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Effectiveness of Some Selected Natural Filter Media for On-Site Small-Scale Treatment of Medium Strength Greywater

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ABSTRACT: Greywater represents a potential resource of water that can be recycled to meet the standards for safe discharge or non-potable uses. This study evaluated the performance of sand, charcoal, and saw dust filters in reducing Biochemical Oxygen Demand (BOD_5), Total Dissolved Solids (TDS), pH, Phosphate-phosphorus (PO_4-P), and Nitrate-nitrogen (NO_3-N) in greywater. Greywater was fed into a simple filtration system (SFS) with sand, charcoal and saw dust filters each of height 16 cm in three plastic containers of the same size: internal diameter 19 cm and height 22 cm each and operated for two weeks. Sand efficiently reduced the concentrations of BOD_5, phosphate-phosphorus (PO_4-P) and TDS while charcoal and saw dust were less efficient. Sand, charcoal, and saw dust reduced influent BOD_5 by 97.65%, 61.20% and 66.12%; PO_4-P by 99.92%, 83.98% and 20.56%; NO_3-N by 28.30%, 58.80% and 39.21%; and TDS by 47.18%, 7.94% and 29.69%, respectively for the two-week experimental period. Overall, sand appeared to be the most suitable filter for improving greywater quality for discharge or non-potable uses in terms of organic matter reduction. Effective performance of the charcoal and saw dust filters for the treatment of greywater need further investigation.

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Water resources are continuously experiencing pressure from the depletion caused by anthropogenic activities resulting from rapid urbanization, industrialization and the struggle for water among individuals (Bani-Melhem *et al*., 2015). Domestic wastewater may be identified as either greywater or black water. Greywater may be defined as the water (aside lavatory water) created from domestic chores including cooking and washing dishes, laundry and bathing (Anda *et al*., 2010; Al-Mashaqbeh *et al*., 2012; Mohamed *et al*., 2013a; Al-Gheethi *et al*., 2016). In most developing countries, domestic wastewater is discharged directly into the surroundings without proper treatment, with consequent adverse effects on health of plants and animals, economic activities, the quality of groundwater and the environment as a whole (WWAP, 2017). For instance, discharge of untreated or poorly treated greywater has been associated with contamination of natural water and the environment as a whole resulting in about 2.1 million deaths per year from infectious diseases (Gibson *et al*., 2010; Riffat, 2012; UNICEF/WHO, 2015). The levels of salts, solids, organic load, nitrogen, phosphorus and pathogens in grey water may also differ extensively (Gross *et al*., 2005) and may be based totally on the quantity of water used (Morel and Diener, 2006). Recent studies by Travis *et al*. (2010) and Dalahmeh *et al*. (2011) have reported organic nutrients together with fats and surfactants as complicated pollutant in grey water and can affect soil and crops and this has triggered the necessity for greywater treatment before discharge. Another study conducted by Travis *et al*. (2008) reported that oil and grease from grey water may build up in soils and negatively impact the ability of the soils to absorb water. Gross *et al*. (2005) in their study in the Israeli Negev desert similarly reported that, the accumulation of salts and surfactants within the soil is possible because of the long-time period of irrigating arid soils with grey water, causing damages in soil residences and toxicity to plant life. Consequently, it is important to collect and treat greywater for the health of the public and the environment (Katukiza *et al*., 2014; Al-Gheethi *et al*., 2016; Bani-Melhem *et al*., 2015). Several types of natural filtration processes ranging from low cost simple treatment methods using filter materials such as sand, course-size bricks, charcoal, sawdust, and coconut shell, oyster shell, peat soil and fly ash to expensive and high technology treatment methods like activated sludge process (ASP) and trickling filters (TF) have been reported in literature as capable of treating greywater. This study employed three natural

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filter media (sand, charcoal and saw dust) in reducing the concentrations of the analyzed parameters in the grey water. According to the Ghana 2010 Population and Housing Census (GSS, 2014), the Kassena-Nankana East Municipality does not have wastewater treatment system. Hence wastewater is discharged into the environment untreated, and this has the potential to lead to contamination of surface waters, upper soils and ground water (Norah *et al*., 2015). This may also create obnoxious environment over time and particularly allow pathogenic bacteria and other disease causing microorganisms to proliferate and provide breeding places for mosquitoes. This phenomenon has necessitated a research into identifying cheap and readily available natural media for use in removing some pollutants. The outcome of this research will provide useful information in the broader context of environmental protection and for the purpose of evaluating the suitability of various natural filters for small-scale greywater treatment option. The overall aim of this experimental study was to evaluate the suitability of selected natural filter media for small-scale close-to-nature treatment of greywater for safe discharge into the environment. Specifically, the following objectives were set: a) to determine the quality of the generated greywater as against the WHO standard for waste water, b) to assess the treatment efficiency of the selected natural filter media (sand, charcoal and saw dust), and c) to compare the removal efficiency of the selected natural filter media with time.

MATERIALS AND METHODS

Study Area: The research was done in the Kassena-Nankana Municipal of the Upper East region, Ghana. The population of the Municipality, according to the 2010 population and Housing Census, is 109,944, representing 10.5% of the region's general population (Fig 1). The climatic situation of the Kassena-Nankana Municipality is described by the dry and wet seasons that are stimulated by two air loads – the North-East trade winds and the South-Westerly's (Tropical Maritime). Day temperatures are high recording 42° Celsius (especially between February and March) and night time temperatures can be as low as 18° Celsius. The Municipality observes tropical maritime air mass between May and October and has average annual rainfall of 950 mm (GSS, 2014). The bucket and stopwatch method was used to measure the amount of greywater generated per hour (Goel, 2011; Adonadaga *et al*., 2019). The bucket and stopwatch method is less expensive and allow for a safe estimation of grey water without directly coming into contact with it (Mohamed *et al*., 2016). A bucket of a known volume (10L) was placed under the grey water outlet and the time taken to get full was measured using a stop watch. Measurement of greywater was done at peak hours within a day. Table 1 shows the hourly and daily grey water discharge.

Greywater Estimation: The ECOWAS hall, an all-male student's hall of residence on the Navrongo Campus of the University for Development Studies (UDS) was selected for this study, primarily because greywater from the hall comes from bathrooms, kitchen and laundry activities undertaken by the students.

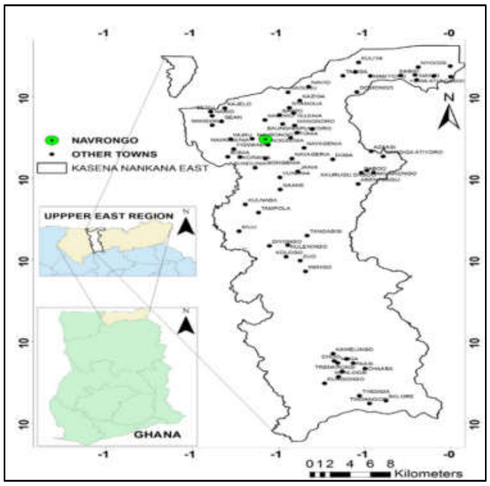

Fig 1. Map of Ghana showing the location of Upper East Region and Kassena-Nankana East Municipal

Table 1. Greywater estimation for hourly and daily discharge.

Time	Average Time (in hours)	Hourly Discharge (Q_H) (l/h)	Daily Discharge (Q_D) (l/h)
Morning	0.24	41.7	1000.8
Afternoon	0.27	37.04	888.96
Evening	0.21	47.62	1142.88

Filter Media Preparation: Three filter materials namely saw dust, charcoal and sand were prepared. These materials are readily available as residual waste materials in the study area. The media were sieved and washed thoroughly with clean water until clarity of drained filtrate was obtained (Mensah and Udofia, 2017). They were then spread on rubber screens and exposed to sunlight to reduce amount of moisture present and also provide an efficient adsorbent surface area. Finer charcoal particles were eliminated as they can rapidly clog the system. Similarly, larger particles were removed as they contribute to the fast flow with less treatment (Niwagaba *et al*., 2014).

Experimental Design and Operation: The design consisted of three stages by utilizing polypropylene plastic containers (Zhang and Scholz, 2008) as shown in Fig 2. The first stage of the design employed a container of height 32 cm and internal diameter of 27 cm with a capacity of 20 L which served as greywater feed tank. A PVC pipe with a diameter of 1.5 cm connects the storage tank 19.5 cm long at its bottom which leads into the second stage of the design. In this second stage, the pipe from the storage tank is designed to connect the top of three (3) different-colour plastic containers with the same size: internal diameter 19 cm and height 22 cm placed next to each other. The first container (light-blue) from left hand side contains sand filled up to 16 cm, the same height for charcoal in the second container (light-green) and saw dust in the third container (pink). The base of each container in the second stage of the design was perforated and fitted with tubes to permit the flow of effluent from the filter media. The last stage of the design comprised of three transparent polyethylene containers (filtrate containers) of the same height 21.5 cm, internal diameter of 15 cm and volume of 5 L each placed at the base of each filter containers to collect the filtrate. Labels were kept on every plastic container for ease of identification.

Fig 2. Design of the Experimental Set-Up

The experimental setup was operated for a period of one month, beginning from May, 2019. Gravels were employed as a base support medium for all the filter media. Mosquito net and wire mesh were placed between the gravels and the filter media in order to avoid the smaller grained size media from being washed along with the effluent (Mohamed *et al*., 2013b). The grey water used for this experiment has not been pre-treated. The greywater was poured into the storage tank and the pipe regulator opened to allow flow by gravity into the three separate containers with the different filter media. The effluent tube was tightly corked to keep the grey water in the filter containers for two days for an effective adhesion and absorption through the liquid-solid physical contact after which the corks were removed and the effluent collected from the collection containers. Effluent samples were labelled and packaged for laboratory analysis.

Fig 3: Effluents from Sand (SND), Charcoal (CHL) and Saw dust (SDT)

Laboratory Analysis: Greywater and effluents samples from the various filter media were analyzed for the following parameters according to standard methods (APHA, 2017): Biological Oxygen Demand (BOD_5), Phosphate-phosphorus (PO_4-P), Nitrate-nitrogen (NO_3-N), Total Dissolved Solids (TDS) and pH.

RESULTS AND DISCUSSION

Greywater Generation: The quantities of greywater discharged hourly and daily from the hall of residence are shown in Fig. 4. It was observed that the discharge peaked in the evening with a discharge of 47.62 l/h followed by 41.7 l/h in the morning and 37.04 l/h being the least in the afternoon. The daily discharges were calculated based on these values, giving an average discharge of 1010.88 l/d. Generally, the quantity of greywater generated is primarily based on the availability of water, living conditions, and residents' habits (Al-Mashaqbeh *et al*., 2012; Ghaitidak and Yadav, 2013). The variations in discharge may be due to the number of students present at the hall within that time of the day and the patterns of water use. The largest amount of greywater discharge was recorded in the evening. This might be due to the fact that students cook, do their laundry and bath mostly at this time. In relation to greywater generation, Mohammed *et al*. (2016) have reported that there are three main streams of greywater: the bathroom, the kitchen, and doing laundry. Reasons for the lowest discharge recorded in the afternoon could be because majority of students are out for lectures or library so less greywater generation activities such as bathing, cooking and washing.

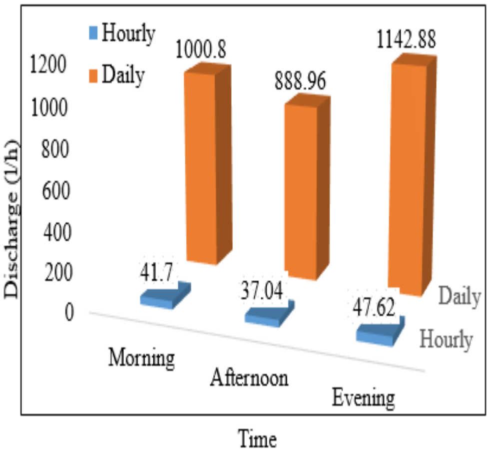

Fig 4. Discharge from the sample site

Greywater Quality: The pH of 8.3 for the greywater is within the WHO (2006) guideline of 6.5 – 8.5 for wastewater discharge. Total Dissolved Solids level in the greywater was 1172 mg/l which is higher than the guideline value of 1000 mg/l. Biological Oxygen Demand (BOD_5) concentration was 183 mg/l, exceeding the WHO (2006) guideline value of 50 mg/l. Values of Phosphate-phosphorus PO_4-P and NO_3-N were within their guideline values (Fig 5).

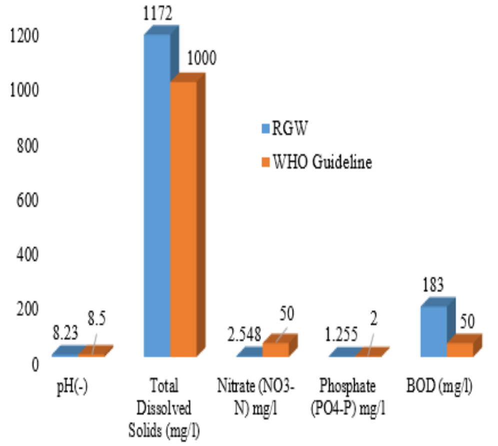

Fig 5: Concentration levels of greywater parameters against WHO (2006) guideline values.

Greywater is enormously low in suspended solids and turbidity, with a greater proportion of the contaminants being mostly dissolved (Al-Jayyousi, 2003). The TDS recorded in this study is similar to the 1404 mg/l reported by Sonume and Ghate (2004). Niwagaba *et al.* (2014) stated that the excessive TDS level may be because of the reality that greywater may additionally comprise of an exquisite deal of detergents that have salts and whilst the grey water degrades, the salts crumble and are released resulting in the excessive concentrations. However, Bani-Melhem *et al.* (2015) have reported lower TDS levels of 319 mg/l where the bathroom greywater was accrued from a building of the Faculty of Natural Resources on the Hashemite College, AL-Zarqa, Jordan and have attributed this to the source and the type of soap products used by the employees in the University. Despite that greywater is generally generated by using cleaning products for body washing, dish washing and laundry, its composition varies with the region and general lifestyle of the citizens (Al-Jayyousi, 2003; Jefferson *et al.*, 2004; Morel and Diener, 2006). The high BOD reported by this study is supported by other studies that reported values between 120-1307mg/l (Abdel-Shafy *et al.*, 2014). These high BOD levels have been attributed to the presence of high natural fraction most likely coming from the human body in the course of washing or bathing (Mohammed *et al.*, 2013a). Another source of high BOD may be due to the pieces of food wastes and oil or carbohydrates/starch from washing utensils and cooking.

Filter Media Performance: Sand achieved 88.52% reduction in BOD, 42.66% reduction in Total Dissolved Solids (TDS), 89.48% reduction in PO_4-P and 28.3% reduction in NO_3-N (Table 2). All these effluent values met the discharge guidelines of the WHO (2006).

Table 2. Performance of the various filter media

Sand	**WEEK ONE**		
Parameter	RGW	SND	$\% R = \frac{RGW-SND}{RGW} \times 100$
TDS (mg/l)	1172	672	42.66%
NO_3-N (mg/l)	2.548	1.827	28.30%
PO_4-P (mg/l)	1.255	0.132	89.48%
BOD_5 (mg/l)	183	21	88.52%
Charcoal	**WEEK ONE**		
Parameter	RGW	CHL	$\% R = \frac{RGW-CHL}{RGW} \times 100$
TDS (mg/l)	1172	1079	7.94%
NO_3-N (mg/l)	2.548	1.05	58.80%
PO_4-P (mg/l)	1.255	0.201	83.98%
BOD_5 (mg/l)	183	71	61.20%
Sawdust	**WEEK ONE**		
Parameter	RGW	SDT	$\% R = \frac{RGW-SDT}{RGW} \times 100$
TDS (mg/l)	1172	951	18.86%
NO_3-N (mg/l)	2.548	1.549	39.21%
PO_4-P (mg/l)	1.255	0.997	20.56%
BOD_5 (mg/l)	183	62	66.12%

NB: RGW= Raw greywater; SND= Sand filter; CHL= Charcoal filter; SDT= Sawdust filter; %R=Percentage reduction

Charcoal showed a decrease of 61.2% in BOD, a slight decrease of 7.94% in the TDS level, 83.98% in PO_4-P reduction and 58.8% reduction in NO_3-N. However, the percentage reduction in TDS by the charcoal filter media was not enough to render the effluent safe for discharge. For the saw dust media, the reductions achieved are as follows: BOD, 66.12%; TDS 18.86%;

PO_4-P 20.56% and NO_3-N 39.21% (Table 2). The reductions were adequate for all the analysed parameters to meet the discharge guideline values. A comparison of the performance of the various filter media for BOD and TDS is shown in Figures 6 and 7 respectively below.

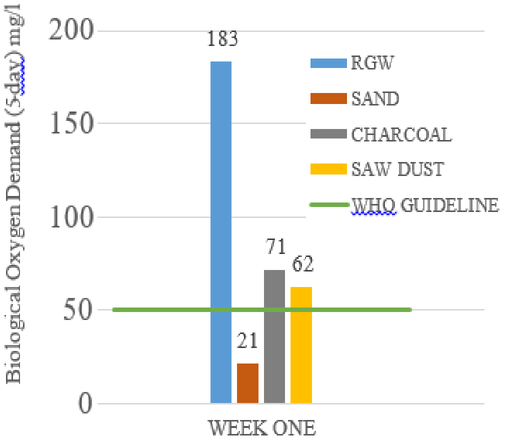

Fig. 6. BOD: Comparison of influent greywater with effluent from the three filter

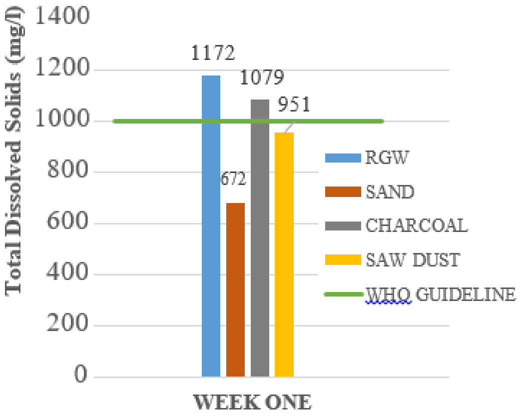

Fig. 7. TDS: Comparison of influent greywater with effluent from the three filter media

BOD_5 reductions achieved in this study ranged from 61.20% to 88.52%, with sand recording the highest and charcoal the lowest. This highest percentage reduction by sand could be because of its high adsorption/retention capacity. The BOD_5 reduction achieved by saw dust filter was lower than the 70% reported by Savage and Tyrel (2005) who used wood chips. Although Ratola *et al*. (2003) have attributed the reduction of BOD_5 in effluent of living filter (bark or sawdust) to adsorption, Dalahmeh *et al.* (2012) have also associated it to microorganisms which may be present on the filter. The neem charcoal used in this study achieved a PO_4-P reduction of 83.9%, indicating a higher efficiency compared to the 11-17% recorded by Ahsan *et al.* (2001) who used coconut charcoal. A higher adsorption of mineral PO_4-P compared with the organic forms of phosphate on charcoal could be the reason for the efficiency of the charcoal filter. The PO_4-P elimination efficiency by the saw dust filter was 20.56% which is far lower compared to the 97% reported by Dalahmeh *et al.* (2012) using tree bark. Possible reasons for this low reduction are the low PO_4-P concentration in the greywater, the small length of the saw filter and the presence of oil from the kitchen (Travis *et al.*, 2010). Also, the longer the greywater remains in the treatment process, the greater the chance of an effective treatment (Mohammed *et al.*, 2016). The PO_4-P reduction of 89.48% by the sand filter was also higher than the 58% reduction reported by Tamini *et al.* (2010). Adsorption is the major mechanism for PO_4-P reduction in sand filter and the potential of the sand to bind phosphorus is based totally on pH and the Ca, Fe and Al content of materials inside the sand (Pell and Nyberg, 1989; Arias *et al.*, 2001). The 39.12% NO_3-N reduction efficiency recorded by this study is similar to the 35% reduction reported by Lens *et al.* (1993). Dalahmeh *et al.* (2012) have stated that aerobic conditions may prevail in living filter (bark or saw dust) which is associated with the nitrification of most of the mineralized nitrogen. This could partly explain the low reduction achieved. Although charcoal achieved the highest NO_3-N reduction (58.80%), this was still lower than the 96.6% and 90.94% reported for bio charcoal and activated charcoal (Healy *et al.*, 2007; Berger, 2012).

Conclusion: The study was conducted to assess the suitability of some natural materials for use in treating greywater within the Kassena-Nankana East Municipality. The sand filter was found to be the most efficient as it recorded the highest removal efficiency for TDS, PO_4-P and BOD_5. It is recommended that the experiment be run for a longer time, preferably a month, in order for a proper correlation between the removal efficiency and time to be established. Also, a column filtration system of the three media, based on their porosity, effective surface area and bulk densities should be developed and tested.

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