecal coliform level before filtration was 60 cfu/100ml, reducing to 8 cfu/100ml after filtration. E. coli levels also averaged 25 cfu/100ml before filtration and decreased to 4 cfu/100ml after filtration. The presence of salmonella was zero (0) in both unfiltered and filtered wastewater sludge liquid phase.

The total coliform value recorded by Kwabla (2017) was $\leq 37.4 \times 10^3$ cfu/100 mL, which is higher than the levels recorded in this study before and after filtration, at 200 cfu/100 mL and 100 cfu/100 mL, respectively. Furthermore, according to Adu-Ofori (2019), the recorded value ranged from 14×10^7 to 53×10^7 counts/100 mL, with an average count of 296×10^6 counts/100 mL, which is higher than the figures in this study before

and after filtration. Regarding the contaminant removal efficiency of the system, the designed roughing filter achieved a total coliform removal efficiency of 50%, which is significantly lower than the 99.93% and 99.99% reported by Adu-Ofori (2019) and Mensah (2017), respectively. Ostad-Ali-Askari et al. (2019) also observed a substantial decrease in total coliform when employing a sand filter for water filtration. A similar reduction in total coliform was reported by Bali et al. (2011), who recorded a 53.29% decrease after filtration. This value aligns with the 50% removal observed in this study and further confirms the filter's effectiveness. The faecal coliform counts in the sludge from the study site were as high as 60 CFU/100 mL before filtration. After filtration, the faecal coliform count was reduced to 8 CFU/100 mL, indicating a removal efficiency of 86.67%.

Although Bali et al. (2011) also recorded a 58.95% decrease in faecal coliform after the wastewater sludge liquid phase was filtered, this decrease is lower than the 86.67% observed in this study, which is

also less than the reduction reported by Mensah (2017). Several factors may have contributed to the variation in faecal coliform removal rates, though an important one is the system's ability to reduce coliform counts. The *E. coli* count has dropped significantly, from 28 to 4 colony-forming units (CFU) per 100 mL, indicating an 84% reduction in *E. coli* through filtration. This falls within the removal rate range of 45-99.99% for slow sand filters, as noted by Chen et al. (1998). In a study conducted by Mensah (2017), a similar trend was observed, with an even higher reduction rate in *E. coli*, at 97.6%. The microbial concentration in wastewater sludge liquid phase determines whether the

wastewater is suitable for reuse in irrigation. Wastewater with high *E. coli* levels is likely to contain other harmful bacteria as well (Edberg et al., 2000). The *E. coli* value after filtration in this study is higher than that found by Allende et al. (2015), who reported average *E. coli* levels of 1 CFU/mL for vegetables eaten raw (Category A) and for vegetables, processed foods, or fruits not directly irrigated (Category B). From their perspective, based on the *E. coli* levels in our filtered water, it would not be suitable for vegetable irrigation. Nonetheless, the *E. coli* levels after filtration in this study align with the results of Kwabla (2017), who reported levels of less than 10 CFU mL/1.

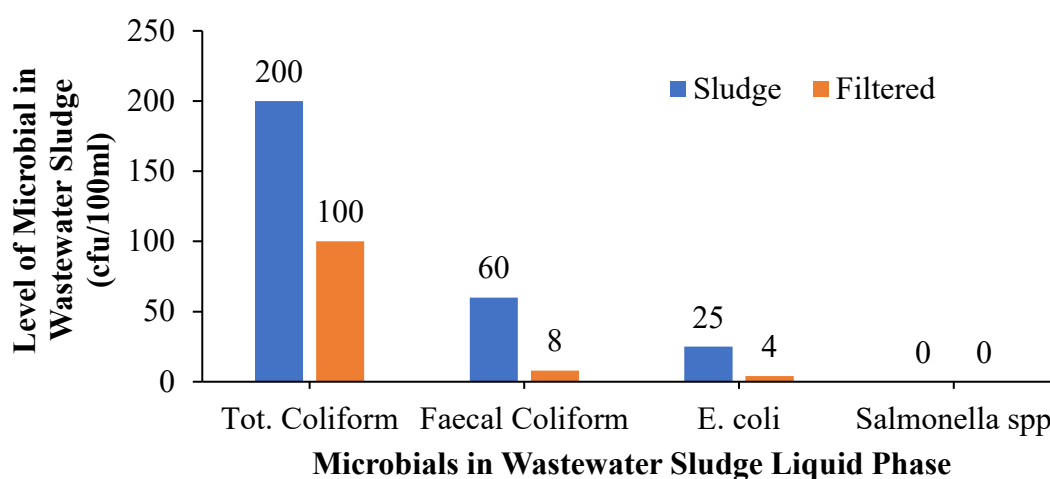


Figure 13: Volumes of Microbial in Wastewater Sludge Liquid Phase Before and After Filtration

Conclusions

In conclusion, this article has demonstrated the feasibility and effectiveness of using a design filter for treating wastewater sludge liquid phase for irrigation purposes and non-critical uses. The design of the filter considers parameters such as flow rate, flow velocity, hydraulic retention time, and up-flow velocity. Local materials like chippings, river sand, and crushed stones help achieve effective and efficient wastewater treatment. The results for the designed filter in the study show that the filter can significantly improve wastewater

sludge liquid phase quality to acceptable limits for irrigation and also reduce wastewater's sludge liquid phase impact on the environment. These findings highlight the potential for wastewater sludge liquid phase to play an important role in developing sustainable and effective irrigation systems and in addressing the challenges of managing water resources in agriculture. Further research is needed to validate the filter design system and to explore its scalability and applicability in other domains.

Author Contributions

D. A. was responsible for the conceptualization, methodology, formal analysis, investigation, and original draft preparation of this research study. A.G.S. and T.A.A were responsible for reviewing and editing the manuscript. Additionally, A.G.S. was responsible for visualisation, and both A.G.S. and T.A.A. provided supervision for the project. Finally, A.G.S. was responsible for project administration. All authors have reviewed and approved the manuscript.

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Declaration of Conflicts of Interest

The authors confirm that they have no conflict of interest to declare.

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