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Biosand Filter as a Household Water Treatment Technology in Ghana and its Eco-business Potential

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ABSTRACT

Biosand filter basically applies a system of sand, gravels and biologically active microorganisms to remove unwanted substances from drinking water. Field trials of the biosand filter for domestic water treatment in rural communities have shown remarkable health gains from its application. As such, there are calls to scale up its application in developing countries. This study investigated factors that may influence the acceptability of the biosand filter at the household level in rural communities in Ghana. The study further applied lifecycle environmental and cost assessments to analyse the eco-efficiency potential of the biosand filter and examined prospects of leveraging this potential for green business development. The key demographic and socio-economic indicators of biosand filter acceptability related to gender, age, education and wealth. Females showed greater interest in the biosand filter, while discrete increase in age, relative advancement in education and economic status of respondents may each increase the prospects of purchasing biosand filter. Compared to local sachet water production, which was considered as a quasi-alternative to the biosand filter, it was established that the latter has superior eco-efficiency, provided quite comparable profitability and potentially viable for eco-business development.

Keywords: Water treatment, biosand filter, rural households, eco-efficiency

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ABBREVIATIONS

BSF	Biosand filter
CWSA	Community Water Supply Agency
HWTS	Household water treatment and safe storage
LCA	Life Cycle Assessment
LCC	Life Cycle Cost
LCE	Life Cycle Environmental Load
LDPE	Low Density Polyethylenes
MDGs	Millennium Development Goals
NGOs	Non-governmental Organisations
NTU	Nephelometric Turbidity Units
POU	Point-of-use
PVC	Polyvinyl chloride
REP	Rural Enterprises Programme
SODIS	Solar disinfection
SW	Sachet Water
TPI	Total Performance Indicator
UNICEF	United Nations Children's Fund
UV	Utility Value
WHO	World Health Organisation

1. INTRODUCTION

It is often said that water is life. This is because water is central across all economic sectors and a critical factor for human development (World Bank, 2014). Sustainable management of water, therefore, positively affects the wellbeing of individuals and communities, and would stimulate green growth. Unfortunately, there are serious water management challenges confronting the world today. The worst affected are rural communities in developing countries. According to the World Health Organisation (WHO), 1.1 billion people lack access to safe drinking water in the developing world (WHO, 2004). The lack of access to clean water and sanitation cause approximately 1.8 million deaths each year from diarrhoea and other water and sanitation related diseases, with 90% of the mortality occurring in children under five years. It has been estimated that improved water supply could reduce diarrhoea morbidity by 21%, improved sanitation could reduce diarrhoea morbidity by 37.5%, but improvement of drinking water quality such as point-of-use (POU) water treatments could reduce diarrhoea episodes by as much as 45% (WHO, 2004).

Point-of-use water treatments or household water treatments allow purification of water at the point of consumption. Therefore in areas such as rural communities in developing countries that are unserved by centralized water treatment, POU treatments are normally encouraged (UNICEF and WHO, 2009). Point-of-use water treatments may range from simple processes such as applying a clean cloth or ceramic pot to filter water in households, boiling of water before drinking, applying disinfectant, to other processes such as application of biosand filters (Green, 2008). Biosand filters are perhaps one of the most promising low cost technologies for POU water treatments. The biosand filter basically applies a system of sand, gravels and biologically active microorganisms to remove unwanted substances from drinking water. The system is normally packaged into a hollow plastic or ceramic container, in a form that households can easily use to filter their drinking water. The biosand filter has been shown to have a capacity to even remove viruses from water, when amended with iron oxide (Bradley et al., 2011).

1.1 Objectives and Research Questions

Point-of-use water treatments have a great potential to improve water quality and reduce water-related disease burden in rural communities in developing countries. For this potential to be fully realised, the water treatment options must be culturally acceptable and available to rural folks on a sustainable basis. The key issues then, are how to develop a model that would ensure sustainability in the manufacture and utilisation of these environmentally relevant products in rural communities. Would rural households accept and use biosand water filters? Could rural enterprises leverage the potential of POU water treatments to develop effective, low cost water treatment systems for rural households? This research sought to provide understanding on these issues. The aim of this study, therefore, is to evaluate the acceptability of biosand filters in rural communities in Ghana and assess its potential for eco-business development.

1.2. Literature Review

The concept of clean drinking water and safe sanitation is essential to health. Improved access to these facilities promotes public health and reduces water-, sanitation- and hygiene-related deaths (Montgomery and Elimelech, 2007). Global evidence suggests that regions with poor water and sanitation facilities suffer most from diarrhoeal-related morbidity and mortality (WHO, 2004). Water and sanitation outlook is very gloomy in Sub-Saharan Africa where 42% of the population is without improved water supply and 62% without improved sanitation. The consequence is that the number of deaths due to diarrhoeal diseases is higher in Sub-Saharan Africa, estimated at around 22 deaths per 1000 children, mostly younger than one year (WHO, 2004). The global response to resolving these problems has been led by the United Nations, which as part of its Millennium Development Goals (MDGs) initiated a global policy to halve the proportion of people without access to clean drinking water and basic sanitation by 2015. The WHO also declared the period 2005-2015 as a decade of water. This global policy direction has culminated in mobilising resources, shaping research and venturing into low cost technologies to help improve access to clean drinking water and safe sanitation in developing countries.

The term “improved access” usually refers to households that obtain water from sources that are superior to traditional unprotected ones (Montgomery and Elimelech, 2007). In Ghana, this includes mainly pipe-borne water, boreholes and protected hand-dug wells. It is estimated that 88% of urban dwellers and 64% of rural dwellers in Ghana have improved access to clean drinking water (WHO, 2006). The rest rely on unapproved sources such as raw water from rivers, lakes and ponds for drinking. Over the past decade, water quality in these surface reservoirs has deteriorated and severely impacted by pollution from mining, agricultural and municipal sources. These reservoirs are also open to invasion by livestock such that in certain communities, humans virtually share water with animals. Contaminated water sources, in addition to insanitary environmental conditions, cause perennial outbreak of cholera and other diarrhoael diseases in Ghana each year. Approximately 17,000 cases of diarrhoeal morbidity were reported in Ghana in 2014, with 150 deaths, apparently the worst outbreak of diarrhoea in Ghana since 1982.

In 2009, UNICEF and WHO adopted a 7-point strategy for comprehensive diarrhoea control that included household water treatment and safe storage (HWTS) (UNICEF and WHO, 2009). Since then, the International Network on HWTS co-hosted by the WHO and UNICEF has been actively engaging developing countries to accelerate efforts on establishing national HWTS policies. As of 2012, Ghana and Tanzania were the only countries in Africa that have indicated a national strategy for HWTS that was multi-sectorial in focus and bridging national water and health efforts (WHO, 2012). In the case of Ghana, the national policy on HWTS stipulated that by 2015, at least 90% of population who do not yet have access to potable water in Ghana will consistently practice an effective HWTS method.

1.2.1 Rural water supply in Ghana

Rural water supply in Ghana is facilitated by the Community Water Supply Agency (CWSA). The CWSA was established in 1998 by an Act of Parliament (Act 564) to promote sustainability of safe water supply and related sanitation services in rural communities and small towns. Over the past years, the CWSA has pursued this mandate mainly through the development of groundwater for rural and small communities. Ninety-five percent (95%) of domestic water supplies in rural communities in Ghana reportedly comes from groundwater sources (Awuah et al., 2009) and the CWSA plays the lead role in establishing boreholes and hand-dug wells in many rural communities. Between 2001 and 2006, a total of 6645 community boreholes and 829 hand-dug wells were established by the CWSA (Government of Ghana, 2007). These efforts are complemented by various NGOs operating in the rural water supply sector.

The coverage of rural water supply in Ghana is approximately 64% (CWSA, 2013). This leaves a coverage gap of about 36% in rural water supply in Ghana. Rural communities that lack improved access to water supply usually rely on raw untreated water from rivers, streams, lakes and dams as sources of drinking water (Figure 1). Unfortunately, many of these reservoirs in Ghana are reportedly polluted with various toxic chemicals such as heavy metals (especially from illegal small scale gold mining activities) (Donkor et al., 2005; Donkor et al., 2006; Antwi-Agyei et al., 2009) and pesticides (from agricultural fields) (Ntow, 2001; Ntow et al., 2008; Obiri-Danso et al., 2011). Drinking water from such sources therefore has serious environmental health consequences; it calls for water such sources to be treated domestically before drinking.

Figure 1: Rural dwellers fetching water from a local lake in Northern Ghana.
(courtesy of Izumi Kikkawa)

1.2.2 Point-of-use (POU) water treatment

For persons living in rural areas and urban slums in developing countries that do not have improved access to clean drinking water, POU water treatment provides a safe way to process drinking water. The term "POU water treatment" simply implies that the water is purified at the household level before drinking. The technologies applied in purifying the water must be simple and cheap to ensure accessibility and affordability. With these attributes, POU water treatment technologies are easily deployable in very remote communities. Various POU water treatments exist ranging from simple processes such as boiling of water before drinking to more innovative ones such as the biosand filter. The main POU water treatments reported in Ghana are ultraviolet / solar disinfection, chlorine disinfection and particle removal (Green, 2008). Other households depend on sachet water for drinking purposes. Therefore, although it is not a treatment method, sachet water is recognised as an important alternative for the provision of safe drinking water at the household level in Ghana (Okioga, 2007).

1.2.2.1 Ultra-violet / solar disinfection

Solar disinfection (SODIS) is a simple and cost effective household treatment option in which clear plastic bottles are filled with low-turbidity (<30 NTU) water, shaken vigorously for oxygenation and then left outside, typically for six hours if it is sunny and two days if it is cloudy (EAWAG, 2008). The disinfection is effected by UV radiation from the sun. The effectiveness of SODIS has been confirmed through several research findings (McGuigan et al., 1998; Fujioka and Yoneyama, 2002;

Berney et al., 2006; Heaselgrave and Kilvington, 2012). In areas where SODIS have been applied to disinfect drinking water, there have been health gains such as reduction in cholera and dysentery in children (Conroy et al., 2001; Du Preez et al., 2010; Du Preez et al., 2011). However, since the SODIS process does not involve filtration to remove suspended particles, it is recommended in instances where the water is less turbid. As turbidity of surface water is relatively high in Ghana, the application of SODIS for POU treatment of river water might not be fully efficient.

1.2.2.2 Chlorine disinfection

Chlorine is the most commonly used disinfectant in drinking water treatment. It can be applied in large-scale drinking water treatment as well as at the household level in POU treatment. The use of chlorine as a HWTS method entails treating water with sodium hypochlorite at the point of use. The sodium hypochlorite may be packaged in a liquid or tablet form. The benefits of POU chlorination include reduction of bacteria and most viruses, residual effect against contamination and ease of use, which make it easily acceptable. Chlorine disinfection however has certain drawbacks. It has been found not to be effective against some microbes such as cryptosporidium. It also has lower effectiveness in water contaminated with organic or inorganic compounds and can potentially affect the taste and odour of the water. There are also concerns about potential long-term carcinogenic effects of chlorination by-products (Lantagne et al. 2006).

1.2.2.3 Particle removal

Coagulants such as aluminium sulphate (commonly known as alum) and iron sulphate have been commonly applied to precipitate suspended particles and remove turbidity and other visible contaminants from water at the household level for centuries in many parts of the world (Sobsey, 2002). It is however thought that the application of coagulants is more effective for centralised water treatment facilities. This is because it requires knowledge and skill to apply coagulants effectively. For this reason, coagulant application is less likely to be reliably performed as a POU method.

1.2.2.4 Biosand filter

The biosand filter was designed as a modification of the large-scale, continuously operated slow sand filter, and allows for intermittent water dosing for household use (Sobsey et al., 2008). It was developed in the early 1990s and an estimated 320,000 biosand filters have been installed globally in about 70 countries (Dyck et al., 2009). It is considered one of the most effective low cost POU water treatments.

The most widely used version of the biosand filter is a concrete container approximately 0.9 meters tall and 0.3 meters square, filled with a layer of fine sand below which are layers of gravel. As the concrete housing of the biosand filter makes it heavy and bulky to handle, some new models of the product have applied plastic housing instead, to reduce product bulkiness (Kikkawa, 2008). Biosand filter is operated intermittently by pouring inn untreated water, which then flows down the length of the filter bed by gravity. Filtered water exits the biosand filter from a bottom outlet pipe (usually PVC plastic) that is directed upwards as a standpipe (Figures 2 and 3). The filtered water can then be collected for safe storage. The biosand filter may treat approximately 50 L of water per hour (Liang et al, 2010).

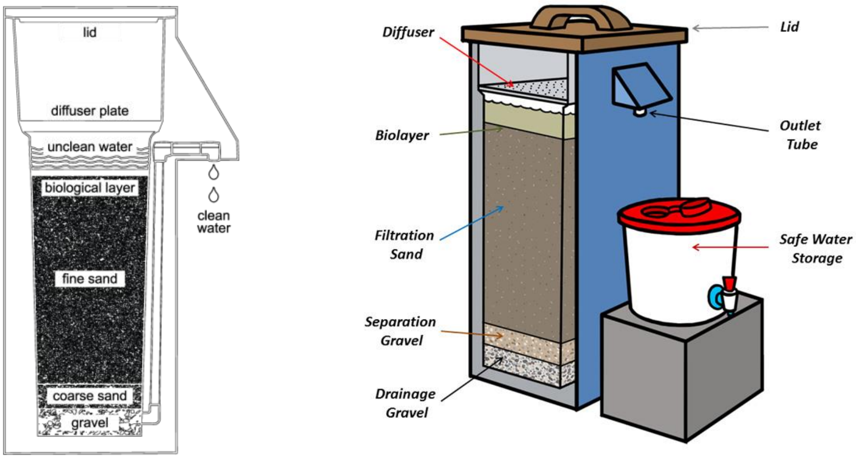

Figure 2: Schematic representation of the biosand filter.

The biosand filter can reduce turbidity by 92 – 95% (Kikkawa, 2008), bacteria by 81 – 100% (Kaiser et al., 2002), protozoa by 99 – 100 % (Palmateer et al., 1999) and viruses by up to 99% (when the filter is augmented with iron oxide) (Bradley et al., 2011). The improvement in water quality is achieved via both biological and mechanical processes. As water passes though the sand layer, pathogens and particles (usually of size > 1.0 mm) are mechanically trapped and filtered out. Smaller pathogens such as bacteria and viruses may similarly be removed when they are attached to larger particles, which cannot pass through the pores of the sand layer. The biosand filter is designed in such a way that the top of the sand layer is not allowed to run dry. A minimum cover of about 1-3 cm water is maintained on top of the sand layer. A complex biological layer consisting of bacteria, fungi, protozoa, rotifera and other tiny organisms develop in the water layer above the sand. This biofilm eats up organic contaminants that may be contained in the water. Microorganisms that may slip through the upper aerobic portions of the sand layer may eventually die off upon reaching the lower anaerobic portions of the sand layer because of lack of oxygen. These mechanisms ensure that the BSF is effective in reducing both turbidity and microbial load of the treated water.

Figure 3: Various examples of the biosand filter.

The biosand filter has been introduced in several developing countries including Ghana, Kenya, Dominican Republic, Cambodia and Afghanistan, mostly through pilot studies and demonstration projects. These experiments have been largely successful providing positive health benefits. It was demonstrated that the application of biosand filter in rural communities in Tamale, Ghana, reduced the incidence of diarrhoea by 60% (Stauber et al., 2012). Other experiments with the biosand filter suggested 47% reduction in waterborne diarrhorea disease in the Dominican Republic (Stauber et al., 2009), 54% reduction in child diarrhoea days in Kenya (Tiwari et al., 2009) and 59% reduction in reported diarrhoea cases in Cambodia (Stauber et al., 2012). The positive health impacts were also confirmed in Afghanistan, where only 16% of those with an operating biosand filter reported cases of diarrhoea, while 71% of those without a biosand filter reported cases of diarrhoea (Mashal, 2011).

The benefits of BSF extend to its ability to filter out some chemical contaminants from water. For instance, when the BSF was modified with zeolites, it reportedly removed up to 80% of calcium, 89% of magnesium, 99% of iron, 56% of arsenic, 54% of fluoride, 37% of nitrate, and 41% of total organic carbon (Mahlangu et al., 2011). The BSF has also reportedly shown potential to remove heavy metals such as cadmium and chromium from water (Biosand Filter, http://www.biosandfilter.org/biosandfilter/index.php/item/302).
The removal of chemical contaminants by biosand filter is possibly achieved via the mechanism of adsorption. The removal of contaminants from water by the mechanism of adsorption is particularly useful when the contaminants are in trace

amounts and could easily escape the action of known methods such as chemical precipitation and reverse osmosis, among others.

1.2.2.5 Sachet water

Sachet water refers to drinking water packaged in small plastic sachets (usually of volume 500 mL). Sachet water, known locally as "pure water" is the form in which drinking water is accessed in public places and many homes in Ghana. There are one-man businesses that produce sachet water at home to sell (Figure 4), as well as multi-million cedi businesses engaged in sachet water production. There is an increasing trend of household dependence on sachet water as source of drinking water in Ghana (Stoler et al., 2012a,b). Many factors are accounting to this. For instance, urban communities not served with piped borne water heavily rely on the sachet water for drinking. Even those served with pipe borne water still rely on the sachet water because of perceived water quality problems pertaining to noticeable amount of settled particles when the water is stored in containers (Stoler et al., 2012b). Rural dwellers who can afford the sachet water prefer it to drinking water from wells and rivers.

In the past (between the 1970s and 1980s), drinking water was vended in Ghana in plastic or metallic cups. The same cup was used to serve several customers, which was considered unhygienic. The vending of water this way was targeted at people who were in transient. Between the 1980s and 1990s, another phenomenon started where drinking water was hand-tied and sold in plastics. Drinking water sold in hand-tied plastics was usually of poor quality because of contamination during the hand-tying process (Okioga, 2007). In the late 1990s, new Chinese machinery that heat-sealed water in a plastic sleeve effectively created the modern sachet that is currently sold on the streets of several West African nations. Filtration and chemical treatment processes were eventually built into some of the high-end machines as well, allowing for the delivery of drinking water of improve and acceptable quality (Stoler et al., 2012b). Thus, sachet water may represent relatively high end alternative of delivering clean drinking water in most Ghanaian households.

Figure 4: A simple production line for sachet bag water.

2. METHODOLOGY

2.1 Questionnaire Administration

Questionnaires were administered to 150 rural households – 50 each in the Offinso and Ejura districts in the Ashanti Region and 50 in the Bongo district in the Upper East Region. The questionnaires were administered at Aborfour, Nyamebekyere and Akomadan villages (all in Offinso district); Bayere-Nkwanta, Nyamebekyere, Amonem, Miminaso, Dromankoma and Bonyo villages (all in Ejura district); and Longo in the Bongo district. These villages were purposively selected because they are remote with limited access to improved drinking water supply (Figure 5). The questionnaires were randomly administered in each of the selected villages to collect data on demographic characteristics, socio-economic characteristics, accessibility to clean drinking water and patronage of POU water filter.

Figure 5: Questionnaire being administered to a female respondent.

2.2 SWOT Analysis

The prospects of developing biosand filter as a rural business entity was evaluated through a SWOT analysis, in which the strength, weakness, opportunity and threat to such a venture in Ghana was ascertained. A Likert 10 point scale questionnaire was developed and sent to 8 experts in the field of environmental science and business management to rank various factors that may potentially influence rural business development pertaining to household water treatment.

There are two sets of factors – internal and external factors. For each internal factor, the experts indicated if it is a source of strength or weakness for the potential rural business and ranked their choices on a scale of 1 to 10 by checking the appropriate box. Likewise, the experts ranked each external factor either as a threat or opportunity on a scale of 1 to 10. Once a factor was considered as a weakness or threat, the corresponding columns for strength or opportunity, respectively, were left blank, and vice versa. For each of the parameters, 1 indicates the least score and 10 the highest. Responses were obtained from 5 experts. The average response of the factors was plotted applying the Inghenia SWOT Tool (Inghenia, 2009) and a strategic vector was identified on the plot that summarized the strength, weakness, opportunity and threat of POU biosand water filter related business venture in Ghana.

2.3 Eco-business Model

Eco-businesses are businesses that provide equal or greater user value at lower environmental load and cost than that offered by conventional ones. Theoretically, an eco-business is one that achieves higher “Total Performance Indicator” (TPI) values than conventional businesses (eqn. 1). The TPI is expressed as a ratio of utility value of a product or service to the geometric mean of the environmental load and cost associated with the product or service (Kondoh and Mishima, 2010).

$$\text{TPI} = \frac{UV}{\sqrt{LCE\ x\ LCC}} \quad \ldots\ldots\ldots\ldots\ldots\ldots 1$$

where:
TPI = Total Performance Indicator
UV = Utility Value
LCE = Life Cycle Environmental load
LCC = Life Cycle Cost

The utility value (UV) is the time integral of product value, assuming that the product value is strongly correlated with its functional performance (Kondoh and Mishima, 2010). That is, $UV = \int_0^{lt} V(t)dt$, where *lt* and *V(t)* denote the lifetime and product value at time t, respectively.

The life cycle environmental load (LCE) is essentially the environmental load encountered in the entire product cycle – i.e. during use, production, distribution and end of life. Mathematically, LCE could be expressed as: $e_{use}\ lt + e_{prod} + e_{dist} + e_{eol}$, where

$e_{use}\ lt$ = environmental load at the product usage stage per unit time
e_{prod} = environmental load at the production stage
e_{dist} = environmental load at the distribution stage
e_{eol} = environmental load at end of life treatment stage

The life cycle cost (LCC) denotes the total cost incurred through the entire product cycle i.e. from production through distribution, use and end of life. It could be expressed mathematically as: $f_{use}\ lt + f_{prod} + f_{dist} + f_{eol}$, where
$f_{use}\ lt$ = cost at the product usage stage per unit time
f_{prod} = cost at the production stage
f_{dist} = cost at the distribution stage
f_{eol} = cost at end of life treatment stage

When a new or potential business is better than previous ones in terms of TPI (i.e. has relatively higher TPI), it is regarded as an eco-business. This is because it is likely to deliver similar utility at lower environmental load and cost. In this study, the TPI-based model was applied to establish the eco-business potential of the biosand filter technology in Ghana, relative to sachet water, which was considered as the highest alternative.

2.4 Statistical Analysis

Data from the questionnaires were presented applying descriptive statistics as well as subjected to probit analysis to predict possible factors that might influence peoples' preference for the POU water filter in rural communities. According to Sperman (2008), probit is based on a latent model:

$$\begin{aligned} P(y_i = 1 \mid x) &= P(y_i^* > 0 \mid x) \text{.................(1)} \quad . 2 \\ &= P(x_i'\beta + \varepsilon_i > 0 \mid x) \\ &= P(\varepsilon_i > -x_i'\beta \mid x) \\ &= 1 - F(-x_i'\beta) \end{aligned}$$

Latent variable: Unobservable variable y* which can take all values in (-∞, +∞). Generally, y_i is the binary dependent variable.

y = 1 represents preference for the POU water filter
y = 0 represents preference for other items
X_i represents the independent variables
X_1 represents gender (male = 1, female = 0)
X_2 represents age (years)
X_3 represents marital status (1 = married, 0 = single)
X_4 represents education (1 = formal education, 0 = no formal education)

X_5 represents economic activity (1 = farmer, 0 = all other activities)
X_6 represents average annual income
X_7 represents personal means of transport (1 = yes, 0 = no)
X_8 represents source of drinking water (1 = river/stream, 0 = other sources)
X_9 represents domestic water treatment (1 = yes, 0 = no)
X_{10} represents satisfaction with current of drinking water (1 = yes, 0 = no)
X_{11} represents incidence of diarrhoea in last two weeks (1 = yes, 0 = no)
X_{12} represents willingness to pay (1 = yes, 0 = no)

3. RESULTS AND DISCUSSION

3.1 Demographic and Socio-economic Characteristics

The age of respondents ranged between 18 and 90 years with an average age of 38.9 years. Majority of the respondents (approximately 32%) were in the age bracket of 18 – 27 years (Figure 6).

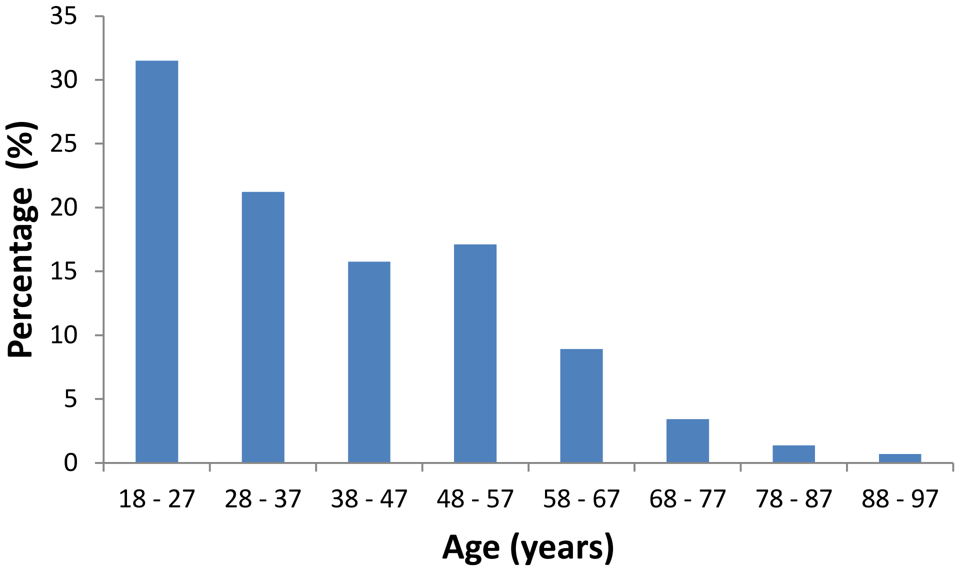

Figure 6: Percentage of respondents and their age brackets.

Fifty-five percent (55%) of the respondents were females and 45% males, while 62% were married and 38% single (Figure 7). A sizeable proportion of the respondents (42%) had no formal education, while 39%, 25% and 4% had primary, secondary and tertiary education, respectively. Majority of the respondents were farmers (64%) as anticipated, given the rural setting of this study. Fifty-one percent (51%) of the respondents sourced their drinking water directly from rivers and streams, 43% from boreholes and wells, while 6% purchased sachet water (Figure 8a). Thus, nearly half of the respondents lacked access to improved water supply. Nevertheless, only 18% reported any form of domestic water treatment (Figure 8b). For the large majority of respondents, (82%) who did not apply any form of treatment to drinking water, cultural reasons (37%) as well as cost / cumbersomeness (31%) of treatment were assigned as the main elements that discouraged POU water treatments, while 19% were not aware of POU water treatments (Figure 8c).

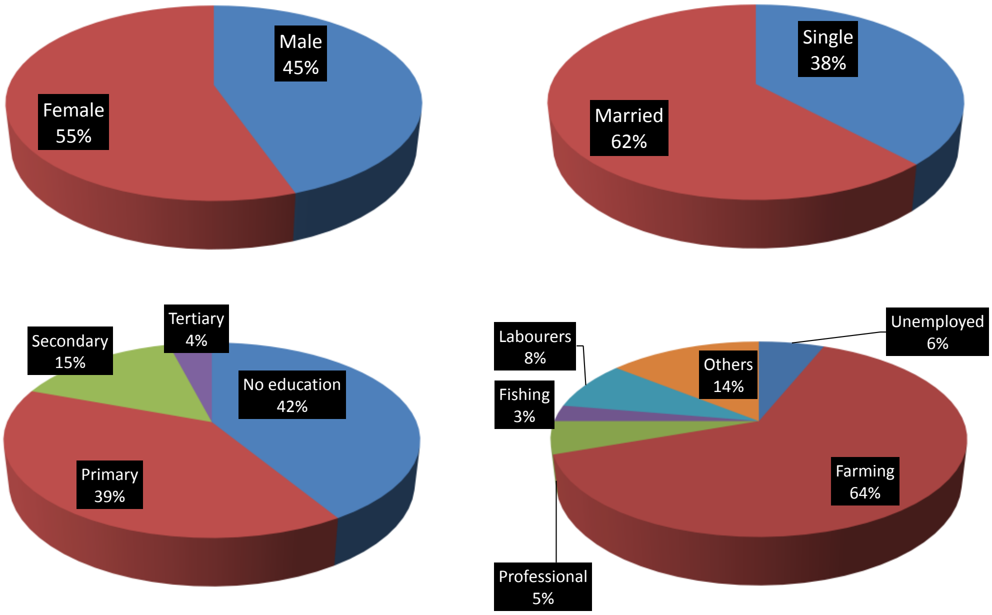

Figure 7: The gender, marital status, educational level and economic engagements of respondents.

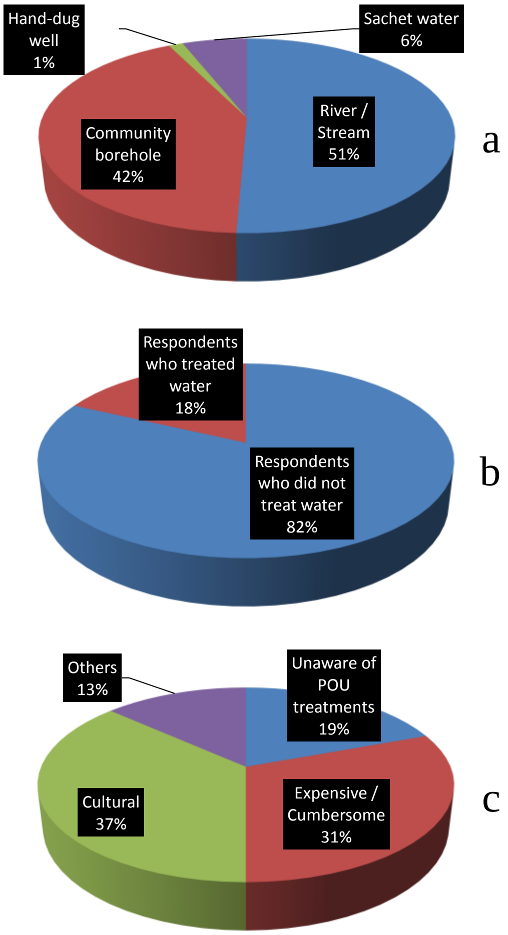

Figure 8: (a) Source of drinking water; (b) proportion of respondents that treated / did not treat drinking water; (c) reasons assigned for not applying domestic water treatment.

One of the fundamental questions in this study was to find out if people were interested in purchasing POU water filters. This was assessed by providing a list of items and respondents were asked to list their preferences in order of importance at purchasing these items. There were seven items in all – mosquito coil/net, water filter, alum, bicycle/motor bike, fertiliser, television and mobile phone. These items cut across various wants in the rural communities, such that the first selected item reflected the most prioritized want and the last, the least prioritized. Fertiliser emerged as the most prioritized with 35% of respondents indicating it as first choice item. Seventeen percent (17%) of respondents also indicated water filter as the most prioritized, 14% selected television first, 12% prioritized mosquito coil / net, 10% prioritized alum, 9% prioritized bicycle / motor bike, and 4% prioritized mobile phone (Figure 9). Thus, the three items that respondents selected mostly as first priority were fertiliser, water filter and television, in decreasing order. This potentially reflects a need for food security, improved access to drinking water and entertainment, respectively. It is consistent with the fact that majority of the respondents were farmers and required fertilizer for their farms. Therefore, given the opportunity, they would first and foremost invest their resources on their farm. It also presupposes that when rural dwellers are assisted to meet their demands for agricultural inputs, they may show greater interest in acquiring and applying the biosand water filter.

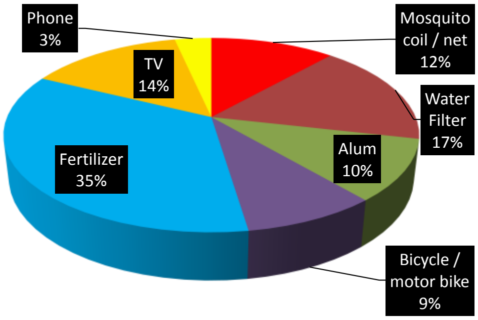

Figure 9: Proportion of items prioritized as first choices by respondents.

The probit model was applied to assess the influence of various demographic and socio-economic factors on the potential to purchase the biosand water filter as first choice preference among the list of items presented to respondents. The parameters considered are listed in Table 1. The slope measured changes in the potential to purchase a water filter against discrete changes in each parameter. The relationships were significant for gender (p=0.008, 99% C.l.), age (p=0.001, 99% C.l.), education (p=0.002, 99% C.l.), transport (p=0.006, 99% C.l.) and satisfaction with one's drinking water (p=0.06, 90% C.l.) (Table 1). Males had a reduced probability (0.19) of purchasing a biosand water filter. This meant that females had greater probability (approximately 0.8) of purchasing the filter. This is consistent with cultural practices in Ghana where domestic water issues are mostly handled by women. Discrete increase in age and progress in the level of education may each increase the prospects of purchasing a water filter at probabilities of 0.008 and 0.29, respectively. Thus, it does appear that as people advanced in age, they may want to use the biosand water filters. Similarly, the odds of using water filters were favourable with progress in one's level of education. Respondents who owned personal means of transport would potentially purchase the water filter at a probability of 0.16. Ownership of a personal transport e.g. a motor-bike may signify wealth in the rural setting in Ghana. Such persons are perceived to be in relatively good socio-economic standing in a village, and could potentially afford to purchase a biosand filter.

Table 1: Results of probit analysis.

Parameter	Slope	Standard Error	z - value
Gender	-0.1868	0.070	-2.66***
Age	0.0078	0.002	3.30***
Marital Status	0.0263	0.074	0.35
Education	0.2900	0.092	3.15***
Occupation	0.0205	0.061	0.33
Income	1.19×10^{-5}	2.0×10^{-5}	0.54
Transport	0.1608	0.059	2.74***
Source of drinking water	0.0359	0.094	0.38
Domestic water treatment	-0.0546	0.0634	-0.86
Satisfaction with drinking water	-0.1140	0.0602	-1.89*
Incidence of diarrhoea	-0.0930	0.067	-1.39
Willingness to pay	0.0013	0.0017	0.75

Note: *** means significant at 1%, ** means significant at 5%, * means significant at 10%, no star means not significant

A question was posed whether respondents were satisfied with their current drinking water. That is, if they liked their source of drinking water. A person who responded yes has a reduced probability (0.11) of purchasing a water filter. The reverse may also hold that those who responded no have greater interest (89% probability) of buying a water filter. It is logical that those who were not satisfied with their drinking water were interested in acquiring a biosand filter.

3.2 SWOT Analysis

Table 2: Average score of factors considered for SWOT analysis.

Weakness										INTERNAL FACTORS	Strength									
10	9	8	7	6	5	4	3	2	1		1	2	3	4	5	6	7	8	9	10
			X							Lack of trained workers										
										In-expensive labour										X
										Availability of equipment							X			
										Owners management										
										Flat management structure										
										Innovation of product										X
										Effective marketing							X			
										Market position (as rural business)								X		
										Less overheads										X
			X							Lack of financial strength										
										Competitive price (low price of product)			X							
Threat										**EXTERNAL FACTORS**	**Opportunity**									
10	9	8	7	6	5	4	3	2	1		1	2	3	4	5	6	7	8	9	10
				X						Fall in cedi exchange rate										
										Raw materials available locally										X
										Low cost raw materials										X
										Income tax exemption					X					
				X						High interest loans										
					X					Poor rural infrastructure										

										Drinking water issues										X
X										Low purchasing power										
					X					Maintenance of product										
							X			End of life of product										
										Location (rural community)										X
										Simple technology										X
										Technology functions without electricity										X
										Low competition						X				
										Suppliers – local							X			
										Consumers – local							X			
							X			Low level of education										

Table 2 provides the average scores of factors that possibly could influence the strengths, weaknesses, opportunities and threats. These average responses served as input data to derive a SWOT plot, applying the Inghenia SWOT tool (Figure 10). The Inghenia SWOT plot is a chart that shows the average of all the factors of the Weaknesses-Strengths axis (vertical axis) and the Threats-Opportunities axis (horizontal axis). The blue arrow indicates the strategic vector towards the ideal situation, which is represented by a green circle located at the upper right angle of the chart (Inghenia, 2009). The yellow circle on the SWOT plot depicts the current position of a rural business in Ghana potentially engaged in biosand filter production or related water treatment for application in rural homes. The concentric circles show the advance towards the ideal situation as time passes.

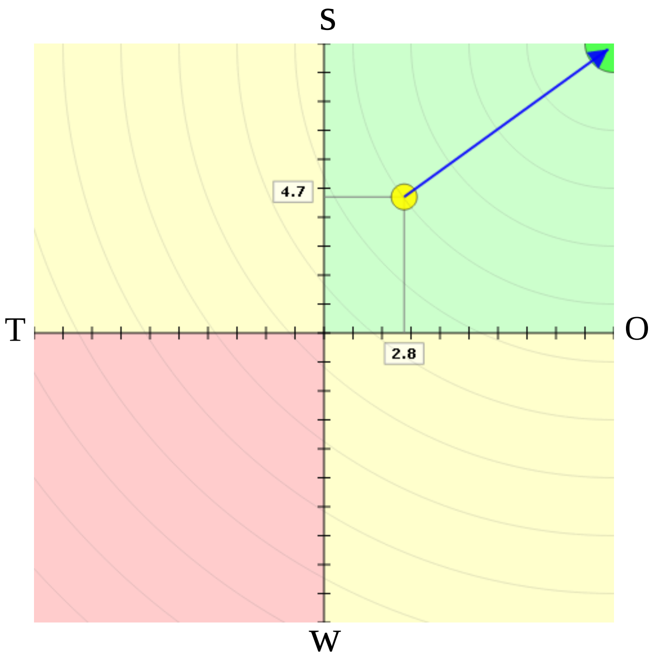

Figure 10: SWOT plot of the biosand filter as a potential business entity in rural Ghana.

On a scale of 1 – 10, the Strength-Weakness axis showed a net strength of 4.7, while the Opportunities-Threats axis showed a net opportunity of 2.8. It is positive that the potential venture occupies a position on the Strength-Opportunity quadrant of the SWOT plot. Thus, both strengths and opportunities outweigh the weaknesses and threats. With an overall strength score of approximately 5 on a 10 point scale, we could classify as average the strength to set up a biosand filter production in rural Ghana. Two main weaknesses were identified as drawbacks to the strengths: (i) lack of trained workers and (ii) lack of financial strength. Considering that the technology involved is simple, individuals could easily be trained and employed. The lack of financial strength is a common problem with respect to small businesses (SMEs) in Ghana (Abor and Biekpe, 2006). But the situation may be worse for those SMEs located in rural areas. Nevertheless there are local avenues that could be explored for financial resources to initiate such a rural venture. For instance, the Ghana Government Rural Enterprises Programme (REP), co-funded by the African Development Bank, may be willing to offer credit to innovative rural enterprises whose activities improve the living conditions in rural areas.

The opportunity for establishing a rural business venture to develop biosand filters in Ghana was relatively low. It scored a net 3.0 on a scale of 10 of the opportunity-threat balance (Figure 10). This is because there were several external factors that were not necessarily favourable. These include plummeting of the value of the cedis, high interest loans at the commercial banks, poor rural infrastructure and low purchasing power of the rural folks. These present quite a hostile environment for rural enterprises. These factors are beyond the control of rural enterprises and require interventions from government to be fixed. In the interim, the net opportunities could be improved if the positive external factors such as income tax exemption, low competition and the fact that raw materials could be sourced locally are maximized. Further, increasing the customer base in the future by expanding the enterprise to serve both rural and urban dwellers could enhance the opportunities.

3.3 Eco-business Potential

The main task under this objective was to conduct a life cycle assessment (LCA) to establish the major environmental load and life cycle cost of the potential activity (biosand filter production) against the highest alternative (sachet water production). For an LCA, it is important that an appropriate functional unit is set to determine the equivalence between the alternatives under consideration. As the present LCA compares water treatment, the functional unit was set at a 1 m^3 (i.e. 1000 L). Thus, each relevant factor considered in this LCA process was evaluated in relation to 1 m^3 of treated drinking water. The LCA was conducted for a short term of five years.

3.3.1 Total volume of treated water

On the average, the biosand filter could treat about 50 L (0.05 m^3) of water per hour (Liang et al, 2010). Six hours of water treatment by the biosand filter, thus, would yield sufficient drinking water for a rural household. At this rate, the biosand filter may generate approximately 109.5 m^3 (i.e. 0.05 x 6 x 365 m^3) of treated drinking water in the first year of application. Five percent annual reduction in the efficiency of the biosand filter may be assumed due to pore clogging effect. To counteract this effect, households may increase the daily duration of filtration by about 30 minutes in each successive year. Based on reported experiences in Ghana where 1,910 ceramic clay pot filters were produced and sold in two years by an NGO (PATH, 2007), and in Kenya where 400 biosand filters were produced and sold by a small business entity in one year (Moi, 2001), a production capacity of about 500 to 1000 filter units per year was assumed regarding biosand filter production by a small rural enterprise in Ghana. Assuming the high end of this range, that is a production capacity of 1000 units annually, the total volume of biosand filter treated water in one year is estimated at 109.5 m^3 x 1000 = 109500 m^3, which translates into 547500 m^3 in 5 years.

Process	Life cycle phase	Flow	Flow property	Amount (per year)	Amount (functional unit equivalence)*	Eco-factor**	Impact on environ-mental resources (UBP)***
Biosand Filter (BSF)	Production	Gravels, quarry sand	Mass (g)	46880000	428.13	0.03 (UBP/g)	12.844
		Diesel (for transport of gravels, quarry sand)	CO_2 emissions (g)	1196000	10.92	0.46 (UBP/g)	5.024
		Water (to wash gravels, sand media)	Volume (m^3)	500	0.0046	3.3 (UBP/m^3)	0.015
	Distribu-tion						
	Use						
	End of life						
	Total (annual						*17.883*

	load)						
	5-year load						*89.415*

In the case of sachet water production, the yield of treated water was estimated applying the packaging rate of the sachet machine of about 2000 sachets per hour (each sachet contains 500 mL (0.0005 m^3)). Assume an enterprise operating a single sachet machine, which is the case of most small-scale rural sachet water production setups. As the sachet machine is operated for approximately 12 hours/ day, it yields 2000 x 12 x 0.0005 m^3 = 12 m^3 of drinking water daily. Assuming 6 days of work in a week, the annual yield of drinking water from sachet water production could be estimated as 12 x 6 x 52 = 3744 m^3. Thus, cumulatively, about 3744 x 5 m^3 = 18720 m^3 of drinking water may be produced from the sachet water production in 5 years.

3.3.2 Life cycle environmental load (LCE)

Table 3: Life cycle environmental load of drinking water treatment by biosand filtration.

* Denotes the amount of annual flow that accounted for 1 m^3 of biosand treated water. It was obtained by dividing the annual amount by the estimated annual volume of biosand treated water (109500 m^3).
** Eco-factor (eco-point for weighing of impact) based on ecological scarcity method 2013 (Federal Office of the Environment- Switzerland, 2013).
*** The impact on environmental resources was derived as a product of amount (functional unit equivalence)* and eco-factor**. UBP is the reference unit for the ecological scarcity method.

Table 4: Life cycle environmental load of sachet water production.

Process	Life cycle phase	Flow	Flow property	Amount (per year)	Amount (functional unit equivalence)*	Eco-factor**	Impact on environ-mental resources (UBP)***
Sachet water (SW)	Produ-ction	Electricity	Hydro (MJ)	32.05	0.0086	1 UBP/MJ	0.0086
	Distri-bution	Diesel (for transport of sachet water to consumers)	CO_2 emissions (g)	4784000	1277.78	0.46 UBP/g	587.78
	Use	Plastic wastes (26208 kg generated annually)	Environ-mental effect (MJ/kg)	2117606.4	565.60	281.6 UBP/kg	159272.96
	End of life						

	Total (annual load)							*159860.75*
	5-year load							*799303.73*

* Denotes the amount of annual flow that accounts for 1 m^3 of biosand treated water. It was obtained by dividing the annual amount by the estimated annual volume of sachet water produced (3744 m^3).
** Eco-factor (eco-point for weighing of impact) based on ecological scarcity method 2013 (Federal Office of the Environment- Switzerland, 2013).
*** The impact on environmental resources was derived as a product of amount (functional unit equivalence)* and eco-factor**. UBP is the reference unit for the ecological scarcity method.

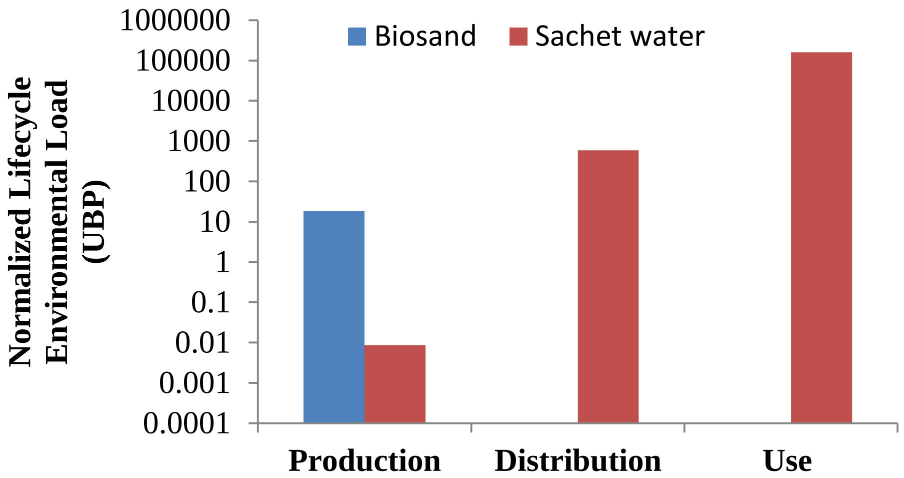

Figure 11: Life cycle environmental load associated with the treatment of 1 m^3 of water over a period of one year for biosand and sachet water systems.
(The environmental load is expressed in UBP – the reference unit for ecological scarcity method (Federal Office of the Environment – Switzerland, 2013)).

3.3.3 Life cycle cost (LCC)

Table 5: Life cycle cost of drinking water treatment by biosand filtration.

Process			**Material cost (GHC) (future value at 5%)**						
Biosand Filter (BSF)	Life cycle phase	Flow	Initial cost	Year 1 (2014)	Year 2 (2015)	Year 3 (2016)	Year 4 (2017)	Year 5 (2018)	Total (5 years)
	Produ-ction	Plastic container	50000	52500	55125	57881.25	60775.31	63814.08	
		Sand	10000	10500	11025	11576.25	12155.06	12762.82	
		Gravels	12000	12600	13230	13891.5	14586.08	15315.38	
		Variable cost	10000	10500	11025	11576.25	12155.06	12762.82	
	Distri-bution								
	Use								
	End of life								
	Total			*86100*	*90405*	*94925.25*	*99671.51*	*104655.1*	*475756.9*
	*Total (FU equival-ence)**			*0.79*	*0.83*	*0.87*	*0.91*	*0.96*	*4.34*

*The functional unit equivalence of total cost was computed by dividing the annual cost by the estimated annual volume of biosand treated water (109500 m^3).

Table 6: Life cycle cost of sachet water production.

Process			**Material cost (GHC)**						
Sachet Water (SW)	Life cycle phase	Flow	Initial cost	Year 1 (2014)	Year 2 (2015)	Year 3 (2016)	Year 4 (2017)	Year 5 (2018)	Total (5 years)
				Asset depreciation @ 20% (Depreciation expense)					
	Produ-ction	Water treatment plant	40000	8000	6400	5120	4096	3276.8	*26892.8*
		Sachet machine	7164.8	1432.96	1146.368	917.0944	733.6755	586.9404	*4817.038*
		Water tank	6000	1200	960	768	614.4	491.52	*4033.92*
				Future value @ 5%					
		Variable cost	20000	21000	22050	23152.5	24310.13	25525.63	*116038.3*
				Asset depreciation @ 20% (Depreciation expense)					
	Distri-bution	Truck	40000	8000	6400	5120	4096	3276.8	*26892.8*
				Future value @ 5%					
		Diesel	38610	40540.5	42567.53	44695.9	46930.7	49277.23	*224011.9*
	Use								
	End of life								
	Total			*80173.46*	*79523.9*	*79773.49*	*80780.91*	*82434.92*	*402686.8*
	*Total (FU equiva-lence)**			*21.41*	*21.24*	*21.31*	*21.58*	*22.02*	*107.56*

*The functional unit equivalence of total cost was computed by dividing the annual cost by the estimated annual volume of sachet water (3744 m^3).

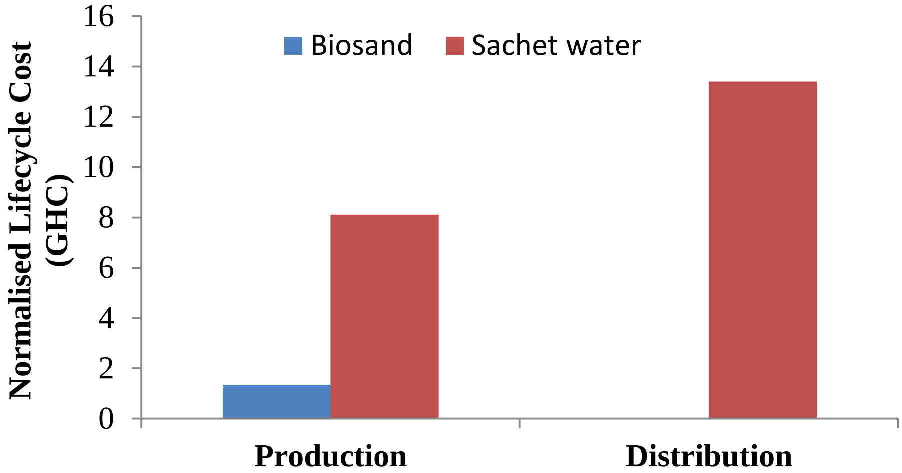

Figure 12: Life cycle cost associated with the treatment of 1 m^3 of water over a period of one year for biosand and sachet water systems.

3.3.4 Utility value

The utility value of a product is the time integral of product value, assuming that the product value is strongly correlated with its functional performance (Kondoh and Mishima, 2010). Product value is often measured in terms of its economic value as the maximum amount of other things that a person is willing to forgo (usually the highest alternative) to have that product (www.ecosystemvaluation.org). This means that should households turn to the use of biosand filters for domestic water treatment, the value of the biosand filter could be given by the market price of the highest alternative they forwent, in this case, sachet water.

A rural household dependent on sachet water would consume approximately 8760 L (8.76 m^3) of drinking water in a year. This figure was estimated from an average rural household size of 12 individuals and the presumption of daily water intake of 2 L per person for 365 days (Green, 2008). Considering that 1 L of sachet water presently costs 0.4 GHC, the cost of yearly consumption of sachet water for a rural household could be estimated as 8760 x 0.4 GHC = 3504 GHC. Over a five year period, the utility value could be estimated as:

$$UV = \int_0^5 3504\,(t)dt$$

= 17520 GHC.

This also represents the value that a household places on biosand filtered water when they forgo sachet water.

3.3.5 Total performance indicator

From eqn 1:

$TP1_{BSF} = UV / \sqrt{(LCE_{BSF} \times LCC_{BSF})}$

$= 17520 / \sqrt{(89.42 \times 4.34)} = 889$

$TPI_{SW} = UV / \sqrt{(LCE_{SW} \times LCC_{SW})}$

$= 17520 / \sqrt{(683240.45 \times 107.56)} = 2$

The TPI of the biosand filter is therefore two orders of magnitude greater than that of sachet water, thus, establishing the biosand filter as a process with superior eco-efficiency potential. One of the advantages of estimating the TPI of processes is that it helps to clarify bottlenecks limiting the enhancement of performance (Kondoh et al., 2008). It was identified that the biosand filter generated relatively greater environmental load during production, but has negligible impact at the other stages of the product lifecycle (Figures 11 and 12). This is because the gravels and sand applied as inputs in this process were obtained from extractive activity, which has considerable environmental impact (Table 3). It is however important to note that these materials can easily be returned to soil or recycled at the end of product life cycle for future production of the filters. The environmental load associated with the biosand filter production could be reduced if appropriate wastewater treatment is integrated in the production process. Considering that the wastewater generated in this process is not necessarily toxic, the treatment process could constitute a simple mechanism that allows the turbid water to filter through soil media into groundwater.

With regards to the sachet water production, the highest impact emanated from plastic wastes during the use phase of the product life cycle. In the absence of an impact method that directly quantified the impacts from plastic wastes, energy consumed in the production of these plastics was indirectly applied as a surrogate of the environmental effect from the plastics. Approximately, 80.8 MJ/kg is reportedly consumed in the production of low density polyethylenes (LDPE) (Ritland et al., 2014). Thus, each kg of plastic waste may contain about 80.8 MJ of energy, which is about 1.76 times the energy content of equivalent weight of unrefined crude oil (45.8 MJ/kg) (FOEN, 2013). This amount of energy may be required to melt a kg of the plastics for recycling. Given that unrefined crude oil has an eco-point of 160 UBP/kg (FOEN, 2013), an eco-point of 281.6 UBP/kg (i.e. 160 UBP/kg x 1.76) was assumed for plastic wastes. The production of sachet water consumes approximately 0.088 MJ/day (Nwanya et al., 2013), which translates into 32.05 MJ/year. As most producers of sachet water in Ghana depended on the national grid of electricity, which is largely hydro, to operate sachet water packaging machine, the eco-point of hydro energy of 1UBP/MJ (FOEN, 2013) was assumed for the associated ecological impact (Table 4).

3.3.6 Profitability analysis

A better TPI is an indicator of superior environmental efficiency, but does not necessarily presuppose that a process is profitable. Thus, superior TPI alone is not adequate to entice investment in a particular product. Profitability or economic viability is equally important. The next task then was to assess the profit potential of the drinking water treatment alternatives under consideration (Table 7). The following parameters were assumed for a small sachet water producing enterprise in order to estimate the revenue that may accrue from the business: production capacity – 2000 units/hour, operating for 12 hours per day, and 6 days in a week. Estimated total number of sachets produced annually (i.e. in 52 weeks) = 2000 x 12 x 6 x 52 = 7488000. Based on this production capacity and the factory price of sachet water, annual revenue projections were made (Table 7). Similar projections were made for the production of biosand filter, assuming a production capacity of 1000 units and the current and projected price of the biosand filter (Table 7). The profit was estimated by subtracting the total cost (LCC) from the total revenue. That is:
Profit = Revenue – Cost.
The 5-year profit projections for SW and BSF production, as summarised from Table 7, are indicated below:

$$Profit_{SW} = Revenue_{SW} – LCC_{SW}$$
$$= GHC\ 620{,}755.2 – 402{,}686.7 = GHC\ 218{,}068.5$$

$$Profit_{BSF} = Revenue_{BSF} – LCC_{BSF}$$
$$= GHC\ 663{,}075.8 – 475{,}756.9 = GHC\ 187{,}318.9$$

The biosand filter production is thus profitable, although its profit margin (GHC 187,318.9) was slightly lower (by a factor of approximately 1.2) than that of sachet water production (GHC 218,068.5) in five-year projections.

Table 7: Five-year projections of profit margins of biosand filter and sachet water production.

	Year 1 (2014)	Year 2 (2015)	Year 3 (2016)	Year 4 (2017)	Year 5 (2018)	Total (5 Years)
Biosand Filter (BSF)						
Unit price (GHC)*	120	126	132.3	138.915	145.86075	
Number of units produced	1000	1000	1000	1000	1000	
Estimated revenue (GHC)	120000	126000	132300	138915	145860.75	663075.8

Life cycle cost (GHC)	86100	90405	94925.25	99671.51	104655.1	475756.9
Profit (GHC)	*33900*	*35595*	*37374.75*	*39243.49*	*41205.65*	*187318.9*
Sachet Water (SW)						
Unit price (GHC)*	0.0150	0.0158	0.0165	0.0174	0.0182	
Number of units produced	7488000	7488000	7488000	7488000	7488000	
Estimated revenue (GHC)	112320	118310.4	123552	130291.2	136281.6	620755.2
Life cycle cost (GHC)	80173.46	79523.9	79773.49	80780.91	82434.92	402686.7
Profit (GHC)	*32146.54*	*38786.5*	*43778.51*	*49510.29*	*53846.68*	*218068.5*

*Price projections for 2015 onwards were estimated as 5% increment on the previous year's price. The estimated profit is before tax.

4. CONCLUSION

The present study examined the acceptability of the biosand filter in Ghana, as well as its environmental efficiency and economic viability in delivering safe drinking water for rural households. The key demographic and socio-economic indicators of biosand filter acceptability related to gender, age, education and wealth. Females were more inclined to accept the biosand filter. Also, biosand filter acceptability may improve with advancement in age and education of individuals. Persons who were relatively wealthy or in good socio-economic standing in the villages may also accept the biosand filter more readily. Cultural reasons emerged strongly for not applying any household water treatment method.

From SWOT analysis, it was concluded that the strengths and opportunities for setting up biosand filter production as a small scale rural business venture outweighed the weaknesses and threats. The opportunities were however relatively low because of unfavourable external factors. These include high interest loans at the commercial banks, poor rural infrastructure and low purchasing power of the rural folks. These present quite a hostile environment for rural enterprises. These factors are beyond the control of rural enterprises and require interventions from government.

Compared to sachet water production, which was considered as the highest alternative with respect to drinking water provision in Ghanaian households, it was established that the biosand filter has superior eco-efficiency and provided appreciable profitability as a rural enterprise. The fact that the biosand filter is ecologically efficient and potentially profitable meant that it could be produced and pursued as a green business venture, which is desirable in a green economy.

5. POLICY OPTIONS

The following policy recommendations are intended to help scale up household water treatment in Ghana and build up local interest in the biosand filter. This is in line with the national policy on Household Water Treatment and Safe Storage (HWTS) which seeks to extend HWTS methods to majority of persons who do not have access to improved sources of drinking water.

- Considering that cultural reasons emerged quite strongly for not applying any household water treatment, and also given the fact that acceptability of the biosand filter increased with education, it is essential that education is used as a tool to lessen cultural hindrances and facilitate behavioural change for the application of household water treatment methods. Education on HWTS could be included in community health outreach programmes, especially at districts that lack improved access to drinking water.

- The biosand filter should be projected as a key HWTS method because of its environmental efficiency and cost effectiveness. A single biosand filter has the potential to treat about 547.5 m^3 of drinking water for a household over a period of five years. This translates into a savings of about GHC 2190 for a household that otherwise would have relied on sachet water, assuming current selling price of GHC 0.2 per 500 mL of sachet water.

- It is recommended that the potential of the biosand filter should be maximized not only for rural communities but for urban communities as well. The biosand filter will be useful for those living in urban slums that lack portable drinking water. The recent cholera outbreak in Ghana with over 17,000 reported cases and 150 deaths, which occurred mostly in urban areas (the worse since 1982), provide clear basis that such household water treatment methods are equally relevant for urban communities.

- Increased application of household water treatment methods such as the biosand filter has the potential to reduce household dependence on sachet water, which could indirectly help in reducing the plastic waste menace currently confronting the environment in Ghana.

- Finally, small scale business enterprises should be encouraged to invest in the production of biosand filter, considering that it can be a profitable venture, in addition to the ecological incentive and health benefits it provides. The government could create an enabling environment for such small green businesses to thrive, for instance, by providing tax exemptions as well as access to credit to facilitate the establishment of these businesses.

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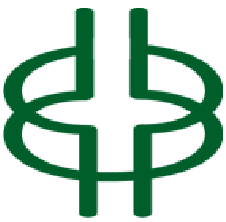
MATE MASIE

"What I hear, I keep"-Symbol of wisdom, knowledge and understanding.

NEA ONNIMNO SUA A, OHU

"He who does not know can know from learning, -Symbol of life-long education and continued quest for knowledge.



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"Wisdom knot" – Symbo of wisdom, ingenuity, intelligence and patience.

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