Removal of Bacteria and Viruses from Water in Rural Areas of Developing Countries

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S.W.A.N is an initiative started by Dr. Massoud Pirbazari of the University of Southern California focusing on the improvement of drinking water quality for citizens of developing countries. SWAN's goal is to provide comprehensive and visually based information so that people, at the household level, can treat their water, and in turn, improve their health and well-being.

THIS SITE IS UNDER CONSTRUCTION.
All material included in this presentation have been adapted from sources* outlined on the final slide.

We would like to thank those whose work has been pivotal in the creation of this site.

(See Reference Page for Sources)

To the Visitor,

Your comments and suggestions would be appreciated. Please direct your thoughts to Cara Magnabosco at magnabos@usc.edu

Thank you.

Introduction:

1.1 billion people

lack access to improved water sources

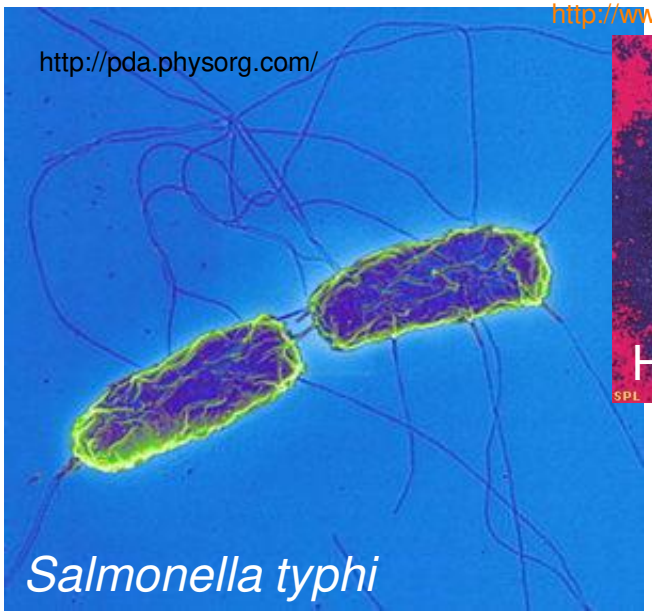
Southern Sindh Province, Pakistan

http://www.waterencyclopedia.com/images/wsci_01_img0144.jpg

Introduction:

6000 children

Bacteria and Viruses Leading to Diarrheal Disease:



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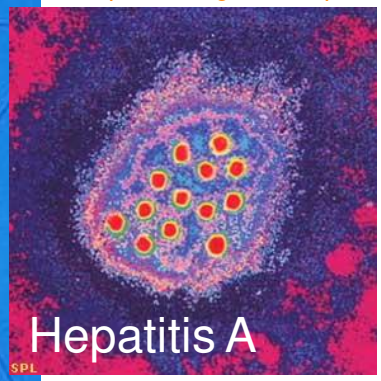


Bacteria (1-5µm)

- *E. coli*
- *Salmonella typhi*
- *Shigella spp.*
- *Yersinia enterocolitica*

Viruses (responsible for 80% of waterborne disease outbreaks)[1]

- Adenoviruses (0.08µm)
- Enteroviruses (0.02-0.03µm)
- Hepatitis A virus (0.02-0.03µm)
- Hepatitis E virus (0.027-0.034µm)
- Rotaviruses (0.05-0.065µm)

*Leading cause of childhood diarrhea

[1] for which infectious agents were identified

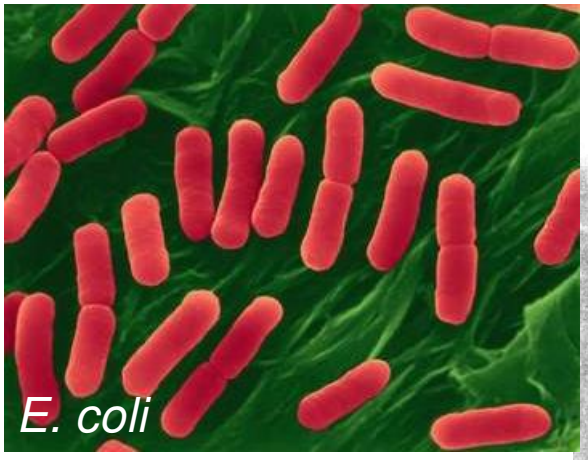
Bacteria and Viruses Leading to Diarrheal Disease:

Pathogen	Health significance	Persistence in water supplies [a]	Resistance to chlorine [b]	Relative infective dose [c]	Important animal source
Bacteria					
Campylobacter jejuni, C. coli	High	Moderate	Low	Moderat e	Yes
Pathogenic					
Escherich ia coli - Pathogenic *Escherich ia coli* - Toxigenic	High	Moderate	Low	High	Yes
Salmonella typhi	High	Moderate	Low	High[d]	No
Other *salmonellae*	High	Long	Low	High	Yes
Shigella spp.	High	Short	Low	Moderate	No
Vibrio cholerae	High	Short	Low	High	No
Yersinia enterocolitica	High	Long	Low	High(?)	Yes
Pseudomonas aeruginosa[e]	Moderate	May mu ltiply	Moderate	High(?)	No
Burkholderia pseudomallei					
Mycob acteria					
Legionella					
Viruses					
Adenoviruses	High	?	Moderate	Low	No
Enteroviruses	High	Long	Moderate	Low	No
Hepatitis A	High	?	Moderate	Low	No
Hepatitis E	High	?	?	Low	No
Norwalk virus	High	?	?	Low	No
Rotavirus	High	?	?	Moderate	No(?)
Small roun d viruses	Moderate	?	?	Low(?)	No

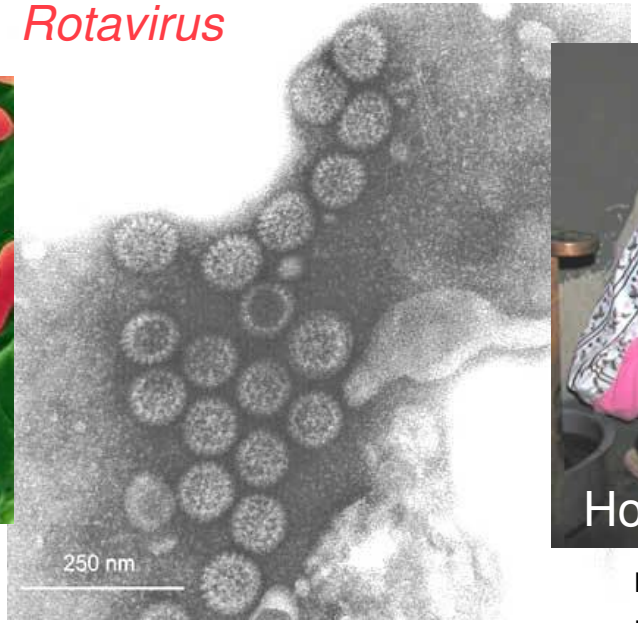
Improving Drinking Water Quality

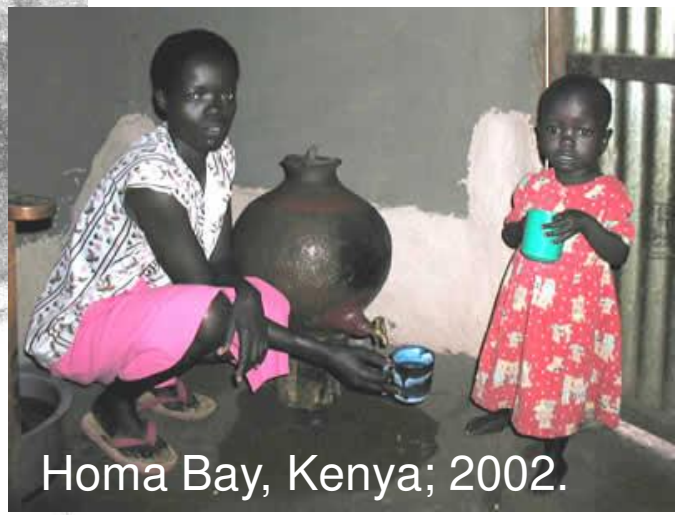
Effectiveness:

A comparison based on reductions in household diarrheal disease



Rotavirus





http://www.cdc.gov/globalidplan/boxes/box20.htm

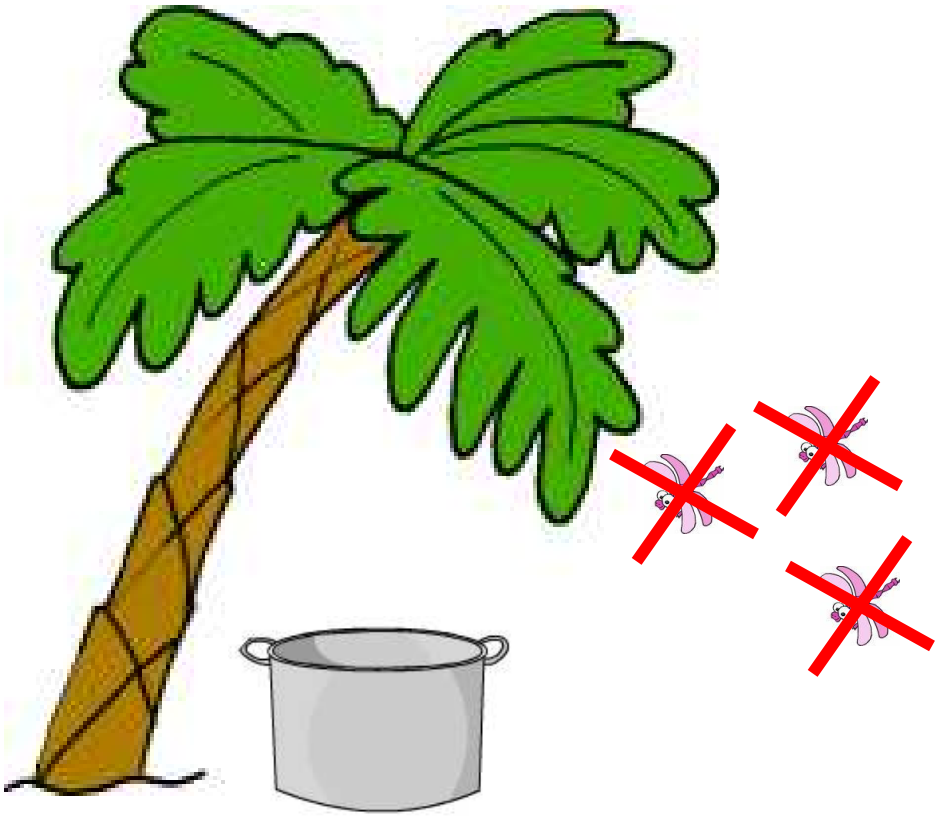
http://www.oulu.fi/electronoptics/sekal_kuvia.html

http://www.astrographics.com/GalleryPrintsIndex/GP2144.html

- **Chlorine:** 46% reduction
- **Filtration:** 40% reduction
- **Flocculation and flocculation/disinfection:** 38% reduction
- **Solar radiation and heating:** 35% reduction

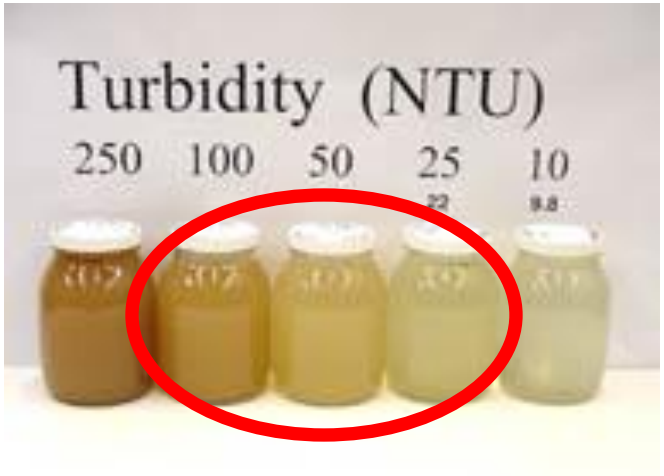
Household/ Pre-Treatment

Shading



- Covering filtration system or placing it in a shaded area
- Decreases the probability of algal bloom
- Decreases windblown contamination
- Keeps bird droppings and bugs out of water supply

Sedimentation



http://www.water.ncsu.edu/watershedss/info/images/TurbidityJars.jpg

= Turbidities where sedimentation is most effective

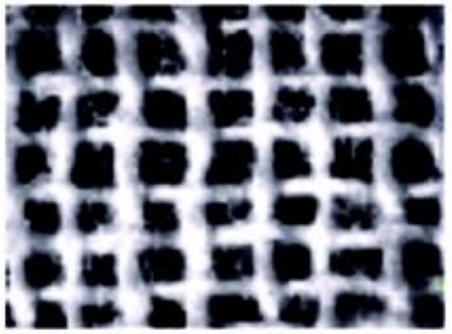
- Collecting water and letting it sit undisturbed
  - Allows large particles to settle
- Recommended for turbidities between 20 and 100 NTU
- Short term (less than 12 hrs) sedimentation is effective for water with high suspended solids load
- Long term sedimentation is recommended for extremely turbid water
  - often accompanied by the development of algal blooms
- Most effective when followed by other treatments

Boiling

WHO

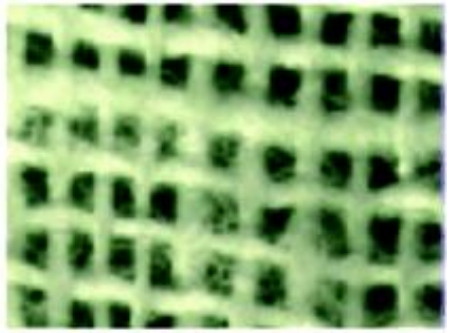
- **Recommended:** Rolling boil for 1 to 5 minutes
  - however, heating at 55°C for several hours is also effective
- **Advantage:**
  - effective in destroying all classes of waterborne pathogens
- **Disadvantage:**
  - 1kg of wood needed to boil 1 liter of water
    - costly, both economically and environmentally

Cloth Filter



New Sari

- Using pores of cloth as a filter
- Folding an old cotton sari 4-8 times = using a 20 μm filter
  - one layer of sari = 100 μm filter
    - can remove all zooplankton, most phytoplankton and *Vibrio cholerae*
- Old saris are more effective than new saris because pores shrink due to wear

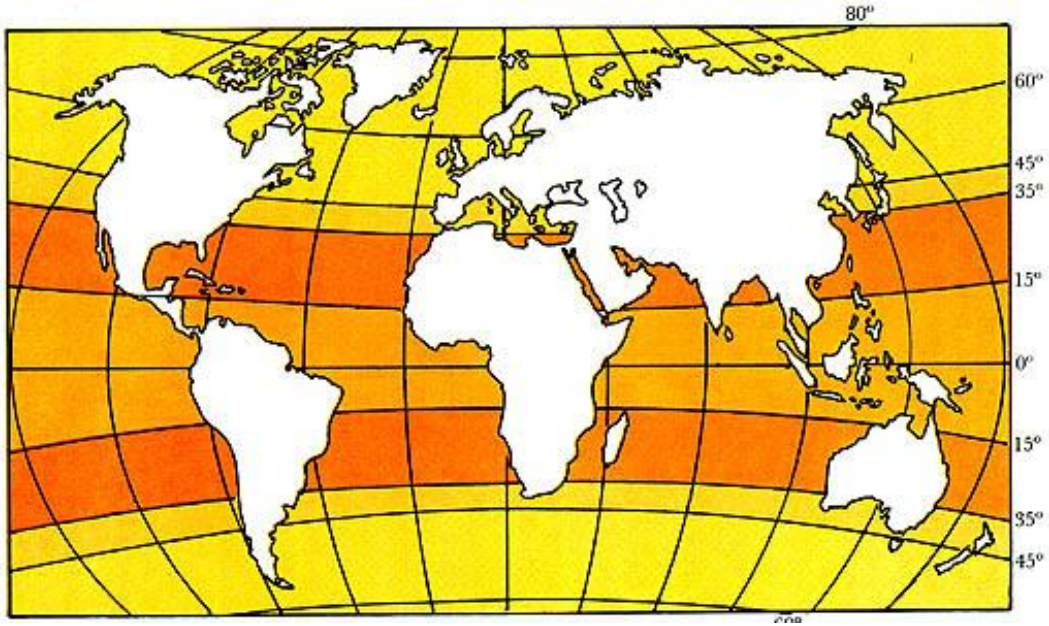


Old Sari

Sari photos courtesy of Kori S. Donison

Household Treatment

Solar Disinfection:
General Info



- Heating water to temperatures of 55° C in clear plastic bottles
- Water placed in sun for several hours
- Heat and UV-a radiation inactivates waterborne microbes

Feasibility of solar disinfection based on latitude

- Most favorable
- Moderately favorable
- Less favorable
- Least favorable

Image courtesy of Iman Yazdani

Solar Disinfection:
How To

Images courtesy of http://www.rcsi.ie/sodis/index.htm

Solar Disinfection:
How To

Images courtesy of http://www.rcsi.ie/sodis/index.htm

Solar Disinfection:
How To

* Paint bottles on back side to increase heat absorption

Images courtesy of http://www.rcsi.ie/sodis/index.htm

Solar Disinfection:
How To

Images courtesy of http://www.rcsi.ie/sodis/index.htm

Solar Disinfection:
Advantages and Disadvantages

~30 NTUs

Advantages	Disadvantages
• Microbial inactivation by pasteurization • Simple to use • Low cost • Does not change the chemical quality of water • Improved bacterial inactivation in aerobic water • Opaque or black bottle system achieves temperatures high enough to inactivate viruses • Effective in water with low to moderate turbidity (<30 NTUs)	• Requires several hours to disinfect & even longer (2 days) in cloudy weather • Limited to volume of bottle (~1 L) →Each household needing several bottles to supply water • Provides no chemical disinfectant residual; water must be consumed in a day or so • High turbidity interferes with micro-bial inactivation; pre-treatment must be undertaken if water's highly turbid • Requires pre-aeration

Ceramic Filter:
General Info

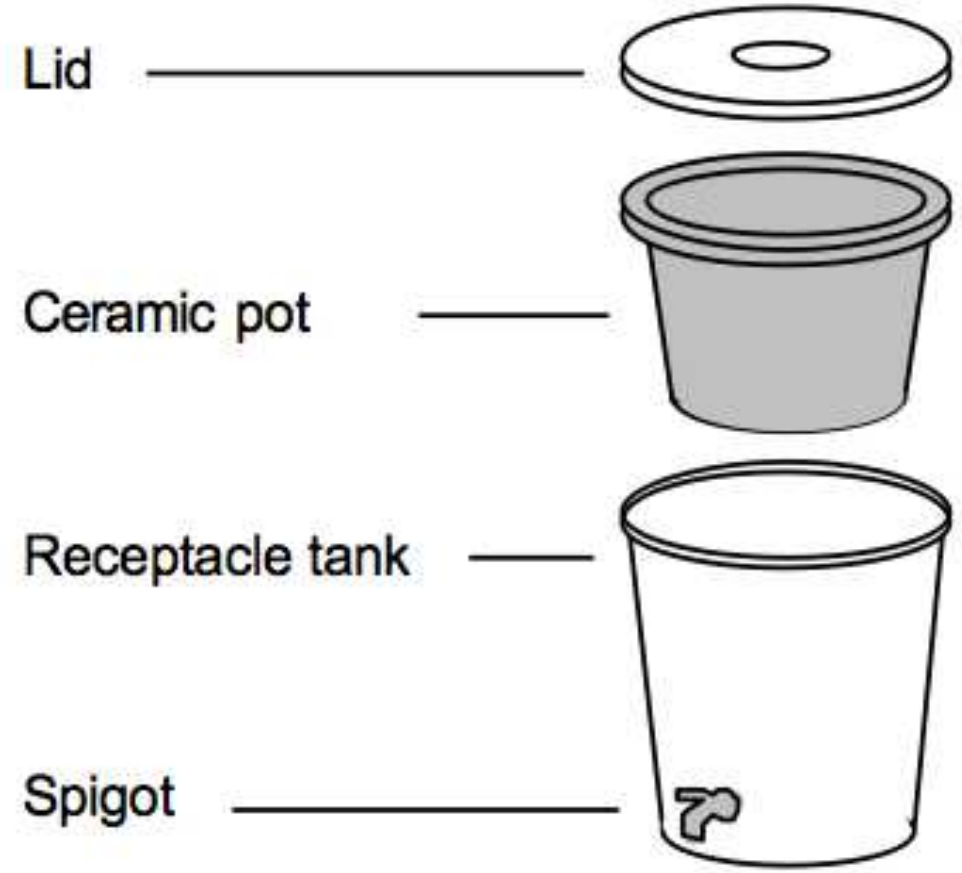
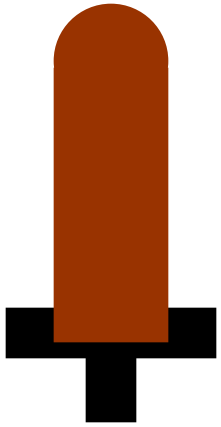


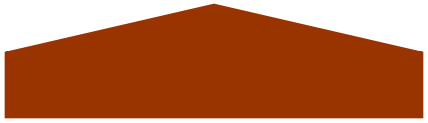
Image courtesy of Potters for Peace

Ceramic Filter:
Candle, Disk, & Pot

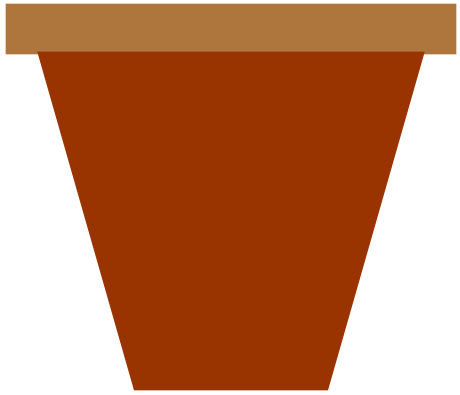
Image courtesy of Robert W. Dies



Candle Filter



Disk Filter



Pot Filter

Ceramic Filter:
Candle Filter

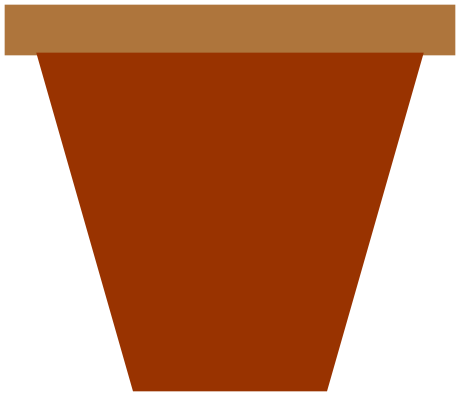
- Consists of 2 containers and a ceramic candle filter screwed into the base of the upper container (Often 2-3 filters)
  - Very low flow rate [5 candles = 300-840 mL/hr/candle)]
- Water is poured into the upper container and allowed to filter through the ceramic filter into the lower collection vessel
- Capacity of 10-20 L
- **Disk Filter Manufacturers:**
  - Puro, Himal, Kimal, Swagat, and Milton: India, price* 600-1600 Nepalese Rupees (USD $8.00-$21.00)

* Price for 1-3 candles + 2 containers + lid and spigot
- Cost can be greatly reduced by purchasing plastic bucket separately from the Indian candle filter

Ceramic Filter:
Disk Filter

- Consists of an upper and lower container with a ceramic disk inserted between the 2 containers (plastic, terracotta, or metal)
- Water is poured into the upper container then allowed to filter through the disk into the lower collection vessel
- Potential for leakage along the interface between the disk and container
- **Disk Filter Manufacturers:**
  - TERAFIL: India, approximate price (for disk filter only)
    25 Indian Rupees (USD $0.49)
  - Locally made: Nepal, approximate price (disk filter only)
    76 Nepalese Rupees (USD $1.00)

Ceramic Filter:
Pot Filter



- Consists of colloidal silver-impregnated ceramic pot perched inside a collection bucket
- Typically, filter is 17 L in capacity and storage/collection unit ranges from 7.5-20 L
- Typical flow rate ranges from 1.0-1.75 L/hr
- **Disk Filter Manufacturers:**
  - Potters for Peace: wholesale price USD $9.00
  - Can be local made through local workshops using method outlined in *Ceramic Filter: How it's Made*

Ceramic Filter:
Cleaning and Maintenance

The ceramic pot should be cleaned once per month or when the flow rate begins to slow down.

Image courtesy of Potters for Peace

Ceramic Filter:
Cleaning and Maintenance

Clean the inside surface of the lid with soapy water and let it dry. Place the lid on a level surface with the clean side facing up.

Carefully lift the ceramic pot out of the receptacle and set it on the lid. Touch only the rim when lifting the ceramic pot. Do not touch the outside of the ceramic pot with dirty hands and do not set it on an unclean surface.

Image courtesy of Potters for Peace

Ceramic Filter:
Cleaning and Maintenance

Scrub the inside of the ceramic pot with a cloth or soft brush and rinse with clear water. **DO NOT** use soap to clean the ceramic pot.

Clean the receptacle tank and spigot with soapy water.

Image courtesy of Potters for Peace

Ceramic Filter:
Cleaning and Maintenance

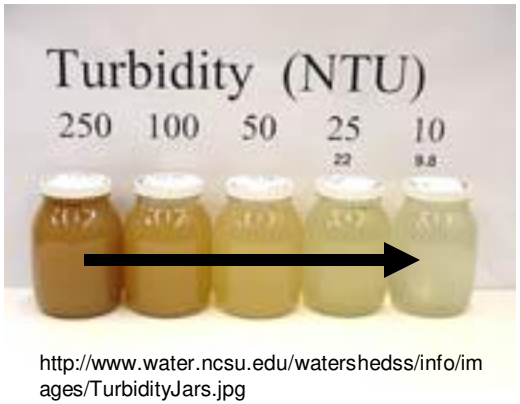
Put the ceramic pot back into the receptacle tank immediately after cleaning to prevent recontamination.

Ceramic Filter:
Advantages and Disadvantages

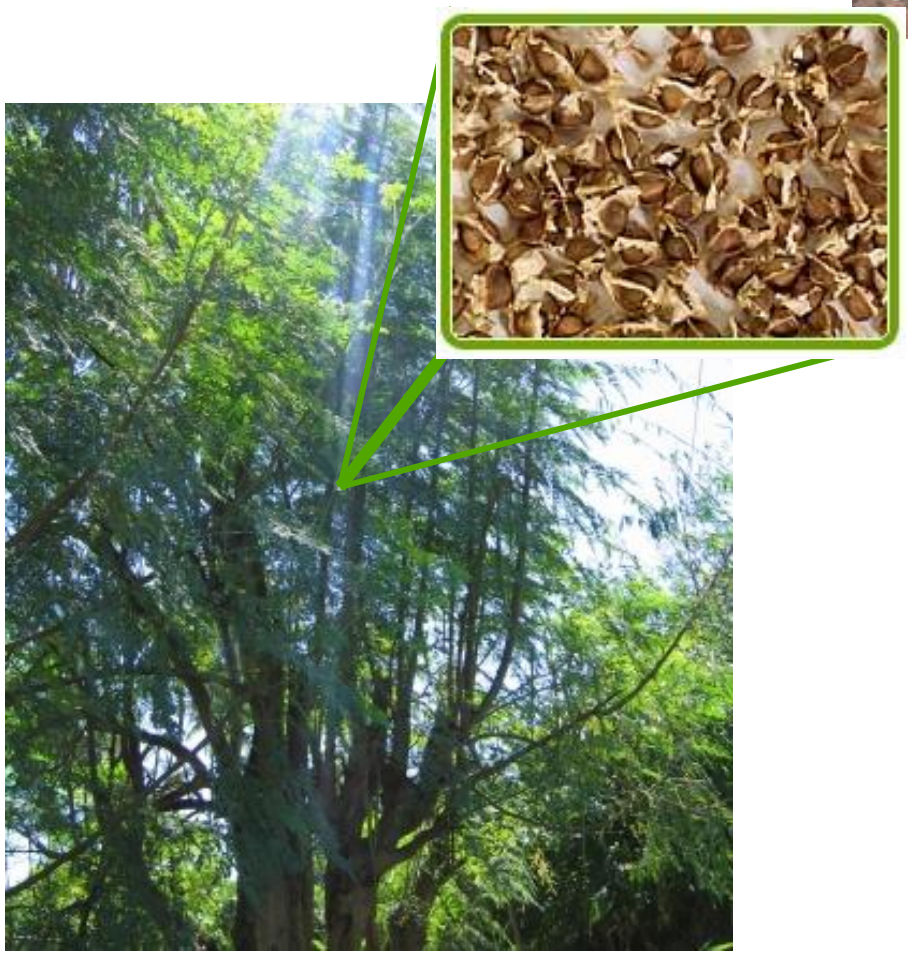
Advantages	Disadvantages
• Relatively cheap to manufacture and produce • Ceramic trade is well established in many countries • Materials are often readily available • If designed and used properly, can remove >99% of indicator organisms and reduce turbidity to below guideline values of WHO • Quality filters are ideal for use at the household level	• Filter maintenance and reliability depends on the user • Fragile and easily break • Requires regular cleaning • Quality control is difficult to maintain • Quality filters may not be affordable for some • Difficult to promote the development of effective ceramic filters for household water treatment

Moringa Tree:
A Natural Alternative

http://www.rfppl.ethz.ch



http://www.water.ncsu.edu/watershedss/info/images/TurbidityJars.jpg



http://www.indiamart.com/moringa/

- 50-150 mg of ground seed + small amount of clean water needed for water treatment
- Soluble proteins possess a positive charge and, therefore, act as a natural cationic polyelectrolyte
- Reduces water with turbidities of 270-380 NTUs to 4 NTUs

Community Treatment

Slow Sand Filtration:
General Info

- **Filter bed:** consists of a layer sand above a layer of fine gravel that sits on top of a layer of coarse gravel
- **Lid**: covers filter when not in use
- **Diffuser Plate:** sheet of plastic with holes drilled in a grid pattern
  - Spreads water poured into the filter evenly over the surface of the sand

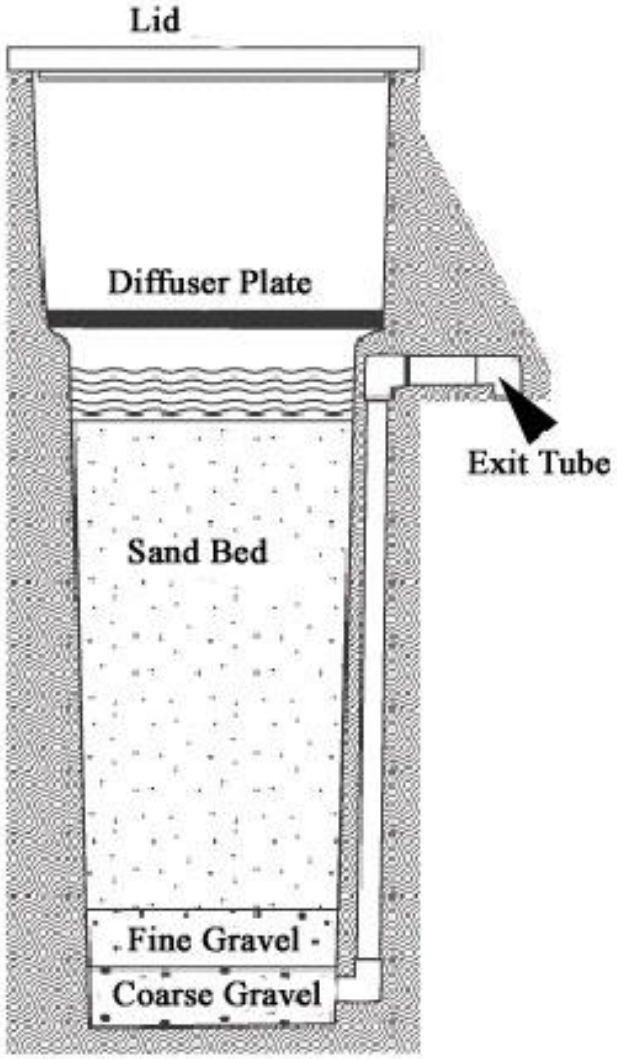


Image courtesy of Kori S. Donison

Slow Sand Filtration:
Cleaning and Maintenance

- Sanitize the effluent tube and gravel
- Pour water into the filter's head space slowly with the diffuser plate in place
- Use separate buckets to pour filtered water and collect filtered water
- Do not connect anything to the outflow pipe
- When not in use, lid should be kept on filter
- Keep fingers away from outflow pipe
- Animals should be kept away from filter
- Treated water spout should be wiped with a clean cloth and chlorine weekly

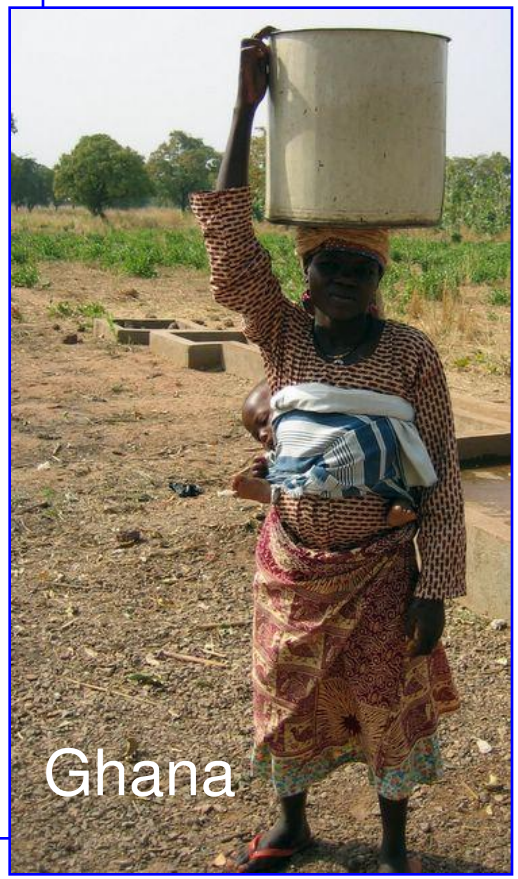


Image courtesy of MIT Water and Sanitation

Slow Sand Filtration:
Cleaning and Maintenance *cont'd*

- When the flow rate slows from ~60 L/hr to 18 L/hr, clean sand
  - Remove diffuser plate from the filter
  - Swirl water in the head space with 2 fingers until turbidity is visible in water
  - Dirty water (but not sand) should be removed with a cup
  - Repeat until water above sand is clear
  - Level sand by hand and replace diffuser plate
  - Fill water to approximately 5 cm above filter bed
- Resume filtering in 2 days

Slow Sand Filtration:
Advantages and Disadvantages

Advantages	Disadvantages
• Constructed from materials such as sand and concrete which are available in many countries • Materials do not break easily or need replacing • No chemicals need to be added - Saves money; doesn't lead to any negative health effects • Removes parasites, bacteria, and certain toxins • Easy to maintain • High flow rate	• Filter must be used on a regular basis to maintain removal efficiency • Cannot remove color or dissolved compounds • Extremely heavy, hard to move, and movement may disrupt the carefully leveled sand and gravel beds • Will clog and require more maintenance if water is highly turbid • Users must remember to store enough clean water for several days prior to cleaning the filter

Chlorination: General Info

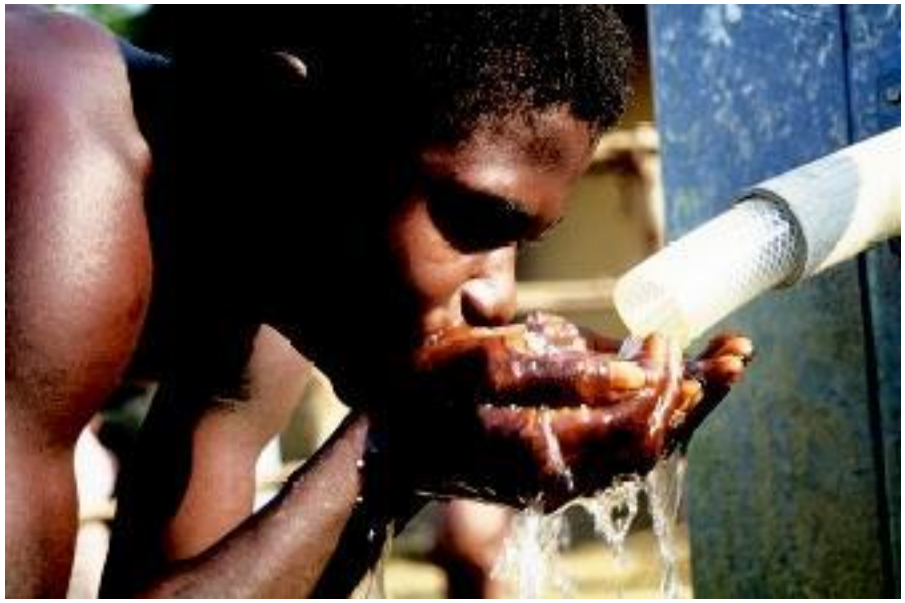
- Highly effective against nearly all waterborne pathogens

- At doses of a few mg/L and contact times of about 30 minutes, free chlorine generally inactivates more than 99.9% of enteric bacteria and viruses

http://web.mit.edu/watsan/images/Nepal/General/Nepal_Kathmandu-Dugwell_Water_Bathing.jpg

Chlorination:
Various Types

http://www.waterencyclopedia.com/Ge-Hy/Human-Health-and-Water.html



- Gaseous Elemental Chlorine
  - Cl_2
- Liquid Sodium Hypochlorite
  - NaOCl
- Solid Calcium Hypochlorite
  - $(Ca(OCl)_2)$

$(Ca(OCl)_2)$

http://corporateportal.ppg.com/NA/CalHypo/Accutab/industrial/chlorination/Accu-Tab_SI_Tablets.htm

www.dkimages.com

http://web.mit.edu/watsan/img_nepal_chlorine.htm

Chlorination:
Chlorine Gas

- **Cost:** >$100 (US Dollars)
  - ↳ Not as common at the household level
- Can be generated on-site by reacting chlorate or chlorite salts with acids; however, reactants may not be available and some are hazardous

Advantages	Disadvantages
• Highly micro-biocidal	• Poor residual • Has to be generated on-site - Some technologies require special facilities and trained personnel

Chlorination:
Sodium Hypochlorite & Calcium Hypochlorite

- **Cost:** Less than $10 (US Dollars)
- Most widely used drinkng water disinfectant

Advantages	Disadvantages
• Easy to use • Effective against most pathogens • Stable residual	• Not available worldwide • Some users object to taste and odor

UV Radiation:
General Info

Image courtesy of WHO

- UV inactivates microbes primarily by chemically altering nucleic acids
- **Parts:** Mercury arc lamp and UV-transmitting tube
- **Effectiveness:** Inactivates >99.9% of microbes
- **Position of lamps:**
  - Mounted
  - Submerged

UV Radiation:
Mounted Lamps vs. Submerged Lamps

MOUNTED LAMP	
Advantages	**Disadvantages**
• No physical, chemical or biological film occurs that requires cleaning	• Some UV radiation loss due to atmospheric and surface absorption
SUBMERGED LAMP	
Advantages	**Disadvantages**
• Intimate lamp contact with the water • Water mediated cooling of lamps • Maximum UV exposure to water	• Lamp requires protective sleeves that require regular cleaning due to fouling (physical, chemical or biological film) that reduces UV passage into water

UV Radiation:
Advantages and Disadvantages

Advantages	Disadvantages
• Effective for inactivating waterborne pathogens • Doesn't require use of chemicals • Doesn't create taste, odor, or toxic chemical by-products	• A reliable source of electricity is needed to power the lamp • Lamps need to be replaced every 1-2 years • No protection from post-treatment contamination • High cost at the household level

Proper Storage

Proper Storage:
Common Problems in Storage

Villagers in Ghana store water in large-mouthed pots which increases the risk of contamination or recontamination of drinking water.

http://web.mit.edu/watsan/index.htm

- Water collected for domestic use often becomes re-contaminated or further contaminated by unsafe consumer storage and handling at the consumer level
- **Factors:**
  - unsanitary and inadequately protected
  -water collection storage container
  - dispensing methods
  - inadequate cleaning of vessels

Proper Storage:
Ideal Container

http://www.loveuganda.com/images/Shop/jerrycan.jpg

- **Shape:**
  - 10-25 liters capacity
  - Rectangular or cylindrical with one or more handles and flat bottom
- **Material:** lightweight oxidation-resistant plastic
- **Style:**
  - Fitted, 6-9 cm screw cap opening
  - Fitted, durable, protected and easily closed spigot or spout to dispense water
- **Commonly found as:**
  - Jerry cans
  - Plastic beverage containers
  - Some urns

How to Construct a Ceramic and Slow Sand Filter

Courtesy of RDI Cambodia

Ceramic Filter:
How it's Made













Ceramic Filter: How it's Made

Collect Materials

Clay and Rice Husks, Coffee Husks, and/or Sawdust are collected

Courtesy of RDI Cambodia

Ceramic Filter:
How it's Made

Make Materials Appropriate Size

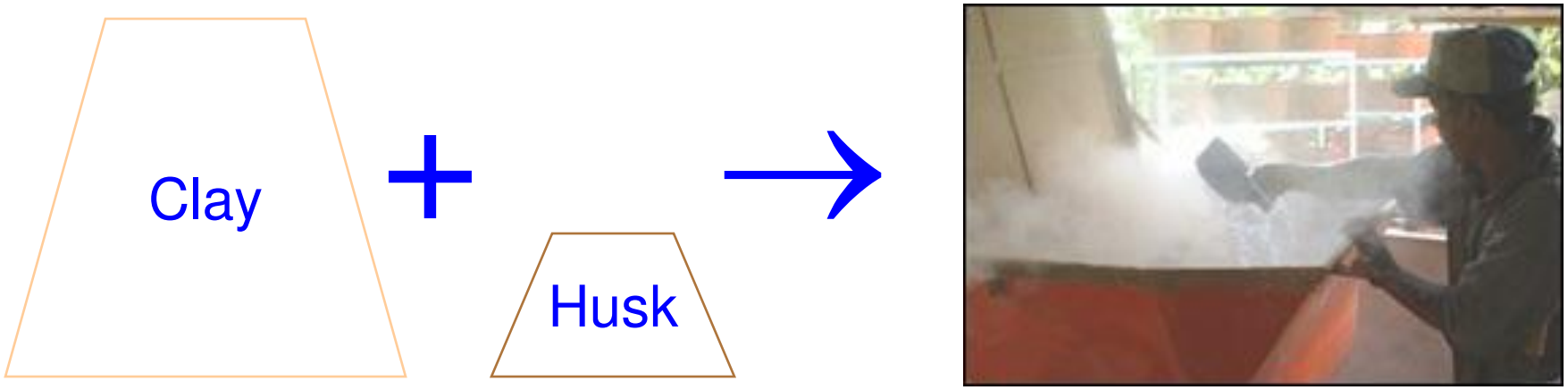
Dried bricks are broken up through hammering in a mill.

Rice husks, coffee husks, and sawdust are hammered and sifted to the appropriate size.

Courtesy of RDI Cambodia

Ceramic Filter: How it's Made

Mix Materials



Clay and rice husk, coffee husk, or sawdust (~4:1 ratio) are mixed with water in a modified mortar mixer and then kneaded into 10 kg pieces

Courtesy of RDI Cambodia

Ceramic Filter:
How it's Made

Shape Pot

The 10kg clay mixture is then put in an aluminum caste and pressed in either a manual or hydraulic press to form the water pot shape

Courtesy of RDI Cambodia

Ceramic Filter: How it's Made

Cleaning/Tracking

The pots are cleaned and then air dried.

Courtesy of RDI Cambodia

Ceramic Filter:
How it's Made

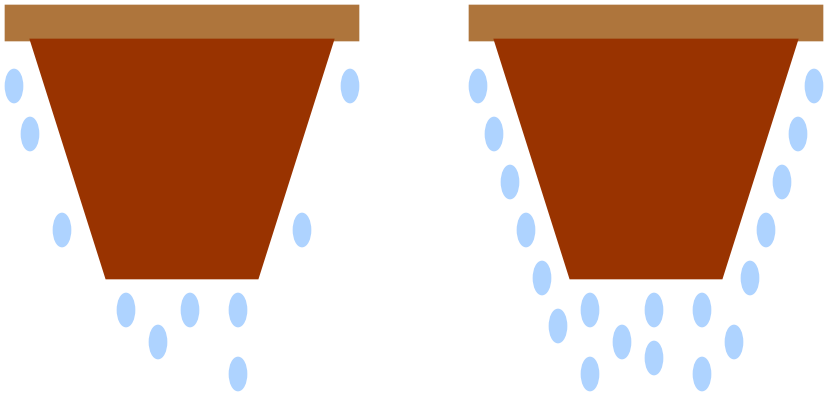
Dry Pots

Pots are laid out to air dry and then fired in a traditional kiln. The high temperatures of the kiln burn the rice husks, coffee husks, or sawdust to ashes--creating small pores in the pot.

Courtesy of RDI Cambodia

Ceramic Filter: How it's Made

Cool/Test Pots



The pots are left to cool and then undergo testing to make sure the pores are big enough to allow an efficient flow rate, yet small enough to effectively filter harmful bacteria.

Courtesy of RDI Cambodia

Ceramic Filter: How it's Made

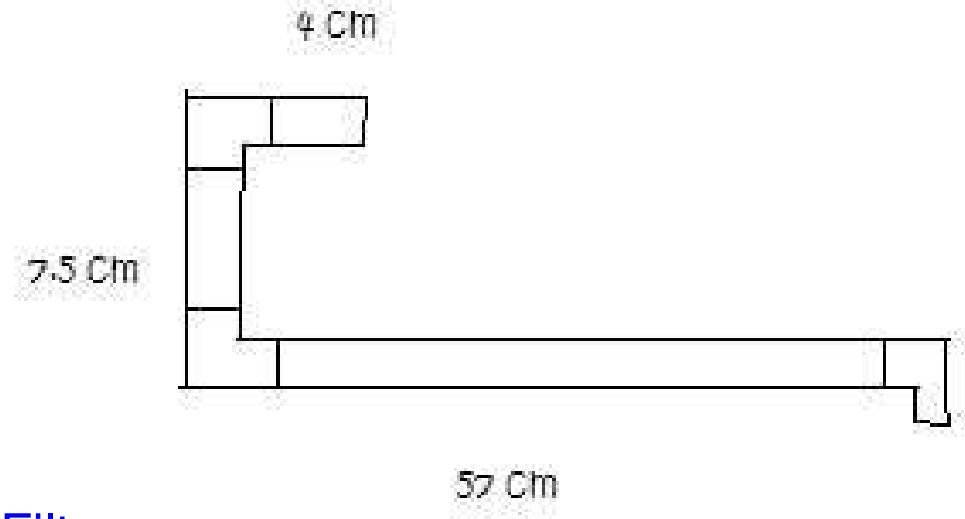
Apply Colloidal Silver

After tests, pots are coated inside and out with colloidal silver to deactivate bacteria.

Courtesy of RDI Cambodia

Slow Sand Filtration:
Construction*

1. **Outflow Pipe**
   i. 12 mm diameter PVC T-joint threaded on both sides
   ii. Two 12 mm 90º PVC elbow joints
   iii. 57 cm, 7.5 cm, and 4 cm of 12 mm diameter PVC pipe
   iv. PVC adhesive



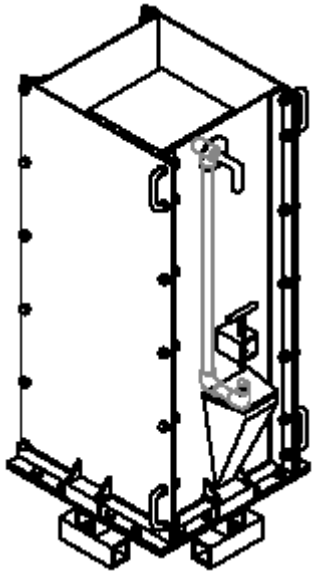
*based on design of BioSand Filter

Image courtesy of Kori S. Donison

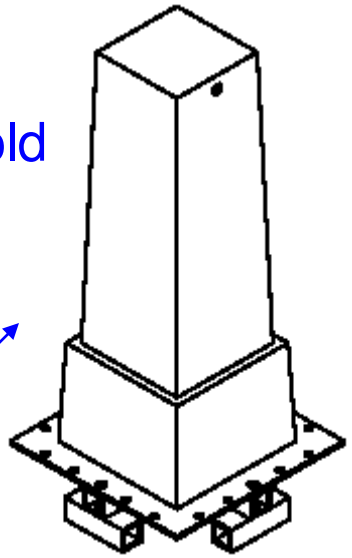
Slow Sand Filtration:
Construction

2. Filter

i. Filter mold (BioSand)
ii. 45 kg of cement
iii. 51 kg of river sand
iv. 70 kg of 5 mm gravel



Filter mold



Finished filter

Image courtesy of Kori S. Donison

Process

- Grease mold with oil
- Install pipe onto the outer portion of mold
- Bold inner and outer portion of mold together
- Add water to concrete and mixed w/ a ratio of:
  - *1 (cement) : 2 (river sand) : 3 (5 mm gravel)*
- Fill 1/3 of the way up, remove air bubbles, repeat 3 times
- Let dry; 12 hrs in dry climate, 24hrs in more humid climate

Slow Sand Filtration:
Construction

1. **Diffuser plate**
   i. 1/8 inch holes should be drilled in plastic approximately 2 inches apart throughout the plate
   ii. Place snugly in filter

Image courtesy of Kori S. Donison

How Ceramic Filters and Chlorination Treat Water

Ceramic Filter:
How it works

- Ceramic filter is placed inside the top of a large storage container
- Contaminated water is poured into the ceramic pot
- Filter uses size exclusion to strain out waterborne particles and microbes
- Removal is dependent on size, shape and surface chemistry of the particle relative to the pore size of the filter

Courtesy of RDI Cambodia

Chlorination:
How it Works

- Damages cell wall
- Alters cell membrane,destroying selective permeability
- Denatures the protein
- Alters the colloidal nature of the protoplasm
- Inhibits enzyme activity
  - Hydrolysis reaction occurs which yields HOCl
  - HOCl undergoes ionization which yields OCl^-
    - OCl^- is responsible for deactivating the bacteria and viruses

http://web.mit.edu/watsan/images/Nepal/General/Nepal_Kathmandu-Dugwell_Water_Bathing.jpg

Countries Experiencing Drinking Water Shortages

Water for All: Making it Happen

The United Nations proclaimed the years 2005 to 2015 as the Decade of Water for Life.

http://www.who.int/water_sanitation_health/monitoring/jmp2005/en/index.html

https://www.cia.gov/library/publications/the-world-factbook/print/gh.html

RDI Cambodia

Cambodia

- 88% of deaths are due to water borne illness

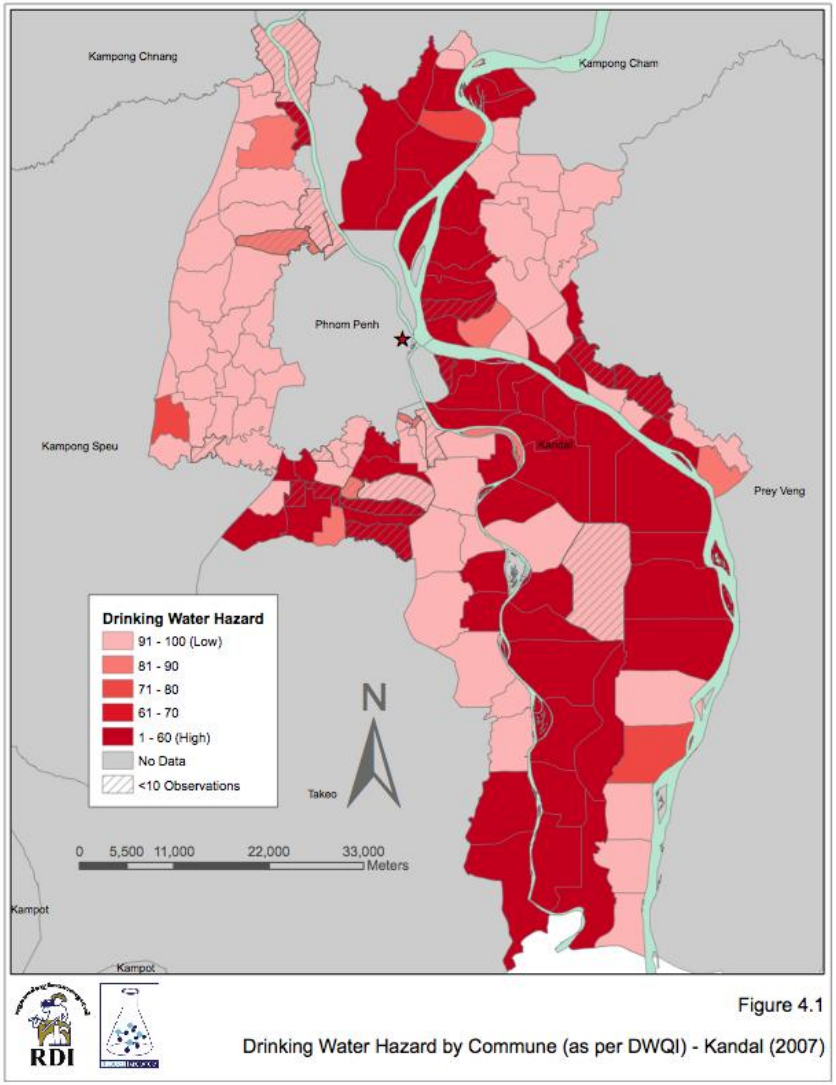


Figure 4.1

Drinking Water Hazard by Commune (as per DWQI) - Kandal (2007)

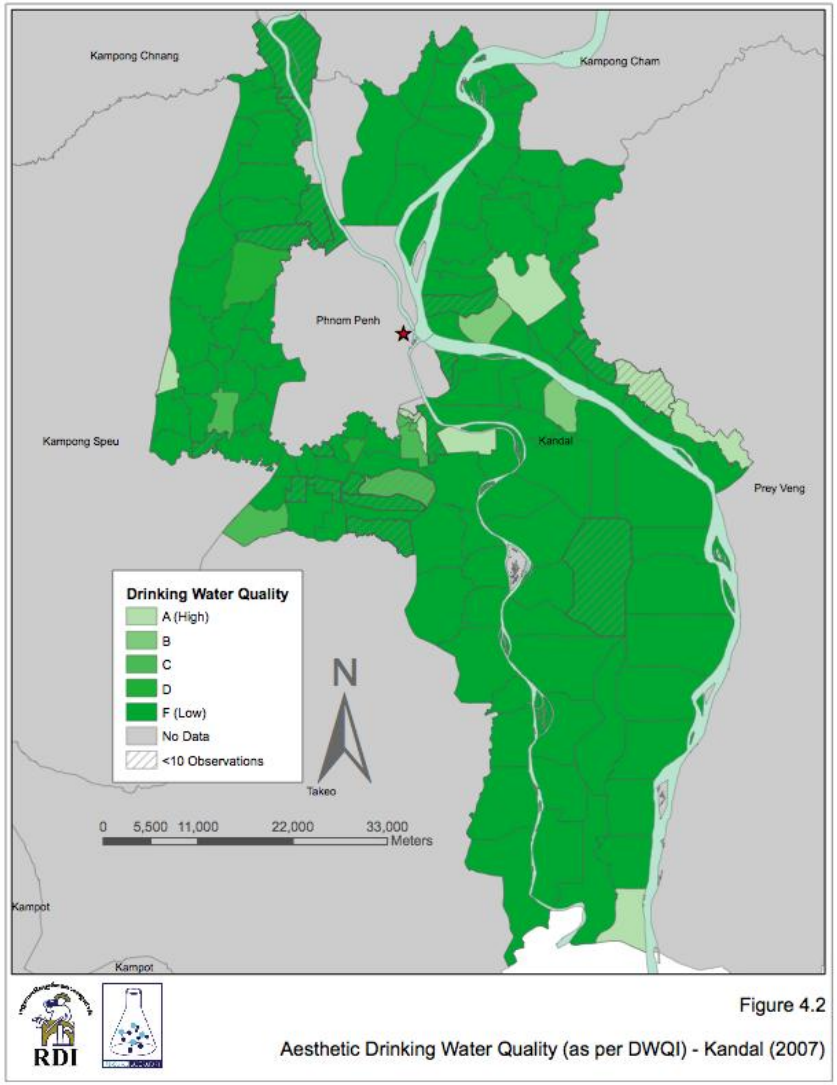


Figure 4.2

Aesthetic Drinking Water Quality (as per DWQI) - Kandal (2007)

Dominican Republic

Location	*Source Water* **E. coli** *Concentration (CFU/100 ml)*	*Source Water Total Coliform Concentration (CFU/100 ml)*	*Percent of Total Coliform Consisting of* **E. coli**
MAO			
Hundidera	255	1044	24%
Entrada de Mao	252	1873	13%
Los Martinez	17	2000+	<1%
DAJABON			
Cajuco	267	1937	14%
Las Matas de Santa Cruz	128	9360	1%
PUERTO PLATA			
Playa Oeste	33	9682	0%
Los Dominguez	10	1086	1%
Javillar de Costambar	13	344	4%

Location	**Filter Age[a] in January 2004**	**Funding Organization**	**Cost to User (Dominican pesos, US dollars)**	**Subsidized Cost (Dominican pesos, US dollars)**	**Total Cost (Dominican pesos, US Dollars)**
MAO					
Hundidera	10 months	INDENOR	600 (26)	600 (26)	1200 (52)
Entrada de Mao	2 years	Canadian Embassy	400 (17)	400 (17)	800 (34)
Los Martinez	1.25 years	Canadian Embassy	600 (26)	600 (26)	1200 (52)
DAJABON					
Cajuco	3 months	Rotary Club	200 (9)	Unknown	Unknown
Las Matas de Santa Cruz	0.5-2 years	Sold at cost to user	1000-1500 (43-65)	0 (0)	1000-1500 (43-65)
PUERTO PLATA					
Los Dominguez	6-12 months	Rotary Club/ Robert Hildreth	200 (9)	Unknown	Unknown
Playa Oeste	1 year	Rotary Club/ Robert Hildreth	200 (9)	Unknown	Unknown
Javillar de Costambar	1 year	Rotary Club/ Robert Hildreth	500 (22)	Unknown	Unknown

- **Major Income:** tobacco farming
- **Recommended Treatment:** Slow sand filtration

https://www.cia.gov/library/publications/the-world-factbook/print/gh.html

Ghana

- **Environmental issues:**
  - Recurring drought in North
  - Inadequate supplies of potable water
- **Water related diseases:**
  - Diarrheal diseases
  - Typhoid fever
- 2nd highest number of reported cases of Guinea Worm (a parasite) Disease in the world

https://www.cia.gov/library/publications/the-world-factbook/print/gh.html

Haiti

- **Main Water Source:** Surface Water
  - Because of deforestation, there are periods with large amounts of water and periods of drought
- **Other Water Sources:**
  - Groundwater (relatively hard)
  - Precipitation
- **Recommended Water Treatment:**
  - Solar Disinfection

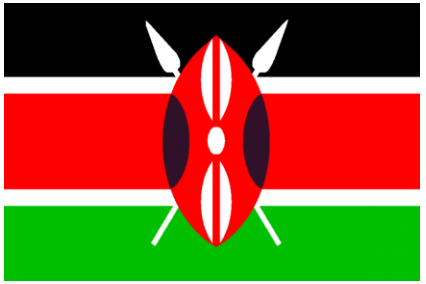
https://www.cia.gov/library/publications/the-world-factbook/print/gh.html

Nyanza Province, Kenya

- 66% of population lack access to safe drinking water
- Rainwater most popular water source
- Average 205 NTUs (unusually high)
- **Preferred water treatment**: Boiling
- **Recommended**: Ceramic Filter
- **Natural**: Abundance of Moringa Tree

https://www.cia.gov/library/publications/the-world-factbook/print/gh.html

Nairobi, Kenya



- 12% of population have access to piped water
- 6% have access to adequate sanitation

http://www.scoop.co.nz/stories/PO0703/S00273.htm

https://www.cia.gov/library/publications/the-world-factbook/print/gh.html

Nepal

- 81% of population has access to either piped municipal water sources or well water sources
  - However, municipal water supplies are rarely chlorinated → contamination
- Mortality ≤5 yrs is 108.4/1000 live births
- **Most common household treatment**: Candle Filter
- **Recommended**: Filtration and Chlorination

https://www.cia.gov/library/publications/the-world-factbook/print/gh.html

Nicaragua

- 88% of population in rural areas lack access to safe drinking water
- Over 60% of population lives in poverty
- **Infant mortality:** 66 out 1000 live births in children under 5
- **Recommended Water Treatment**: Ceramic Filter

https://www.cia.gov/library/publications/the-world-factbook/print/gh.html

https://www.cia.gov/library/publications/the-world-factbook/print/gh.html

Peru

Cerrito Buena Vista, Arequipa

- 54% of population live below the poverty line
- 81% of Peruvians had access to improved drinking water (2002)
  - only 66% of rural residents
- **Major Water Source:** Irrigation canals
- **Current Water Treatment:**
  - Ceramic candle filters
  - Chlorination
- **Recommended Treatment:** Ceramic Filter

Cost Comparison of the Table Filter and Safe Water System in Peru

Water Treatment Option	Capital Cost	O&M Costs / year
Table Filter (household filtration)	$6.40[23] [TF w/o 2 candles]	$5 [2 candles]
Safe Water System (household chlorination)	$9.80 [$6 (*bidon*) + $0.30 (chl. bottle) + $3.5[24] (chl. generator)]	$3 [$0.25/month for chl. production]

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This list is not inclusive, more references will be added in the future.

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