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ORIGINAL ARTICLE

Drinking Water Treatment using Hybrid Biosand Filter with Locally Produced Coconut Shell Carbon for Brgy. San Juan, Kalayaan, Laguna, Philippines

Joseph J. Magdalera[1*], Patricia Ann J. Sanchez[2], Marisa J. Sobremisana[3], Ramer P. Bautista[4]

[123]School of Environmental Science and Management, University of the Philippines Los Baños, College, Laguna, Philippines

[4]College of Engineering and Agro-Industrial Technology, University of the Philippines Los Baños, College, Laguna, Philippines

*E-mail: jjmagdalera@up.edu.ph

***Abstract*:** Lack of access to safe drinking water is a challenging issue worldwide. People from developing countries, especially those living in rural areas, consume water from unprotected sources. Contaminated water can transmit diseases such as diarrhea. Treatment of drinking water is necessary to prevent the spread of water-borne diseases. The Biosand filter is a widely known point-of-use technology for removing microorganisms and other contaminants in drinking water. The Hybrid Biosand Filter (HBF) was developed by incorporating locally produced carbon from coconut shell (activated with 50% sodium chloride solution) together with sand in a conventional Biosand filter. Investigation of four filter systems with varying percentages by volume of carbon revealed that the filter with 75% v/v sand and 25% v/v carbon was the best version which removed 100% of thermotolerant coliform from the raw water sample. This study aimed to determine the social acceptability of the community in Brgy. San Juan, Kalayaan, Laguna, Philippines with the use, fabrication, and maintenance of the HBF for treatment of their drinking water supply. The survey revealed that 66% of the respondents would accept to use the HBF, 71% would be willing to learn how to use it, and 66% would recommend it to others. Moreover, a majority of the respondents (>50%) would be willing to fabricate and maintain their own HBF. Through logistic regression, it was found that the respondents' mean Willingness to Pay (WTP) for treatment of their drinking water is 0.77 Philippine Pesos (0.015 US $) per liter of water filtered from the HBF. From this amount and the average volume of drinking water that every household in the community consumes and the total cost of the HBF fabrication, the payback period of the recommended HBF was computed at 11.91 months. Results of this study would help in better understanding the social dimension of introducing a household drinking water treatment technology (e.g. HBF) to a rural community.

Keywords: drinking water treatment, Biosand filter, social acceptability, water-borne diseases

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1. Introduction

Contaminated water can transmit diseases such diarrhea, cholera, dysentery, typhoid, and polio. Children and women are particularly at risk of these water borne diseases which hinder their overall well-being. About 842,000 people worldwide are estimated to die each year from diarrhea because of unsafe drinking-water, sanitation, and hand hygiene (WHO, 2018).

Studies pointed out that simple low-cost household treatment of drinking water is effective at preventing water related diseases such as diarrhea (Earwaker, 2006). According to UNICEF, as cited by Safford and Lackey (2014), treatment of water at the point-of-consumption is an advantageous solution because it limits recontamination of water from the transport process and requires little to no infrastructure. One such household treatment technique is the biosand filter which was developed by Dr. David Manz at the University of Calgary, Canada in the 1990s. The biosand filter is widely distributed all over the world and is already proven by several studies to be effective in removing microorganisms and other contaminants. Studies have shown that this treatment system requires little maintenance and is easy to fabricate using locally available materials. The biosand filter is used intermittently.

Over the years, various modifications have been done to improve the performance of the biosand filter. Examples of these modified biosand filters are the Arsenic Biosand Filter (or Kanchan Filter) developed by the researchers of Massachusetts Institute of Technology (MIT), the HydrAid Biosand Water Filter, and the locally plastic design biosand filter used by Kikkawa (2008) in her study at Ghana.

The addition of a layer of carbon to improve the performance of biosand filter has been considered. However, the effect on the performance of biosand filter of adding carbon on thermotolerant coliform, turbidity, and color removal at different volumes has not been studied. The surface area available for adsorption of the carbon was also tried to be increased through soaking in a 50% sodium chloride (NaCl) solution which is a low-cost activation method.

On the social acceptability aspect of using biosand filter, no studies have been conducted to assess the acceptability of a community in using, fabricating, and maintaining the modified version of this treatment technology particularly the addition of carbon which was locally made. Maycumber (2009) pointed out that the main challenge in the implementation of biosand filter is developing ways to transfer the said technology to the community in a sustainable manner.

1.1 Objectives

The general objective of this study is to design, fabricate, evaluate, and recommend the Hybrid Biosand Filter (HBF) with locally produced coconut shell carbon for Brgy. San Juan, Kalayaan, Laguna, Philippines for improvement of drinking water quality of the community. The specific objectives of this study are as follows:

1.1.1 Design, fabricate, and evaluate the performance of HBF with locally produced coconut shell carbon activated with 50% NaCl solution;

1.1.2 Determine the social acceptability for the use, fabrication, and maintenance of the HBF; and

1.1.3 Estimate the community's mean willingness to pay (WTP) for treatment of their drinking water and the payback period of the HBF.

The overall flowchart of this study is shown in Figure 1.

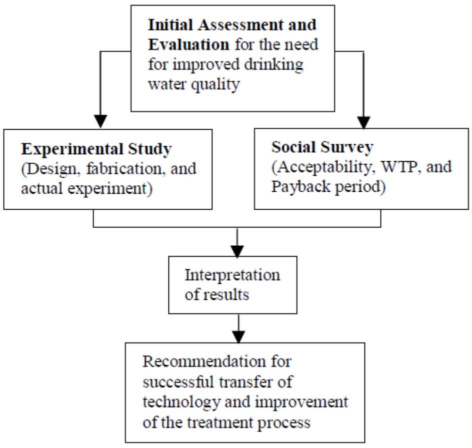

Figure 1. Study flow chart

2. Methodology

2.1 Study Area

Barangay San Juan is one of the three barangays of Kalayaan (Figure 2) which is a third class municipality in the province of Laguna in the Philippines.

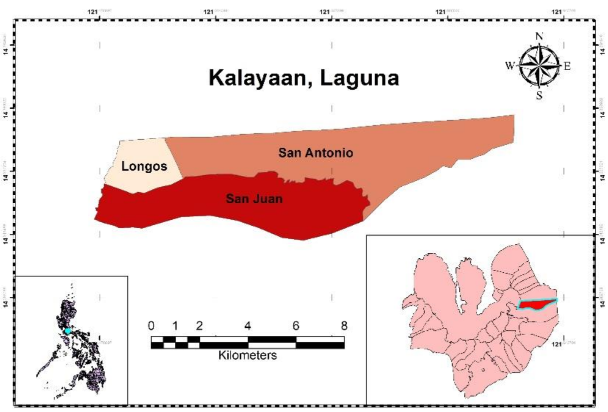

Figure 2. Map of Kalayaan, Laguna

The municipality of Kalayaan is rich in water resources. In 2008, there is an upgrading of the water supply system. Barangay San Juan's water supply system is managed by the barangay government officials (Comprehensive Land Use Plan).

2.2 Carbon Production and Characterization

2.2.1 Carbon Source

Few local farmers particularly in the Brgy. San Antonio, which is one of the three barangays in Kalayaan, are engaged in copra manufacturing. Coconut shells are waste materials of copra production. The coconut shells came from the copra production site owned by a local farmer in Sitio Kalayaan, Brgy. San Antonio.

2.2.2 Carbon Production

Figure 3 shows the steps done to produce carbon from locally available coconut shell.

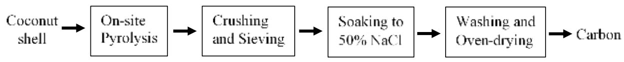

Figure 3. Steps in carbon production

2.2.3 Carbon Characterization

The carbon were tested for pH, moisture, particle size, total ash, bulk density, apparent density, iodine number, butane activity, methylene blue adsorptive capacity, methyl orange adsorption, and surface morphology.

2.3 Sand Preparation and Characterization

The sand came the riverbanks of Porac, Pampanga, Philippines and were purchased from a local supplier of construction materials. This type of sand was chosen because it was not difficult to locate, it was available in large quantity, and it contained less silt, dust, and clay. The preparation of sand and to be used in the HBF involved three basic steps: screening, washing and sterilization. The sand were tested for mass mean diameter, volume mean diameter, volume surface mean diameter, bulk density and specific surface.

2.4 Filter Fabrication

2.4.1 General Steps of Filter Fabrication

There are six main steps in the filter fabrication as shown in Figure 4.

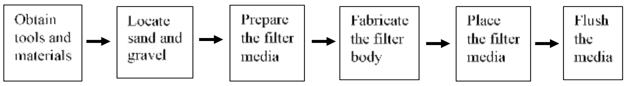

Figure 4. Process of filter fabrication

2.4.2 Filter Design and Specifications

The four filter systems used in the experimental study were fabricated at Jefcor Laboratories, Inc. All filter containers were clean unused garbage receptacle made of polypropylene (PP) with a capacity of 84 L when empty. The filter media are stacked one above the other inside the containers. To avoid mixing of the filter media and being carried away by the treated water at the outlet tube, the filter media are separated by sterilized filter cloths with holes that have diameters less than the particle diameter of the smallest filter media.

The outer height of filter containers is 71 cm. The outlet tube is 1 inch in diameter and 52 cm in height. By principle, the height of the water inside the filter is the same with the height of the water inside the filter tube. The level of the top portion of the outlet tube is 5 cm above the surface of the sand so that a 5 cm depth of standing water is always maintained. The amount of water supplied in excess of the 5 cm depth from the surface of the sand will flow out of the outlet tube. The capacity of every filter is 27 L of treated water. The design parameters of the filter systems in the experimental study are shown in Table 1.

Table 1. Design parameters for the filter systems

Parameters	Design Values
Filter loading rate	19 L/m^2/min
Filter capacity	27 L
Standing water depth	5 cm
Pause period	24 hours
Dosing volume	5 L (per day)
Container volume	84 L
Diffuser volume	16 L
Super fine sand diameter	0.17 mm
Fine sand diameter	0.36 mm
Carbon diameter	1.51 mm
Separating gravel diameter	0.92 mm
Drainage gravel diameter	1.91 mm

The underdrain system of the filters is a t-shaped one inch-diameter pipe perforated with 70 holes that are 1/8 inch in diameter each. The water being treated in the each filter is going to penetrate the holes of the underdrain system before discharging through the outlet tube. The diffuser is also used to evenly distribute the raw untreated water and to reduce the filter loading rate so as not to disturb the standing water. The bottom of the diffuser was perforated with 221 holes with 1/8 inch diameter each.

2.5 Experimental Study

2.5.1 Experimental Set-up

Four biosand filtration systems were fabricated: one control unit and the other three were the hybrid test units. The conventional biosand filter, labelled as Filter A, contained sand (fine sand and super fine sand) and gravel (drainage gravel and separatory gravel). The other three hybrid test units, labeled as B, C, and D, had an added carbon layer from locally available coconut shell but with different percentages by volume of the total volume of the sand in Filter A: 10% (Filter B), 25% (Filter C), and 50% (Filter D) volume by volume respectively, replacing 10%, 25%, and 50% of the sand volume of Filter A.

The top most layer was the sand. Two types of sand were used for all the filters: superfine sand

(0.17 mm surface mean diameter) and fine sand (0.36 mm surface mean diameter). The next layer was the carbon layer for filters B, C, and D. The separatory gravel layer followed the carbon layer. The bottom most layer was the drainage gravel layer.

The experimental study was conducted to investigate the performance of the four filter units in thermotolerant coliform, color, and turbidity removal and the effects of varying volume and consequently varying height of the additional carbon layer to the other water quality parameters such as pH, Total Dissolved Solids (TDS), salinity, electrical conductivity, Biochemical Oxygen Demand (BOD), and Chemical Oxygen Demand (COD).

Repeated measures ANOVA was used to determine the statistical difference of the effects of varying volume and height of carbon layer among the filters to the water quality parameters mentioned. All data were interpreted to determine the recommended filter design for drinking water treatment of Brgy. San Juan. Figure 5 shows the experimental set-up for the 45-day experiment.

Figure 5. Experimental set-up

2.5.2 Raw Water Source and Collection

The same source of raw untreated water sample were supplied to the filters A, B, C, and D every day for the entire duration of the experimental study so the quality of raw water for all filters were the same. An untreated surface water (stream) source in Brgy. Kaytapos, Indang, Cavite was used as raw untreated water sample in the experimental study. The water source in Brgy. Kaytapos is similar with the water source of the locality in Brgy. San Juan, Kalayaan, Laguna: a stream in the nearby mountain which is part of the Sierra Madre mountain range. The water source in Indang, Cavite was chosen since it had a high quantity of thermotolerant coliform (6.9 MPN/100 mL) and high value of turbidity (19 NTU) based on the initial test conducted.

2.5.3 Filling and Pause Cycle

The filling and pause cycle were completed in a day (24 hours). Five liters of raw water were dosed to each filter every 24 hours of 45-day filling cycle. The filter loading rate (19 L/m^2/min) was constant for all the filters. During the 24-hour pause period or the period between dosing, a standing water which was 5 cm in depth was maintained in all the filters to allow the formation of shmutzdecke or biolayer composed of microorganisms that contribute to increased pathogen removal (Center for Affordable Water and Sanitation Technology, 2009).

2.5.4 Sampling, Testing, and Analysis

The water quality parameters tested for untreated raw water and treated water were thermotolerant coliform, color, turbidity, BOD, COD, pH, TDS, salinity, electrical conductivity, and temperature. Dissolved oxygen level and total and free chlorine for the raw water were tested to know if the microorganisms needed for biological treatment could thrive in the raw water to be treated. All analysis were conducted at Jefcor Laboratories, Inc.

2.6 Social Survey

2.6.1 Sample Size Determination

The Cochran's formula (Cochran, 1977) was used to determine the sampling size. This allows the calculation of the ideal sample size with a defined level of precision, confidence interval, and the estimated proportion. Calculating a sample size of a large population (whose degree of variability is not known, the maximum variability (which is equal to 50% at p =0.5) and taking 95% confidence level with 10% margin of error, the sample size was determined to be 96.

2.6.2 Data Collection Procedure

The social survey was conducted in Brgy. San Juan on 8 December 2018. Eight enumerators were assigned to conduct face-to-face survey with randomly chosen 96 individuals who represented their own households. The enumerators were trained and oriented one day before the conduct of the actual survey. The one-day survey was divided into two sessions: morning and afternoon. Visual aids containing the photographs of the HBF were shown to the respondents to aid in their responses especially in the social acceptability aspect of the HBF. Samples of untreated raw water and treated water from the HBF were also shown to the respondents so that they could compare and would have an idea on the appearances of the water samples.

2.6.3. Survey Instrument

A survey using questionnaires were used to answer the second and third specific objectives of the study. The survey questions that were asked to the respondents were based on the modified survey questions from similar studies by Peletz (2006) and Johnson (2007). The survey topics include the following: socio-demographic profile of respondent, socio-demographic profile of household, economic profile of household, diarrheal knowledge and prevalence, household hygiene and sanitation, water availability and accessibility, water use and storage, water quality perception, social acceptability, and Willingness to Pay.

2.7 Willingness to Pay

Logistic regression or logit model was used to estimate the mean WTP of respondents for drinking water treatment using the HBF. Single bound dichotomous choice approach was used in the questionnaire design for WTP. There were six bid prices asked namely Php 1.00, Php 3.00, Php 5.00, Php 10.00, Php 15.00, Php 20.00. The computed number of questionnaires per bid price was 16 for 96 sample size. After the actual survey, questionnaires were collated and analyzed. STATA 11 software by StataCorp (2009) was used to analyze the summarized survey data.

3. Results and Discussion

3.1 A Need for Hybrid Biosand Filter

Fifty-five percent of the respondents in the survey consumed water from unprotected sources (barangay water connections, communal wells, and private wells). Drinking water quality results revealed that there were sources of drinking water in Brgy. San Juan which did not pass the Philippine National Standards for Drinking Water (PNSDW) in thermotolerant coliform particularly from the communal well beside the creek and from the Gintong manok reservoir tank which supplied water to households. The average diarrhea cases in Kalayaan was 265 per year and children 0 to 4 years old were mostly affected. The information presented justified the reason of developing the HBF, a household level and affordable drinking water treatment technology.

3.2 Comparison of Soaked and Unsoaked Carbon

The summary of characteristics of carbon soaked with 50% NaCl solution and the unsoaked carbon is shown in Table 2. The data proved that soaking with 50% NaCl could increase the volume mean diameter, specific surface, iodine number, butane activity, methylene blue adsorptive capacity, methyl orange adsorption, and the carbon bed life for methylene blue adsorption of the locally produced coconut shell carbon for better contaminant removal. The surface morphology through Scanning Electron Microscope (SEM) also proved this. The 50% NaCl solution was effective in activating the carbon but not to the extent of producing a standard activated carbon with typical range of 500 to 1,200 mg/g Iodine number.

Table 2. Summary of characteristics of soaked and unsoaked carbon samples

Parameters	Soaked Carbon	Unsoaked Carbon
Volume Mean Diameter	0.99 mm	0.48 mm
Specific Surface	88.83 cm^2/g	87.99 cm^2/g
Moisture Content	4.47%	12.4%
Bulk density	0.56 g/mL	0.57 g/mL
Apparent density	0.69 g/mL	0.70 g/mL
pH	7.4	6.8
Total Ash	1.09%	No data
Iodine Number	138	130
Butane Activity	5.3%	2.8%
Methylene Blue Adsorptive Capacity	41.03 mg/g	20.02 mg/g
Methyl orange adsorption	64.85%	64.1%
Carbon Bed Life for Methylene Blue Adsorption	1,182.08 L water/L carbon	650.6 L water/L carbon

3.3 Recommended HBF based on Performance

The criteria in choosing the recommended HBF based on performance for the 45-day experimental study are the following: thermotolerant coliform removal, able to reach 100% thermotolerant coliform removal, able to maintain 100% thermotolerant coliform removal, turbidity reduction, color reduction, and time of carbon usage before replacement. Based on those criteria (summarized in Table 3), Filter C was chosen as the best version because it has the highest thermotolerant coliform removal, it was the first to reach 100% thermotolerant coliform removal on the 25th day of the experiment, it was able to maintain 100% thermotolerant coliform removal during the three consecutive samplings until the last day of the experiment, it reduced the turbidity of raw untreated water by 100%, and it removed the color of the raw untreated water by 92%-95%. However, it was proven statistically that there was no significant difference among the filters in thermotolerant coliform of treated water and % reduction in thermotolerant coliform. Nevertheless, Filter C was proven to be the best filter based on the criteria set in recommending the best filter system based on performance. Filter D has the highest time of carbon usage before replacement which is 4.2 years. Filter C has 2.1 years for its carbon to be replaced which is still a long time before replacement of new set of carbon. TDS, electrical conductivity, salinity and pH were not included in the considerations for the recommended filter system because their values in the treated water were strongly and significantly associated with their values in raw untreated water. In other words, higher or lesser values of these variables in treated water were associated/related to greater or lesser values in raw untreated water.

Table 3. Criteria/considerations in choosing the recommended filter system based on performance

Criteria/Considerations based on Performance	Filter C
Thermotolerant Coliform Removal	75.4% to 100%
Able to reach 100% thermotolerant coliform removal	Day 25

Able to maintain 100% thermotolerant coliform removal	3 consecutive samplings
Turbidity reduction	100%
Color reduction	92% to 95%
Time of carbon usage before replacement (Basis: methylene blue adsorption)	2.1 years

3.4 Social Acceptability of the HBF

The acceptability of the community for the use of HBF with locally produced coconut shell carbon is important to determine the success of the implementation of this technology and similar applications to a community in need. Respondents of the survey were shown pictures of the HBF developed (recommended HBF is Filter C from the experimental study). The processes during fabrication, operation, and maintenance were presented in layman's term so that the respondents can have a better picture of the HBF and its purpose.

3.4.1 Social Acceptability on the Use of HBF

The survey revealed that majority (66%) of the respondents are willing to accept the use of HBF and they are willing to drink the treated water from it. Reasons of the respondents in accepting the use of HBF were the following: (1) for drinking water to have a better quality; (2) for drinking water to be safe for consumption; and (3) it was proven scientifically to be effective in treating the drinking water from unsafe sources. Nineteen percent are not willing to accept the use of HBF and 15% are unsure of their decision. Negative response to the social acceptability for the HBF were due to the following reasons: (1) respondents are already contented in the quality of their drinking water source; and (2) for them this would be an additional burden financially and to their time.

3.4.2 Social Acceptability on HBF Fabrication

The Likert Scale used in the study is a five point scale (from strongly disagree to strongly agree) which is used to allow the respondent to express how much they agree or disagree with a particular statement in the study. The Likert scale rating of the responses on the statement that they would be willing to fabricate their own HBF is 3.65 which is above average indicating that majority of the respondents would be willing to fabricate their own HBF.

3.4.3 Social Acceptability on HBF maintenance

When asked if the respondents would be willing to maintain their own HBF, the Likert scale rating was 3.74. Majority of the respondents would also be willing to maintain their own HBF for sustainable use.

3.4.4 Other Information on Social Acceptability of the HBF

In terms on the social acceptability of using locally produced carbon as one of the filter media in the HBF, majority of the respondents in Brgy. San Juan agrees with it as reflected in the Likert Scale Rating of 3.78.

Sixty six (66) percent of the respondents said that they would recommend to others the use of HBF. The reasons for this include helping others to have a better quality of drinking water, providing others with the knowledge about the HBF, and giving awareness about the spread of waterborne diseases from untreated sources. Seventy one (71) percent are willing to learn how to use it and 66 % are willing to share their learnings about the HBF to others. In general, majority of the respondents would accept the use of HBF, would be willing to fabricate and maintain it, and would be willing to recommend it to others. When asked who would be main responsible in fabricating and maintaining the filter, majority

(48%) of the respondents answered barangay officials, 44% said the households themselves, and 13% suggested the municipal government.

3.5 Estimation of Willingness to Pay for Drinking Water Treatment using HBF

Table 4 shows the number of respondents that positively and negatively responded to the varying bidding prices (Php 1.00, 3.00, 5.00, 10.00, 15.00, 20.00) for valuing the services of HBF in improving their drinking water quality.

Table 4. Distribution of respondents within the sample population that answered ‘yes’ and ‘no’ to the bids.

WTP Response	Frequency	Percentage
Positive (Yes)	67	70%
Negative (No)	29	30%
Total	96	100%

Majority of the respondents (72%) who answered ‘Yes’ in the WTP elicitation question were willing to pay for treatment of their drinking water because they wanted to avail a cleaner water for their family, others (40%) would pay because they wanted to protect the health of their family against water-borne diseases. Other reasons stated include a) payment/professional fee to the inventor of HBF and; b) the respondents could just afford to pay the amount asked.

In contrast, the respondents who answered ‘No’ demonstrated their unwillingness to pay due to the following reasons: a) the respondents did not have any problem if their sources did not undergo any drinking water treatment processes; b) the respondents believed that their currents drinking water sources were already clean and; c) the respondents were poor and could not afford to pay additional expenses at home.

3.5.1 Determination of WTP

The binary WTP (1 or 0) with certainty factor was estimated using the socio-economic and other relevant variables such as diarrhea cases, presence of toilet and washing facility, type of primary drinking water source and other sources, water availability and storage, water quality perception, social acceptability, and willingness to construct/fabricate their own HBF as independent variables. The certainty of responses to the WTP elicitation question were considered to represent only those who provided a strong level of confidence in giving “Yes” to offered bids. The certainty of responses were classified into 1 (very sure, sure) and 0 (very unsure, unsure) before employing a regression analysis. STATA 11 was used in the regression analysis.

3.5.2 Estimated WTP

Using parametric analysis, the estimated household mean WTP for drinking water treatment using the HBF was Php 15.46255 per 20 liter of water or Php 0.77 per liter. The mean WTP is high and near the set maximum bid price which was Php 20.00. After thorough investigation, it was found out that there was relatively high frequency of households willing to pay for the choke price or the maximum bid price. As such, the generated mean WTP cannot be interpreted as accurate. The actual mean WTP could be higher than the estimated household mean WTP in this study. The WTP computed was a conservative value. Nevertheless, the generated mean WTP which is Php 15.46255 per 20 liters of treated water is already high which indicates that the household in Brgy. San Juan has a high WTP in exchange for the improvement of their drinking water quality using the developed HBF with locally produced coconut shell carbon.

3.6 Payback Period of HBF

The payback period is the time required to earn back the amount spent for the fabrication of the HBF. The expenses for filter fabrication, the estimated household mean WTP (Php 15.46 per 20 L of treated water) and the average volume of drinking water that every household in Brgy. San Juan consumes (15.6 liters per day) were used as basis in calculating the payback period for each filter (Table 5). The lowest payback period (252 days) is Filter A or the conventional biosand filter while Filter D, the HBF with the highest percentage by volume of carbon, has the highest payback period (374 days). As more carbon is being incorporated in the filter, the higher is the expenditure hence the higher is the payback period. The range of the payback periods between filters A and D is 122 days indicating that there is a large difference between the maximum and the minimum payback periods. However, if Filter A is excluded, the range is reduced to 22 days indicating that among the HBF's (filters B, C, and D) there are no significant differences in the payback periods. In other words, the carbon significantly affects the expenses in filter fabrication thereby also significantly affecting the payback period of the filters.

Table 5. Payback period of filters A to D

Filter	Filter Description	Payback Period	
		In Months	In Days
A	Conventional biosand filter	8.41	252
B	HBF with 10% v/v carbon	11.59	348
C	HBF with 25% v/v carbon	11.91	357
D	HBF with 50% v/v carbon	12.46	374

4. Summary and Conclusion

The community in Brgy. San Juan, Kalayaan, Laguna, Philippines needs a drinking water treatment system to improve the microbiological and physico-chemical quality of their drinking water sources to achieve the overall goal which is health improvement and community welfare. The HBF – a household level, point-of-use, and affordable drinking water treatment technology, was designed, fabricated, evaluated, and recommended for this purpose. The HBF is a "hybrid" of two effective and common drinking water technology: slow sand filtration and carbon filtration. A locally produced coconut shell carbon was combined with the traditional biosand filter with an aim to improve its performance for thermotolerant coliform, color, and turbidity reduction and know its effect to other drinking water quality parameters. The step by step method of fabricating the HBF and preparing the sand and carbon were presented in this study.

To evaluate the performance of HBF, four biosand filtration systems were investigated in the experimental study: one control unit and the other three were the hybrid test units. The control unit, labelled as filter A, contained sand and gravel like the conventional biosand filter. The other three hybrid test units, labeled as B, C, and D, had an added carbon layer from locally available coconut shell but with different percentages by volume of the total volume of the sand in filter A: 10% (filter B), 25% (filter C), and 50% (filter D) volume by volume respectively. Based on the data gathered in the 45-day experimental study, filter C was the recommended version because it had the highest thermotolerant coliform removal, it was the first to reach 100% thermotolerant coliform removal on the 25th day of the experiment, it was able to maintain 100% thermotolerant coliform removal until the last day of the experiment, it reduced the turbidity of raw untreated water by 100%, and it removed the color of the raw untreated water by 92% to 95%. These design criteria were chosen as basis for the performance evaluation specifically for thermotolerant coliform, color, and turbidity reduction. Before the conduct of the experimental study, the locally produced coconut shell carbon used in the HBF was soaked with 50% NaCl in an attempt to activate the carbon and improve its adsorptive performance. The soaked carbon has a higher iodine number, butane activity, and methylene blue adsorptive capacity than the unsoaked carbon indicating that the soaked carbon contains higher surface area available for adsorption. The 50% NaCl solution was effective in activating the carbon but not to the extent of producing a standard activated carbon with typical range of 500 to 1,200 mg/g iodine number.

A social survey was conducted to the community in Brgy. San Juan to determine the acceptability for the use, fabrication, and maintenance of the HBF. Majority of the respondents were willing to accept the use of HBF and drink water from it (66%), fabricate their own HBF (Likert Scale Rating =3.65), maintain their own HBF (Likert Scale Rating =3.74), accept locally produced carbon as one of the filter media in the HBF (Likert Scale Rating = 3.78), recommend to others the use of HBF (66%), willing to learn how to use it (71%), and willing to share their learnings to others (66%).

Through logistic regression, it was found that the respondents' estimated mean WTP for treatment of their drinking water was Php 0.77 (0.015 US $) per liter of water filtered from the HBF. From this amount and the average volume of drinking water that every household in the community consumes, and the total expenses in the filter fabrication, the payback period of the filters were was computed at 8.4 months for conventional biosand filter, 11.59 months for HBF with 10% v/v carbon, 11.91 months for HBF with 25% v/v carbon, and 12.46 months for HBF with 50% v/v carbon.

Based on the results of the experimental study and the social survey, it is recommended that the community in Brgy. San Juan could use the best version of HBF (filter C) for drinking water quality improvement. The recommended HBF was found to be effective in thermotolerant coliform, color, and turbidity removal. The community has a positive response in the use of HBF for treatment of their drinking water. This is important for the successful implementation of the HBF to the community for its sustainable use.

For the sustainable implementation of the technology developed, it is recommended that the HBF shall undergo an actual test-run to random households in Brgy. San Juan so that the residents shall have a first-hand experience on how the HBF operates. In this way, they shall have a better appreciation of the HBF. The community shall also be educated in the operation of the HBF. It is suggested that the local government unit of Kalayaan shall provide financial support for the fabrication of more numbers of HBF to be distributed to households especially those whose drinking water sources are untreated sources. The people shall also be trained on how to help in the fabrication of the filters and how to maintain them. It is important to conduct follow-up visits with the households to ensure proper use and maintenance of the HBF. Water quality testing (preferably once a month) should be done to check if the HBF is working properly. Water quality parameters and acceptable values shall be based on Philippine National Standards for Drinking Water as recommended by the Department of Health.

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