PERFORMANCE SCREENING OF DESICCANTS USING A SIMPLE GRAVIMETRIC METHOD

ANALYSIS OF WATER QUALITY RESULTS FROM BIOSAND WATER FILTRATION SYSTEMS

THE IMPACT OF LOW-COST FERTILIZATION STRATEGIES ON GROWTH OF DUCKWEED AND AZOLLA

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ECHO Research Notes

# RESEARCH NOTE

# Analysis of Water Quality Results from Biosand Water Filtration Systems

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**Keywords:** biosand, water filtration, water quality, drinking water

**Abstract.** Biosand water filtration is a low-cost approach to improving water quality in communities where more costly technologies are unavailable. ECHO Asia promotes the use of a four-barrel design, developed by Aqueous Solutions, that incorporates char in addition to sand and gravel. This research was done to verify the effectiveness of the four-barrel design installed by ECHO or ECHO partners in Thailand. Community members in upland Northern Thailand were generally positive about the use of biosand filtration for reducing illnesses due to water-borne pathogens. A need was identified for a trained filter custodian, for ongoing maintenance of community biosand filters. Water samples were tested for physical, chemical, and biological indicators of water quality. Water test results indicated that biosand filtration generally improves water quality but is not a guarantee for consistently meeting national standards for drinking water. Modifications for improved performance were identified, which included slowing the flow rate of water into the first barrel, letting water settle in a holding tank prior to filtration, placing crushed char in a layer (vs in a mesh bag) in the respective barrel, and soaking char and removing floating particles of char prior to installation.

## Introduction

ECHO Asia promotes a low-cost water filtration system that utilizes gravel, sand, and char to improve drinking water quality. This system follows a design developed by Aqueous Solutions, for which the specifications can be found at this webpage: Water Treatment System Booklet - 300 Liter Per Day [http://edn.link/fmrxft]. In brief, the system consists of a barrel of gravel, followed by a barrel of sand, then a barrel of biochar, and finally a barrel of filtered water ready for collection.

Rather than distinguish between biochar and charcoal, we use the term "char" in this paper as a general term for carbon-rich biomass subjected to pyrolysis (heat under low oxygen).

In 2025, ECHO Asia conducted research activities on the four-barrel, 200 L biosand water filtration system. ECHO interviewed users of biosand filters about their experience with the system. Water samples from systems (before and after filtration) installed directly by ECHO or installed by ECHO partners were collected. ECHO collaborated with Global Hope Network International (GHNI) who shared results of their water sample tests. Finally, ECHO constructed a biosand filter on the ECHO Asia Impact Centre site in Chiang Mai, Thailand. A series of design modifications were made to try to improve the quality of highly polluted run-off water from rice paddy irrigation, which had been stored in a shallow pond.

**Figure 1.** Dr Krit interviewing a bio-sand water custodian in Houypa village. *Source:* ECHO Asia

## Materials and Methods

### Community survey and feedback

Representatives of six communities in upland Northern Thailand using biosand water filters were interviewed over the phone. Two communities were also visited for in person inspection of the systems and interviews with users.

Most biosand filtration systems operate at community-scale. Many are maintained by churches or community organizations and are used either by their members or the wider community. All communities using the systems lack reticulated treated drinking water systems. Reasons for use of biosand filtration include sedimentation in river or well water, concerns around agricultural chemicals in the water, and prevalence of illnesses linked to poor water quality.

The systems tended to be durable. The automatic float valves used were typically poor quality and broke over time. Leaks were common, and the system could be improved through better pipe fittings and the use of sealants.

Community awareness of maintenance requirements was low. The research team identified a need for a trained filter custodian, who could replace the char annually, and backwash or rake the sand layer as required. Community awareness on the effectiveness of the filter was low. One community surveyed had low use of the filter due to a lack of trust in the system. The team identified the need for communication products to be posted with the filters.

Communities reported no negative health impacts from drinking the water. Within communities, some people boiled water prior to drinking while others did not. One community reported that they saw a reduction in illnesses such as stomach aches and diarrhea associated with water-borne pathogens after installation of the biosand filter. Other people reported cost savings through a reduction in bottled water purchases.

**Figure 2.** Shaun inspecting the biofilm layer in barrel 2 of a system in Houypa village. *Source:* ECHO Asia

Overall, feedback from community members was positive, with the systems saving costs and time, while improving health. The interviews highlighted the need for community buy-in and ownership for long term maintenance and use of the filters.

## Results and Discussion

### Water quality test results

ECHO gathered data from twelve biosand water filtration systems. Of these there were eight systems with water tests prior to filtration as well as after filtration. The tests were analyzed by accredited water testing agencies in Chiang Mai, Thailand. All tests conducted directly by ECHO had the same 21 parameters tested by the Department of Health laboratory, enabling direct comparisons across systems.

The tests cover water physical, chemical, and biological quality as follows:

- Physical: color and turbidity
- Chemical: pH, total dissolved solids (TDS), hardness, nitrates and nitrites, iron, sulfate, chloride, fluoride, manganese, copper, zinc, lead, total chromium, cadmium, arsenic, mercury
- Biological: total coliforms bacteria, *Escherichia coli*

In general, there was very high variability across different systems. Results depended on the original install specifications of the system, maintenance, and most importantly on the quality of the source water. Key lessons learned are distilled below.

**Figure 3.** Checking a bio-sand water filter and taking water samples in Pangfan village.
*Source:* ECHO Asia

**Figure 4.** Water samples being prepared for submission to the laboratory.
*Source:* ECHO Asia

## Color

Color is a measure of dissolved substances in the water, for example rotted leaves or sediment. The Thai Health Department standard is not more than 15 Platinum Cobalt Units (PCU; an indicator of color on a scale of 0 [clear water] to 500 [highest level of dissolved material causing yellowing/darkening of the water]).

In most systems where source water was polluted, color dramatically improved after filtration. Three of the systems had water that exceeded the 15 PCU quality limit before filtration, but after filtration had water that met the required standard. For filters where the source water was already of acceptable quality, the platinum cobalt units (PCU) values after filtration decreased to zero in some systems.

When water was extremely polluted (120 PCU), one system struggled to clean the water enough to meet Health Department standards, only reaching 90 PCU.

**Conclusion:** Biosand filters are effective at filtering for water color improvement. The systems may struggle to filter extremely dirty water.

## Turbidity

Turbidity is a measure of how cloudy the water is due to suspended particles. The Thai Health Department standard specifies not more than 5 Nephelometric Turbidity Units (NTU).

Turbidity was improved by filtration in all systems. In systems with lower pre-filtration turbidity levels, the filters were typically effective at removing sediment and producing water that met drinking water standards. In three systems, water quality was highly improved, but the improvement was not sufficient to reduce turbidity below 5 NTU.

**Conclusion:** Biosand filters evaluated were effective at removing sediments from water and improving turbidity test results. In very dirty water, they did not remove all sediment.

## pH

The filters typically result in a small increase in the pH of filtered water. This is likely because char is alkaline. The impact is small, and water up to pH 8.5 is within drinking water standards. There is no concern here for drinking water quality.

## Total dissolved solids

Total dissolved solids is a measure of the combined content of all organic and inorganic substances dissolved in a liquid, such as minerals, salts, and metals. The Thai Health Department standard specifies not more than 500 mg per litre.

The biosand filter had little effect on the TDS levels. Of the eight systems with pre and post filtration test results, three had no change (within 1 mg/litre difference from post test results), one system had a small reduction in TDS and four had small increases in TDS. All samples, including those prior to filtration, were well within Thai standards, so there were no data to indicate the impact biosand filtration would have had on water with high TDS. Some of the dissolved minerals and salts making up TDS are typically not effectively removed by sand filters or activated carbon filters. Results of biosand/biochar filtration TDS removal effectiveness in the literature vary, with some studies finding TDS increased post-filtration (Bacchus *et al.*, 2020), while others found removal in the ranges of 30-40% (Fitriani *et al.*, 2024) or 65% (Jaffer and Maad, 2025). Eniola and Sizirici (2023) showed that char-amended biosand filters are capable of reducing most of the inorganic salts/minerals that make up TDS. Filtration effectiveness seems to be typically low, but depend on the filter design.

**Conclusion:** Results show that at low TDS levels, the biosand filter system design had little impact on post filtration TDS. If anything, the filter system on average saw a small increase in TDS. No pre filtration water samples contained high TDS levels, so the filtration potential at high levels is unknown. No strong conclusions can be drawn.

## Hardness

Water hardness is a measure of the total concentration of minerals dissolved in water, primarily calcium and magnesium. The Thai Health Department standard specifies not more than 300 mg per litre.

Similar to TDS, filtration had little impact on hardness levels. In some biosand filters, hardness increased, while in others, it decreased. All samples were well within the Thai standards, so there were no data to show what impact the filter would have on water with high hardness levels. There is some evidence that sand filtration could reduce water hardness levels (Waangsir *et al.*, 2023) .

**Conclusion:** ECHOs tests did not demonstrate an impact of the biosand tests on water hardness despite expectations that they would be at least partially effective. The results are inconclusive.

## Nitrates and nitrites

There was no trend observed in the effectiveness of the biosand filters in reducing levels of nitrates and nitrites. Nitrates in filtered water increased in three sampled systems, reduced in another three systems, and remained the same in two others. Some filters potentially had higher levels of bacteria which convert other forms of nitrogen into nitrate. Other filters may have lacked these bacteria, or had lower levels of nitrogen. High levels of nitrate in drinking water can cause health issues, especially for infants and pregnant women. The levels of nitrate in the water were at most 2% of the Thai maximum standard of 50 mg/l, so this is of no concern.

**Conclusion:** In tested water, the rates of nitrates and nitrates were of no concern for human health. No conclusion can be drawn as to the effectiveness of the filter at reducing these levels.

## Iron

The filters were highly effective at reducing iron content in water. In three filters, iron levels in water were reduced from unsafe levels to below the Ministry of Health limit of 0.3 mg/L.

## Parameters with no trend

There were a wide range of parameters for which either there is no clear trend, or the trend shows stable levels. There are other parameters for which there was no detection pre-filtration so conclusions cannot be drawn on the effectiveness of filtration. These are presented here as a table.

## Total coliforms bacteria

Total coliform bacteria are a group of microorganisms found in soil, surface water, and the intestines of mammals. While most coliforms are harmless, their presence in drinking water can signal that the water supply may be contaminated with harmful pathogens from animal or human waste.

The lab only reported the Most Probable Number of coliforms per 100 millitres (MPN/100 mls) in three cases, while most of the tests only show presence or absence of coliforms. The data were thus insufficient to claim the filters consistently reduced coliforms. In two of the three systems with data on MPN/100 mls, coliform significantly reduced. In only one presence/absence test is there data to show absence of coliforms after filtration. Where we only have post-filtration MPN/100 mls data, it is clear that levels are low.

**Table 1.** Water Quality Parameters with no clear trend

| **Parameter** | **Data** |
|---|---|
| Sulfate | Generally stable pre and post filtration |
| Chloride | Generally stable pre and post filtration. One systems showed post filtration increase, while three showed post filtration decrease, no consistency in results. |
| Fluoride, Manganese, Copper | No consistency in results |
| Zinc, lead, total chromium, cadmium, arsenic, mercury | Most tests showed levels pre-filtration as 'not detected'. Levels generally stable from pre to post filtration. No conclusions as to reduction of parameter can be reached. |

Biosand filters were effective in some systems at reducing total coliform bacteria, but not at eliminating them. Typically, coliform bacteria are present post filtration. In four systems, they reduced coliform bacteria counts to undetectable levels. In only one system coliforms were present prior to filtration and absent afterwards.

What is not captured in the presence/absence test results is any change in the composition of the microbial community, or reduction in total coliform numbers. Coliforms can be expected to live in the biosand filter, but most of these species will not cause sickness. In functional biosand systems, microbes living in the biosand feed on incoming microbes, resulting in a reduction of potentially harmful microbes after filtration. In two systems, the tests measured the quantity of coliforms. The test results found substantial reductions in coliforms from 23 to 2.2 MPN /100 ml in one system, and from over 23 to 9.2 MPN/100 ml in another system.

**Conclusion:** Biosand filters do not produce sterile water. They may reduce the amount of coliforms in the water.

### *Escherichia coli*

*E. coli* in water indicates fecal contamination, meaning human or animal waste has entered the water supply. Some strains of *E. coli* can cause illness in humans. *E. coli* presence is a more reliable indicator of unhealthy microbes in water than total coliforms.

Six of the eight systems for which there is pre and post filtration tests had no *E. coli* in the water prior to filtration. There were two systems in which filtration removed *E. coli*. There was only one system with *E. coli* after filtration.

**Conclusion:** Biosand filters are generally effective at removing *E. coli*, however there is evidence that some systems may not perform effectively.

## ECHO design tests

ECHO Asia constructed a biosand filter to test if highly contaminated fishpond water could be filtered enough to meet Thai Ministry of Health standards for drinking. See the Annex section of this document for more details of the design.

In summary, the first test results showed that the biosand filter was not capable of producing safe drinking water. A range of design modifications were made, with visual assessment of the water made at each step to check if the filtration was improving. Finally, the team submitted another water sample for testing.


**Figure 5.** Recording specifications of the thickness of layers of different particle sizes. *Source:* ECHO Asia

Table 2 and figures 6 and 7 below show that the second design was much more effective at improving color and turbidity results and reducing iron content. Even though the first design resulted in visibly dirty water after filtration, both the first design and the modified design had coliforms detected after filtration. Both designs effectively removed *E. coli*.

**Table 2.** Subset of water quality parameters tested at ECHO's Regional Impact Center in Thailand.

| **Parameters*** | **Design 1 pre filtration** | **Design 1 post filtration** | **Modified Design pre filtration** | **Modified Design post filtration** |
|---|---|---|---|---|
| Color | 120 | 90 | 40 | 8 |
| Turbidity | 90.6 | 61.2 | 78.7 | 15.1 |
| Iron | 0.342 | 0.209 | 0.797 | 0.217 |
| Total coliform bacteria | detected | detected | >23 | 23 |
| *Escherichia coli* | detected | not detected | 1.1 | <1.1 |

*Units of measure for parameters were Platinum Cobalt Units (color), Nephelometric Turbidity Units (turbidity), mg/L (iron), and Most Probable Number/100 ml (coliform bacteria and *E. coli*; unless the tests [Design 1] only showed absence or presence).

**Figure 6.** Before (left) and after (right) filtration with the first design.
*Source:* ECHO Asia

**Figure 7.** Before (left) and after (right) filtration with the modified design.
*Source:* ECHO Asia

See the Annex section of this document for more details of the original and modified designs. Modifications generally brought the design closer to the exact specifications outlined by Aqueous Solutions. They included:

- Reducing the flow rate and speed into the first barrel
- Letting water settle in a holding tank prior to filtration
- Reducing the particle size of sand and gravel, and increasing the depth of the layers with smaller particles
- Removing the char from a mesh bag, and instead placing it in a layer in the barrel

1. Crushing char to smaller particle size (<2 cm diameter)
2. Soaking char in clean water prior to installing, and removing floating particles of char (assumed to be less water-permeable)

## Conclusion

Our conclusion is that the biosand water filter needs to be constructed according to the design specifications to perform well. The biosand filter can dramatically improve water quality but will not always improve water quality to meet drinking water standards.

## References


Aqueous Solutions. 2016. Water Treatment System Booklet-300 Liter Per Day. https://www.aqsolutions.org/wp-content/uploads/2022/06/blue-barrel-system-manual_2022.pdf

Bacchus, A., R. Daniel, and A. Parsram. 2020. "To compare the removal efficiency of two constructed biofilters (biosand and biochar water filtration ssytems) for irrigation in two areas in West Coast Berbice." *Journal of Biology and Nature* 11, no. 1 (2020): 23–36. Accessed February 16, 2026. https://mail.ikprress.org/index.php/JOBAN/article/view/5052.

Eniola, J.O. and B. Sizirici. 2023. Investigation of biochar- modified biosand filter performance for groundwater treatment for drinking water purposes: A laboratory and pilot scale study. *Journal of Water Process Engineering*. 53. 103914. 10.1016/j.jwpe.2023.103914.

Fitriani, N., R.M.S.R. Mohamed, M. Affandi, R.R. Nurdin, S.B. Kurniawan, and N. Ni'matuzahroh. 2024. "Performance of Intermittent Slow Sand Filter Processing Units in Treating Food Court Wastewater." *Journal of Ecological Engineering* 25 (1): 117–130. https://doi.org/10.12911/22998993/159399

Jaffer, Ahmed A., and F. Maad. Al Juboury. 2025. "Enhanced Biosand Filtration with Cane Papyrus for Improved Physicochemical and Microbial Contaminant Removal in Water Treatment." *Civil and Environmental Engineering* 21, no. 2: 1139–65. https://doi.org/10.2478/cee-2025-0085.

Waangsir, F. W., G.P. Arnawa, J.J Sadukh, and D.G. Suluh. 2023. The use of various filtration media in lowering the level of water hardness. *Journal Penelitian Pendidikan IPA*, 9(3):1182-1186. https://doi.org/10.29303/jppipa.v9i3.3086


## Annex

## Design of Filter Systems Built and Tested by ECHO in Asia

### Materials and cost

Table 3 outlines the material used for the first filter construction. The materials used for the second filter were similar, with changes to the ratio and size of gravel and sand. The price of the second filter was around 5,000 Thai Baht (around $USD 160).

### System design and setup

In round one of the trial, a complete biosand water filtration system was assembled and installed in accordance with the standard design of the ECHO Asia farm. This was modeled after the Aqueous

**Table 3.** Biosand water filter materials and cost

| No. | Item | Quantity | Unit Price (THB) | Total Cost (THB) |
|---|---|---|---|---|
| 1 | 200 L plastic barrels | 4 | 500 | 2,000 |
| 2 | Elbow joints | 4 | 6 | 24 |
| 3 | Male threaded adapters | 9 | 6 | 54 |
| 4 | Female threaded adapters | 9 | 6 | 54 |
| 5 | Tee connectors | 2 | 9 | 18 |
| 6 | Valves | 8 | 25 | 200 |
| 7 | PVC pipe cement | 1 | 45 | 45 |
| 8 | Thread seal tape | 1 | 25 | 25 |
| 9 | PVC pipe | 1 | 65 | 65 |

Table 3. Biosand water filter materials and cost

| | | | | |
|---|---|---|---|---|
| 10 | Float valve | 1 | 100 | 100 |
| 11 | Large stones (sacks) | 2 | 100 | 200 |
| 12 | Medium stones (sacks) | 7 | 100 | 700 |
| 13 | Small gravel (sacks) | 7 | 80 | 560 |
| 14 | Coarse sand (sacks) | 2 | 50 | 100 |
| 15 | Fine sand (sacks) | 7 | 50 | 350 |
| 16 | Finished char (sack) | 1 | 300 | 300 |
| **Total** | | | | **4,795.00** |

Solutions [2016] design, with a notable change in that the biochar was placed in a mesh bag prior to adding to the third barrel, for ease of replacement. In addition, ECHO team gauged the relative quantity of various sand and gravel layers by eye based on their experience rather than following the exact ratios outlined in the Aqueous Solutions [2016] design.

Raw water from the fish pond, which was highly turbid and untreated, was pumped into a ftank twice daily at 8am and 3pm. Each pumping session lasted approximately 2 hours. When the clean water storage tank reached full capacity, the water was drained and discarded each time. This procedure was carried out daily for 30 days, excluding Saturdays and Sundays.

**Figure 8.** Washing gravel prior to installation.
*Source:* ECHO Asia

**Figure 9.** Wrapping char in mesh bag ready for installation.
*Source:* ECHO Asia

Raw water from the fish pond, which was highly turbid and untreated, was pumped twice daily at 8 am and 3 pm into the pre-filter barrel (tank 1) of a 4-barrel biosand filter design described by Aqueous Solutions (http://edn.link/fmrxft; 2016). Each of the two daily pumping periods were approximately 2 hours in duration, which was sufficient for 200 litres of water to accumulate in the last barrel (tank 4-that stores the cleaned water). At the end of each pumping period, when the last barrel had reached full capacity, the water in the last barrel was drained and discarded. Water was constantly maintained in tank 1, 2, and 3 at maximum capacity to ensure the survival of the biofilm layer. This procedure was carried out daily for 30 days, excluding Saturdays and Sundays. The purpose was to simulate a realistic maximum-use scenario, and allow the development of a biofilm layer prior to water quality sampling.

After the system had been in operation for 30 days, water samples were collected for analysis of water quality based on the specified parameters, such as turbidity, pH, total dissolved solids (TDS), and coliform bacteria. A pre-filtration sample from the intake directly into tank 1 was taken, and a post-filtration sample from the tap from tank 4.

**Figure 10.** Building biosand filter. *Source:* ECHO Asia

**Figure 11.** Taking water samples for laboratory testing. *Source:* ECHO Asia

In round two of the trial, the steps described above were repeated. However, a settling tank was added prior to barrel 1, and the proportions and quantities of filter media in each filtration tank were adjusted to follow Aqueous Solutions design more closely. In addition, char was taken out of a mesh bag and allowed to float freely in the third barrel. Again, a pre-filtration sample from the intake directly into tank 1 was taken, and a post-filtration sample from the tap from tank 4. In addition, water was sampled directly from the fishpond, to determine the impact of the settling tank.

### Comparison of layers of material in round 1 and 2 filters

Table 4 shows the changes made in filter materials from the first to second round of tests, while figure 12 shows the layer height visually.

**Table 4.** Comparison of Material Layers in Biosand Filters

| Barrel | Round 1 | | Round 2 | |
|---|---|---|---|---|
| 1. Gravel Roughing Pre –filter | Gravel | 20 cm | Big stone | 20 cm |
| | Medium stone | 20 cm | Medium stone | 25 cm |
| | Big stone | 25 cm | Gravel | 25 cm |
| 2. Slow Sand Biofilter | Fine sand | 24 cm | Fine sand | 45 cm |
| | Coarse sand | 8 cm | Coarse sand | 4 cm |
| | Gravel | 15 cm | Gravel | 4 cm |
| | Medium stone | 7.5 cm | Medium stone | 7 cm |
| 3. Biochar Adsorber | Biochar | 25 cm | Fine sand | 45 cm |
| | Coarse sand | 6 cm | Coarse sand | 4 cm |
| | Gravel | 15 cm | Gravel | 4 cm |
| | Medium stone | 17 cm | Medium stone | 7 cm |


**Figure 12.** Pink strip showing round 1 and round 2 material depths for the first (left/gravel), second (middle/sand), and third (right/char) barrels. *Source*: ECHO Asia

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ECHO is a non-profit Christian organization.

For further resources, including networking with other agricultural and community development practitioners, please visit our website: www.ECHOcommunity.org. ECHO's general information website can be found at: www.echonet.org.

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