Safe water provision for Northern Ghana

David Barnes ~ Clair Collin ~ Sara Ziff

MIT M.Eng. Thesis Final Presentations
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Project Aim

- Work with Pure Home Water (PHW), a Northern Ghana-based social enterprise marketing safe water technologies
- Work towards PHW goal: *Safe water for 1 million people in Northern Ghana over next 5 years*
- Research additional safe water technologies for Northern Ghana, where 50% lack access to improved water source
Water Challenges in Northern Ghana

- Poverty
  - Low cost options required
- High turbidity water (>50 NTU)
  - Difficult to treat
- Lack of water-infrastructure
  - Household scale technologies
- Water-based disease prevalence
  - Guinea worm
  - Diarrhea
Addressing drinking water needs in Northern Ghana

- Technologies to improve water quality
  - Biosand filter – Clair Collin
  - Siphon filter – Sara Ziff

- Mitigating water scarcity
  - Rainwater harvesting – David Barnes
Clair Collin

Biosand filtration of high turbidity water:
Modifications to standard filter design and safe storage of filtrate
Presentation Overview

- Aims of research

Part I
- Biosand filter (BSF)
  - Overview of BSF technology
  - Design modification options research
  - Selected design optimization
  - Recommended BSF design

Part II
- Safe filtrate storage
  - Necessity for safe filtrate storage
  - Safe storage options
  - Recommended safe storage system

- Integrated BSF and safe filtrate storage system
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Aims of research

- Design a modified biosand filter for treating high turbidity water
- Recommend method for safe storage of filtrate
- Low cost system using locally sourced materials
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Biosand filter technology

- Intermittent slow sand filtration
  - Mechanical filtration of particles
  - Chemical/biological oxidation of organic matter

![Diagram of biosand filter technology]

- Raw water
- Standing water
- Fine sand (<1mm)
- Coarse sand and gravel for support
- Schmutzdecke Biofilm
- Filtered water
Biosand Filter Technology

- Low turbidity source water, <50 NTU
  - Pathogen reduction
    - Bacteria: 1-log – 3-log
    - Viruses: 0.5-log – 3-log
    - Protozoa: 2-log – 4-log
  - Turbidity reduction
    - 85% - 95%

- High turbidity source water, >50 NTU
  - Not known
BSF Design Options

- Goal: reduce turbidity, thereby pathogen contamination
  - Sedimentation – too slow
  - Coagulation & flocculation – too expensive
  - Additional filtration
    - Roughing filtration – too big/complicated
    - Finer sand (0.7 mm) – worth investigating
    - Additional sand (second layer) – worth investigating
BSF Design Options

- Standard BSF
- Superfine Sand Layer BSF
- Dual Sand Layer BSF

Superfine Sand Layer BSF

Upper sand layer
BSF Design Options

- Standard BSF
- Superfine Sand Layer BSF
- Dual Sand Layer BSF

Biologically active zone
BSF Design Options

- Superfine Sand Layer BSF
  - Increased turbidity removal 16%
  - Microbial removal:
    - Total coliform > 85%
    - \((E. coli > 83\%)\)
  - Frequent cleaning disturbs biology

- Dual Sand Layer BSF
  - Increased turbidity removal 38%
  - Microbial removal:
    - Total coliform > 95%
    - \((E. coli > 85\%)\)
  - Frequent cleaning has minimal disturbance on biology
BSF Design Options

- **Superfine Sand Layer BSF**
  - Increased turbidity removal 16%
  - Microbial removal:
    - Total coliform > 85%
    - *(E. coli > 83%)*
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- **Dual Sand Layer BSF**
  - Increased turbidity removal 38%
  - Microbial removal:
    - Total coliform > 95%
    - *(E. coli > 85%)*
  - Frequent cleaning minimal disturbance to biology
Dual Sand Layer BSF

- Design optimization - tests
  - Sand layer depth
    - Upper sand layer 3 cm
    - Lower sand layer
  - 3-day cleaning program
  - Filling frequency
    - Twice per day
  - Filling volume
    - Double filter pore volume
  - Dissolved oxygen concentration profile
- Cost of filter
  - Unmodified ~$17
  - Modified ~$18
Design optimization - results

- Dual sand layer higher indicator bacteria removal than control filter
  - Turbidity >93%
  - *E. coli* >97%
  - Total coliform >71%

- 3-day cleaning program
  - No effect on performance

- Increased filling frequency
  - Decreased performance

- Increased filling volume
  - Decreased performance

- Dissolved oxygen
  - Oxygen reached lower sand layer for biological activity
Recommendations

- Dual Sand Layer BSF
  - High turbidity reduction
  - Efficient microbial reductions
  - Frequently cleaning has minimal disturbance on biologically active zone
  - Achieved with low-cost modifications
- Dual sand layer BSF recommended for further testing
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- Integrated BSF and safe filtrate storage system
Necessity for Safe Filtrate Storage

- Protect filtrate from recontamination from dirty hands, cups and utensils
- Prevent access to animals and children
- Critical to success and sustainability of biosand filter
Safe Storage Options

- Safe storage vessel
  - Jerry can
  - Plastic bucket with lid
  - Dispenser tap
  - Low cost
  - Durable

- Jerry can
  - Difficult to fit tap
  - Bought recycled - plastic impregnated with palm oil

- Plastic bucket with lid
  - Easy to fit tap
  - Bought clean
Safe Storage Options

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Safe Filtrate Storage Recommendations

- High BSF flow rate – villagers did not store filtrate
  - Teach filtering water only as required
- Collect filtrate in safe storage bucket with lid and tap
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**Integrated BSF and safe filtrate storage system**
In areas with high turbidity water, the following system is proposed for further research:

- Dual Sand Layer Biosand Filter
- Safe collection of BSF filtrate

Teach use of filter only when water is required.
Sara Ziff

Siphon Filter Assessment for Northern Ghana
Siphon Filter

- Household ceramic water filter
- Based on ceramic candle filter design
- Fast flow rate (3-5 L/hour)
- Low cost (Current ~ US$10; Future ~ US$5)
- Effective: 99.999% removal found by independent lab
Siphon Filter Use

To Use:

- Place ceramic element in elevated upper container
- Place tap in lower container
- Press bulb to start flow, using siphon effect
Siphon Filter Maintenance

- Filter clogs periodically due to particles
- Backwashing restores flow
- Cloth pre-filter
- At a certain point, scrubbing needed

- End-of-life gauge tells when element too thin
Objective:
To which types of households should PHW market the siphon filter?

Method:
Ghana Field Study

- 24 siphon filters distributed to households
- Household types:
  - lower and upper class
  - turbid and low turbidity water sources
- Water quality testing
- Effective Use survey
Water Quality Findings
Source water characterization

- 48 total source water samples
  - Pipe, borehole, well, dam
- 58% “improved” sources, 42% “unimproved” sources
- Overall high levels of *E. coli*
- Intermediate to high risk level\(^1\)

Water Quality Findings
Filter Performance

- Reported values do not include 6 samples suspected of recontamination
- 90.7% avg. removal of total coliform
- 94.1% avg. removal of *E. coli*
- Turbidity removal influenced by ceramic particle leaching
  - Occurs during first use of filter
  - Aesthetic effect
Water Quality Findings
Recontamination

- Initially, thought could avoid possible recontamination:
  filtered water samples taken from tap
- However, filtered water sometimes had higher levels of coliform than household stored water
- Two possible causes:
  1. bacterial regrowth
  2. taps resting in dirty lower water containers
- Thought to be latter cause, but more research needed
Recommendation
Safe Storage Container

- Now: lower containers usually buckets or jerry cans →
  - Difficult to keep clean
- Siphon filter needs safe storage container
  - Maintain microbial quality of filtered water
- Recommended design →
- Could be marketed with siphon filter

[Diagram of siphon filter and storage container]
Effective Use Findings
Large Clay Pots as Upper Containers

- Large clay pots often used as water storage containers
- Not easily elevated
- However, distance between upper water level and tap sufficient if clay pot full
- Recommendation: Pictorial instructions for large clay pot users
Effective Use Findings
Backwashing/Scrubbing

- Backwashing and scrubbing process not well understood
- 75% of households did not understand backwashing →
- Scrubbing better understood
  - More intuitive?
- 33% scrubbed the filter during study
  - Source water for all was turbid
  - Backwashing not performed
- Over-reliance on scrubbing will shorten life of ceramic element
  - Esp. for turbid water

![Pie chart showing backwash and scrubbing usage and understanding.](chart.png)

- Backwashed: 8%
- Knew how to backwash but had not practiced: 17%
- Did not remember how to backwash: 75%

(n = 24)
Effective Use Findings

Settling

- Reduces turbidity
- Decreases necessary frequency of scrubbing
- Only 33% of users drinking dam water throughout study settled water
- Indicates settling not readily adopted

![Pie chart showing 33% of households adopted settling practice, 67% did not settle water.](chart.png)
Overall Findings
Middle vs. Lower Class

- Lower class households often drank highly turbid water
- However, class not found to influence how effectively filters were used
Overall Findings
High vs. Low Turbidity Water

- High turbidity water:
  - Filters clogged frequently
    - Study participants did not consistently maintain filter (backwashing, settling)

- Low turbidity water:
  - Filter maintenance less crucial
    - Filter clogged infrequently even with little maintenance
Comparison of Siphon Filter to Other Options

Established treatment options considered for marketing by PHW:
- Siphon filter
- Chlorine
- Alum (coagulant)
- Kosim ceramic pot filter
Comparison of Siphon Filter to Other Options
Low Turbidity

<table>
<thead>
<tr>
<th>Treatment Option</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Siphon Filter</td>
<td>Low cost</td>
<td>Safe storage not included</td>
</tr>
<tr>
<td></td>
<td>Small</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fast flow rate</td>
<td></td>
</tr>
<tr>
<td>Kosim Pot Filter</td>
<td>Integrated safe storage</td>
<td>Higher cost</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Large</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Slow flow rate</td>
</tr>
<tr>
<td>Siphon Filter</td>
<td>Infrequent purchase</td>
<td>Recontamination issue</td>
</tr>
<tr>
<td></td>
<td>No wait</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fast flow rate</td>
<td></td>
</tr>
<tr>
<td>Chlorine</td>
<td>Effective disinfection</td>
<td>Consumable</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wait required</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Disinfection byproducts</td>
</tr>
</tbody>
</table>
# Comparison of Siphon Filter to Other Options

## High Turbidity Treatment Option

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<tr>
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<tr>
<td><strong>Siphon Filter</strong></td>
<td>Infrequent purchase</td>
<td>Extensive maintenance</td>
</tr>
<tr>
<td></td>
<td>Low cost</td>
<td>Recontamination issue</td>
</tr>
<tr>
<td><strong>Alum plus Chlorine</strong></td>
<td>Simple</td>
<td>Consumable</td>
</tr>
<tr>
<td></td>
<td>Effective disinfection</td>
<td>Relatively expensive</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Disinfection byproducts</td>
</tr>
<tr>
<td><strong>Siphon Filter</strong></td>
<td>Cleaning options other than scrubbing</td>
<td>Extensive maintenance required</td>
</tr>
<tr>
<td></td>
<td>Fast flow rate</td>
<td></td>
</tr>
<tr>
<td><strong>Kosim Pot Filter</strong></td>
<td>Less maintenance required</td>
<td>Scrubbing only cleaning option</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Slow flow rate</td>
</tr>
</tbody>
</table>
Recommendations to PHW

- More research needed with safe storage container to resolve recontamination
- Siphon filter education:
  - Detailed literature
    - Pictorial and technical English/translated versions
  - Specialized training
- Turbid water users:
  - Advise settling
    - Simple, free
  - Suggest alum
    - < US$4.50/year
    - However, may be too much of a hassle/cost
Recommendations

- Choice of treatment option is not clear-cut, especially for users of highly turbid water
- PHW should discuss options with potential buyers
Assessment of Rainwater Harvesting in Northern Ghana

David Barnes
Overview

- Introduction
- Objectives
- Current Status
- Economic
  - Cost/m³
- Technical
  - Reliability
- Water Quality Analysis
  - Tank/Cistern Water Quality
- Conclusions/Recommendations
Introduction

Objective

- Assess the current state of rainwater harvesting
- Assess performance and potential for scaling up
Methods

- RWH Technical Surveys
- Household surveys for Presbyterian Tank Program household RWH systems
- Water quality sampling
  - 3M Petrifilm and Colilert
- Pricing of system components
- Interviews with contractors, NGO’s, local government
Current Status of Rainwater Harvesting in Northern Ghana

- Three NGO’s
  - Schools, Hospitals/Health Clinics
    - World Vision
    - New Energy
  - Households
    - Presbyterian Church and Pure Home Water
- Government program at school’s
- Do-it-yourself informal rainwater harvesting
- Two rainwater harvesting systems >50 yrs old
  - Savelugu Hospital
  - Veterinary College
System Designs

Three Design’s

- 10m$^3$ Ferrocement Tank
  - $\$708$ US

- 30m$^3$ Cement Block Tank
  - $\$2750$ US

- 75m$^3$ Cement Block Tank-Octagonal
  - $\$3500$ US
Ability to Pay for Household RWH

- Estimated as 5% of annual income\(^1\)
  - Urban= $64 USD/yr
  - Rural= $26 USD/yr
- Presbyterian Tank Program with no interest
  - $35 USD/yr ($708 USD/20 years)
- Rural unaffordable, urban affordable

## Presbyterian Tank Program

<table>
<thead>
<tr>
<th></th>
<th>Demand Scenario 1</th>
<th>Demand Scenario 2</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
</tr>
</thead>
<tbody>
<tr>
<td># of Users</td>
<td>Roof Area (ft²)</td>
<td>Reliability (5 L/day/capita)</td>
<td>Reliability (20 L/day/capita)</td>
<td>Unit Cost (USD/m³)</td>
</tr>
<tr>
<td>High</td>
<td>7</td>
<td>772</td>
<td>99.9%</td>
<td>78%</td>
</tr>
<tr>
<td>Average</td>
<td>14</td>
<td>369</td>
<td>96%</td>
<td>26%</td>
</tr>
<tr>
<td>Low</td>
<td>20</td>
<td>200</td>
<td>43%</td>
<td>5%</td>
</tr>
</tbody>
</table>

- Various reliability and demand scenarios and their resulting unit costs per cubic meter
- No discounting
## Community RWH sites

<table>
<thead>
<tr>
<th>Tank Name</th>
<th>Rooftop Area (ft²)</th>
<th>Storage Capacity (ft³)</th>
<th>Demand (gal/day)</th>
<th>Reliability %</th>
<th>Cost (USD)</th>
<th>Unit Cost (USD/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>World Vision</td>
<td>12149</td>
<td>1766</td>
<td>433</td>
<td>68</td>
<td>8333</td>
<td>$1.02</td>
</tr>
<tr>
<td>Pong Tamale Health Clinic</td>
<td>500</td>
<td>18</td>
<td>4.2</td>
<td>75</td>
<td>300*</td>
<td>$3.45</td>
</tr>
<tr>
<td>Pong Tamale Vocational School (1)</td>
<td>612</td>
<td>35</td>
<td>262</td>
<td>5</td>
<td>500*</td>
<td>$1.38</td>
</tr>
<tr>
<td>Pong Tamale Vocational School (2)</td>
<td>748</td>
<td>35</td>
<td>262</td>
<td>6</td>
<td>500*</td>
<td>$1.12</td>
</tr>
<tr>
<td>Pong Tamale Health Center</td>
<td>753</td>
<td>2649</td>
<td>50</td>
<td>91</td>
<td>3500</td>
<td>$2.78</td>
</tr>
<tr>
<td>Savelugu Hospital</td>
<td>819</td>
<td>2649</td>
<td>262</td>
<td>11</td>
<td>3500</td>
<td>$4.40</td>
</tr>
</tbody>
</table>

* Cost estimated, tank cost unknown
Alternative Technologies

Adapted from Murcott et al., 2008

RWH: 1-10 $/m^3
Design Issues

- Dead Storage
- Leaky taps/tanks
- Guttering!
- Expense and Subsidy
  - Tank Cost
- Maintenance
Cost Competitiveness

- If capital is available, RWH systems are cost competitive with alternative technologies with no discounting.
- Ability to Pay indicates that average rural residents would be unable to afford Presbyterian 10m³ tank, even without interest.
- Currently almost entirely subsidized
  - Sustainability and upscale?
Water Quality

- Presbyterian Tank Program
  - 42% (6 out of 14) positive for total coliform contamination greater than 10 CFU/100 ml
  - 14% (2 out of 14) positive for *E.coli* contamination greater than 10 CFU/100 ml
  - 100% of fetched water samples contaminated
- Recommend use of filter
  - *Kosim*
- Could be used with rainwater and for filtration of supplementary source (i.e. dugout)
- Further water quality investigations should be conducted
Recommendations

- Low-hanging fruit
  - Fully gutter existing systems to improve reliability
  - Suggest water filtration with RWH programs
    - Can also use with supplementary source
  - Install guttering where water tanks are installed
    - Schools, hospitals, community centers
  - Address design issues to improve efficiency
    - Recommended where no improved water source available (bore, piped)
Recommendations for PHW, Northern Ghana

- Further Research on New Household Water Treatment Options
  - Dual Sand Layer Biosand Filter + safe filtrate storage
    - Effective microbial reductions in high turbidity water
    - Low-cost modification to standard BSF
  - Siphon Filter
    - Resolve recontamination issue, then,
    - Recommended for treating low turbidity water
    - Compares favorably to other PHW products

- Water Scarcity
  - Rainwater harvesting
    - Expensive, supplemental technology
    - Recommended where no improved water source available and where water storage tanks required anyway
    - Competitive with other technologies on a unit cost basis
    - Capital investment required
Thank you

- Questions are welcome!