11.479J / 1.851J Water and Sanitation Infrastructure in Developing Countries
Spring 2007

Household Water Treatment and Safe Storage Technologies

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Week 7, 11.479J / 1.851J
March 20, 2007




MIT Master of Engineering

Teams in Brazil

1999, 2000

For more than a decade during the late 80s and 1990s, I worked with Prof. Emeritus Donald Harleman on innovative and low-cost wastewater treatment for the developing world

In 1998, I was an invited guest speaker to the 2nd International Women and Water Conference. Kathmandu, Nepal

I learned about the need for safe and accessible water from these Nepali village women

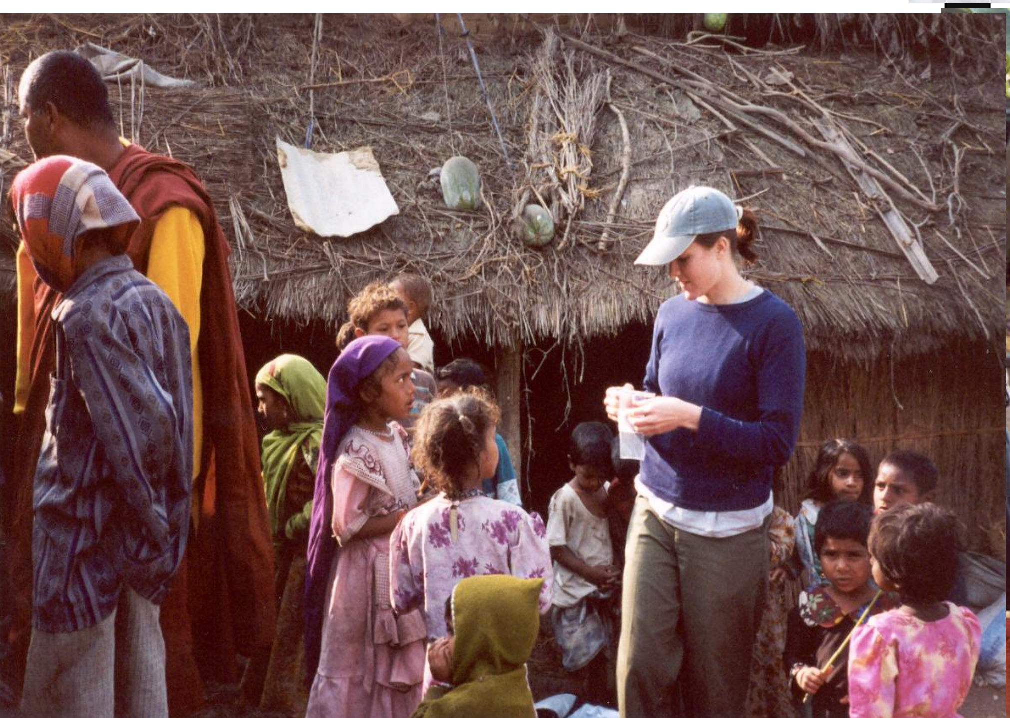
Since 1998, about 20 MIT student teams have done engineering thesis and MBA projects on household drinking water treatment and safe storage (HWTS)

We call this initiative

H2O-1B

Clean Water for 1 Billion People

Student's work is primarily field-based engineering research



We have worked with NGOs, municipal governments, research labs and development organizations

We have been leaders and innovators and in a new area of research and development:

Engineering Design for Developing Countries

especially

- **Household Water Treatment and Safe Storage (HWTS)**

We have produced a body of material on household water treatment and safe storage:

Theses, group reports, term papers, PowerPoint presentations, videos, articles, peer-reviewed publications and a Web Site:

- **http://web.mit.edu/watsan**

Do HWTS Technologies Detract from Ultimate Goal of Universal Piped Water Provision?

Multiple Barrier Approach: A Watershed Systems-based Approach to Water Safety

- "Securing the microbial safety of drinking water supplies is based on the use of multiple barriers, from catchment to consumer, to prevent the contamination of drinking water and to reduce contamination to levels not injurious to health. Safety is increased if multiple barriers are in place, including protection of water resources, proper selection and operation of a series of treatment steps and management of distribution systems (piped or otherwise)."

(WHO, GDWQ, 2004)

Multiple barriers to protect drinking water are applied in various locations

- **Watershed (Source) Protection**
- **Treatment: centralized and decentralized**
- **Piped Distribution: safe distribution to the public standpipe or home compound**
- **Non-piped - Community and Household Distribution: safe transport from the source to the point-of-use**
- **Storage: reservoirs, community and home storage**

HWTS Technologies

Examples of Household Safe Storage and Water Treatment Processes and Systems

- I. Safe Storage
- 1. Plastic or modified clay pot safe storage containers

- II. Disinfection
- 2. Boiling
- 3. Household chlorination
- 4. SODIS and UV disinfection

- III. Particle Removal Technologies
- 5. Cloth Filtration
- 6. Ceramic Filters
  - Candle Filters
  - Pot Filters
- 7. Biosand Filters
- 8. Coagulation/Precipitation Only

- IV. Membrane / Reverse Osmosis
- 9. Membrane, Reverse Osmosis, Ultrafiltration, Nanofiltration

- V Combined Systems
- 10. Coagulation/Precipitation + Chlorine Disinfection (e.g. PUR)
- 11. Filtration + Disinfection + Aesthetics (Hindustan Lever, Pure-it)

- VI. Chemical Removal Systems (not covered in this presentation)

CDC Safe Storage Vessel Characteristics

- Standardized volume (10 - 30 liters), with handles shaped to facilitate transport and use.
- Durable, easy-to-clean material.
- Inlet diameter between 6 and 9 cm
- Durable spout or spigot allowing a discharge rate of 1 liter per 15 seconds at outlet.
- Instructions for use, cleaning container and disinfecting its contents permanently attached to vessel.

Disinfection

Household Chlorination

- Household Chlorination using locally produced and distributed chlorine solution.

- Safe Water Storage in plastic containers with narrow mouths, secure lids and dispensing spigots to prevent recontamination.

- Education: Influence hygiene behaviors and increase awareness about the dangers of contaminated water and waterborne disease.

The “Safe Water System” Approach

Safe Water System Products

Pros and Cons of Household Chlorination / "Safe Water System" Approach

- PROS
- Applied properly and with a water that is not excessively turbid, this provides a safe, disinfected water supply
- Residual chlorine is simply measured
- Clinically proven
- Inexpensive

- CONS
- Chlorine taste and smell
- Some customers only use it sporadically, like "medicine" or just for their young children
- Must wait 30 minutes before drinking treated water
- Chlorine availability
- Storage issues

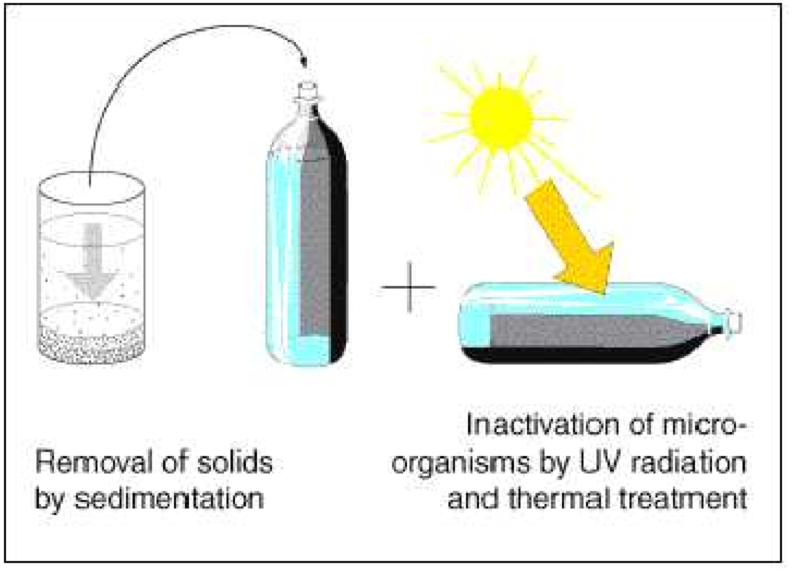
Cost = about $7 to $10 per family per year

Image removed due to copyright restrictions.

Solar Disinfection (SODIS)

What is SODIS?

- PET plastic bottles exposed to solar radiation for 1-2 days to disinfect drinking water
- Variations:
  - Exposure time
  - Clear, black or reflective surface



SODIS

- SODIS was invented by Prof. A. Acra *et al.* of American University of Beirut, Lebanon in 1982.
- Researchers at the Swiss Federal Institute of Environmental Science and Technology (ETH-EAWAG/SANDEC) took up extensive studies of SODIS beginning in 1991.
- MIT students have investigated SODIS in Nepal and Haiti since 1999.


1 27 '00

Pros and Cons of Solar Disinfection

- PROS
- Scientifically proven
- Highly effective against a wide range of microbial contaminants
- PET plastic bottles widely available

- CONS
- User acceptance and sustained behavior change?
- Weather dependency
- Must expose bottles 1 day for safe water
- Users in hot climates may reject hot water

Cost = about $1 per family per year

UV Lamp Disinfection

Photographs removed due to copyright restrictions.

Filters




Cloth Filtration for Guinea Worm or Cholera Removal

Pros and Cons of Cloth Filters

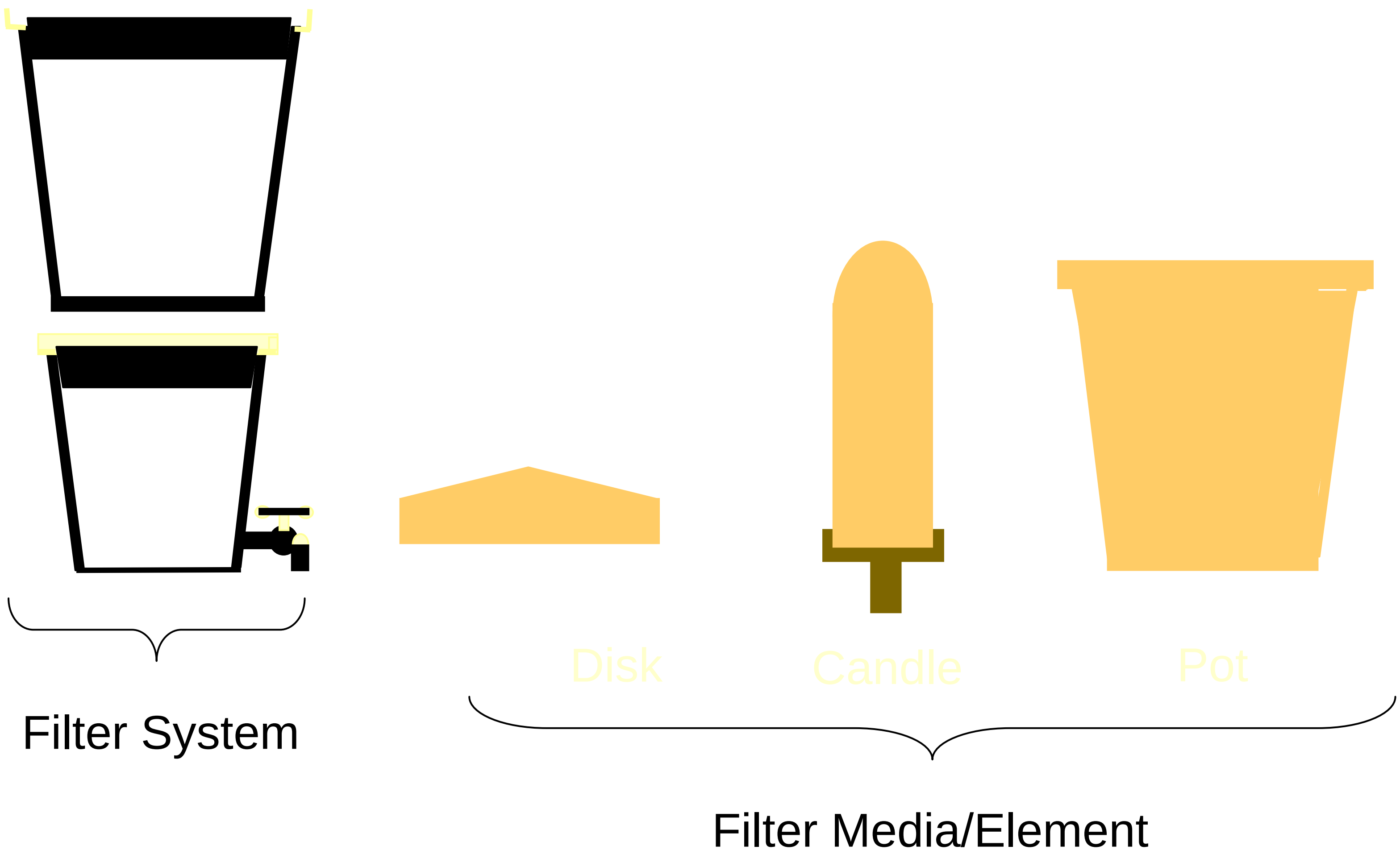
- PROS
- Effective at removal of guinea worm
- Simple and readily available

- CONS
- Must be kept clean so as not to be a source of other microbial contamination
- Does not address other possible contaminants of concern

Cost = $0.10 – 1.00

Ceramic Filters

Ceramic Water Filter Types



Pros and Cons of Ceramic Filters

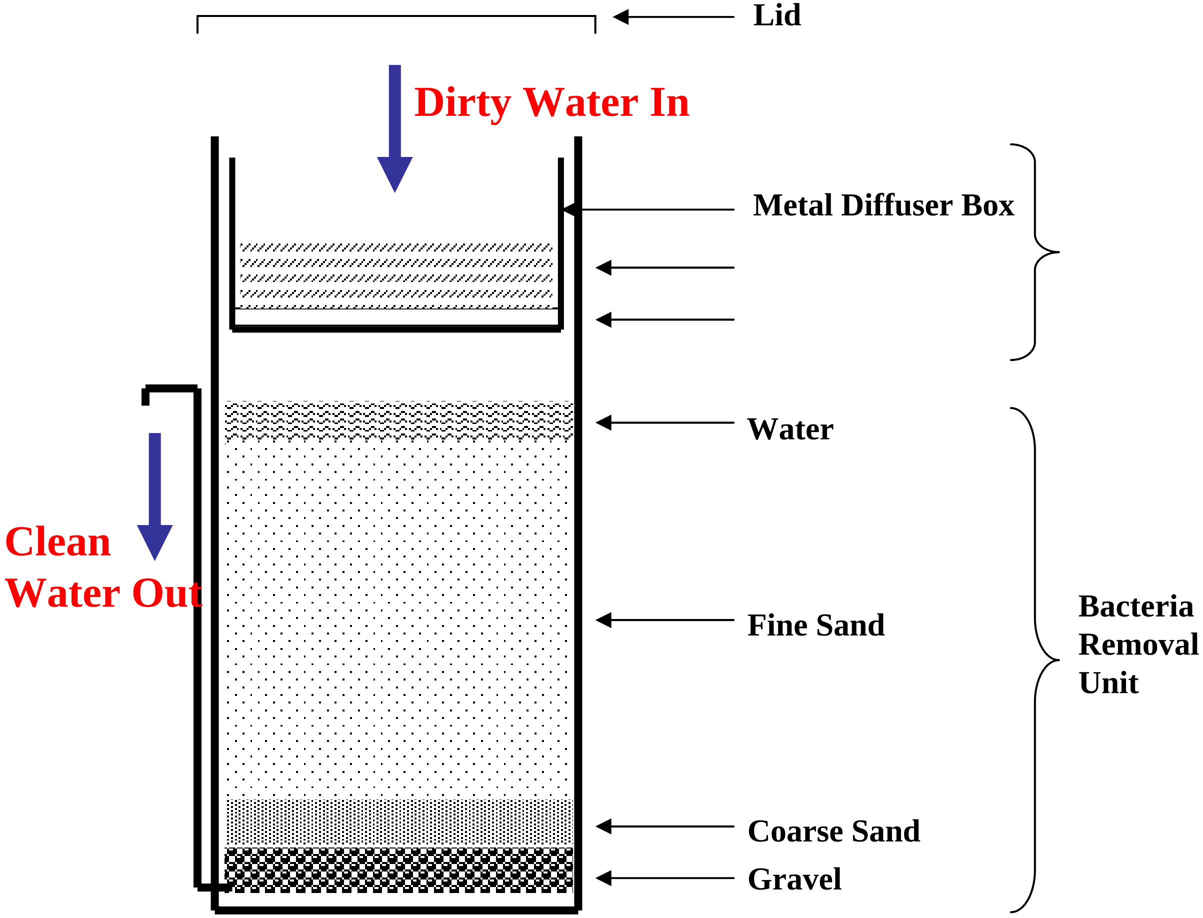
- PROS
- About 90 – 99% removal of bacteria
- Can be constructed of local materials (clay, sand, concrete, plastic) by local producers and create local jobs

- CONS
- Requires regular cleaning once filter becomes clogged
- Flow rates are slow and may not provide sufficient water quantity
- Ceramics can break if handled improperly

Cost = about $5 - $40

Biosand Filters

Biosand Filter



Pros and Cons of Biosand Filters

- PROS
- About 90 – 99% removal of bacteria
- Can be constructed of local materials (clay, sand, concrete, plastic) by local producers
- Can create local jobs
- High flow rate compared to many other household systems
- Extremely durable

- CONS
- Requires proper maintenance
- Does not provide safe water protection in the first 1-2 weeks of use, while the biological layer develops
- Must be properly maintained by cleaning about once per month
- Does not provide safe water directly after regular cleaning

Cost = about $15 - $75 depending on size and materials

Coagulation

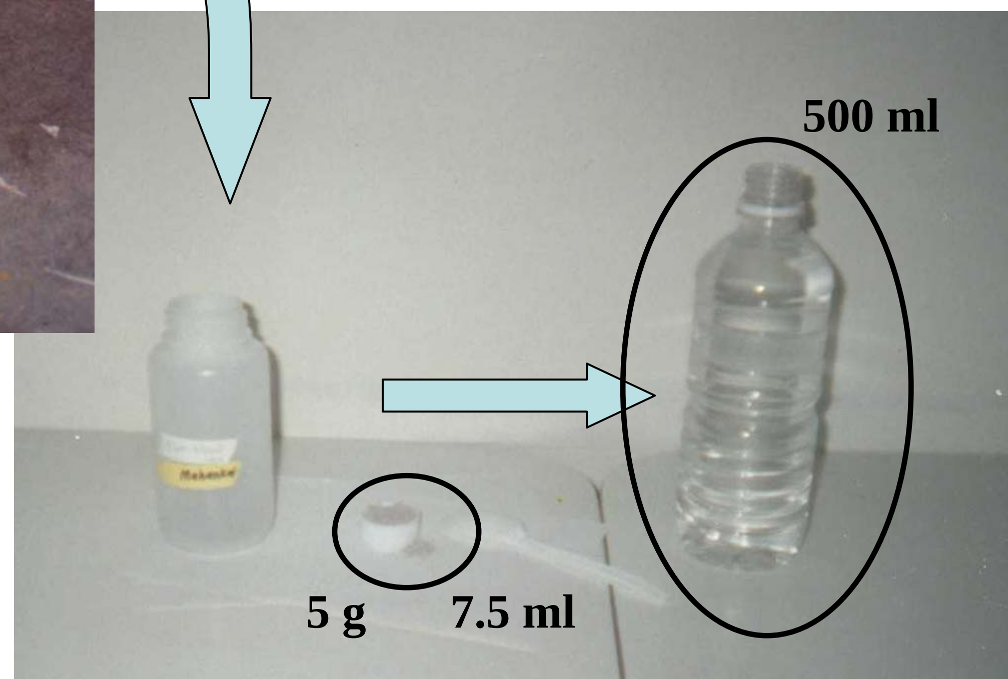



Jar Testing of Coagulants – a standard approach using a flocculator is shown

Photo: Frederick Chagnon, 2003)

Manual Coagulation (with Alum)

Applying 40 mg/l dose



Water Treated through Manual Coagulation with Alum

- 30 seconds under ~ 1.5 rotations per second
- 10 minutes under .5 rotations per second
- 30 minutes under 0 rotations per second

Water Treated through Manual Coagulation with Alum

Raw Water

Coagulation Regime

Settling Time

0 min

Settling Time

30 min

Membrane Processes

Membrane & Reverse Osmosis

- Many types of membranes exist: micro-filtration, electrodialysis, ultra-filtration, nanofiltration
- Membranes are able to reject or select passage of certain dissolved species
- Reverse Osmosis is a pressure-driven process that retains ions and passes water. Pressure exceeds the osmotic pressure of the salts against a semi-permeable membrane, forcing pure water through and leaving salts behind
- RO is commonly used in the water industry for desalination or treating brackish water
- Membranes can also remove particulates, color, trihalomethanes, and some inorganics (hardness)

TTY QUAN (Beijing, China)

Image removed due to copyright restrictions.

#	Type	Cost RMB	Cost US$
1	Polypropylene	20	2
2	GAC	30	3
3	Carbon Block	30	3
4	Softener	80	8
5	R/O		
6	Volcanic Minerals		
7	GAC		

Retail Cost = RMB 2,980 (US$300)

Combined Treatments

Coagulation-Disinfection Product

PROS

- Combines turbidity removal with microbial disinfection
- Measurable chlorine residual
- Simple to use
- Visually impressive improvement in water clarity.
- Clinically proven

CONS

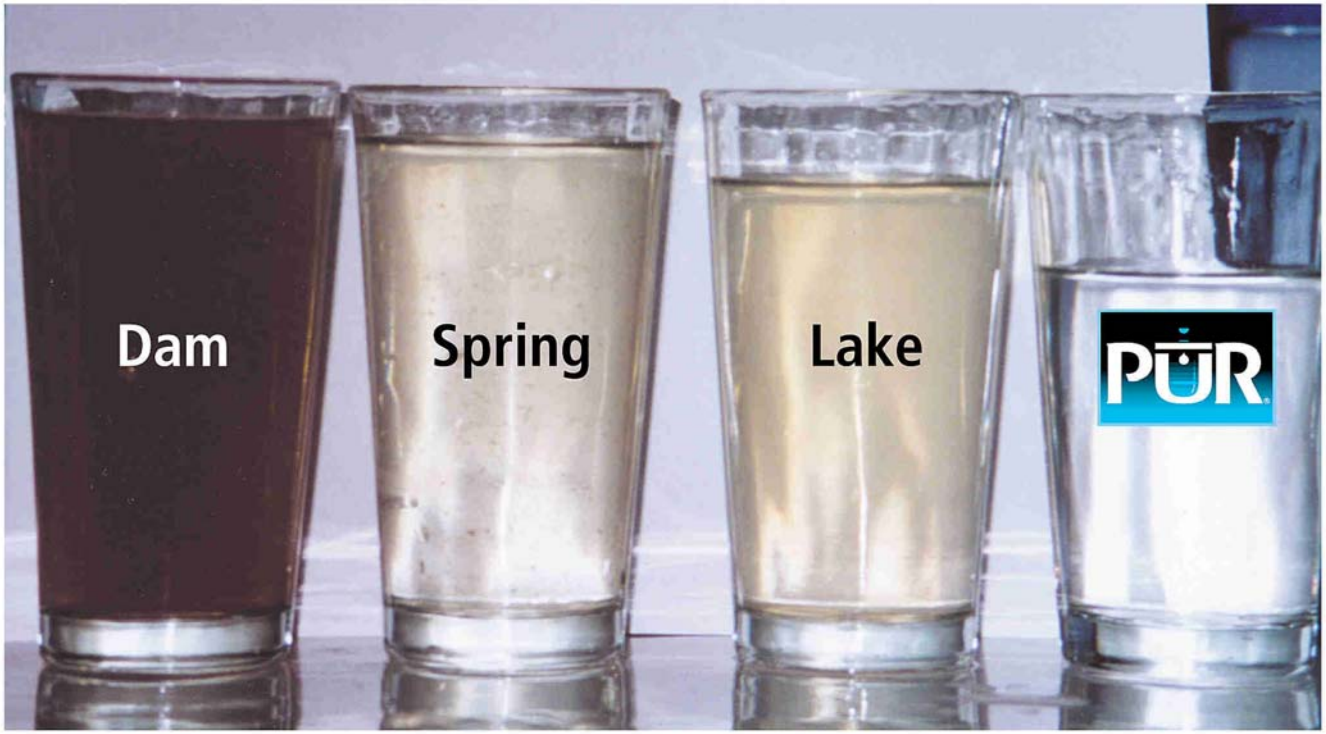
- Comparatively expensive
- Customers use it sporadically as “medicine” and/or only for young children
- Issues with user acceptance
- Available in limited number of countries

Image removed due to copyright restrictions.

Cost = about $0.05/sachet or about $80/year per family depending on use

Drinking Water Samples

Dam Spring Lake Treated



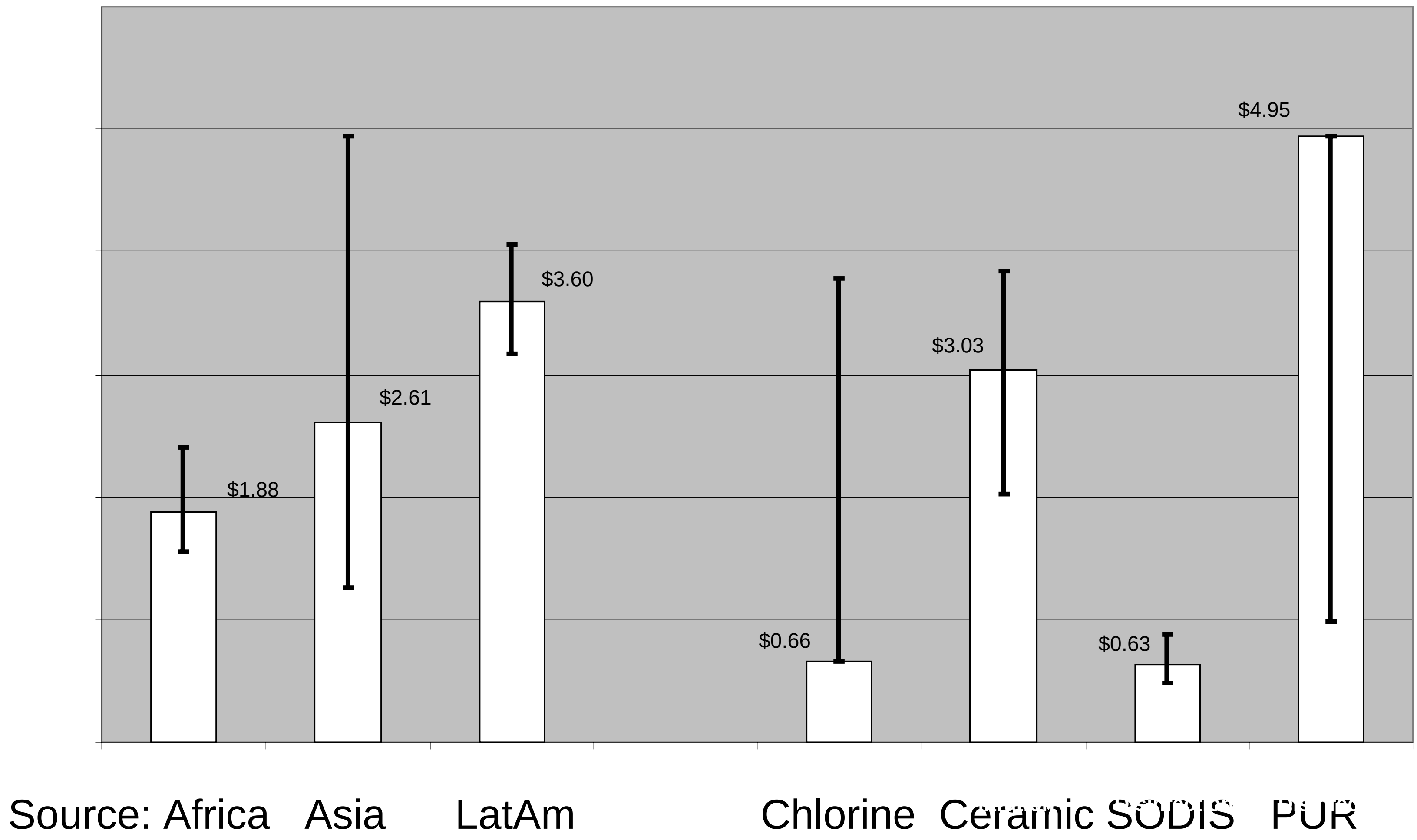
Turbidity (NTU)

Dam	Spring	Lake	Treated
1850	55	37	1

Some HWTS Cost Data

Summary of Cost Estimates

Mean annual cost per person in US$ of source and household Interventions (error bars represent range of costs)



Clasen T (2006). Household-based water treatment for the prevention of Diarrheal diseases. PhD Thesis, London University, 291pp.

Retail Prices of HWTS in Ghana

HWTS Systems	US$
1. Safe Storage -Modified Clay Pot w/ 1/2 " brass tap (40L)	$8
2. Safe Storage - plastic vessel w/tap (50 L)	$8
3. Ceramic Pot Filter	$12
4. *Nnsupa* Candle Filter	$25
5. Biosand Filter w/ Kanchan™ style plastic bucket (50 L)	$14
6. SODIS	≈$1/year
7. Household Chlorination 8. PUR	≈$4/year 5¢/sachet

Status of HWTS Implementation

Summary Statistics on HWTS Mapping

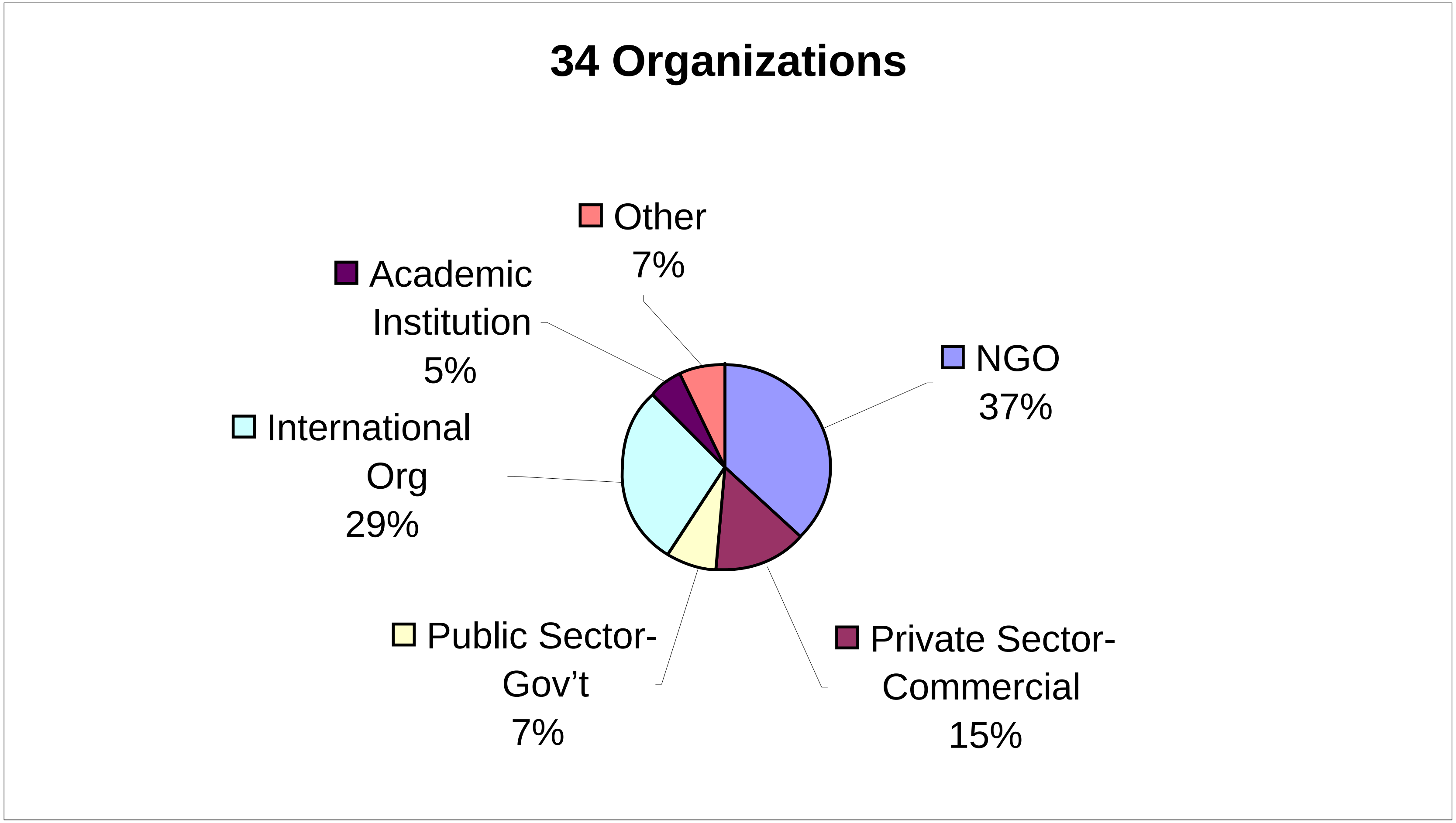
- 36 respondents from implementing organizations to date representing > ½ of the Network's 70+ members
- 52 countries with HWTS projects
- 9 HWTS technologies

Implementation Organization Survey

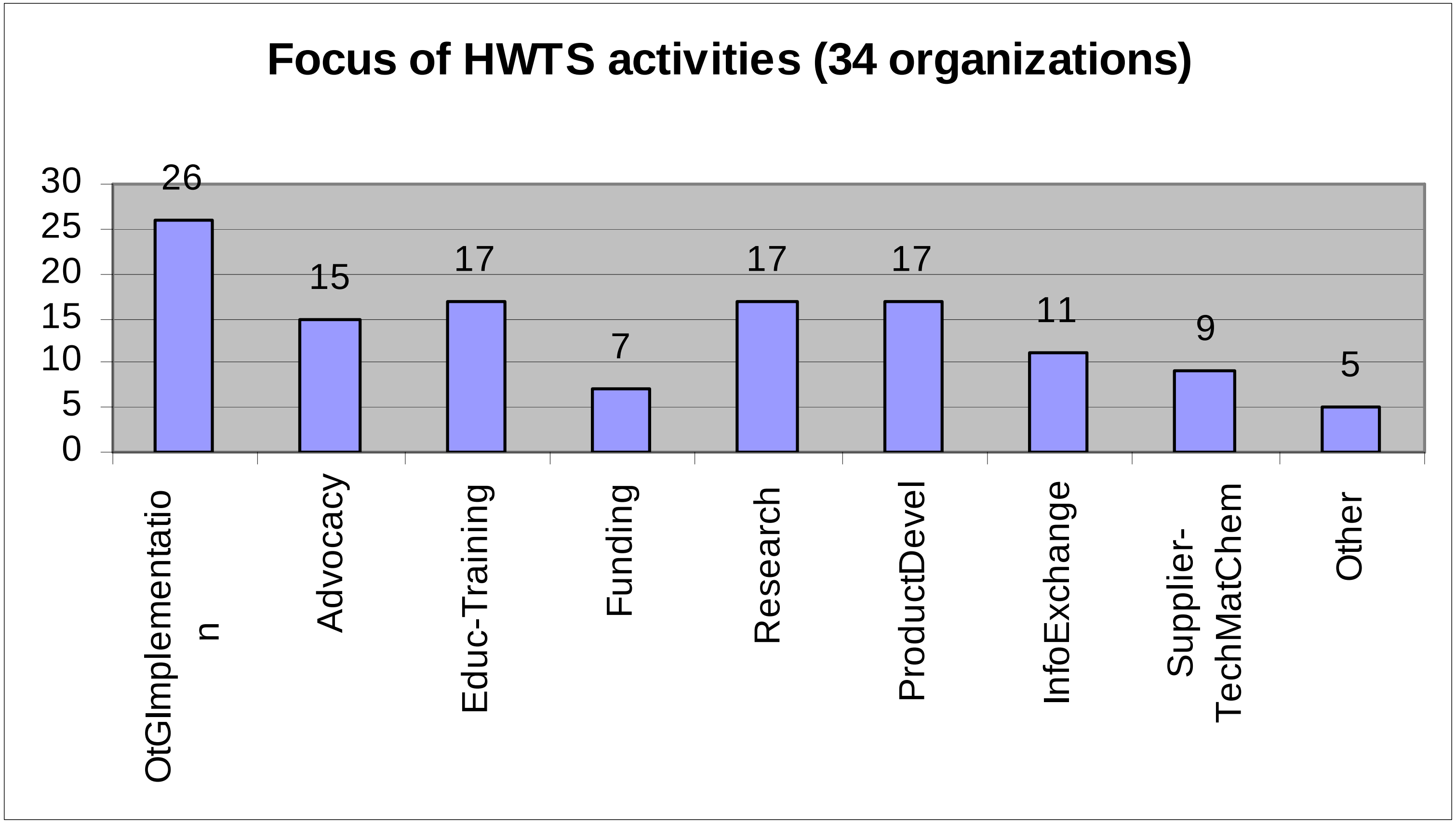
Image removed due to copyright restrictions.

- Current Version: 1
- Length: 4 pages
- Target: HWTS Implementation Organizations
- Time Required: 30 Minutes
- **http://www.who.int/household_water/implementation/en/**

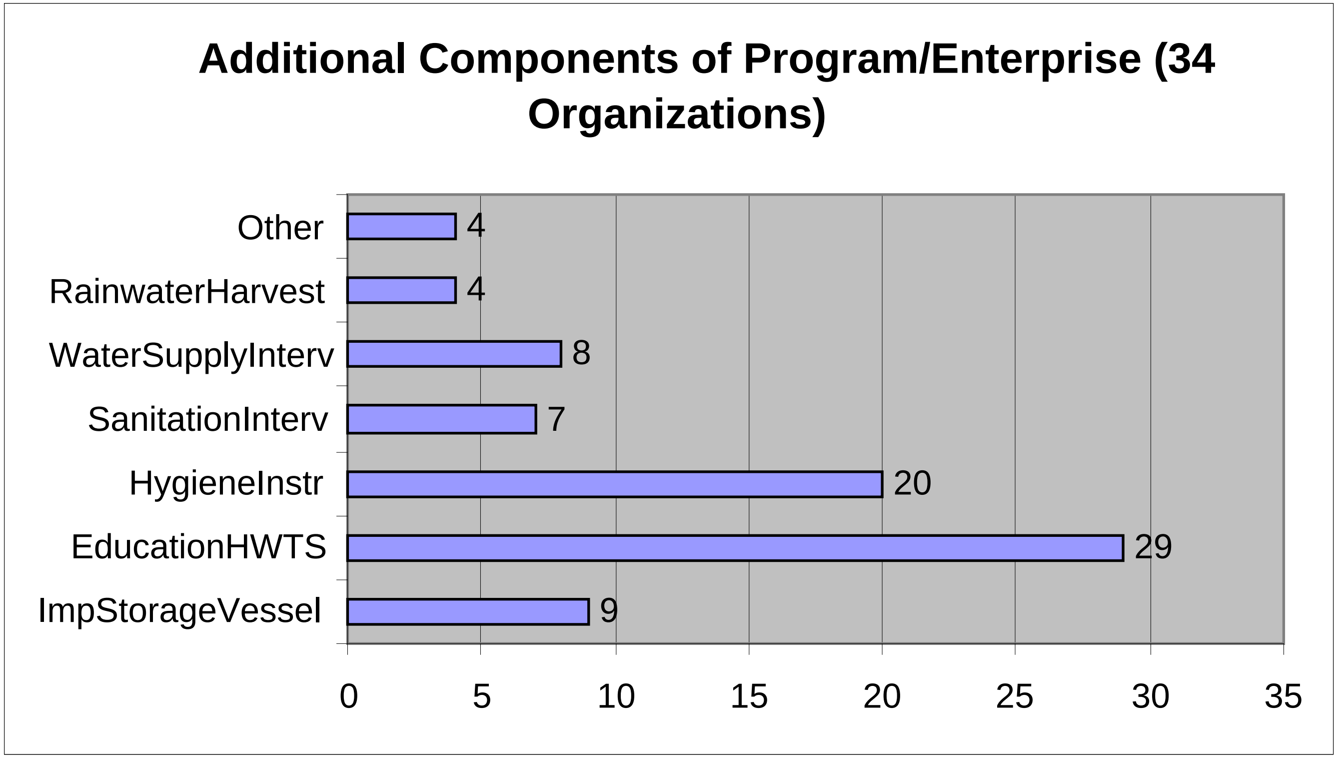
HWTS Survey Responses - Organization Types



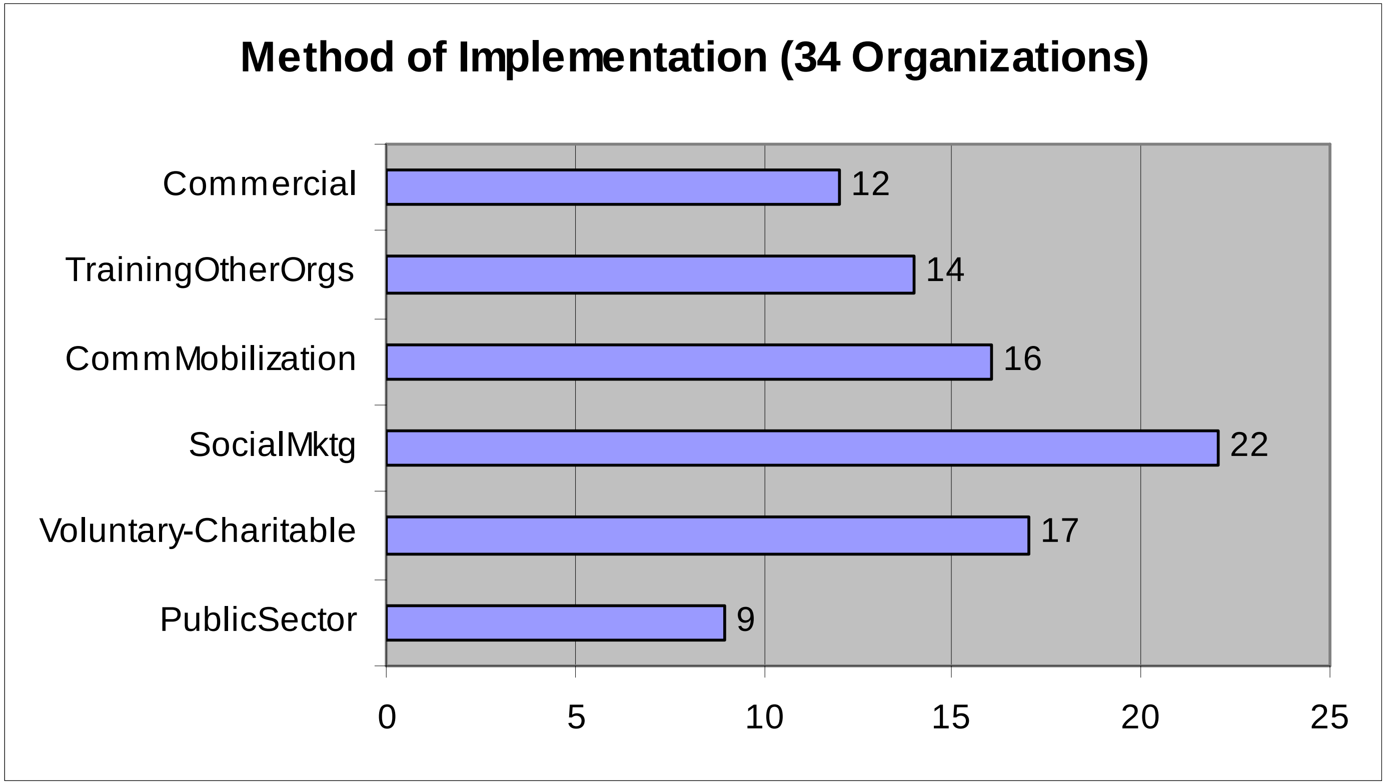
Survey Responses – Focus of Activities



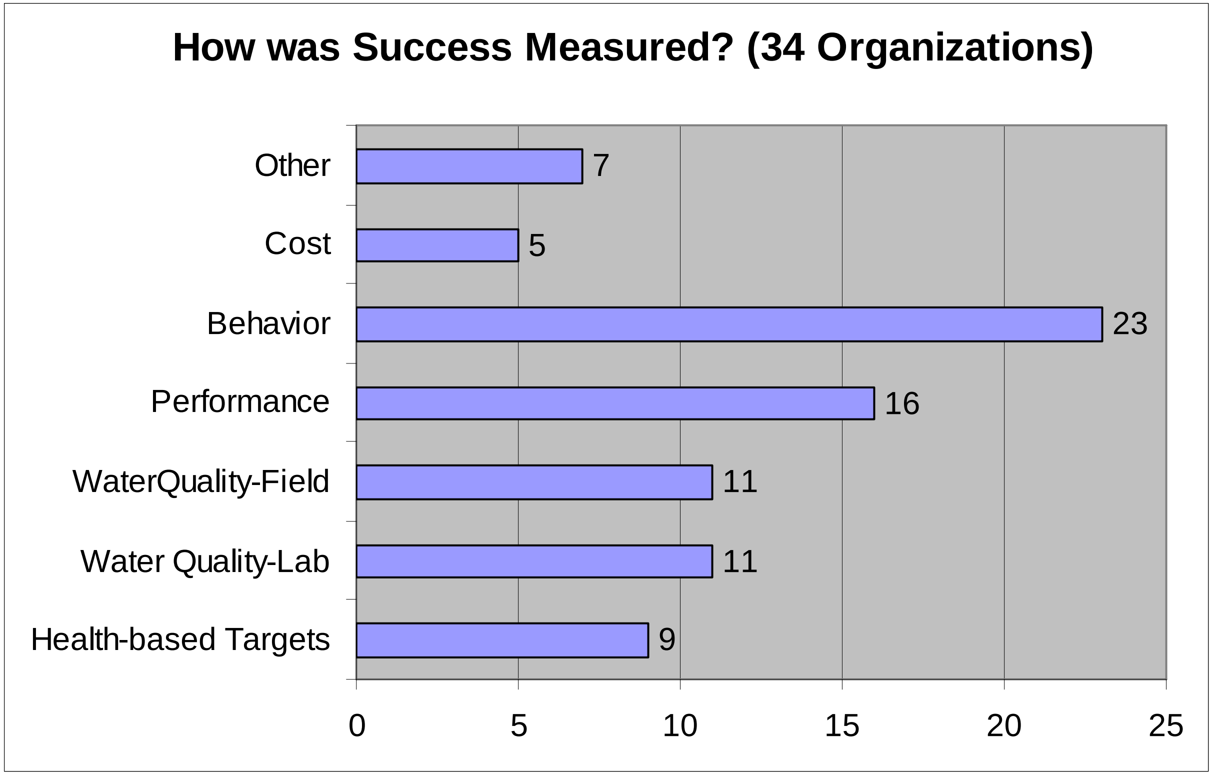
Additional Components of Program

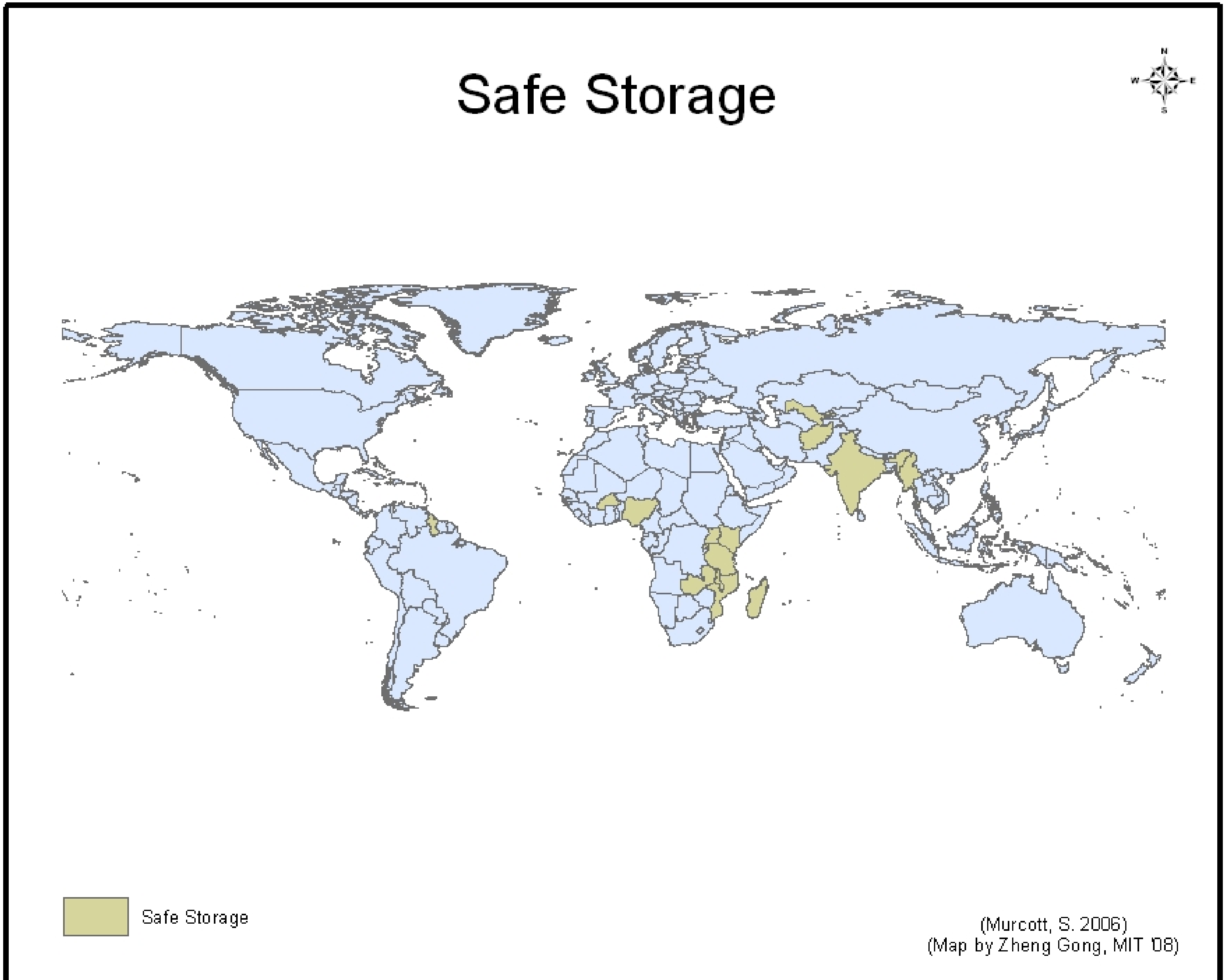


Method of Implementation



Evaluation Methods?




Safe Storage
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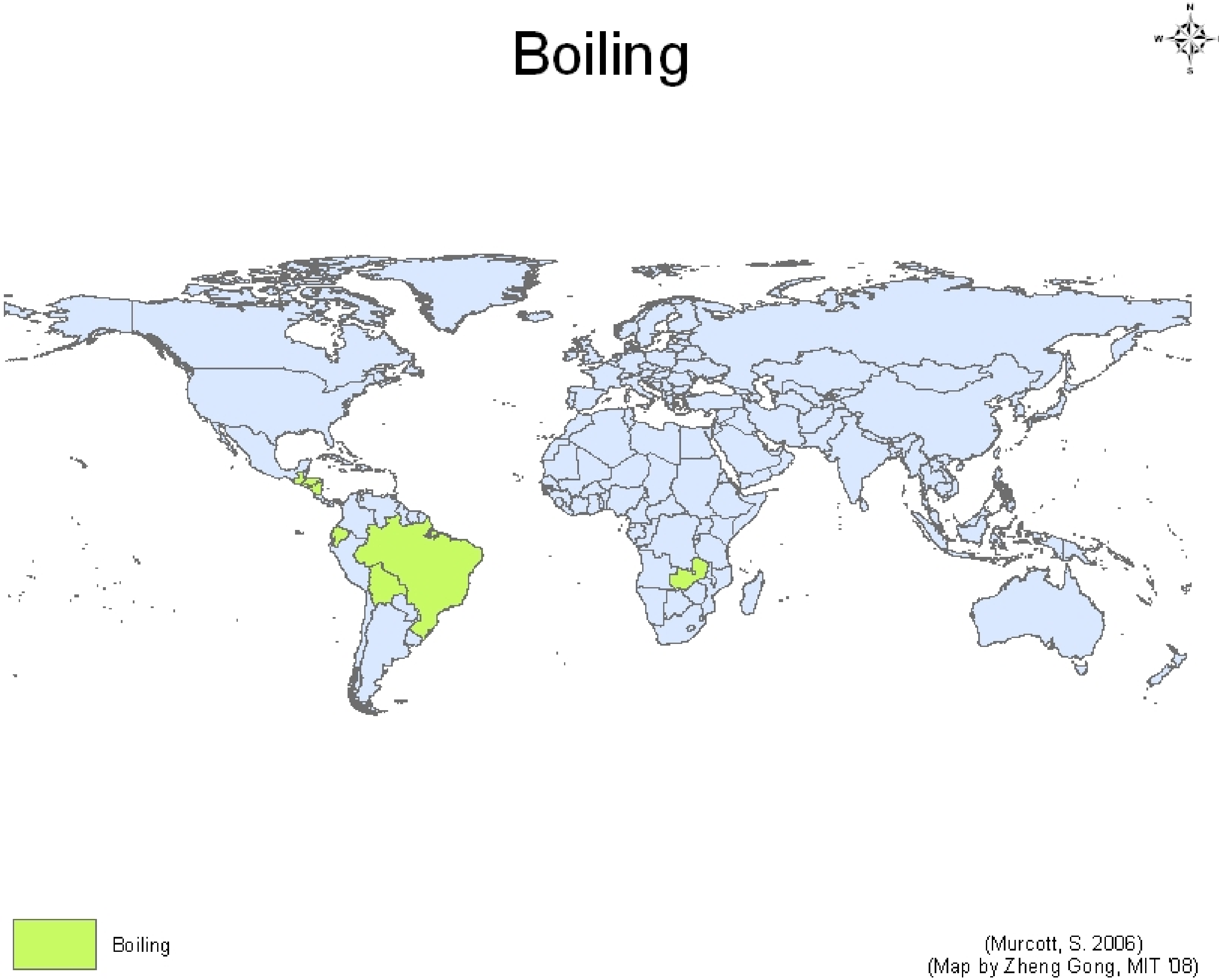
Safe Storage
(Murcott, S. 2006)
(Map by Zheng Gong, MIT '08)

16 Safe Storage Countries

- Afghanistan
- Burkina Faso
- Guyana
- Haiti
- India
- Kenya
- Madagascar
- Malawi
- Mozambique
- Myanmar
- Nigeria
- Rwanda
- Uganda
- United Republic of Tanzania
- Uzbekistan
- Zambia

Boiling

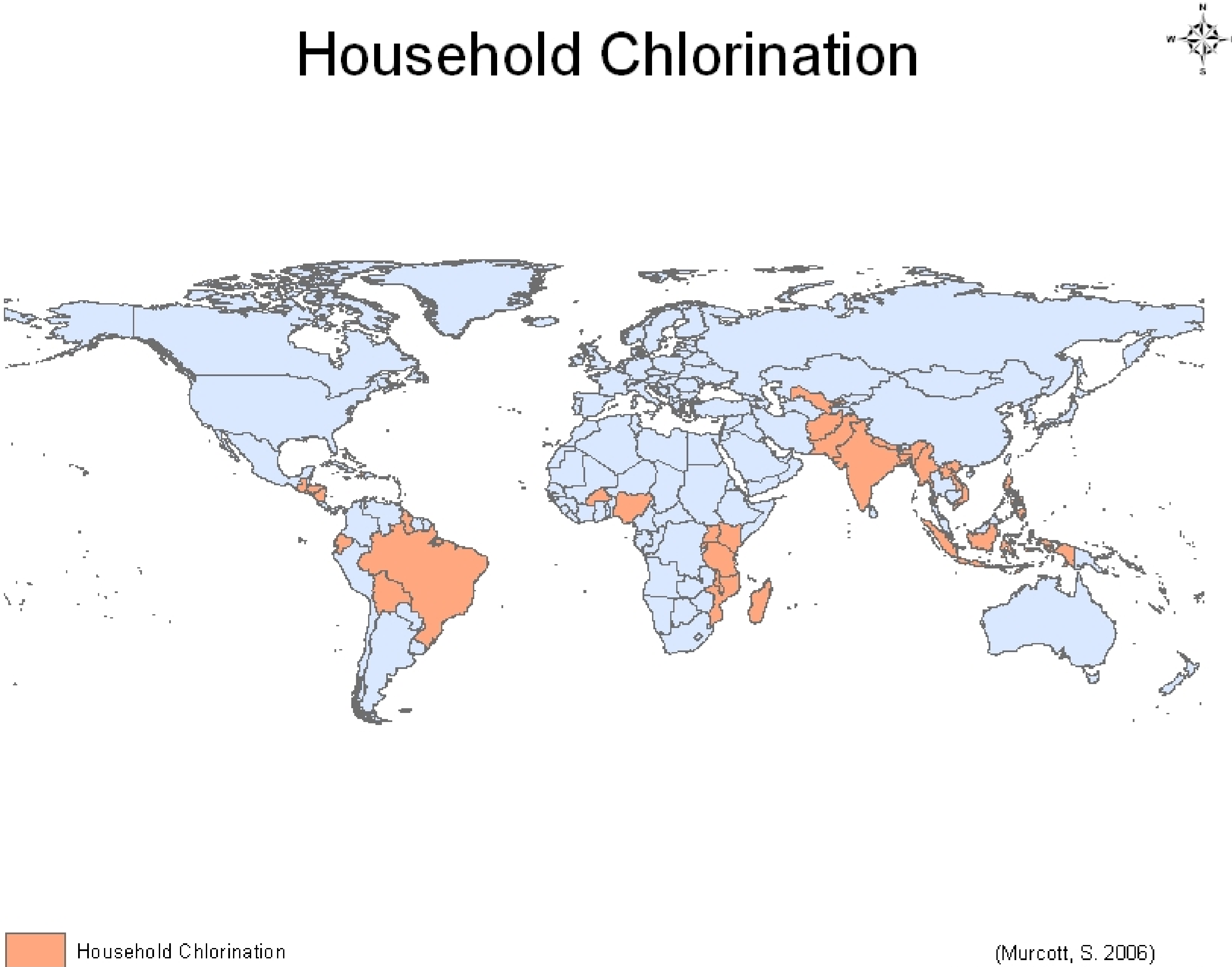


(Murcott, S. 2006)
(Map by Zheng Gong, MIT '08)

8 Boiling Countries

- Bolivia
- Brazil
- Ecuador
- El Salvador
- Guatemala
- Honduras
- Nicaragua
- Zambia

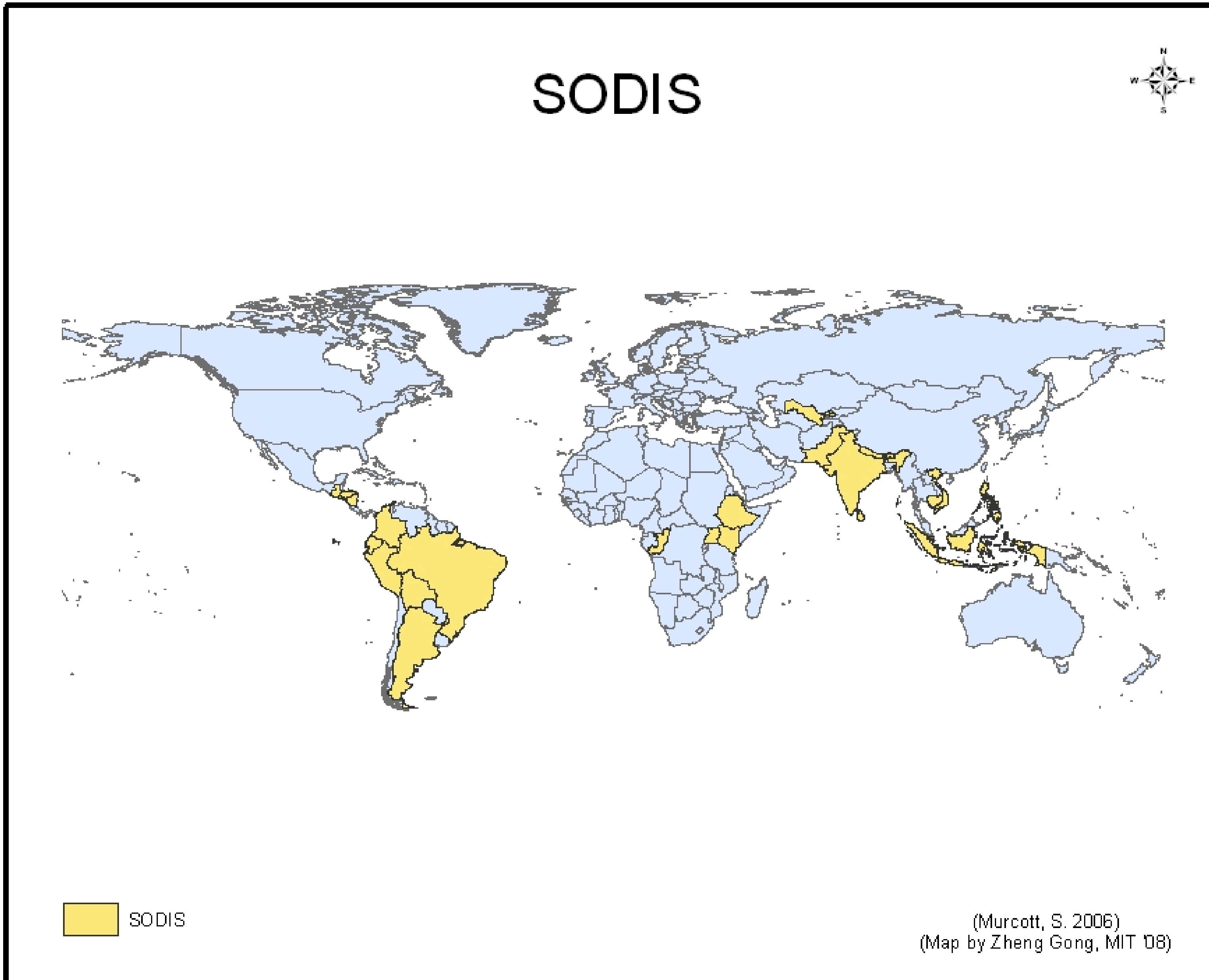
Household Chlorination



(Murcott, S. 2006)
(Map by Zheng Gong, MIT '08)

29 Household Chlorination Countries

- Afghanistan,
- Bangladesh,
- Bolivia,
- Brazil,
- Burkina Faso,
- Ecuador,
- El Salvador,
- Guatemala,
- Guyana,
- Haiti,
- Honduras,
- India,
- Indonesia,
- Kenya,
- Lao
- Madagascar,
- Malawi,
- Mozambique,
- Myanmar,
- Nepal,
- Nigeria,
- Pakistan,
- Philippines,
- Rwanda,
- Tanzania,
- Uganda,
- Uzbekistan,
- Vietnam


SODIS
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SODIS
(Murcott, S. 2006)
(Map by Zheng Gong, MIT '08)

34 SODIS Countries

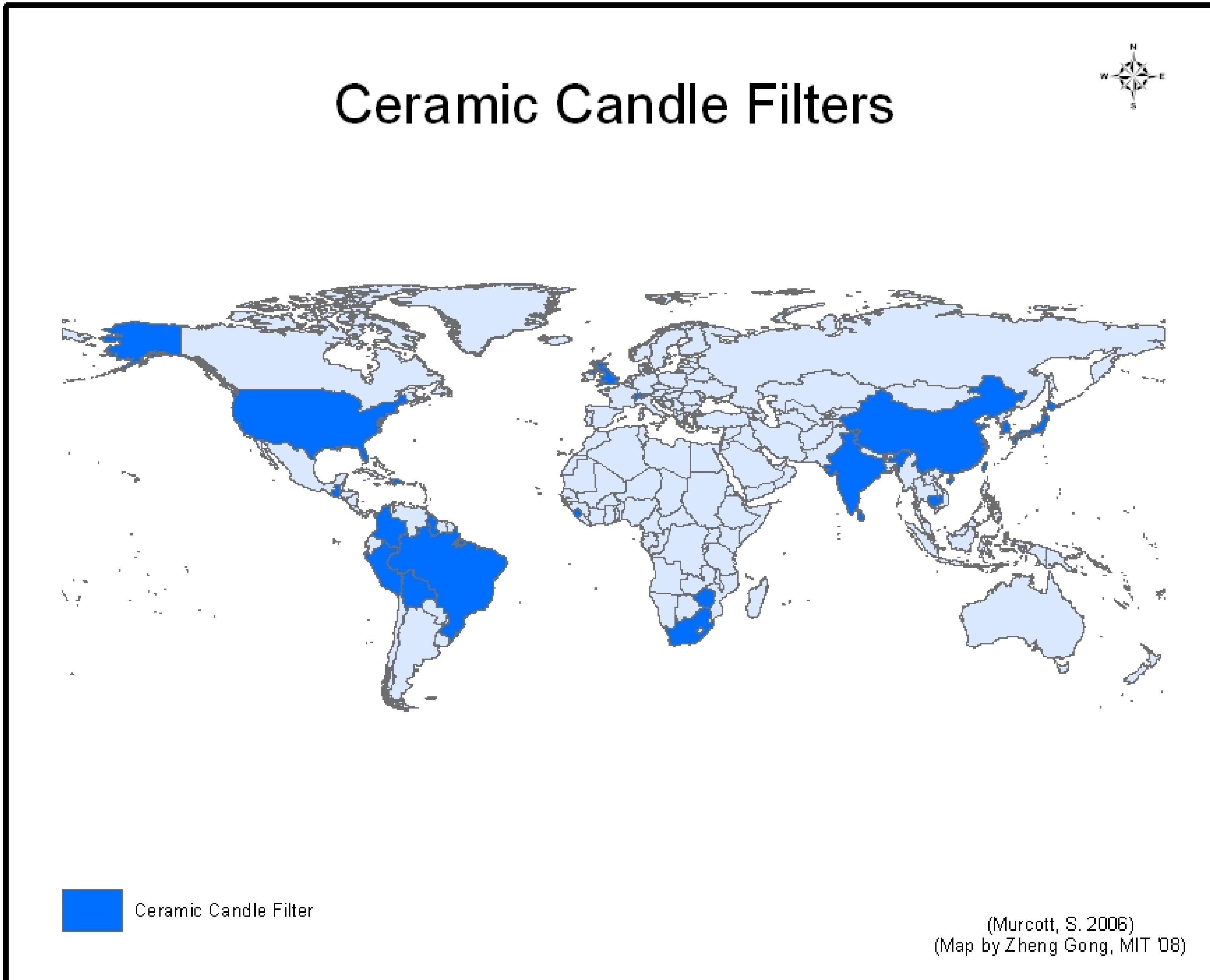
- Argentina
- Bhutan
- Bolivia
- Brazil
- Burkina Faso
- Cambodia
- Cameroon
- China
- Colombia
- Congo
- Ecuador
- El Salvador
- Ethiopia
- Guatemala
- Haiti
- Honduras
- India
- Indonesia
- Kenya
- Kingshasa
- Madagascar
- Nepal
- Nicaragua
- Pakistan
- Peru
- Philippines
- Senegal
- South Africa
- Sri Lanka
- Thailand
- Togo
- Uganda
- Uzbekistan
- Viet Nam

Ceramic Pot Filter

(Murcott, S. 2006)
(Map by Zheng Gong, MIT '08)

8 Ceramic Pot Countries

- Cambodia
- Ecuador
- Ghana
- India
- Nepal
- Nicaragua
- Thailand
- Vietnam


Ceramic Candle Filters
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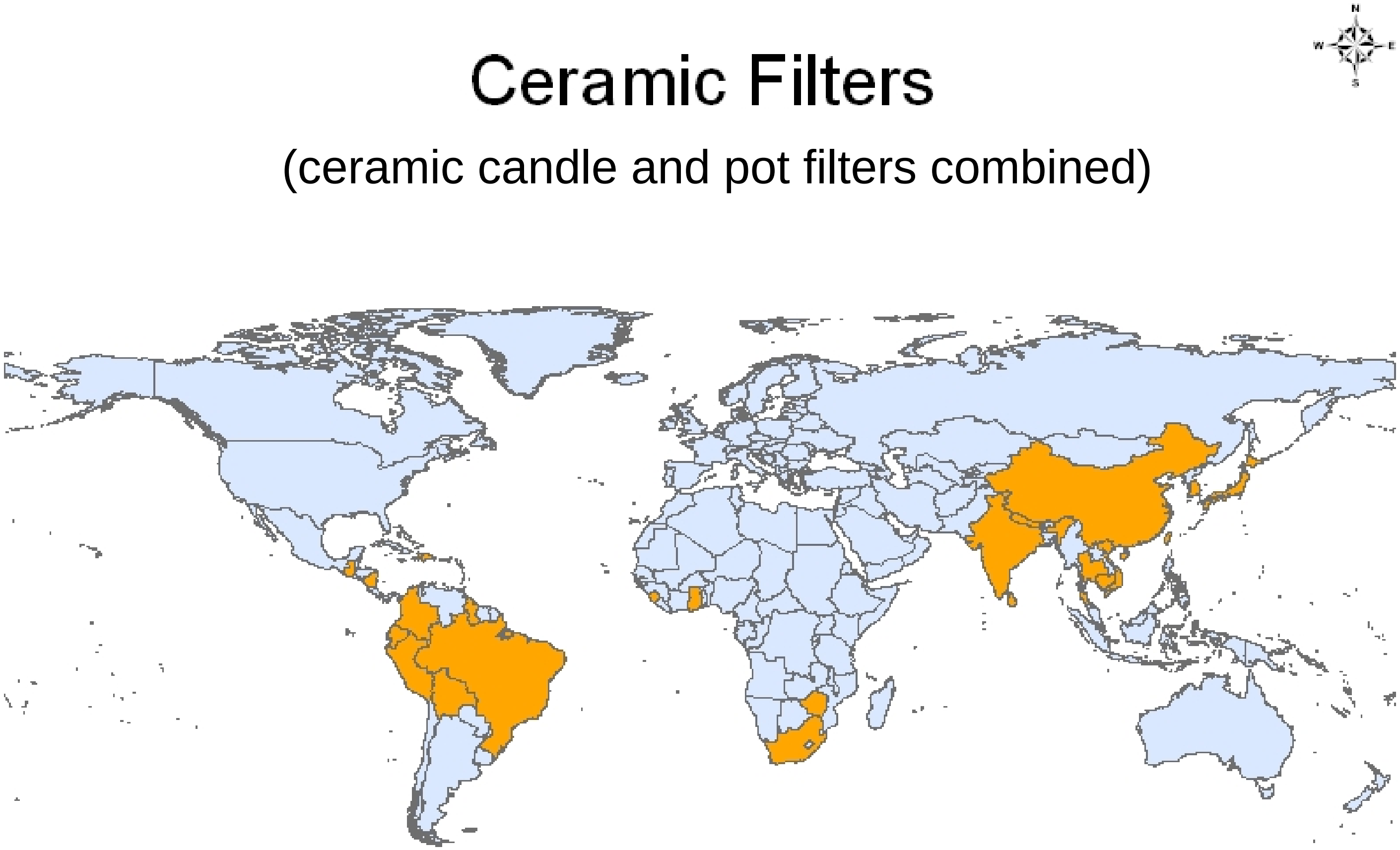
Ceramic Candle Filter
(Murcott, S. 2006)
(Map by Zheng Gong, MIT '08)

20 Ceramic Candle Filter Countries

- Bolivia
- Brazil
- Cambodia
- China
- Colombia
- Dominican Republic
- Guatemala
- Guyana
- Haiti
- India
- Japan
- Korea
- Peru
- Sierra Leone
- South Africa
- Sri Lanka
- Switzerland
- United Kingdom
- United States
- Zimbabwe

Ceramic Filters

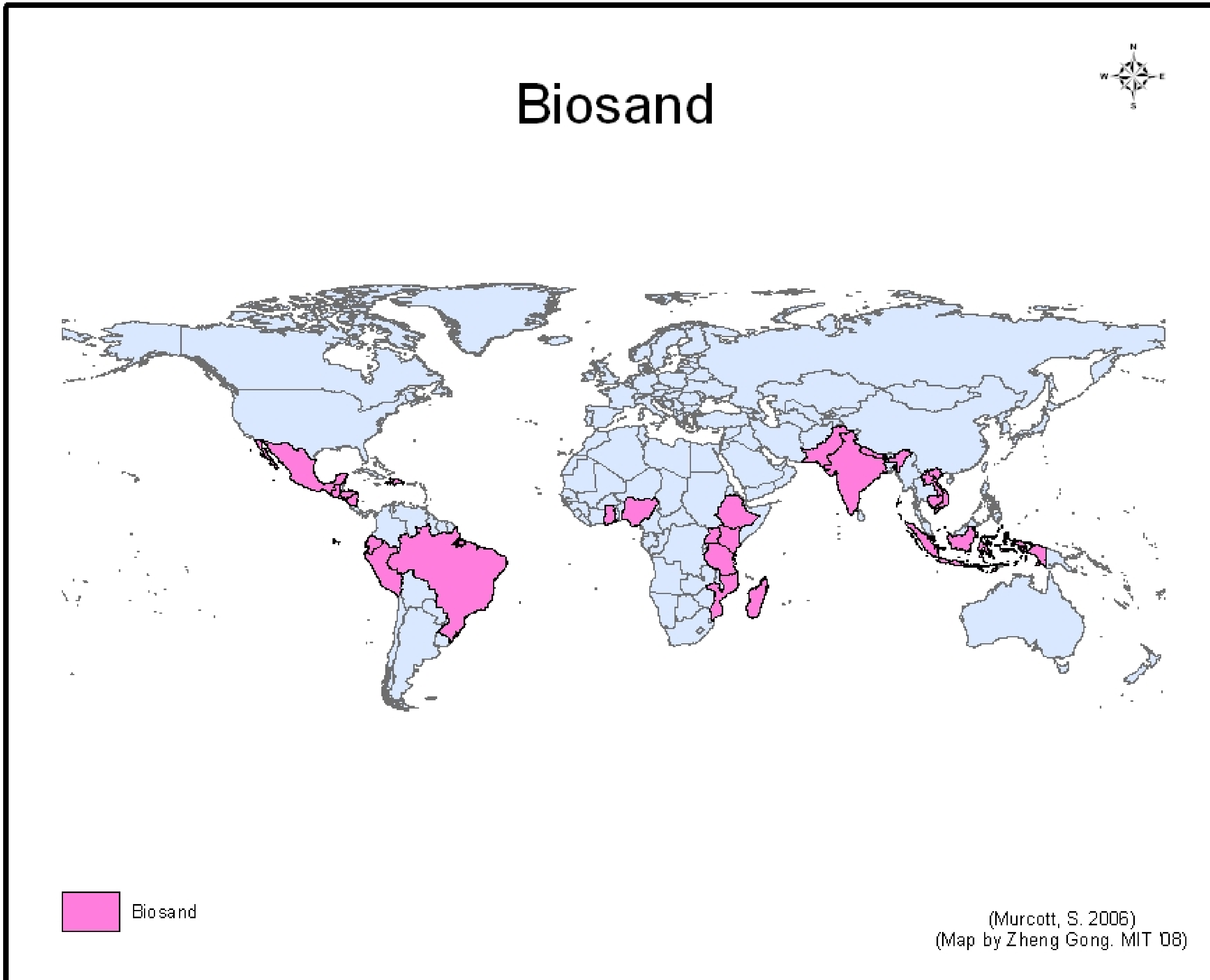
(ceramic candle and pot filters combined)



(Murcott, S. 2006)
(Map by Zheng Gong, MIT '08)

23 Ceramic Filter Countries – All Types

- Bolivia
- Brazil
- Cambodia
- China
- Colombia
- Dominican Republic
- Ecuador
- Ghana
- Guatemala
- Guyana
- Haiti
- India
- Japan
- Korea
- Nepal
- Nicaragua
- Peru
- Sierra Leone
- South Africa
- Sri Lanka
- Thailand,
- Vietnam
- Zimbabwe


Biosand
N
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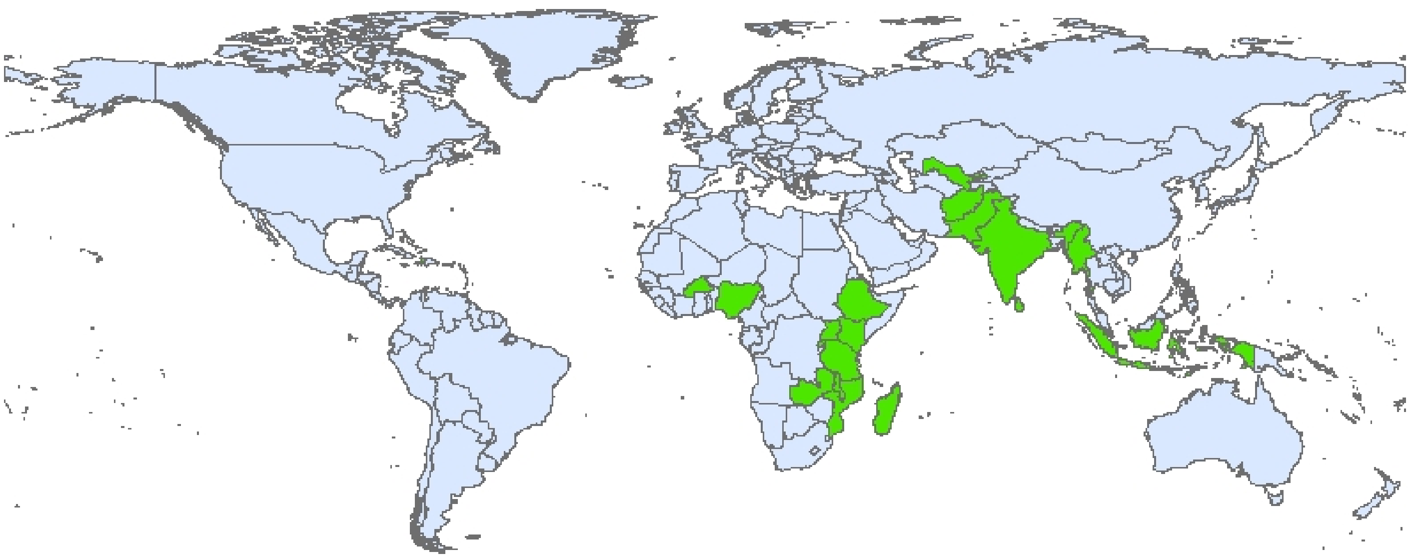
Biosand
(Murcott, S. 2006)
(Map by Zheng Gong. MIT '08)

25 Biosand Filter Countries

- **Brazil,**
- **Cambodia,**
- **Dominican Republic**
- **Ecuador,**
- **El Salvador,**
- **Ethiopia,**
- **Ghana,**
- **Guatemala,**
- **Haiti,**
- **Honduras,**
- **India,**
- **Indonesia**
- **Kenya,**
- **Lao PDR,**
- **Madagascar,**
- **Mexico,**
- **Mozambique,**
- **Nepal,**
- **Nicaragua,**
- **Nigeria,**
- **Pakistan,**
- **Peru,**
- **Tanzania,**
- **Uganda,**
- **Vietnam**

Coagulant+Chlorine Disinfectant Sachet



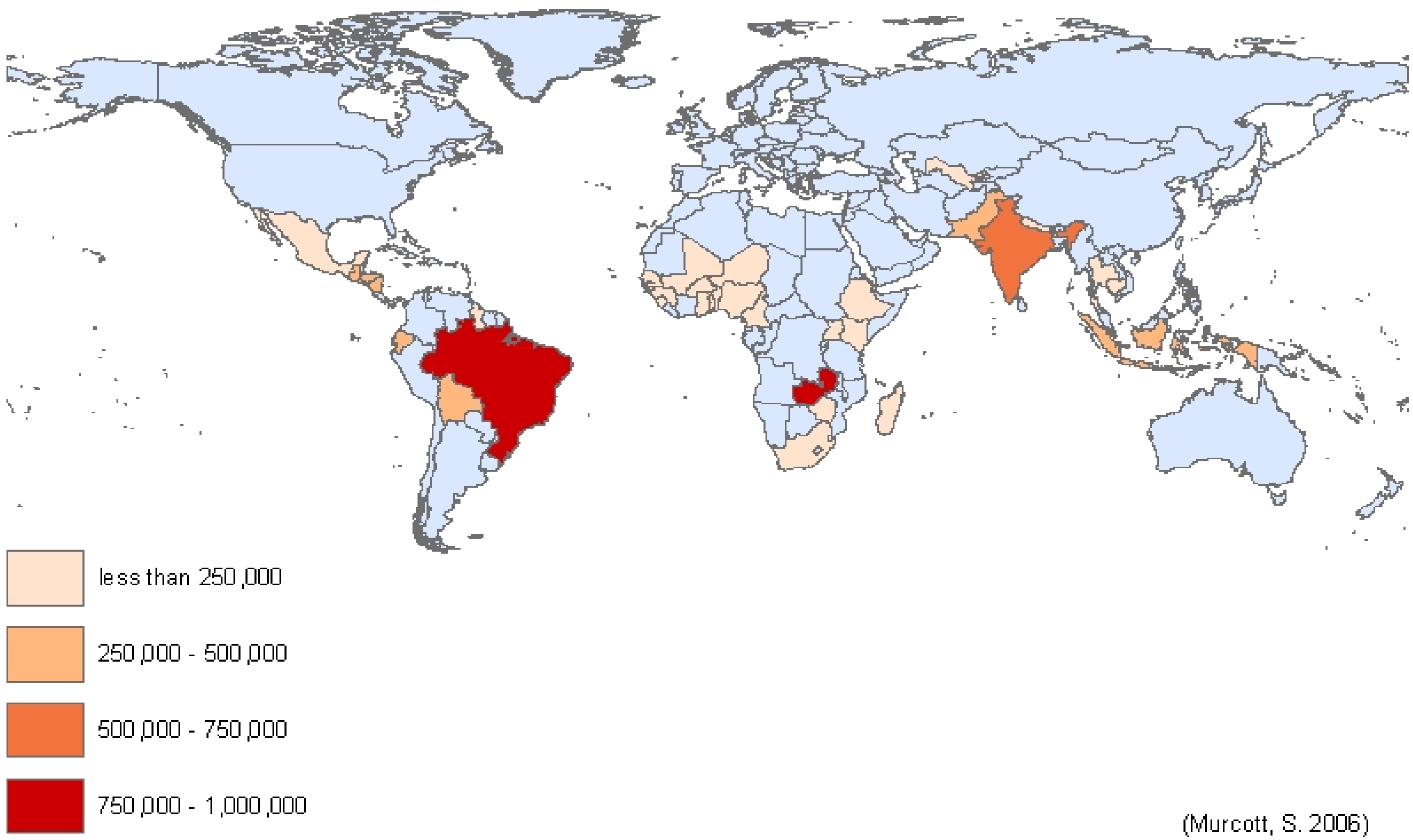
Coagulant+Chlorine Disinfectant Sachet

(Murcott, S. 2006)
(Map by Zheng Gong, MIT '08)

19 Coagulation + Chlorine Disinfection Sachet Countries

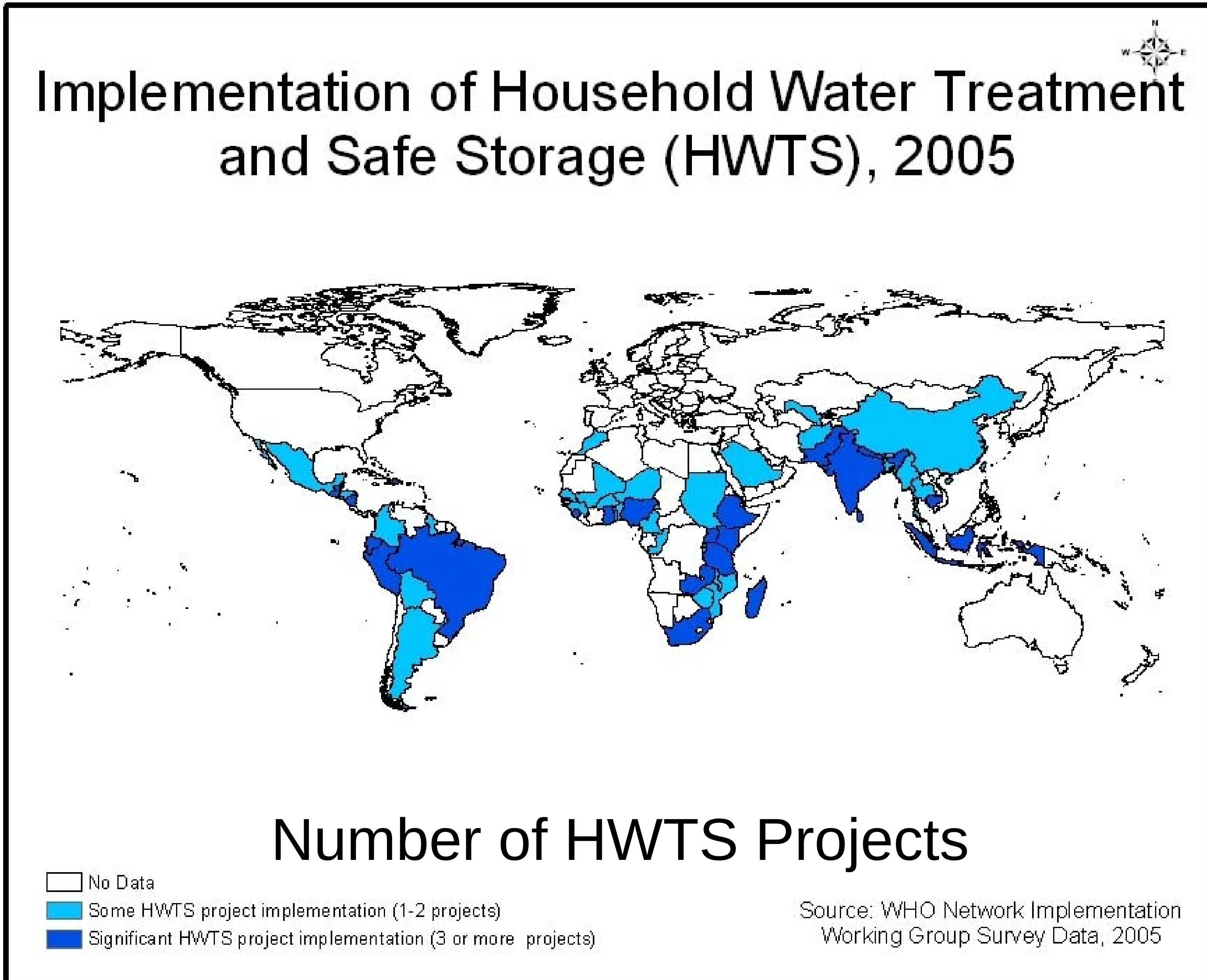
- Afghanistan
- Burkina Faso
- Ethiopia
- Haiti
- India
- Indonesia
- Kenya
- Madagascar
- Malawi
- Mozambique
- Myanmar
- Nigeria
- Pakistan
- Rwanda
- Sri Lanka
- Uganda
- United Republic of Tanzania
- Uzbekistan
- Zambia

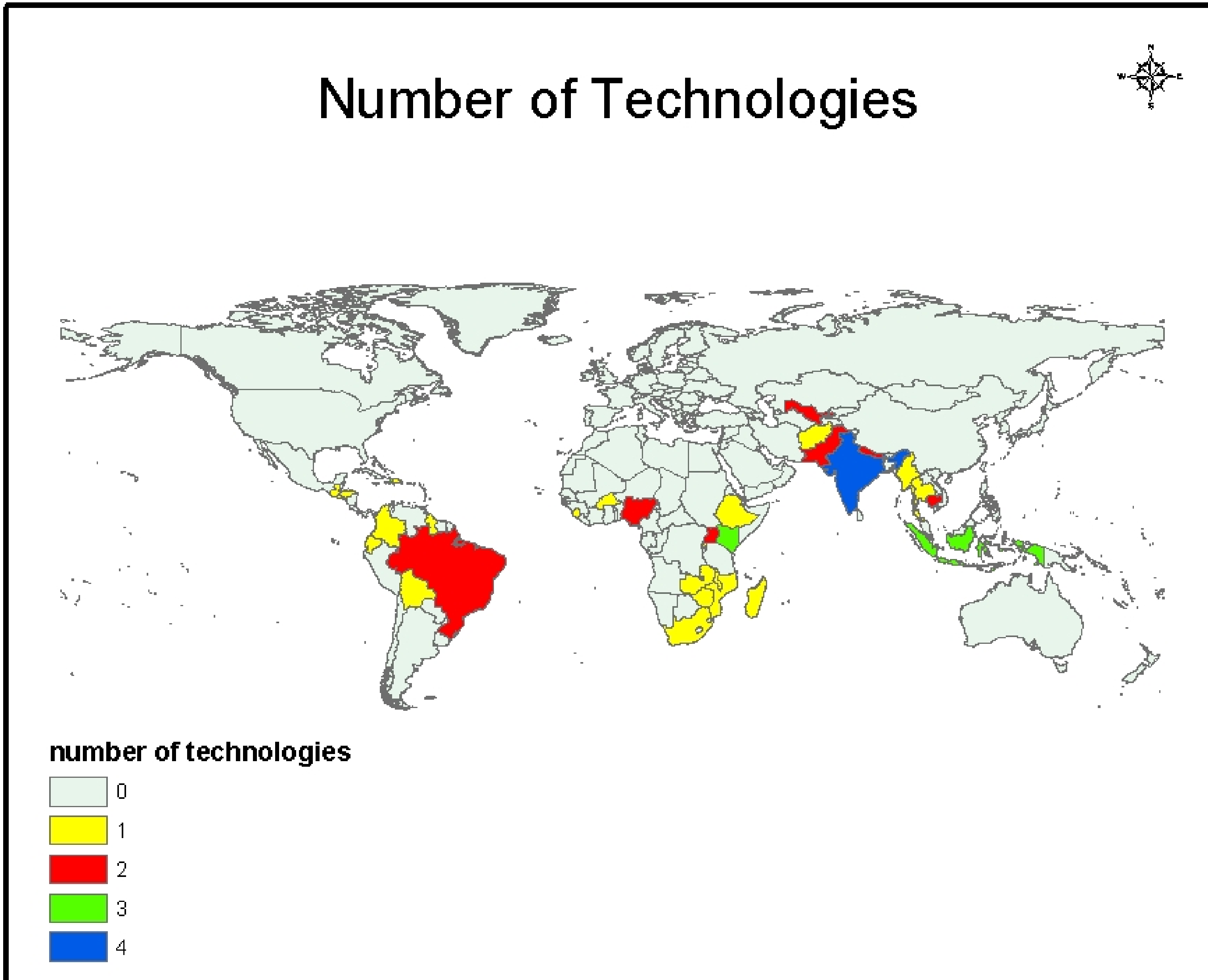
Number of Beneficiaries



(Murcott, S. 2006)
(Map by Zheng Gong, MIT '08)

Number of HWTS Projects




Number of Technologies
N
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number of technologies
0
1
2
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4

EXCERPT
Daily and Long-Term Behavioral and "Sustained Use" Targets in Implementing, Scaling up, Monitoring and Evaluating Household Water Treatment

and Safe Storage Technologies



Susan Murcott
Massachusetts Institute of Technology
Civil and Environmental Engineering Department
Quito Ecuador
October 5, 2005

Definitions – Targets or "Meta-indicators" of Household Drinking Water Treatment and Safe Storage (HWTS) Behavior

- **Daily Behavioral HWTS Targets**: Short-term, day-to-day behaviors related to household drinking water treatment and safe storage activities. These targets/indicators are focused on **"behavior in the present."**

- **Long-Term Behavioral HWTS Targets** = "Extent of Coverage/Use/Sustained Use" = Long-term behaviors (month/months, year/years) related to household drinking water treatment and safe storage activities. These targets/indicators are focused on "**behavior over time."**

Monitoring Daily Behavioral Targets

Based on discussions at a lunch meeting at WHO Network Bangkok Conference
(Maria Elena Figueroa, June 2005)

Consistent Water Treatment

Definition	Measurement	Data Source
(i) Household has treated water for drinking every day. Treatment may or may not occur every day. Frequency of treatment will depend on type of technology used and number of household members (ii) All members in the household drink this treated water.	From total households in the implementation area get all 3 measurements if time and resources allow: (i) Number of households that report having treated water for drinking in the house. (ii) Number of households that show treated water in the house. (iii) Number of households with a negative test for E.Coli in their treated water, OR positive test for chlorine residual among those using household chlorination	Household-based data; preferably population-based survey. Data will include: (i) self-reported information; (ii) direct observation at end of survey (iii) tests for water safety

Safe Storage

Definition	Measurement	Data Source
4 scenarios are: (i) Household stores water in a narrow-mouth container. It is covered with a hard cap or lid, not a cloth (cloth can get into water re-contaminating it) w/tap. (ii) Household has a wide-mouth container that has a hard cover with a tap. (iii) Household uses a jerry can with tap and tap is of hard material (iv) Household stores water in SODIS bottle or covered water filter that has a tap	From total households in study area: Number of households that have any of the 4 possible scenarios of safe water storage	Household-based data; preferably population-based survey. Data will include: (i) self-reported information; (ii) direct observation at end of survey

Proper Management (serving water)

Definition	Measurement	Data Source
(i) Ideal scenario: Water is served directly from the container without the use of a ladle or cup that is introduced into the water; (ii) Less ideal scenario: Water is served using a dedicated ladle or a cup with a handle that is stored in a fixed place out of reach of children and covered from dust and hands.	From total households in study area: (i) Number of households that serve water directly from the container without using any device to draw water from the container; (ii) Number of households that serve water using a ladle or a cup with a handle without touching the water, AND ladle or cup is stored in a fixed place out of reach of children and covered from dust and hands.	Household-based data; preferably population-based survey. Data will include: direct observation at end of survey

Cognitive Behavioral Variables

Variable	Documentation ?
1. **Knows** that: (i) water source is not safe for drinking; (ii) safe water prevents diarrhea;	Most documentation shows mixed results in predicting water treatment behavior
2. **Agrees** that water needs to be treated to make it safe for drinking,	Most documentation also shows mixed results
3. Agrees that the technology is effective in making water safe for drinking,	Needs to be measured in population-based survey
4. Agrees that chlorine-based or chemical additive treatment products are safe	Needs further documentation
5. Agrees that one can make the time to treat water at home,	Needs to be measured in population-based survey to assess its role on behavior
6. Agrees that water treatment is among the priorities in the home,	Needs to be measured in population-based survey
7. Thinks others in the community **treat** their water consistently.	Needs further documentation

Emotional –Behavioral Variables

Variable	Documentation?
Has confidence in treating water	Needs further documentation in population-based surveys
Likes the taste of treated water	Needs further documentation in population-based surveys
Feels good (sense of satisfaction) by providing treated water for all members in the household,	Not yet documented

Social Interaction – Behavioral Variables

Variable	Documentation
Others have recommended to treat water at home	Some intervention studies have started to use this variable but it needs to be further documented to understand its role in predicting behavior
Advocates water treatment to others in the community,	Not yet documented

Monitoring
Long-term Behavioral Targets
“Extent of Coverage”
“Impact”
“Use/Sustained Use”

Acceptance Level (Example from KWAHO, 2004)

Item	Value	Percent
Total target households	20,000	
Number households reached/trained (out of total target households)	9,000/20,000	45%
Regular users (out of household reached/trained)	8.000/9,000	88%
Irregular users (our of households reached/trained)	110/9,000	3%
Non-users (out of households reached/trained)	780/9,000	9%
Overall acceptance level	8,000/20,000	40%
Acceptance level (out of number of households reached/trained)	8,000/9,000	89%

Market Penetration

- Market penetration (for one-time purchase HWTS units)

$$= \frac{\text{total number of units of product sold}}{\text{total population of the given country}}$$

- Market penetration (for recurrent purchase HWTS products)

$$= \frac{\text{(total \# units sold) / (total \# units for 1 year's safe water)}}{\text{total population in the given country}}$$

- Example: Assume 1.8 M bottle of chlorine are sold in Zambia in 1 year. It takes 12 bottles per year to provide safe water for one household (based on volume of bottle, concentration, etc).
  Population of Zambia = 10 M, therefore:

  $$\text{Market penetration} = \frac{1.8\text{ M} / 12}{10\text{ M}} = 0.015$$

(From email exchanges – Susan Murcott and Rob Quick)

Adoption and Sustained Use

- Rate of Adoption (ROA)
  = # people using HWTS system after 1 month
  # people originally receiving HTWS

- Rate of Sustained Use (ROSU)
  = # people using HWTS system after 1 year
- **# people originally receiving HWTS system**

- What is the ROA of your organization's intervention?

- What is the ROSU of your organization's intervention?

(From Implementation Organization "Long Survey" applied in Kenya by Baffrey,R. and Murcott,S. June, 2005)