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Research article

Antimicrobial and coagulation potential of *Moringa oleifera* seed powder coupled with sand filtration for treatment of bath wastewater from public senior high schools in Ghana

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ABSTRACT

The use of natural plant extracts for treatment of water in some parts of the world has been recorded throughout human history. An example is the use of *Moringa oleifera* in water purification due to its coagulation properties. However, the efficiency of the treatment systems largely depends on the design of the system and its operation. The aim of this study was to investigate the efficiency of *Moringa oleifera* seed powder coupled with sand filtration in treating greywater from public senior high schools in the Bolgatanga Municipality and Kasena Nankana West District in the Upper East Region of Ghana. Microbial and physico-chemical properties of greywater collected monthly from the senior high schools was analyzed. *Moringa oleifera* seed powder was added to raw greywater and then filtered through a sand filter bed. Physico-chemical and microbial parameters of the treated greywater were then analyzed. Mean turbidity, TDS, TSS, T. phosphate and T. nitrogen of the raw greywater was 312.5 ± 76.58 NTU, 445.6 ± 86.77 mg/L, 160.0 ± 28.68 mg/L, 89.3 ± 7.76 mg/L and 30.19 ± 3.63 mg/L respectively whiles average BOD, COD, *E. coli* and Total coliform were 1032.5 ± 252.40 mg/L, 1736.0 ± 431.59 mg/L, 84.75 x 10^6 ± 94.01 x 10^6 N/100ml and 184.25 x 10^s ± 181 x 10^6 N/100ml respectively. After treatment, there was percentage reduction in turbidity (98.14%), TDS (72.7%), TSS (98.9%), T. phosphate (75.64%), T. nitrogen (43.11%), Total coliform and *E. coli* (>99%) were recorded. Turbidity was 0.1 NTU and did not meet the WHO standard for drinking water but T. hardness, *E. coli* and pH was in line with the WHO limit for drinking water. However, BOD increased, and this could be attributed to the significant protein content in the seed of *Moringa oleifera*. *Moringa oleifera* seed powder coupled with sand filtration demonstrated the antimicrobial and coagulative potential as turbidity and *E. coli* of the raw bath greywater from the senior high schools reduced by >98% and >99.99% respectively after treatment.

1. Introduction

Wastewater produced from showers, bathroom, laundry and kitchen are generally referred to as greywater. Greywater form about 60–70% of household wastewater (Khalaphallah, 2012). Khalaphallah (2012) further asserts that 50–60% of the composition of total greywater is from handwashing and bathing whereas around 25–35% is from laundry activities. However, most of this greywater generated in developing countries like Ghana is released on the ground surface without any treatment (Fagan, 2015) causing environmental pollution. This is despite the assertion by Juvekar (2015) who posits that, grey water contains fewer pathogens hence it is easier to treat and to recycle onsite for various purposes.

Abdel-Kader (2012) asserts that several wastewater treatment options exist for the treatment of grey water with the ultimate cost being dependent on the technology being applied. The treatment system varies from simple diversion of the greywater for irrigation or dust suppression to integrated sophisticated systems Eriksson and Donner, 2009. Common greywater treatment options range from simple systems such as natural systems to complex systems such as Rotating Biological Contactor, Sequencing Batch Reactor and Membrane Bioreactors (Abdel-Kader, 2012). These treatment systems according to Lambe and Chougule (2015), is composed of stages of treatment that remove floating matter, turbidity, BOD, bacteria and odour.

Filtration, reverse osmosis and adsorption form the basic methods of Physicochemical treatment systems whiles biological treatment methods

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is characterized by the use of specific microorganisms at different levels of sunlight and oxygen exposure (Oteng-Peprah et al., 2018). Huhn et al. (2015) assert that, the cost and energy requirements of the treatment systems vary and usually increase as the level of treatment increases. This has resulted in the preference of the natural systems such as sand or gravel filters, constructed wetlands etc. These natural systems are considered sustainable, eco-friendly and low cost and better suited for small-scale treatment of greywater (Huhn et al., 2015).

With grey water composed of high levels of turbidity, the potential of *Moringa* extracts in the treatment process cannot be underestimated. Al-Gheethi et al. (2017) reported an efficiency of 83.63% in removing turbidity at a dosage of 120 mg/L. They further assert that *Moringa* seed extract produces less amount of sludge when used as coagulation agents when compared to alum. Additionally, Lea (2010) further posits that the use of *Moringa* seed extract achieved 90.00–99.99% bacterial removal in untreated water. Filtration primarily removes particles using specific filter media such as sand, activated charcoal, polyurethane foam, fibrous material and bricks (Oteng-Peprah et al., 2018). Sand filtration media is considered easy to construct, low cost and an efficient technique for treating water (Abdel-Shafy et al., 2014). With this model, the wastewater flows through a sand or gravel filter medium allowing particles to be retained.

The use of *Moringa oleifera* seed powder is because of to its ability to reduce turbidity and microbial presence in water. Furthermore, *Moringa oleifera* extract is environmentally friendly, non-harmful and biodegradable, and does not alter the conductivity and pH of the treated wastewater.

The study seeks to assess the efficiency of *Moringa oleifera* seed powder coupled with sand filtration in treating bath greywater from selected public senior high schools in in the Upper East Region of Ghana which face water scarcity.

2. Materials and methods

2.1. Study area

The study took place in Bolgatanga located on latitudes 10°30′ and 1°55′ North and Longitudes 0°33′ and 1°00' and Kasena Nankana West District located approximately between latitude 10.97° North and longitude 01.10° West in the Upper East region of Ghana. The area has population density of 118.4 persons/km^2. Bolgatanga is located at the center of the region and is the regional capital (see Figure 1).

2.2. Study locations

The survey was conducted in Sirigu senior high school (N10.948364, W0.941234) from the Kasena Nankana West District and Bolgatanga technical school (N10.805783, W0.873479).

A total of 2 senior high schools were used for the study; 1 from Bolgatanga Municipal and the other from Kasena Nankana West District.

2.3. Study design

A cross-sectional study design was adopted for the characterization of the greywater. The study was carried out from March to June 2019. Random sampling was done 4 times within the period (Once every month). Raw greywater samples were collected from both boys and girl's dormitory in Bolgatanga Technical Senior High School in the Bolgatanga Municipality and Sirigu Senior High School in the Kasena Nankana West District.

2.4. Sample location

Samples were collected from 4 locations within the schools. 2 from each school; one from male dormitory and the other from the girl's dormitory. Using Global Positioning System (GPS). Coordinates of the sampling points were taken and recorded in a field notebook. The sample locations included Sirigu senior high school (N10.948364, W0.941234) in Kasena Nankana West District and Bolgatanga Technical Senior High School (N10.805783, W0.873479) in the Bolgatanga Municipal.

2.5. Sampling procedure

With the help of a clean 750 mL plastic bottle, about 750 mL of grey water samples was vigorously agitated and collected from outfalls of the bathhouses of both the boys' and girls' dormitories. Sampling was done was done once every month from March to June 2019 between 6:00 am and 7:00 am. The sampling bottles were tightly covered and appropriately labelled. They were then stored in a cold ice chest and hurriedly transported to the Environmental Quality Laboratory at Kwame Nkrumah University of Science and Technology, Kumasi, Ghana. The sampling containers were prepared for the sampling by washing in hot water and detergent and thoroughly rinsing with hot water, followed by a distilled water rinse to remove all detergent.

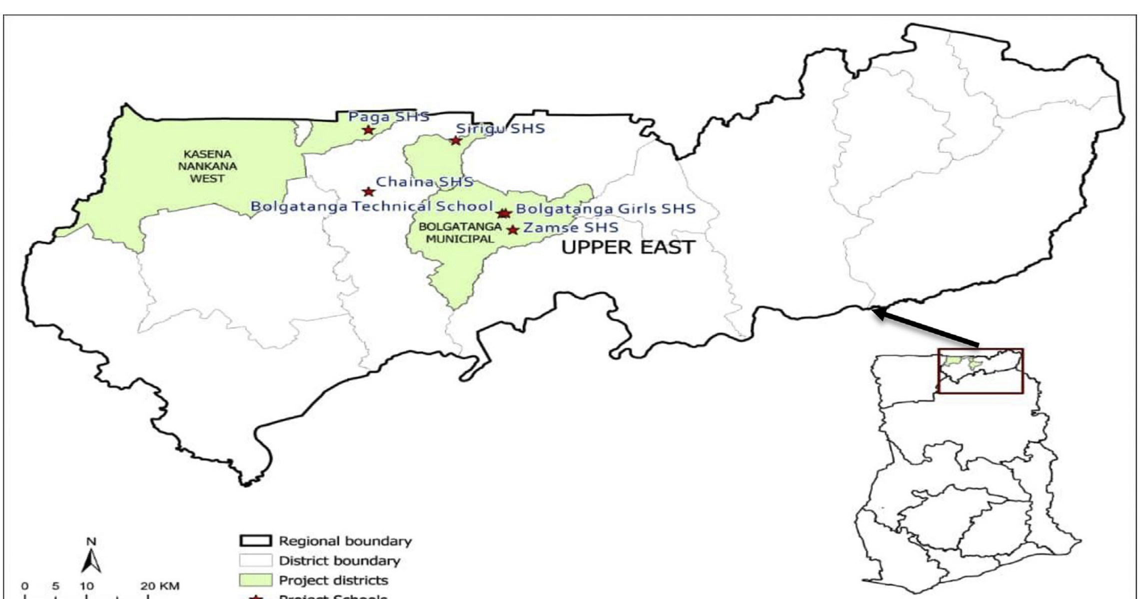

Figure 1. Study Area Map Showing the location of the Schools within the Ghana Map.

2.6. Laboratory analysis

Parameters monitored in the laboratory included turbidity, biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solid (TSS), total dissolved solid (TDS), total hardness, phosphate, nitrate, alkalinity, pH, bacterial and conductivity levels.

2.6.1. Temperature, pH, TDS and EC

The probes of a handheld digital PC 300 Waterproof instrument were inserted into the samples of greywater from the study locations and the temperature and pH measured. The sample was then agitated by stirring and allowed to stabilize. The device was then adjusted to allow other parameters to be measured. The values of TDS and EC were then recorded.

2.6.2. Total suspended solids (TSS)

100 mL of the greywater sample was well mixed. This was filtered through a pre-weighed glass-fiber filter. The filter retained some residue, and this was then dried for 1 h in an oven at 105 °C. Cooling of the residue was done in a desiccator and the residue weighed again. The difference in weight of the filter was due to the total suspended solids and is calculated using the formula below:

$$\text{mg total suspended solids/L} = \frac{(\text{A} - \text{B})\text{mg} \times 1000}{\text{sample volume, mL}}$$

A = weight of glass fiber filter only + dried residue (mg) and.
B = weight of glass fiber filter only (mg).

2.6.3. Dissolved oxygen

An airtight BOD bottle was used to collect samples of the greywater and allowed to stabilize. The probe of WTW Oxi 3205 was inserted into the stabilized samples.

2.6.4. Five-day biochemical oxygen demand (BOD_5)

A measured volume of the greywater was transferred into a 300 mL BOD bottle. This was then topped up with dilution water until it overflowed. A blank was created by filling another 300 mL BOD bottle with dilution water. Using a DO meter, the initial dissolved oxygen concentrations of the diluted and blank sample were measured. The diluted and blank samples were stored in an incubator for 5 days at 20 °C. The amount of dissolved oxygen remaining in the samples after the 5 days was measured and the 5-day BOD calculated using the formula below:

$$\text{BOD}_5, \text{mg/L} = \frac{\text{DO}_1 - \text{DO}_2}{\text{P}}$$

DO_1 = DO of diluted sample immediately after preparation, mg/L,
DO_2 = DO of diluted sample after 5-day incubation at 20 °C, mg/L,
P = decimal volumetric fraction of sample used.

2.6.5. Chemical oxygen demand (COD)

10 mL of the sample of greywater was added to 1g of HgSO4 in a reflux flask and mixed. 10 mL of 0.0417M $K_2Cr_2O_7$ solution was then added to the flask and mixed. 20 mL of conc. H_2SO_4 was added slowly to the contents of the flask. Cooling the flask simultaneously under running water, 1 mL of silver sulphate solution was added. The process was repeated using the same volume of distilled water as the blank. The solution was then boiled under reflux for 2 h after which 45 mL of distilled water was added. The solution was subsequently cooled under running water. 2 drops of ferroin indicator was added to the solution. A light blue/green colour appeared. The residual solution was titrated with 0.1M Ferrous Ammonium Sulphate (FAS) solution to reddish brown endpoint. The COD was calculated using the formula below:

$$\text{COD as mg } O_2/\text{L} = \frac{(\text{V1} - \text{V2}) \times \text{M} \times 8000}{\text{mL sample}}$$

where:
V1 = mL FAS used for blank,
V2 = mL FAS used for sample,
M = molarity of FAS (0.1M).
8000 = milliequivalent weight of oxygen × 1000 mL/L.

2.6.6. Phosphate

The ADR/3900 Spectrophotometer was used. Phosphate was measured by selecting Program 490 P React.PV from the Hach Programs. A clean, round sample cell was filled with a known volume of greywater sample and diluted to 10 mL. Contents of one PhosVer 3 phosphate Powder Pillow was added to it. The sample cell was immediately capped and turned upside down to mix the contents and a two-minute reaction period recorded. A blank was created by filling a sample cell with 10 mL distilled water. This was thoroughly wiped and placed in the cell holder of the spectrophotometer. The phosphate concentration of the blank in mg/L PO_4^{3-} concentration was measured. A two-minute reaction period was allowed for the prepared sample cell, after which it was wiped thoroughly and then placed in the cell holder. The concentration of phosphates was subsequently measured in mg/L PO_4^{3-}.

2.6.7. Nitrate-nitrogen

The concentration of Nitrates–nitrogen was determined by ADR/3900 Spectrophotometer using the Cadmium Reduction method. Program 353 N, Nitrate MR was selected from the hatch programs. A clean, round sample cell was filled with a known volume of greywater sample and diluted to 10 mL. Contents of one NitraVer 5 Nitrate Reagent Powder Pillow was added to it. The sample cell was immediately capped and turned upside down vigorously to mix the contents and a one-minute reaction period recorded. A five-minute reaction period is also started. A blank was created by filling a sample cell with 10 mL distilled water. This was thoroughly wiped and placed in the cell holder of the spectrophotometer. The Nitrate-nitrogen concentration of the blank in mg/L NO_3–N concentration was measured after pressing the zero button. A five-minute reaction period was allowed for the prepared sample cell, after which it was wiped thoroughly and then placed in the cell holder. The concentration of Nitrate-nitrogen was subsequently measured in mg/L NO_3–N.

2.6.8. Turbidity

10 mL of the greywater sample was measured and transferred into the sample cell. A tissue paper was used to thoroughly clean the surface of the sample cell and then placed into the instrument light cabinet with a light shield covering it. The turbidity was read.

2.6.9. Microbial parameters

2.6.9.1. Total coliforms and Escherichia coli (E. coli).

The membrane filter technique using Chromocult Coliform Agar was used. 1 mL of the wastewater sample was added to a 99 mL. Three serial dilutions with 99 mL dilution of dilution water and 1 mL of the resulting solutions were performed. The final solution was filtered through a sterile micropore filter by suction. Coliforms were trapped by the filter. Chromocult Coliform Agar was placed in a petri dish. Sterile forceps was then used to place the filter membrane aseptically and rolled onto the Chromocult Coliform Agar. The dish was capped, inverted and placed in an incubator at 35 °C for 24 h. After the 24 h, the number of Salmon to red colonies and the dark blue to violet colonies were recorded by visual inspection as coliforms and *E. coli* respectively. The two colonies together form as total coliforms.

2.7. Data analysis

Results of the raw greywater parameters after laboratory analysis were manually inputted into Microsoft Excel software (2016). GraphPad Prism 5 software was used to analyze categorical variables using chi-square at confidence interval of 95% with p value ≤0.05 considered significant. The mean of each of water quality parameters recorded from the study area was compared with GSA/WHO standards.

2.8. Treatment of bath greywater using Moringa oleifera seed powder and sand filtration

2.8.1. Design of the treatment system

The design drawings were done using AutoCAD software (2018) tool and imported into pdf format. Figure 2 shows the plan and section through the model treatment system installed.

2.8.2. Design specifications of the greywater treatment setup

Using cement (Diamond brand, Ghana), sand and stones from the local environment and water from a nearby borehole, the treatment setup was built. The composition of the treatment system was as follows;

(i) *Inlet Pipe*: This is was made up of a 50 mm (2 inch) PVC pipe.
(ii) *Collection Tank 1*: The dimension of the tank was 400 mm × 650 mm x 500 mm with a valve to control flow rate of untreated raw grey wastewater into chamber B taking into consideration the bottom slope. 125 mm blocks were laid using a mortar of mix ratio of 1:4 for the chamber and neatly finished with rendering of mix ratio 1:3 mortar. Base of the chamber was constructed with concrete of mix ratio 1:3:6 then cement finish with 5% slope.
(iii) *Filtration Chamber*: The filtration unit was also constructed with dimensions 575 mm × 650 mm x 600 mm. 125 mm blocks were laid using a mortar of mix ratio of 1:4 for the chamber and neatly finished with rendering of mix ratio 1:3 mortar. The base of the chamber was constructed with concrete of mix ratio 1:3:6 after which the floor was finished with 5% slope towards the opening at the exit of the system. Within the filtration unit, different filtration was used to fill up the chamber as described below. This media was made of a 2-layered vertical filtration unit. The bottom layer was made up of fine sand of size 125 μm–250 μm. This was followed by another layer of course to medium sand (Size 0.5mm–2mm). The fine sand has a thickness of 400 mm thick with the coarse sand having a thickness of 2 00 mm. The filter chambers were arranged in stepped down manner to ensure a consistent flow rate into the third and final chamber.
(iv) *Collection Tank 2***:** The size of the collection tank (Chamber C) was 450 mm × 600 mm x 1200 mm. 125 mm blocks were laid using a mortar of mix ratio of 1:4 for the chamber and neatly finished with rendering of mix ratio 1:3 mortar.

2.8.3. Testing of the treatment system

2.8.3.1. Preparation of Moringa oleifera seed powder. Dry pods of *Moringa oleifera* were obtained from Zuarungu, a community in the Bolgatanga Municipality. Using bare fingers, the seed coats were removed to get out the kernels. The kernels were then dried in the sun for about 6 h daily for 7 days on a clean straw made mat. After that, traces of dirt were removed manually before they were grinded using local wooden mortar and pestle. After obtaining a very fine consistency, they were sieved using a locally manufactured wooden mesh of approximate size of 500 μm sieves.

2.8.3.2. Determination of the optimum dosage of Moringa oleifera seed powder

2.8.3.2.1. Jar test method. Using the standard operating procedure for the jar test method, 5 different clean 1L beakers were filled with the raw untreated wastewater. The pH of the raw water was taken, and each beaker dosed with different amounts of the *Moringa oleifera* seed powder while keeping the 6th beaker without any coagulant dosage but filled with the wastewater to serve as the blank (Control).

Contents in the various beakers were stirred rapidly with a flocculator machine initially about 100 RPM for 1.0 min to ensure an intense contact between the coagulant and the colloidal particles. During the rapid mixing, there was destabilization of the colloids into small (micro) flocs. The contents were then stirred slowly (about 25 RPM) for 20 min to allow for the formation of larger (macro) flocs. The stirring was stopped and samples in the beakers allowed to settle for 30 min. These larger flocs then settled over time. Sedimentation of the macro flocs then followed. The various beakers were sampled periodically, and physico-chemical and microbial properties of the treated samples were determined.

To test the efficiency of the system, raw grey water from the bathroom was channeled into the collection chamber 1 through a 3-inch PVC pipe. The raw greywater was agitated and about 0.75 mL of raw grey wastewater was collected in a clean empty 0.75 mL sample bottles for laboratory analysis. Then after, about 96 g of *Moringa oleifera* seed powder were then added to about 48 L of raw grey water in chamber A. They were then agitated and allowed to settle after 2 h.

The samples were again collected in a similar manner for laboratory analysis. The valve between collection tank 1 and the filtration chamber was opened to allow the *Moringa oleifera* seed powder dosed water to flow into the filtration chamber B. They were then led to the collection tank 2. The treated greywater in the final collection chamber was sampled where both physico-chemical and microbial parameters were compared to the raw water samples as well to WHO/EPA/GSA guidelines

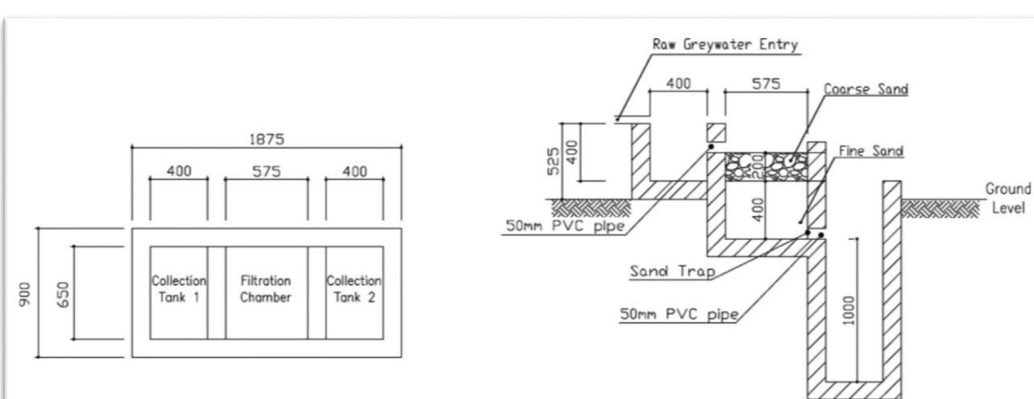

Figure 2. Plan and section through the Treatment System.

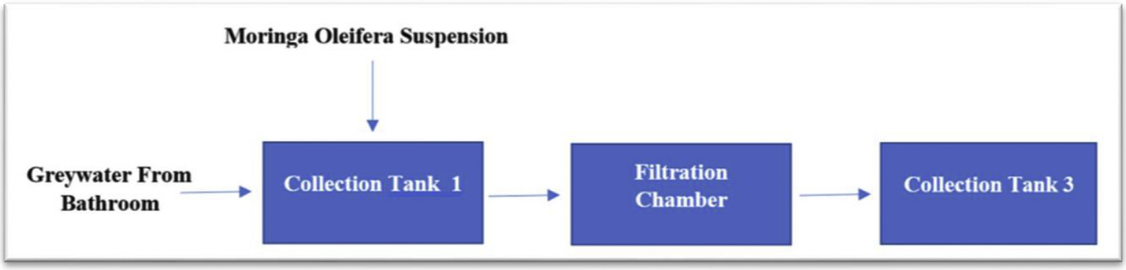

Figure 3. Schematic diagram of grey water treatment setup.

for grey water re-use for non-potable uses. Figure 3 provides a schematic representation of the treatment setup.

3. Results

3.1. Characterization of the raw greywater

Results of measured parameters of the raw greywater is shown in Table 1. Results showed that the average turbidity for greywater from Bolgatanga Municipal was higher than Kasena Nankana West. Though the difference was not statistically significant ($p = 0.0537$) when compared with each other, however they both did not meet the WHO/GSA allowable limits for greywater turbidity. The mean conductivity of the grey water from the Bolgatanga Municipal and Kasena Nankana West District were 734.1 ± 104.2 μS/cm and 1886 ± 349.3 μS/cm respectively. The conductivity of the greywater from Kasena Nankana West District was significantly higher than from Bolgatanga Municipality ($p = 0.0049$) with both conductivities being above the GSA allowable limits for greywater conductivity. Also, TDS concentrations of the greywater from Bolgatanga Municipal (308.3 ± 80.02 mg/L) was lower than that of Kasena Nankana West District (1541 ± 809 mg/L) and this was statistically significant ($p < 0.0001$). Further analysis showed that TDS of greywater was within the GSA allowable limits for TDS of greywater but that of Kasena Nankana was above the limit. Furthermore, an analysis of the pH in the greywater revealed that grey water from Bolgatanga Municipal was lower than that of Kasena Nankana West District, however the difference was not statistically significant ($p = 0.1803$). However, the greywater from both areas was in line with WHO/GSA allowable limits for greywater pH.

Further results show that TSS level in the greywater from Bolgatanga Municipal was lower than that of Kasena Nankana West District. However, this was not statistically significant ($p = 0.3998$) when results for the two areas were compared. Similarly, COD of the greywater from Bolgatanga Municipal (1439 ± 228.2) was lower than that of Kasena Nankana West District (1928 ± 867.5) and this was statistically significant ($p = 0.0023$). Further analysis of BOD values from the Kasena Nankana West District (1031 ± 380.1) was significantly higher ($p = 0.0143$) than that from the Bolgatanga Municipality (895.3 ± 135.5). The TSS, COD and BOD of the raw greywater did not meet WHO/GSA allowable limit for these pollutants in raw greywater. Similarly, Other parameters such as Total Phosphate, Nitrogen, Alkalinity and Total hardness did not meet the WHO/GSA allowable limit for these pollutants in raw greywater. The Phosphate and Nitrogen concentrations in the raw greywater from Kasena Nankana West District were 38.57 ± 5.020 mg/L and 117.0 ± 16.40 mg/L respectively, whereas their levels in greywater from Bolgatanga Municipal were (27.18 ± 2.345 mg/L) and (80.38 ± 6.660 mg/L) respectively.

The hardness and T phosphate of the greywater were higher for Kasena Nankana West District than in Bolgatanga Municipal and this was statistically significant ($P = 0.0044$) for Total Alkalinity and not statistically significant for T phosphate ($p = 0.4697$).

E. coli detected in all 8 samples of raw greywater that were collected from the two study locations as shown in Figure 4 did not meet WHO/GSA allowable limits for greywater. The average *E. coli* in the sampled grey water from the Bolgatanga Municipal was 7E+08 N/100 ml whereas the greywater from the Kasena Nankana West District had average *E. coli* of 9E+08 N/100 ml. The *E. coli* counts in greywater from the Kasena Nankana West District was higher than that from the Bolgatanga

Table 1. Comparison of physico-chemical characteristics of grey water generated in Kasena Nankana West District and Bolgatanga Municipal to WHO standard for greywater reuse for non-potable use and GEPA/GSA standards for effluent discharge.

Parameter	Sample from Bolgatanga Mean ± SEM	Sample from Kasena Nankana Mean ± SEM	P-value	WHO Standard for Greywater Reuse for Non-potable uses (2006)		GEPA/GSA Standard for Effluent (2012)
				Restricted Use	Unrestricted Use	
pH	6.879 ± 0.1811	7.363 ± 0.3097	0.1803	6 to 9	6 to 9	6 to 9
Turbidity (NTU)	287.4 ± 48.60	227.8 ± 107.1	0.0537	≤2 NTU	≤2 NTU	75
Colour (TCU)	381.1 ± 68.97	302.5 ± 138.9	0.0848			
Conductivity (μS/cm)	734.1 ± 104.2	1866 ± 349.3	0.0049			750
T.D.S (mg/L)	308.3 ± 80.02	1541 ± 809.0	<0.0001			1500
T.S.S (mg/L)	159.0 ± 30.41	110.8 ± 42.40	0.3998	≤30 mg/l		50
COD (mg/L)	1489 ± 228.2	1928 ± 867.5	0.0023			250
BOD_5 (mg/L)	895.3 ± 135.5	1031 ± 380.1	0.0143	≤30 mg/l	≤10 mg/l	50
Total Phosphate (mg/L)	27.18 ± 2.345	38.57 ± 5.020	0.0624			2
Total Nitrogen (mg/L)	80.38 ± 6.660	117.0 ± 16.40	0.0298			50
Total Hardness (mg/L)	140.5 ± 18.63	318.0 ± 24.77	0.4697			
T Alkalinity (mg/L)	173.3 ± 16.59	334.9 ± 56.63	0.0044			

Footnote: T.D.S-Total Dissolved Solids, T.S.S-Total Suspended Solids, BOD_5-5 day Biochemical Oxygen Demand, COD-Chemical Oxygen Demand, GSA-Ghana Standards Authority, GEPA-Ghana Environmental Protection Agency, WHO-World Health Organization, Number of sampling times = 4, Number of samples collected = 8. The relative significance of the variables between the two areas is determined by the P-values.

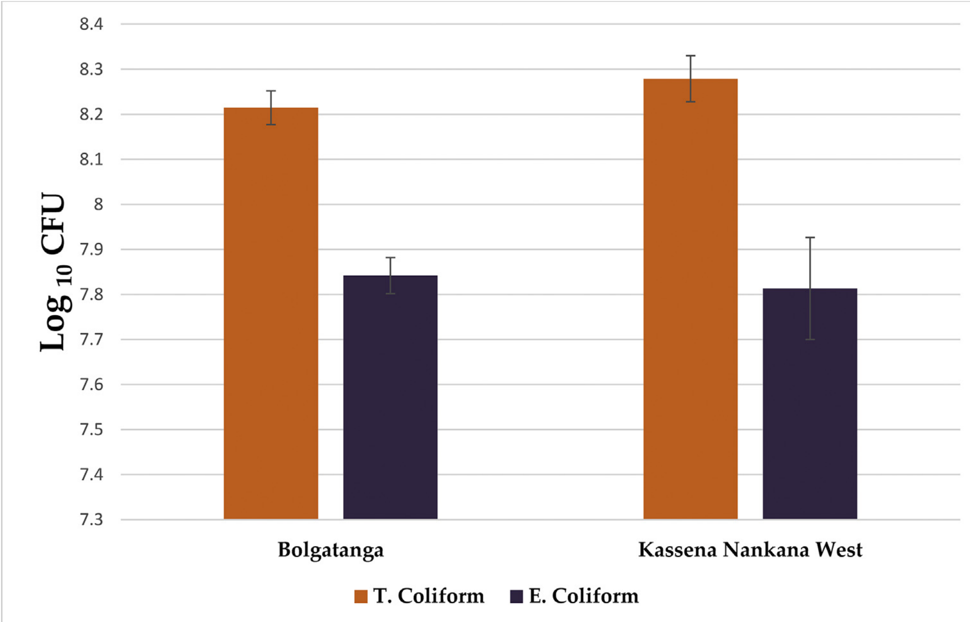

Figure 4. Comparison of microbial characteristics of grey water generated in Kasena Nankana West District and Bolgatanga Municipal.

Municipal, but the difference was not statistically significant ($p = 0.1995$).

The average Total Coliform counts in the sampled grey water from the Bolgatanga Municipal was 1.68E+09 N/100ml whereas the greywater from the Kasena Nankana West District had average Total Coliform count of 1.95E+09 N/100ml. The Total Coliform count in greywater from the Kasena Nankana West District was higher than that from the Bolgatanga Municipal but was not statistically significant ($p = 0.7996$). Additionally, both Total Coliform and *E. coli* counts for both study areas did not meet WHO and GSA standard for effluent discharge.

3.2. Treatment of greywater using Moringa oleifera seed powder

Table 2 compares the physico-chemical parameters of the raw greywater to that of *Moriga Oleifera* dosed greywater. Various dosages (0.5 g/L, 1 g/L, 1.5 g/L, 2 g/L and 2.5 g/L) of *Moringa oleifera* seed powder at a settling time of up two hours was used. This sought to obtain the optimum dosage of the *Moringa oleifera* seed powder that would provide the most improved turbidity, colour and *E. coli* after treatment. As shown in Table 2, the 2.0 g/L dosage of *Moringa oleifera* seed powder after a settling time of 2 h resulted in significant improvement in the water quality parameters. TSS, COD, BOD, Phosphate and Nitrogen levels of 3 mg/L, 656 mg/L, 250 mg/L, 6.82 mg/L, and 43.2 mg/L respectively were recorded. Additionally, total hardness, total alkalinity, turbidity, Total coliform and *E. coli* recorded concentrations of 185 mg/L, 283.04 mg/L, 8.2 NTU, 500 N/100ml and 0 N/100ml respectively. The dosage of 2.0 g/L produced the highest improvement in turbidity, colour and *E. coli* when compared to the other dosages of as shown in Table 2.

Applying an optimum dosage of 2.0 g/L dosage of *Moringa oleifera* seed powder after a settling time of 2 h to raw greywater produced greywater with improved characteristics as shown in Figure 5. Turbidity, Colour, Total Suspended Solids (TSS) and Phosphate reduced by 97.4%,

Table 2. Determination of optimum dosage of *Moringa oleifera* seed powder using jar test method.

Parameter	*Moringa* Oleifera Seed Powder Dosage					
	0 (Blank)	0.5 g/L	1.0 g/L	1.5 g/L	2.0 g/L	2.5 g/L
pH	7.66	7.42	11.5	7.52	7.53	7.66
Turbidity (NTU)	275	18	7.5	8.93	8.2	9.13
Colour (TCU)	350	20	15	10	10	15
Conductivity (μS/cm)	988	1022	1015	1043	1044	1072
T.S.S (mg/L)	110	7.2	4.5	3.6	3	4.8
C.O.D (mg/L)	336	208	416	608	656	736
BOD_5 (mg/L)	128	79	150	230	250	280
Total Phosphate (mg/L)	12.32	8.46	8.03	7.75	6.82	5.83
Total. Nitrogen (mg/L)	33.4	34.2	36	39.4	43.2	44.4
Total. Hardness (mg/L)	136	144	160	160	185	224
Total. Alkalinity (mg/L)	312.32	297.68	283.04	292.8	283.04	312.32
Total coliform (N/100ml)	5700	2000	1200	700	500	300
E. coli (N/100ml)	1300	500	300	0	0	0

Footnote: T.D.S-Total Dissolved Solids, T.S.S-Total Suspended Solids, BOD_5-5 day Biochemical Oxygen Demand, COD-Chemical Oxygen Demand.

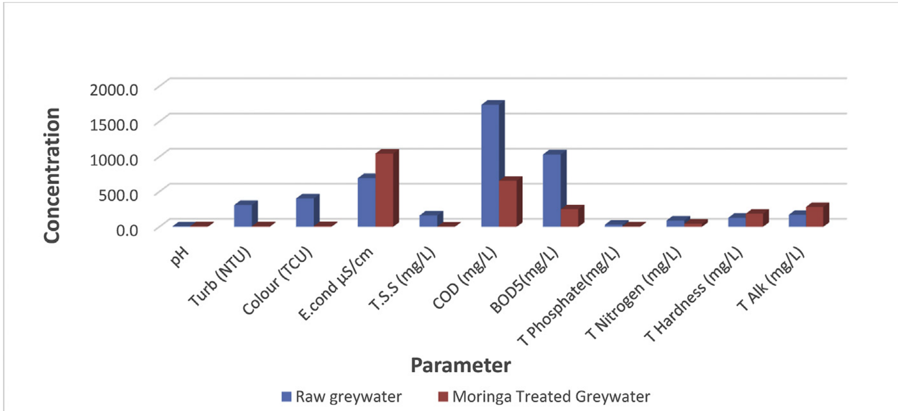

Figure 5. Comparison of physico-chemical water quality parameters of raw and treated greywater after of *Moringa oleifera* seed powder to raw grey water.

97.5%, 98.1% and 44.6% respectively. Total coliforms reduced by 91% and *E. coli* by >99% and this is shown in Figure 6. However, other parameters increased significantly. This included COD (95.2%), BOD (95.2%), Nitrogen (24.3%) and hardness (36.03%). Also, pH and alkalinity reduced marginally by 1.7% and 9.37% respectively.

3.3. Filtration of Moringa Oleifera seed powder dosed greywater

Analysis of characteristics of the greywater after the sand filtration of the grey water dosed with *Moringa oleifera* seed powder is presented in Figure 7. From the Figure, it is observed that the turbidity of greywater was 5.1 NTU from the initial 8.2 NTU after application of moringa oleifera powder. This shows a further reduction of 37.8%, attributed to the impact of the sand filtration. This however did not meet the WHO allowable limits for greywater reuse for non-potable purposes such as toilet flushing and 0.1 NTU above WHO allowable limit for potable water. The pH measured was 7.53 and was within the range for greywater re-use for non-potable uses such as toilet flushing by WHO. The TSS concentrations recorded in the treated greywater was 1.2 mg/L. The sand filtration had resulted in a further reduction of 60%. COD concentrations in the greywater was 528.1 mg/L after the sand filtration; there was a marginal reduction of 19.5%. Further analysis of BOD values after the filtration showed a value of 139 mg/L. This corresponded to further reduction of 44.4%. The Phosphate and Nitrogen concentrations in the raw greywater were 3.0 mg/L and 19.1 mg/L respectively corresponding to 56.7% and 55.8% respectively. Hardness level measured was 81.2 mg/L, corresponding to further reduction of 56.1%.

4. Discussion

4.1. Characterization of the raw greywater

The raw greywater from both the Kasena Nankana West District and Bolgatanga Municipal showed higher concentrations of physical, chemical and microbial water quality parameters when compared to the Ghana EPA 2012 standards for effluent discharge and this captured in Table 1. However, all the samples recorded a pH which is neutral to moderately alkaline and this was within the allowable limits of the Ghana EPA standards for effluent discharge. The pH could be attributed to the use of detergents and soap-base products which often turn out to be alkaline in nature. This is in line with Oteng-Peprah et al. (2018) who asserts that detergents, shampoo and soaps could result in significantly high pH readings in grey water.

Electrical conductivity measured though high was within the range for greywater as predicted by Oteng-Peprah et al. (2018), who in a study of greywater stated between 14 and 3000 µS/cm. This reinforces the outcome of our finding and could be attributed to the high concentration of dissolved ions in the raw water used in bathing as the most common source of water observed for bathing was underground water. MOFA (2011) reported same and concluded that underground waters were mostly used in the study areas. Since underground waters are usually characterized by dissolved minerals as the water flows through different geologic formations increasing the conductivity levels within the water, this could be the reason for the high conductivity levels recorded. This assertion is line with Oteng-Peprah et al. (2018) who posited that

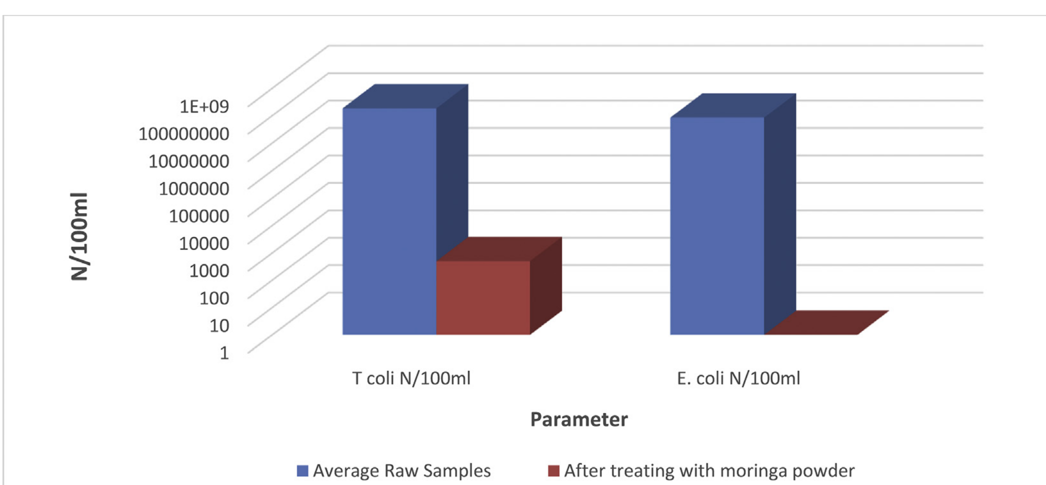

Figure 6. Comparison of microbial water quality parameters of raw and moringa treated grey water from the female hostel in Bolgatanga Technical senior high school.

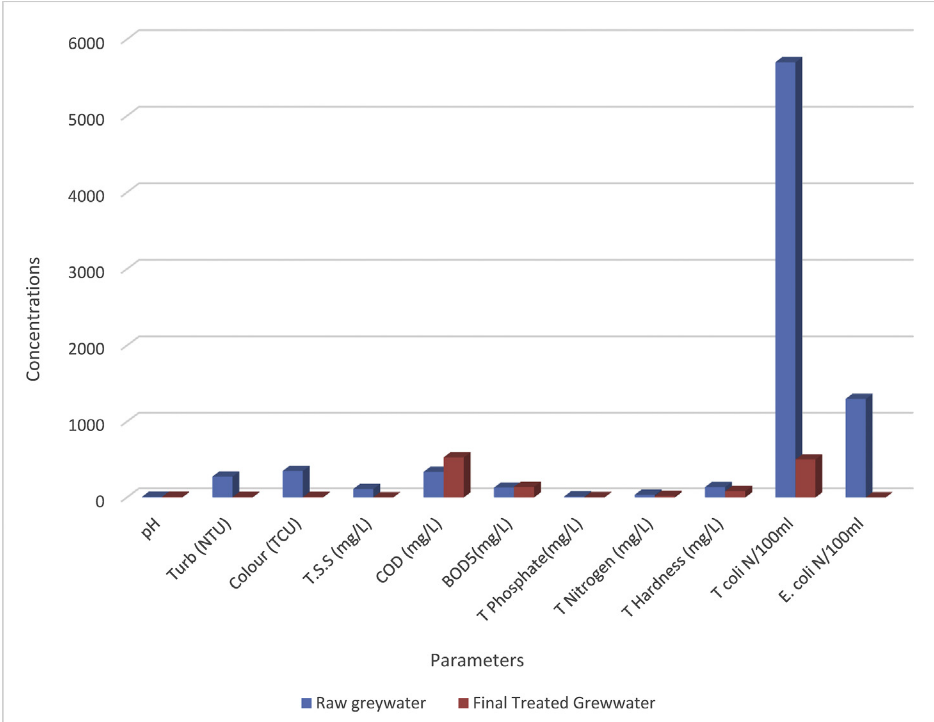

Figure 7. Comparison of water quality parameters of raw and final treated greywater from the female hostel in Bolgatanga Technical senior high school.

underground waters and water scarce areas have significantly higher conductivity readings. Another study by Oyem et al. (2014) also indicate that the presence and characteristics of geologic rocks and mineral types affect the conductivity of water, which in turn influences the TDS levels in the greywater.

TDS levels are higher in waters sourced from underground through different geologic formations and water scarce areas due to the presence of the dissolved irons according to Oteng-Peprah et al. (2018). This could be the reason for the relatively high values for TDS in the study areas. Turbidity levels recorded for both study areas were significantly high and beyond the acceptable limit by Ghana EPA, 2012 for effluent discharge as outlined by Diallo (2016). This may also be attributed to the quantity of detergents and soap-base products during bathing. Water from the study areas is usually from underground sources and generally have high hardness levels. This finding is supported by Fahmi et al. (2011), who in a study to remove turbidity and hardness from hardwater asserted that high level of hardness was possibly due to the geological formation. Total hardness of water is classified by WHO as soft to very hard depending on the level of hardness, 49–120 mg/l as soft to moderately hard, 130–180 mg/l as hard and 190–400 as very hard. All the samples were within the moderately hard to very hard water. This results in the use of more soap to ensure lathering and this increases the cloudiness of the greywater, thereby increasing turbidity. This is in line with Oteng-Peprah et al. (2018), who reported high turbidity levels in greywater is due to use of soaps in laundry.

Nitrogen levels were generally higher in both grey water sources from the two study areas. This could be attributed to the presence of urine in the waters. This assertion is supported by Fagan (2015) who in study of greywater from the households in Northern Ghana reported that the high levels of nitrogen was due to the presence of urine in the water. Nitrogen, in the forms of nitrate, nitrite, or ammonium, is a nutrient needed for plant growth and in excess may cause the growth of aquatic plants and algae and cause eutrophication. This is significant as in most discharge points in the school, the growth of algae was observed.

The levels of BOD and COD in the greywaters sampled from the two areas were very high and beyond the allowable limit of Ghana EPA for effluent discharge as well as to greywater parameters from various low-income and middle-income countries as reported by Oteng-Peprah et al. (2018). This could be attributed to the equally high levels of nitrate and phosphate in the greywaters from both study areas. Furthermore, this high contents of COD of the treated greywater could be attributed to the use of soaps and other detergents in bathing and this was in line with Al-Gheethi et al. (2017) who posited that high presence of detergent compounds resulted in the increase in COD of greywater.

Faecal contamination of the greywater was significantly high after the characterization of the greywater from the two study areas. The *E. coli* and Total coliform levels in greywater from the study areas were very high and this could be attributed to poor hygiene practices such as open defecation and reduced frequencies of cleaning bathrooms. Laundry activities in the bathrooms may also be reason for the faecal contamination in the greywaters. This is in line with studies by Oteng-Peprah et al. (2018), who identified poor personal hygiene and washing of faecal Eriksson and Donner, 2009 contaminated clothes as major contributor of faecal contamination. Another study by O'Toole et al., 2012 detected Pathogenic *Escherichia coli* in greywater with majority of the water originating from laundry sources during a microbial monitoring programme in Melbourne, Australia.

4.2. Characterization of the treated greywater

In this test, *Moringa oleifera* seed powder was used mainly for its coagulating and anti-microbial abilities. The addition of 2.0 g/L dosage of *Moringa oleifera* seed powder as determined via a jar test improved the water quality significantly. Analysis and comparison of the characteristics of treated greywater with WHO standards for greywater reuse for non-potable uses such as toilet flushing indicated that, parameters such as pH and *E. coli* were the only parameters that were within the allowable limits for non-potable uses such as toilet flushing. Other parameters such as turbidity, Total coliform and BOD were above the allowable limits for non-potable uses such as toilet flushing. This is shown in Table 3. The treated greywater was also compared to allowable limits for drinking water set by the WHO. The results indicated that marginal difference in

Table 3. Comparing the Characteristics of Treated Greywater to WHO Standards for Greywater Reuse Toilet Flushing, WHO Standard for Drinking Water, GSA/GEPA Standards for Effluent Discharge and UK greywater standards for W.C flushing.

Parameter	Characteristics of treated greywater	WHO allowable limits for unrestricted use (Toilet flushing, laundry, landscape irrigation and construction)	WHO standards for drinking water	GEPA/GSA standards for effluent (Wastewater)	UK greywater standards for W. C. flushing
pH	7.53	6–9	6.5–8.5	6–9	5–9.5
Turbidity (NTU)	5.1	≤2 NTU	≤5	75	<10
Colour (TCU)	10	-	-	-	
Electrical conductivity (μS/cm)	1044	-	-	750	
T.S.S (mg/L)	1.2	-	-	50	
T.D.S (mg/L)	-	-	1000	1500	
C.O.D (mg/L)	528.1	-	-	250	
BOD5 (mg/L)	139	≤10 mg/l	-	50	
Total Phosphate (mg/L)	3	-	-	2	
Total Nitrogen (mg/L)	19.1	-	≤10	50	
Total Hardness (mg/L)	81.2	-	500	-	
Total Alkalinity (mg/L)	283.04	-	-	-	
Total Coliforms (N/100ml)	500	≤100/ml	-	400	
Escherichia. Coli (N/100ml)	0	≤10/ml	0	10	250

Footnote: T.D.S-Total Dissolved Solids, T.S.S-Total Suspended Solids, BOD_5-5 day Biochemical Oxygen Demand, COD-Chemical Oxygen Demand, GSA-Ghana Standards Authority, WHO-World Health Organization.

the turbidity of the treated greywater (5.1 NTU) to that of drinking water (≤5.0 NTU). Furthermore, the turbidity of the treated greywater was in line with the United Kingdom (U.K) allowable limits for greywater reuse for toilet flushing. Hardness also was in line with the allowable limit for drinking water as set by WHO. However, parameters such as T. Nitrogen did not meet the WHO allowable limit for greywater. The BOD, COD, Conductivity and Total coliform did not meet Ghana Standards Authority (GSA) allowable limits for greywater reuse as shown in Table 3.

4.3. Efficiency of the treatment system

Analysis of the results comparing the treated greywater to the raw greywater show a percentage reduction in Turbidity (97.4%) and TSS by 98.1% which agrees with Oteng-Peprah et al., 2018 who in a research on the on the efficiencies of various treatment systems reported that *Moringa oleifera* could reduce turbidity by 96–98% and TSS by up to 88% and between 53 and 93% when used together with filtration system as done in the study. Furthermore, there was a percentage removal in Total coliforms (91%) and *E. coli* (>99%). This finding is also opined by Lea (2010) who reported that the use of *Moringa* seed extract achieved 90.00–99.99% bacterial removal in untreated water. pH reduced marginally by 1.7% and this reflected no significant alteration in the initial pH of the raw greywater. This was in line with Shan et al., (2017) who in a similar study of the use of *Moringa oleifera* seed as a natural coagulant for wastewater treatment and heavy metals removal reported no significant alteration of *pH* in the treated water.

However, COD and BOD increased by 95.2% and 95.2% respectively. This increase in BOD and COD from our study could be attributed to the significant protein content in the seed of *Moringa oleifera* seed. This is also opined by Shan et al. (2017) who in a similar study reported significant increase in COD and BOD after treatment and attributed it to the oil content of the *Moringa oleifera* seed cake. Shan et al. (2017) further argued that this increase could also result in odour problems if the water is not used quickly but stored for some time due to potential decomposition. However, the study did not cover the maximum allowable time for the storage of *Moringa* treated water if additional treatment cannot be afforded.

The final treatment via sand filtration of the *Moringa oleifera* seed powder treated water resulted in the reduction of Phosphate and Nitrogen contents by 55.8% and 56.7% and this agrees with Oteng-Peprah et al. (2018) who in research on the efficiencies of various treatment systems reported that filtration could result in the removal of 5–98% of nitrates and up to 100% of phosphate. The turbidity of greywater further reduced to 5.1 NTU from the initial 8.2 NTU after application of *Moringa oleifera* seed powder. This shows a reduction in the turbidity levels of the moringa treated water by 38%. This could be attributed to the impact of the sand filtration which further reduced the TSS by 60% and improved the turbidity. This is in line with Oteng-Peprah et al. (2018) who reports that filtration could reduce TSS by up to 93%. COD concentrations in the greywater was 528.1 mg/L after the sand filtration; a marginal reduction of 19.5%. Also, analysis of BOD values after the filtration showed a measurement of 139 mg/L and this corresponded to further reduction of 44.4%. This is line with Oteng-Peprah et al. (2018) who in a research on the on the efficiencies of various treatment systems reported that filtration systems could reduce COD by 37–94% and BOD by 89–98%.

Despite the high efficiency of the treatment system, when compared to other studies, some parameters such as COD and BOD did not meet the allowable limit of WHO/GSA. This could be attributed to heavily polluted nature of the raw greywater from these study areas.

5. Conclusion

The study sought to investigate the use of low-cost system in treating greywater to optimize water use in public senior high schools in Ghana. The study demonstrated that, the use of *Moringa oleifera* seed powder coupled with sand filtration, is an efficient treatment mechanism of greywater for non-potable uses such as toilet flushing and cleaning. *Moringa oleifera* seed powder coupled with sand filtration, exhibited coagulation and antimicrobial efficiency in reducing turbidity and *E. coli* in raw greywater to meet allowable WHO standards for drinking water. However, it is recommended that, for purposes of storage, the greywater must be further treated preferably addition of an aeration chamber to eliminate biodegradable contaminants; otherwise the greywater will quickly become septic and may produce odors. However, further studies need to be done to determine the maximum duration of time *Moringa oleifera* seed powder treated water can be stored if further treatment of biodegradable contaminants is not done.

Declarations

Author contribution statement

Richard Agbo Kwabena Ntibrey: Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Francis Atta Kuranchie: Conceived and designed the experiments; Wrote the paper.

Samuel Fosu Gyasi: Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

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