Sandec: Department of Water and Sanitation in Developing Countries

eawag
aquatic research

Sandec Training Tool 1.0 – Module 3

Household Water Treatment and Safe Storage (HWTS)

Summary

The supply of safe drinking water quality and quantity is important to prevent water and excreta-related diseases. Currently, 1.1 billion people still lack access to an improved water supply, and far more rely on unsafe drinking water containing bacteria, viruses, parasites, and also chemical pollutants. Contamination can occur at the source, during delivery or through inaccurate handling and storage at household level.

Water treatment at its point-of-use – the household – is a significant and highly effective instrument in reducing the global disease burden as it lowers the risk of recontamination and can be rapidly deployed by vulnerable populations.

This module presents the most important and promising household water treatment and safe storage (HWTS) technologies, including physical, chemical and biological treatment processes:

- SODIS is an effective method making use of solar radiation to disinfect small quantities of drinking water in plastic bottles.
- Different filtration systems, such as slow sand, ceramic or defluoridation filters are used for water treatment. Their removal efficiencies of different chemical or microbial contaminations depend on the filter material.
- Boiling or pasteurisation of water is a simple – but expensive – method to reduce pathogen concentrations.
- Chemical disinfection with chlorine leads to destruction and inactivation of pathogens, especially bacteria and viruses.

Use of the most appropriate technologies is dependent on local criteria, such as water quality at the source or cultural preferences. A combination of the different systems may be necessary to entirely remove microbial and chemical contamination. If the water is highly turbid, pretreatment, such as sedimentation, coagulation or filtration, is often a prerequisite to render the HWTS system effective. Once safe for drinking, the water will have to be protected from recontamination. Appropriate vessels and correct handling of the stored water will ensure safe storage of drinking water.

Not all the water used by a household has to be of excellent quality, merely the amount used for drinking or preparing food consumed uncooked should be treated, i.e. generally less than five litres per person and day. Ready access to water is essential as it leads not only to an increased quantity of water used for hygiene purposes and improved health but also to time saving – a factor benefiting mainly women and contributing to their emancipation.

To increase coverage and uptake of a HWTS approach, all stakeholders have to be involved in a collaborative effort. Initiatives must include community participation, education and behavioural change. To achieve a sustainable application of a new HWTS system, a feasibility study should be conducted before starting the project.

Though chlorination and SODIS were found to be the most cost-effective HWTS technologies, other systems should not be neglected in the context of further criteria.

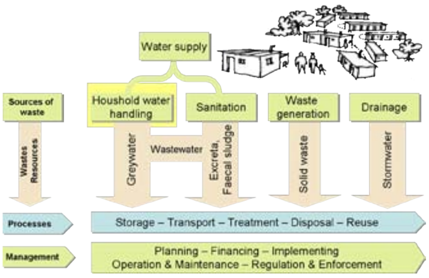

Figure 1: Household water treatment and safe storage (HWTS) in the context of water and sanitation.

Not included in Module 3

- ▸ Water resource management
- ▸ Water sources, lifting and distribution

Publishing details

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These lecture notes and matching PowerPoint presentations are available on the CD of Sandec's Training Tool. They can be ordered from: info@sandec.ch

Cover photo: Boy proudly presenting SODIS bottles in Vietnam. (Source: Eawag/Sandec)

Content

1.1 What is safe drinking water?

- **Safe drinking water includes microbial, chemical and aesthetic aspects.**
- **The supply of safe drinking water quality and quantity is important to prevent water and excreta-related diseases.**

According to the drinking water quality guidelines of the World Health Organisation (WHO), water is essential to sustain life, and a satisfactory (adequate, safe and accessible) supply must be available to all. Access to safe drinking water is the key to health. Every effort should be undertaken to achieve a drinking water quality as safe as practicable. Infants, young children, people who are debilitated or living under unsanitary conditions and the elderly are at greatest risk of water-related disease. The nature and form of drinking water standards may vary among countries and regions. There is no single, universally applicable approach. (WHO, 2006a, p. 1)

Microbial safety

The greatest microbial risks are associated with ingestion of water contaminated by human or animal faeces. Faeces can be a source of pathogenic bacteria, viruses, protozoa, and helminths. Faecally derived pathogens are the principal concerns in setting health-based targets for microbial safety. Microbial water quality often varies rapidly and over a wide range. Short-term peaks in pathogen concentration may increase disease risks considerably and trigger outbreaks of waterborne diseases. Furthermore, by the time microbial contamination is detected, many people may have already been exposed. Drinking water contaminated by waterborne diseases should be particularly avoided as it could lead to the simultaneous infection of a large number of persons and affect a potentially high proportion of the community.

In addition to faecally-borne pathogens, other microbial hazards (e.g. guinea worm) may be of public health concern. The infective stages of many helminths, such as parasitic roundworms and flatworms, can be transmitted to humans through drinking water. These pathogens should be absent from drinking water, since a single mature larva or fertilised egg may already cause an infection. While water can be a significant source of infectious organisms, many of the waterborne diseases can also be transmitted by other routes, including person-to-person contact, droplets, aerosols, and food intake. (WHO, 2006a, p. 3)

Pathogen	Infectious dose
Shigella	10^{1-2} organisms
Campylobacter jejuni	10^{2-5} organisms
Salmonella	10^{5} organisms
Escherichia coli	10^{8} organisms
Vibrio cholerae	10^{8} organisms
Giarda lamblia	10^{2-5} cysts
Entamoeba histolitica	10^{2-5} cysts

Table 1: Infectious dose of enteric pathogens. (Mandell et al., 1995 in Meierhofer et al., 2002, p. 29)

Chemical safety

Health concerns associated with chemical constituents of drinking water differ from those associated with microbial contamination. They arise primarily from the ability of chemical constituents to cause adverse health effects after prolonged periods of exposure. Few chemical constituents of water can lead to health problems after a single exposure, except if the drinking water supply is subjected to a massive accidental contamination. Moreover, experience reveals that in many of these incidents the water becomes undrinkable owing to unacceptable taste, odour and appearance. Numerous chemicals may occur in drinking water, however, only a few are of immediate health concern in any given circumstance, such as:

- Exposure to high levels of naturally occurring fluoride can lead to mottling of teeth and, in severe cases, crippling skeletal fluorosis.
- Similarly, excess exposure to naturally occurring arsenic in drinking water may lead to a significant risk of cancer and skin lesion.
- Other naturally occurring chemicals, including uranium and selenium, may also give rise to health concern when they are present in excess.
- The presence of nitrate and nitrite in water has been associated with methaemoglobinaemia, especially in bottle-fed infants. Nitrate may arise from the excessive application of fertilisers or from leaching of wastewater or other organic waste into surface water and groundwater.
- Particularly in areas with aggressive or acidic waters, the use of lead pipes and fittings or solder can result in elevated lead levels in drinking water, which cause adverse neurological effects.

(WHO, 2006a, p. 6)

Aesthetic aspects

Water should be tasteless and odourless. In assessing the quality of drinking water, consumers rely generally on their senses. Since the microbial, chemical and physical water constituents may affect appearance, odour or taste of the water, the consumer will assess the quality and acceptability of the water on the basis of these criteria. Although these substances may have no direct health effects, a highly turbid and coloured water of objectionable taste or odour may be regarded as unsafe by consumers and therefore rejected. In extreme cases, consumers may avoid aesthetically unacceptable but otherwise safe drinking water in favour of more pleasant but potentially unsafe sources. It is therefore wise to be aware of consumer perceptions. (WHO, 2006a, p. 7)

Module 2 contains details on the health aspects of drinking water.

Quantitative aspects

Individual drinking water needs vary depending on climate, physical activity and culture. For high water consumers, about two litres per day are required for a 60-kg person and one litre per day for a 10-kg child. <www> (WHO)

However, water is not only needed for drinking purposes but also for cooking, cleaning, or personal hygiene. The quantity of water is also important to prevent water-related diseases, i.e. if a mother has enough water available for hygienic purposes, like washing hands, she also reduces the risk of diseases for herself and her family. This module addresses mainly the quality of drinking water.

Contaminants	Guideline values or recommendations
E. coli, Faecal coliforms	0 CFU / 100ml (CFU: Colony forming units)
Turbidity	0.1 - 5 NTU (NTU: Nephelometric turbidity units)
Colour	15 TCU (TCU: True colour units)
Iron	Not of health concern at concentrations normally observed in drinking water
Manganese	0.4 mg/litre
Arsenic	0.01 mg/litre
Fluoride	1.5 mg/litre (Volume of water consumed and intake from other sources should be considered)
Nitrate	50 mg/litre (short-term exposure) 0.2 mg/litre (long-term exposure)

Table 2: Guideline values for different contaminants. (Compiled from WHO, 2006a)

Further questions

- ▸ Can the household members themselves control the drinking water quality?
- ▸ Are the consumers aware of the type of contamination of their drinking water? (e.g. excess fluoride, helminth eggs or other sources?)
- ▸ In the event of a lack of safe drinking water, is it healthier to drink only small amounts of contaminated water or should two litres per day be consumed to prevent dehydration despite the risk of infection?

Additional info

▸ WHO (2006): Guidelines for drinking water quality [electronic resource]: incorporating first addendum. Vol. 1, Recommendations. – 3rd ed. WHO, Geneva. www.who.int/water_sanitation_health/dwq/gdwq0506begin.pdf (last accessed 30.07.08)

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1.2 What is our focus?

▸ **This module addresses the treatment of water at household level: potential systems and technologies, their operation as well as their advantages and limitations, including the safe storage of drinking water.**

Health can be compromised when harmful bacteria, viruses or parasites contaminate drinking water either at the source, through seepage of contaminated runoff water or within the piped distribution system. Moreover, unhygienic handling of water during transport or within the home can contaminate previously safe water. For these reasons, many with access to improved water supplies through piped connections, protected wells or other improved sources are, in fact, exposed to contaminated water. Therefore, potentially billions of people can benefit from effective household water treatment and safe storage. (WHO, 2007, p. 10)

Household treatment can often provide the health benefits of safe water to underserved populations much faster than it will take to design, install and deliver piped community water supplies. (Sobsey, 2002, p. iii)

While toxic chemicals in drinking water are an important public health concern, it has been repeatedly demonstrated and generally accepted that the most important and immediate risks to human health of using contaminated drinking water are those from enteric microbes of faecal origin or other sources. Hence, this training tool module centres on systems and technologies for the protection and improvement of the microbiological quality of household water as well as for prevention and control of water-related microbial diseases. However, some technologies reduce both waterborne microbes and also certain toxic chemicals. (Sobsey, 2002, p. 1)

Terminology

Household-level approaches to drinking water treatment and safe storage are also commonly referred to as managing the water at "point-of-use". This term or its abbreviation "POU" typically describes the same procedures as other abbreviations derived from household water treatment, like "HHWT" or "HWT" or "HWTS". (The "S" in "HWTS" refers to safe storage.) "Household water management" is also commonly used and can encompass both treatment and storage. All these terms can refer to a variety of treatment procedures, for example, with chlorine or other chemical disinfectants, sunlight or UV lamps, various filters or flocculation-disinfection formulations. (WHO, 2007, p. 10)

Focus of this module is on the treatment of water at household level. It addresses the systems and technologies used to improve the microbiological water quality, their operation, as well as their advantages and limitations. The question of safe storage of drinking water is also discussed. Once the water is treated, how can it be protected from recontamination?

The aspects of water resource management and water supply are not discussed in detail in this Module.

Further questions

- How can the safety of a seemingly improved water source be determined?
- Could water resource management and water supply influence the application of HWTS systems?

Additional info

- WHO (2007): Combating waterborne disease at the household level. WHO/The International Network to Promote Household Water Treatment and Safe Storage, Geneva. www.who.int/household_water/advocacy/combating_disease/en/index.html (last accessed 30.07.08)

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1.3 What are the objectives of household water treatment and safe storage?

- **The objective of HWTS is not to replace the installation of water supply infrastructure but to complement the effort of providing safe drinking water to the consumers and, therewith, contribute to reducing water-related diseases.**

Currently, 1.1 billion people lack access to improved water sources (e.g. a household connection or a public standpipe, cf. Chapter 2.3). However, many more are supplied with water unsafe for consumption. (WHO/UNICEF, 2000, p. 7)

The Millennium Development Goal 7, Target 10, calls for reducing by half the proportion of people without sustainable access to safe drinking water by 2015. Reaching this target implies tackling both the quantity and quality dimensions to drinking water provision. However, studies suggest that depending on local conditions, a significant proportion of water from these sources may be contaminated. In the light of these findings, great efforts are required not only to extend services to the unserved but also to ensure these services are indeed supplying safe water. (WHO, 2007, p. 13)

A recently published study estimated that improvements in drinking water quality through household water treatment leads to a reduction of diarrhoea episodes by 39 %. (Fewtrell et al., 2005 in WHO/UNICEF, 2005, p. 13)

Household-level interventions can make an immediate contribution to the safety component of this target and would significantly contribute to meeting the MDGs in situations where access to water supplies is secure but household water quality is not ensured. (WHO, 2007, p. 13)

The availability of sufficient water is key to a consistent practice of hygiene behaviour. Therefore, the objective of HWTS is not to replace the installation of water supply infrastructure but to complement the effort in providing safe drinking water to the consumers and, therewith, contribute to reducing global diarrhoea.

A HWTS must:

- Reduce the risk of disease transmission through drinking water by supplying safe water achieved through:
  - protection of the source
  - treatment at the source
  - safe delivery
  - treatment at household level
  - safe storage to prevent recontamination
- Be affordable to all
- Be easy to operate and maintain
- Be culturally acceptable

Further questions

- If investments and efforts are put into HWTS, can treatment at community level be neglected? Or would it be safer to treat the water twice as an additional precautionary measure?
- Is HWTS a permanent solution or only regarded as a temporary measure until an improved water supply with safe water is installed?

Additional info

- WHO (2007): Combating waterborne disease at the household level. WHO/The International Network to Promote Household Water Treatment and Safe Storage, Geneva. www.who.int/household_water/advocacy/combating_disease/en/index.html (last accessed 30.07.08)
- WHO/UNICEF (2005): Water for Life - Making it happen. WHO/UNICEF, Geneva. www.who.int/water_sanitation_health/monitoring/jmp2005/en/index.html (last accessed 30.07.08)

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2.1 What is the global situation?

- **1.1 billion people have no access to an improved water supply, most of them in Asia.**
- **According to a recent review, household-based interventions are about twice as effective in preventing diarrhoeal disease than improved wells, boreholes and communal standpipes.**
- **HWTS is therefore an important instrument in reducing the global diarrhoea burden.**

Globally, 1.1 billion people are without access to improved water supply or nearly one fifth of the world population. (WHO/UNICEF, 2000, p. 7) Figure 2 illustrates the global differences in improved drinking water use.

Within one region, urban coverage is mostly higher than rural coverage, with the greatest differences between urban and rural water access in Africa and Oceania (cf. figure 3).

In 1990, 77 % of the world population used improved drinking water sources. Considerable progress was made between 1990 and 2002, with about 1.1 billion people gaining access to improved water sources. Global coverage in 2002 reached 83 %, putting the world on track to achieve the MDG target. The region that made the greatest progress was South Asia, which increased coverage from 71 – 84 % between 1990 and 2002. This jump was fuelled primarily by increased use of improved water sources in India, with a population of over 1 billion people. Progress in sub-Saharan Africa was also impressive: coverage increased from 49 – 58 % between 1990 and 2002.

But this falls far short of the progress needed to achieve the MDG target to reduce by half the proportion of people without sustainable access to safe drinking water by 2015. Obstacles to accelerating the rate of progress in sub-Saharan Africa include conflict and political instability, high rates of population growth and low priority given to water and sanitation. What's more, breakdown rates of water supply systems in rural Africa can be very high. Despite these obstacles, decentralising responsibility, ownership and providing a choice of service levels to communities, based on their ability and willingness to pay, are among the approaches shown to be effective in speeding up progress. (WHO/UNICEF, 2004, p. 10)

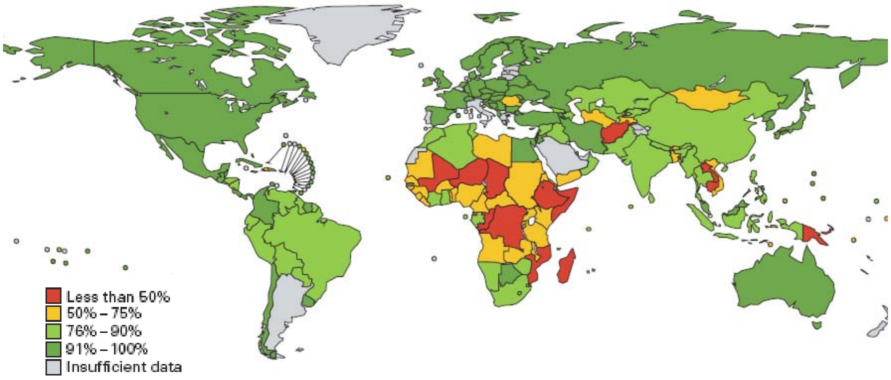

Figure 2: Percentage of population using improved drinking water sources in 2004. (WHO/UNICEF, 2006, p. 8)

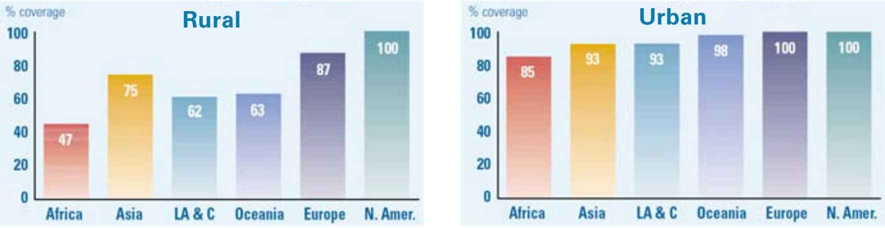

Figure 3: Rural and urban water supply coverage by region. (WHO/UNICEF, 2000, p. 10)

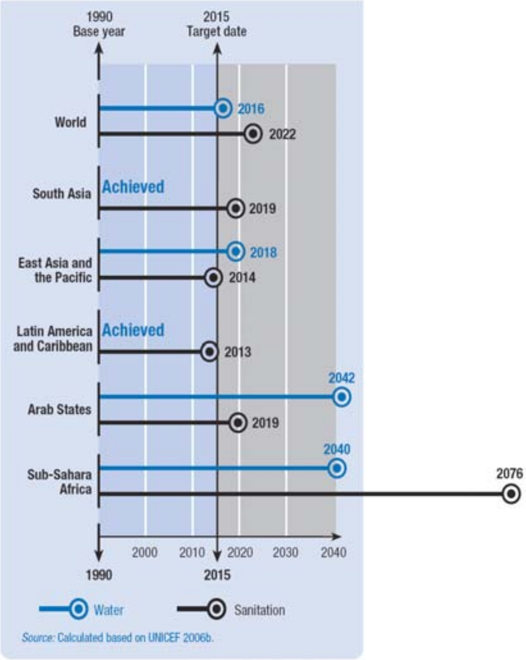

Figure 4: Some regions are off track in reaching the Millennium Development Goal of the water and sanitation target. A key target of MDG 7 is to reduce by half the number of people without sustainable access to safe drinking water by 2015. (UNDP, 2006, p. 57)

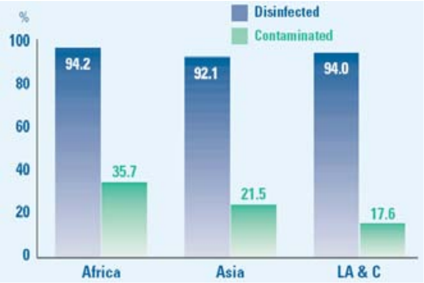

Figure 5: Percentage of water supply effectively disinfected (free residual chlorine > 0.1mg/l), and percentage of drinking water quality test results violating national standards. (Source: WHO/UNICEF, 2000, p. 26)

Drinking water quality

Not all assumingly safe water is actually of good microbiological quality. Figure 5 reveals the proportion of drinking water samples violating national standards as regards microbiological, chemical, physical or aesthetic characteristics. (WHO/UNICEF, 2000, p. 26)

These test results imply that although access to an assumingly safe and disinfected water source is available, it is quite likely that the water is still contaminated and needs further treatment at household level.

Health impact of household-based interventions

According to a systematic review of 15 intervention studies by the World Bank, household-based water treatment and safe storage was associated with a 39 % reduction in diarrhoeal disease morbidity compared to a 25 % reduction by improved water supply. (Fewtrell et al., 2005 in WHO/UNICEF, 2005, p. 13)

A more recent and comprehensive Cochrane review covering more than 38 randomized, controlled trials and 53 000 people in 19 countries revealed that household-based interventions were about twice as effective in preventing diarrhoeal disease (47 %) than improved wells, boreholes and communal standpipes (27 %). (UNICEF, 2008, p. 2)

Further questions

- Why are Arab States and sub-Sahara Africa off track in reaching the goal of reducing by half the number of people without sustainable access to safe drinking water by 2015 (MDG-7, cf. Fig. 4)?
- The urban water supply coverage is comparatively higher than the rural. However, considering the high density of the population in urban areas, is this water unsafer for consumption?

Additional info

- UNDP (2006): Human Development Report 2006. Beyond scarcity: Power, poverty and the global water crisis, New York. http://hdr.undp.org/en/reports/global/hdr2006/ (last accessed 08.08.08)
- WHO/UNICEF (2000): Global Water Supply and Sanitation Assessment 2000 Report. WHO/UNICEF. www.who.int/water_sanitation_health/monitoring/globalassess/en/ (last accessed 30.07.08)

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2.2 What are the disease-causing pathogens and how are they transmitted?

- **Water and excreta-related pathogens belong to the bacteria, virus and parasite groups (protozoa and helminths).**
- **Many of these pathogens have multiple transmission routes, such as through food, water, person-to-person contact, flies or via inadequate hygiene behaviour (e.g. not washing the hands). Application of HWTS systems reduces the risk of transmission through drinking water but not of the other transmission routes.**

Waterborne pathogens belong to the bacteria, virus and parasite groups. Although viruses are often not detected in the water or host, they may account for the largest group of causative agents, followed by parasites and bacteria.

Many common pathogens are not only transmitted through water but also follow other infectious pathways. Poor general hygiene practices are often a significant source of infection. Furthermore, secondary contamination of drinking water due to incorrect water handling is frequently observed in developing countries. The main factors influencing the health-related relevance of pathogens transmitted through water are the pathogens' ability to survive in the environment and the number of pathogens necessary to infect a (human) host. Well-known and widely distributed pathogens and their characteristics are listed in Table 3. (Meierhofer et al., 2002, p. 3)

The application of household water treatment systems, such as SODIS or ceramic filters, improves the quality of drinking water and thus reduces the risk of contracting a disease mainly transmitted by drinking water. Unfortunately, many of these so-called waterborne diseases have multiple transmission routes. Consequently, diarrhoea-causing pathogens can be transmitted to humans through food, person-to-person contact, and flies or through inadequate hygiene behaviour (e.g. not washing the hands). Children are particularly exposed to many different ways of becoming infected, as illustrated in the "F-Diagram": via faeces, fingers, flies/insects, food, field/environment, and fluids/water. (Meierhofer et al., 2002, p. 3)

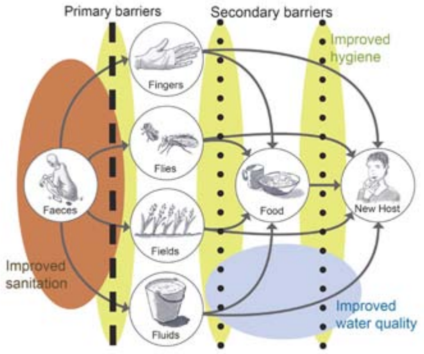


Figure 6: The F-Diagram illustrates the typical transmission routes of pathogens and suggests possible interventions. (Adapted from DFID/WELL, 1998, p. 84)

Pathogen	Health Signifcance	Transmission Routes	Persistence in Water Supplies	Infective Dose
Bacteria				
Camplobacter jejuni, C. Coli	High	• Person-to-person contact • Domestic contamination • Water condtamination • Crop contamination	Moderate	Moderate
Pathogenic E. Coli	High		Moderate	High
Salmonella typhii	High		Moderate	High
Other salmonellae	High		Long	High
Shigella spp.	High		Short	Moderate
Vibrio cholerae	High		Short	High
Yersinia enterocolitica	High		Long	High
Pseudomonas ae.	Moderate		May multiply	High (?)
Aeromonas spp.	Moderate		May multiply	High (?)
Viruses				
Adenovirus	High	• Person-to-person contact • Domestic contamination • Water contamination	?	Low
Polio Virus	High		?	Low
Hepatitis A Virus	High		?	Low
Hepatitis Non-A Virus	High		?	Low
Enterovirus	High		Long	Low
Norwalk Virus	High		?	Low
Norwalk-Like-Viruses (NLV)	Moderate		?	Low (?)
Rotavirus	High		?	Moderate
Protozoa				
Entamoeba hystolitica	High	• Person-to-person contact • Domestic contamination • Contamination through animals	Moderate	Low
Giarda spp.	High		Moderate	Low
Cryptosporidium spp.	High		Long	Low

Table 3: Health significance and transmission routes of water and excreta-related pathogens. (WHO, 1993 and Cairncross et al., 1993 in Meierhofer et al., 2002, p. 3)

Further questions

- Where in the F-Diagram can water quantity help interrupt the transmission routes?
- What activities or sites could lead to an increased infection risk for humans?

Additional info

- Module 2 of Sandec's Training Tool: Environmental Health Aspects of Water and Sanitation.

2.3 What are the contamination risks for drinking water?

- **Firstly, water can be already contaminated at the source (groundwater in a well or spring, rainwater, surface water etc.). However, groundwater is usually of good quality if the source is well protected.**
- **Secondly, it can be contaminated during delivery. Contamination occurs for example due to substandard water distribution systems, intermittent water pressure, illegal connections to the distribution system or during transport.**
- **Thirdly, there is a risk of recontamination via inappropriate transport, handling and storage at the household level.**

Contamination at the source

Improved drinking water sources are defined in terms of technology types and levels of services more likely to provide safe water than unimproved technologies.

Potential risks and hazardous situations associated with various non-piped water sources:

- tubewell fitted with a hand pump
  - ingress of contaminated surface water directly into borehole
  - ingress of contaminants due to poor construction or damage to the lining
  - leaching of microbial contaminants into aquifer
- simple protected spring
  - contamination directly through "backfill" area
  - contaminated surface water causes rapid recharge
- simple dugwell
  - ingress of contaminants due to poor construction or damage to the lining
  - contamination introduced by buckets
- rainwater collection
  - bird and other animal droppings found on roof or in guttering
  - first flush of water can enter storage tank.

(WHO, 2006a, p. 65)

Some of the common drinking water sources are described hereafter.

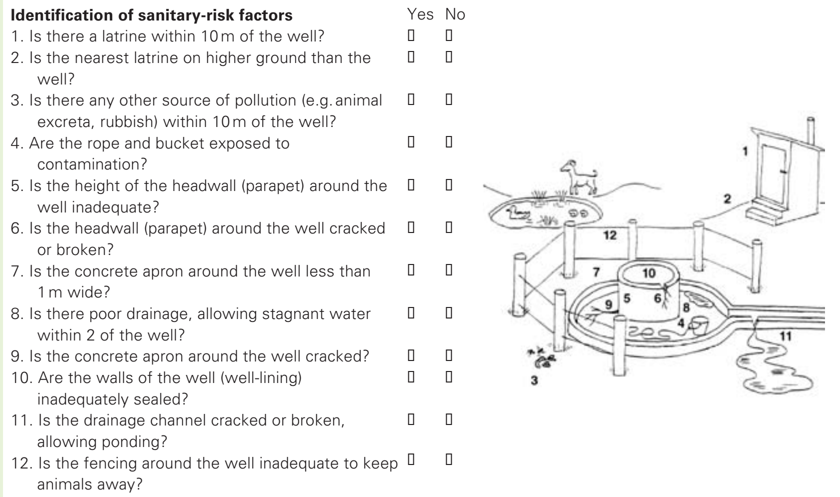
Improved water sources	Unimproved water sources
• household connections • public standpipes • boreholes • protected dugwells • protected springs • rainwater collections	• unprotected wells • unprotected springs • vendor-provided water • bottled water (unless water for other uses is available from an improved source) • tanker trucks providing water

Table 4: Improved and unimproved sources of drinking water. <www> (WHO)

Sanitary survey assessment

A sanitary survey is a risk assessment enabling fieldworkers to assess the likely quality of water. Surveys can be carried out at any of the three points of a water supply scheme:

- at the source and intake
- at the treatment works
- at the distribution system



Identification of sanitary-risk factors	Yes	No
1. Is there a latrine within 10 m of the well?	☐	☐
2. Is the nearest latrine on higher ground than the well?	☐	☐
3. Is there any other source of pollution (e.g. animal excreta, rubbish) within 10 m of the well?	☐	☐
4. Are the rope and bucket exposed to contamination?	☐	☐
5. Is the height of the headwall (parapet) around the well inadequate?	☐	☐
6. Is the headwall (parapet) around the well cracked or broken?	☐	☐
7. Is the concrete apron around the well less than 1 m wide?	☐	☐
8. Is there poor drainage, allowing stagnant water within 2 of the well?	☐	☐
9. Is the concrete apron around the well cracked?	☐	☐
10. Are the walls of the well (well-lining) inadequately sealed?	☐	☐
11. Is the drainage channel cracked or broken, allowing ponding?	☐	☐
12. Is the fencing around the well inadequate to keep animals away?	☐	☐

Figure 7: Sanitary survey assessment. (Lloyd et al., 1991)

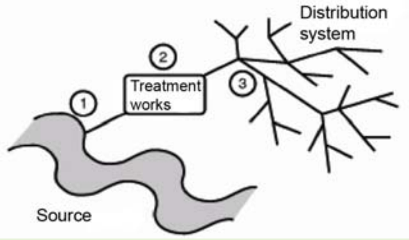


Figure 8: Sanitary survey inspections points. (Lloyd et al., 1991)

Number of positive answers	Risk assessment
> 9	Very high
6, 7, 8	High
3, 4, 5	Moderate
0, 1, 2	Low

Table 5: Evaluation of the survey.

Rooftop rainwater harvesting

Three main components are necessary to collect rainwater for drinking purposes:

- catchment surface
- delivery system to transport the water from the roof to the storage reservoir (gutters and drainpipe)
- reservoir to store the rainwater until it is used. The storage tank is fitted with an extraction device, such as a tap, rope, bucket or pump, depending on the location of the tank.

Photo 1: Rainwater harvesting. (Source: WEDC © Brian Skinner)

Groundwater catchment

Groundwater is the water contained in subsurface rocks and soil, as well as the water accumulating in underground aquifers. Groundwater constitutes 97 % of global freshwater and is an important source of drinking water in many regions of the world. It often requires little or no treatment to be suitable for drinking compared to surface water, which generally needs to be treated, often extensively. (WHO, 2006b, p. 4)

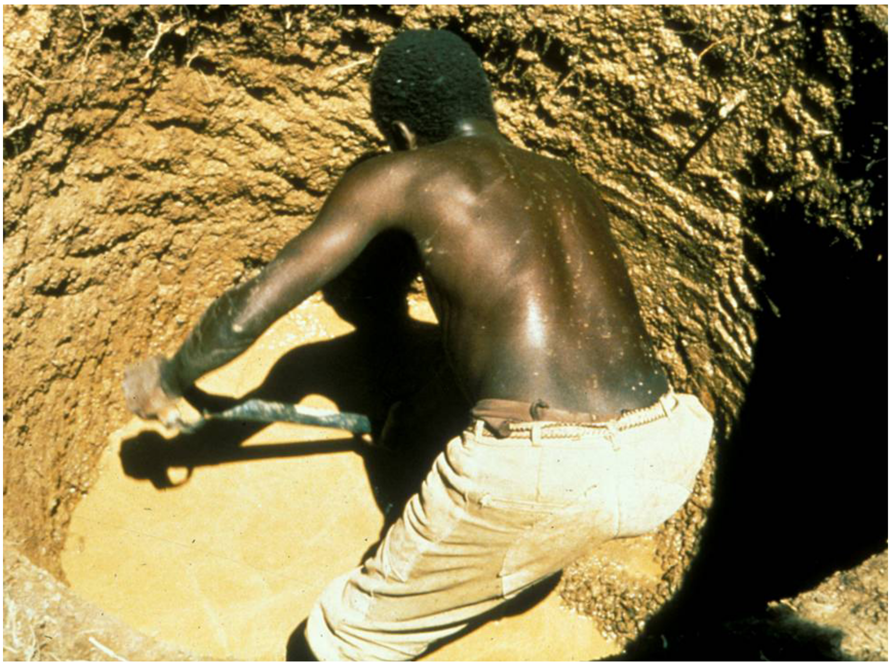


Photo 2: Construction of a dugwell for groundwater use. (Source: Eawag/Sandec)

Comparing the sources

The best option is the use of high quality source water. A change in source or use of a treatment process may alter the water taste, which will possibly be rejected by the community. The risk of surface water contamination is very high. Groundwater is usually much purer than surface water but may be contaminated by natural chemicals or by anthropogenic activities (including the unhygienic use of a bucket and rope in a well). Rainwater harvested from roofs made of sheets or tiles is relatively pure, particularly if the first water after a dry period is allowed to run off to waste. (Skinner et al., 1998)

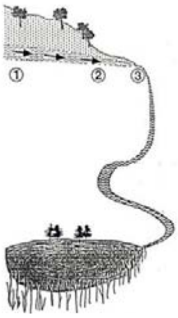
	Source	Advantages	Disadvantages
	Rainwater	• Good microbiological quality • Easy use	• Contains few minerals • Storage necessary
	Groundwater	• Good microbiological quality • Usually no treatment necessary • Easy use ③ (=spring) to difficult use ① (=deep well)	• Contamination possible: ② (=shallow dugwell) and ③.
	Surface water	• Easy access	• Great risk of microbiological contamination • High content of solids and algae • Treatment necessary

Table 6: Comparison of three drinking water sources.

Contamination through delivery

Protection of the distribution system is essential to provide safe drinking water. The nature of the distribution system, which may include many kilometres of pipes, storage tanks, interconnections to industrial users and the potential for tampering and vandalism, give rise to microbial and chemical contamination opportunities. Contamination can occur within the distribution system:

- when contaminated water in the subsurface material and especially from nearby sewers surrounding the distribution system enters because of low internal pipe pressure or through the effect of a "pressure wave" within the system (infiltration/ingress);
- when contaminated water is drawn into the distribution system or storage reservoir through backflow resulting from a reduction in line pressure and a physical link between contaminated water and the storage or distribution system;
- through open or insecure water storage reservoirs and aqueducts, which are potentially prone to surface runoff from the land and to faecal contamination from animals and waterfowl as well as to acts of vandalism and tampering;
- through pipe bursts when existing mains are repaired or replaced or when new water mains are installed, potentially leading to the introduction of contaminated soil or debris in the system;
- through human error from unintentional cross-connection of wastewater or stormwater pipes to the distribution system or via illegal or unauthorised connections;
- through leaching of chemicals and heavy metals from materials such as pipes, solders/jointing compounds, taps, and chemicals used in cleaning and disinfection of distribution systems;
- when petrol or oil diffuses through plastic pipes.

In each case, if the contaminated water contains pathogens or hazardous chemicals, it is likely that consumers will be exposed to them. Even where disinfectant residuals are employed to limit microbial occurrence, they may be inadequate to overcome the contamination or may be ineffective against some or all of the pathogen types introduced. As a result, pathogens may occur in concentrations that could lead to infection and illness.

Where water is supplied intermittently, the resulting low water pressure will allow the ingress of contaminated water into the system through breaks, cracks, joints, and pinholes. Intermittent supplies are not desirable but very common in many countries and frequently associated with contamination. The control of water quality in intermittent supplies presents a significant challenge as the risk of infiltration and backflow increases significantly. The risks may be elevated seasonally as soil moisture conditions increase the likelihood of a pressure gradient developing from the soil to the pipe. Where contaminants enter the pipes in an intermittent supply, the charging of the system when supply is restored may increase risks to consumers, as a concentrated "slug" of contaminated water can be expected to flow through the system. Where household storage is used to overcome intermittent supply, localised use of disinfectants to reduce microbial proliferation may be warranted.

Drinking water entering the distribution system may contain free-living amoebae and environmental strains of various heterotrophic bacterial and fungal species. Under favourable conditions, amoebae and heterotrophs, including strains of Citrobacter, Enterobacter and Klebsiella may colonise distribution systems and form biofilms. There is no evidence of occurrence of most microorganisms from biofilms (except, for example, Legionella, which can colonise water systems in buildings) with adverse health effects to the general population through drinking water, with the possible exception of severely immuno-compromised people. Water temperatures and nutrient concentrations are not generally elevated enough within the distribution system to support the growth of E. coli (or enteric pathogenic bacteria) in biofilms. Thus, the presence of E. coli should be considered as evidence of recent faecal contamination. Natural disasters, including flood, drought and earth tremors, may significantly affect piped water distribution systems. (WHO, 2006a, p. 62)

Recontamination through transport from source and handling at the household level

Once the water has been treated and is safe for drinking, the risk of recontamination through transport and handling at household level should be minimised, for example, by using containers with narrow openings and dispensing devices, such as taps or spigots.

Safe storage is a critical component of household water interventions. Regardless of whether or not collected household water is initially of acceptable microbiological quality, it often becomes contaminated with pathogens of faecal origin during transport and storage. Studies show that use of containers with narrow openings for filling and dispensing devices, such as spouts or taps/spigots, protect the collected water during storage and household use. Improved containers protect stored household water from the introduction of microbial contaminants via contact with hands, dippers, other faecally contaminated vehicles or the intrusion of vectors. <www> (WHO, 2008b)

Further questions

- What are the contamination risks of delivery systems other than piped water (e.g. transport by water vendors)?
- Why do people sometimes resort to the use of surface water despite the qualitatively better groundwater and rainwater?

Additional info

- WHO (2006): Guidelines for drinking water quality [electronic resource]: incorporating first addendum. Vol. 1, Recommendations. – 3rd ed. WHO, Geneva. www.who.int/water_sanitation_health/dwq/gdwq0506begin.pdf (last accessed 30.07.08)

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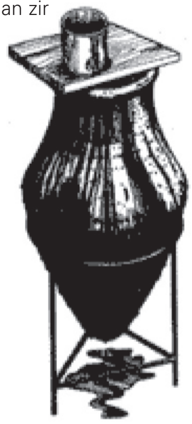
Traditional Egyptian zir

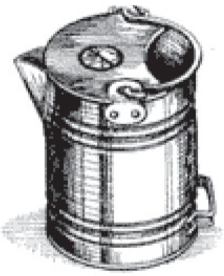


Plastic container used to sell vegetable oil in Zambia

Traditional cantero from El Salvador

Sorai used in an intervention trial in India

Tin bucket used in an intervention trial in Malawi



Plastic container meeting the design criteria of the Centres for Disease Control and Prevention/Pan American Health Organisation and used in an intervention trial in Bolivia.

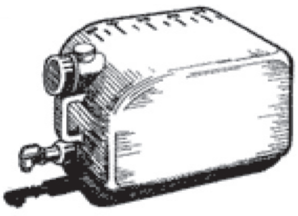


Figure 9: Some examples of traditional and modified water storage vessels to reduce contamination during storage. (Mintz et al., 1995)

2.4 Which water treatment and safe storage systems are used at household level?

- **The available technologies comprise physical, chemical and biological treatment processes.**
- **For highly turbid water, pretreatment is often necessary for the technologies to function efficiently.**
- **For safe drinking water storage, both traditional and modern vessels can be used under certain conditions.**

Of the 83 % of the world population using "improved" water sources, some nonetheless drink water that has been contaminated either at source, during transport or at home. The unserved 17 % have little choice but to carry home water from unsafe sources. Simple techniques for treating water at home and storing it in safe containers could save a large number of lives each year. Since cheap treatment techniques are available, and the impact of improving water quality can be dramatic, household water treatment and safe storage could yield considerable health and economic benefits. (WHO/UNICEF, 2005, p. 28)

If the water at source is highly turbid, pretreatment may be necessary prior to the actual treatment.

A variety of candidate technologies for treatment of household water have been described and many are widely used in different parts of the world. The technologies to improve the microbial quality of household water and reduce waterborne diseases include a number of physical, chemical and biological treatment processes.

The physical processes include:

- boiling
- heating (fuel and solar)
- settling
- filtering
- exposing to solar UV radiation
- disinfecting with UV lamps

The chemical processes include:

- coagulation / flocculation and precipitation
- adsorption
- ion exchange
- chemical disinfection with germicidal agents (primarily chlorine)

A biological process:

- Biologically active layer in slow sand filters

(Sobsey, 2002, p. v)

Many traditional water collection and storage vessels of various materials and sizes are used today in developing countries. But also newer materials, such as aluminium and plastic, have come into widespread use.

Further questions

▸ How do we know if a HWTS technology is actually producing safe water?

Additional info

▸ WHO/UNICEF (2005): Water for Life - Making it happen. WHO/UNICEF, Geneva. www.who.int/water_sanitation_health/monitoring/jmp2005/en/index.html (last accessed 30.07.08)

Download available on the CD of Sandec's Training Tool and from the Internet.

2.5 What are the advantages of household water treatment versus centralised treatment systems

▸ **High efficiency, reduced risk of recontamination and independence from centralised systems are among the most important advantages of water treatment at household level.**

In the past, governments in developing countries have invested much effort in installing sophisticated water treatment plants and public water supply systems, especially in urban areas. However, the conventional water treatment plants often fail to produce water safe for consumption. Lack of trained operators, a reliable supply of chemicals and spare parts, as well as financial constraints often hinder reliable operation and maintenance of the centralised systems. Water shortages frequently lead to water supply interruptions, and leaky distribution systems worsen the situation. Moreover, the rapid population growth in urban areas puts an excessive stress on the existing water and sanitation infrastructures and creates enormous problems in planning and constructing new infrastructures. Thus, the inhabitants of many urban centres and the rural population in developing countries only have access to poor water quality. The individual household therefore has to assume the responsibility for turning contaminated water into safe drinking water. (Meierhofer et al., 2002, p. 2)

HWTS has numerous advantages:

- Treatment can be performed directly at the point of use – the risk of recontamination is reduced.
- Each family is responsible for establishing and maintaining its own safe water, thus resulting in a better control.
- A household water treatment is often far more rapidly established than building a community-based system (this can be especially important in "disaster-related" situations, such as after an earthquake or in a refugee camp).

A growing body of researchers also suggest HWTS as it:

- dramatically improves the microbial water quality
- significantly reduces diarrhoea
- is among the most effective water, sanitation and health interventions
- is highly cost-effective
- can be rapidly deployed and taken up by vulnerable populations

(WHO, 2007, p. 10)

Though household water treatment is an effective and useful approach applicable in many circumstances, questions about acceptability and long-term use have yet to be addressed. (WHO/UNICEF, 2005, p. 28)

Photo 3: Water treatment plant. (Source: Courtesy of WEDC, © Sam Godfrey)

Photo 4: Water treatment at household level in Cambodia. (Source: Eawag/Sandec)

Further questions

▸ Do HWTS also have drawbacks over centralised systems? Which are the drawbacks?

Additional info

▸ WHO (2007): Combating waterborne disease at the household level. WHO/The International Network to Promote Household Water Treatment and Safe Storage, Geneva. www.who.int/household_water/advocacy/combating_disease/en/index.html (last accessed 30.07.08)

Download available on the CD of Sandec's Training Tool and from the Internet.

3.1 What is SODIS (Solar Water Disinfection)?

- **SODIS is a method using solar radiation to disinfect small quantities of drinking water in plastic bottles.**
- **SODIS is most appropriate in areas with high solar radiation, availability of bottles, community motivation, and training of users in the correct and consistent application of SODIS. <www> (CDC, 2008)**

Method

Contaminated water is filled into transparent plastic bottles, preferably PET bottles, and exposed to full sunlight for five hours. During exposure, sunlight destroys the pathogenic bacteria and viruses. A solar radiation intensity of at least 500 W/m^2 is required for five hours for SODIS to be efficient. This is equivalent to five hours mid-latitude sunshine in summer. A synergetic effect of UV-A radiation and temperature occurs if the water temperature rises above 50 °C. The disinfection process then only requires a third of the solar radiation intensity. The water is safe for consumption after one hour of solar exposure at 50 °C. <www> (SODIS)

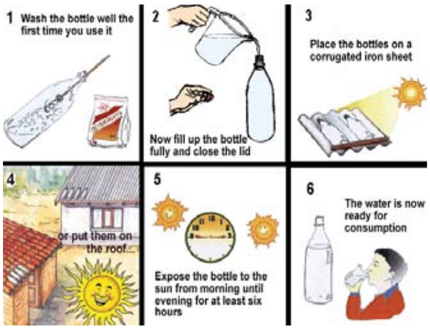


Figure 10: Instruction for SODIS use.

Origin of SODIS

In 1991, Eawag (Swiss Federal Institute of Environmental Science and Technology) and Sandec (Eawag's Department of Water and Sanitation in Developing Countries) conducted extensive laboratory and field experiments to develop and test the Solar Water Disinfection Process (SODIS). Both the laboratory tests and practical experience acquired during field application revealed that SODIS is a simple, low-cost technology with a great potential to improve the health of those still lacking access to safe drinking water.

Since 1995, the SODIS Reference Centre based at Eawag/Sandec is engaged in providing information, technical support and advice to local institutions in developing countries for worldwide promotion and dissemination of the Solar Water Disinfection Process. More than two million people in about 30 countries currently use SODIS. <www> (SODIS)

Synergetic effect. SODIS uses two sunlight components for water disinfection, i.e. UV-A radiation with its germicidal effect and infrared radiation with its pasteurisation effect and water temperature increase. The combined use of both UV-A radiation and heat produces a synergetic effect that enhances the efficiency of the process (cf. Fig. 13).

Solar radiation can be divided into three wavelength ranges: UV radiation, visible light and infrared radiation. UV radiation cannot be perceived by the human eye. It is a very aggressive radiation that can cause severe damage to the skin and eyes and destroy living cells. Luckily, most of the UV-C and UV-B light in the 200 – 320 nm range is absorbed by the ozone (O_3) layer in the atmosphere, which protects the earth from radiation. Only a higher fraction of UV-A radiation in the 320 – 400 nm wavelength range, near the visible violet light, reaches the surface of the earth. UV-A light has a lethal effect on human pathogens present in water. These pathogens are not well adapted to aggressive environmental conditions as they find their specific living conditions in the human gastrointestinal tract. Therefore, they are more sensitive to sunlight than organisms commonly abundant in the environment. UV-A radiation, which directly interacts with the DNA, nucleic acids and enzymes of the living cells, changes the molecular structure and leads to cell death. UV radiation also reacts with the oxygen dissolved in water and produces highly reactive forms of oxygen (oxygen free radicals and hydrogen peroxides). These reactive molecules also interfere with cell structures and kill the pathogens.

Another aspect of sunlight is its longwave radiation, the so-called infrared. Also this radiation cannot be seen by the human eye, but the heat produced by light of the wavelength beyond 700 nm can be felt. The infrared radiation absorbed by the water is responsible for heating it up. Microorganisms are sensitive to heat and most pathogens die after a few minutes at temperatures above 60 °C (cf. "What is water boiling and pasteurisation?" Chapter 3.5). (Meierhofer et al., 2002, p. 11)

Weather and climate. Efficiency of the SODIS process is dependent on the amount of available sunlight. Solar radiation is, however, unevenly distributed and varies in intensity from one geographical location to another, depending on latitude, season and time of day. The most favourable regions for SODIS are located between latitude 15 °N and 35 °N (as well as 15 °S and 35 °S). These semi-arid regions are characterised by the highest amount of solar radiation. Over 90 % of the sunlight touches the earth as direct radiation due to the limited cloud cover and rainfall (less than 250 mm rain and usually more than 3000 hours of sunshine annually). The second most favourable region lies between the equator and latitudes 15 °N and 15 °S. Due to high humidity and frequent cloud cover, the amount of scattered radiation in this region is high (about 2500 hours of sunshine annually). It is important to note that the majority of developing countries are located between latitudes 35 °N and 35 °S. They can therefore rely on solar radiation as an energy source for solar disinfection of drinking water. (Meierhofer et al., 2002, p. 14)

Solar UV-A intensity shows both seasonal and daily variations. The seasonal variation depends on the latitude and is mainly responsible for the climate in that region. Regions near the equator encounter lower variance of light intensity during the year than regions in

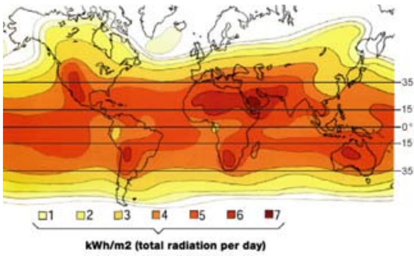


Figure 11: Global solar radiation.

Recommendations and technical user information

- **Cloudiness.** SODIS efficiency is dependent on the amount of available solar energy.
  - Expose the bottle to the sun for one day if the sky is cloudless or up to 50 % cloudy (a five-hour exposure time is technically sufficient, however, since users may not wear a watch, a one-day exposure is recommended to be on the safe side).
  - Expose the bottle to the sun for two consecutive days if the sky is more than 50 % cloudy.
  - One hour exposure time is sufficient at a water temperature of at least 50 °C.
  - During days of continuous rainfall, SODIS does not perform satisfactorily. Rainwater harvesting or boiling is recommended during these days.
- **Turbidity.** SODIS requires relatively clear raw water of less than 30 NTU (= Nephelometric Turbidity Units).

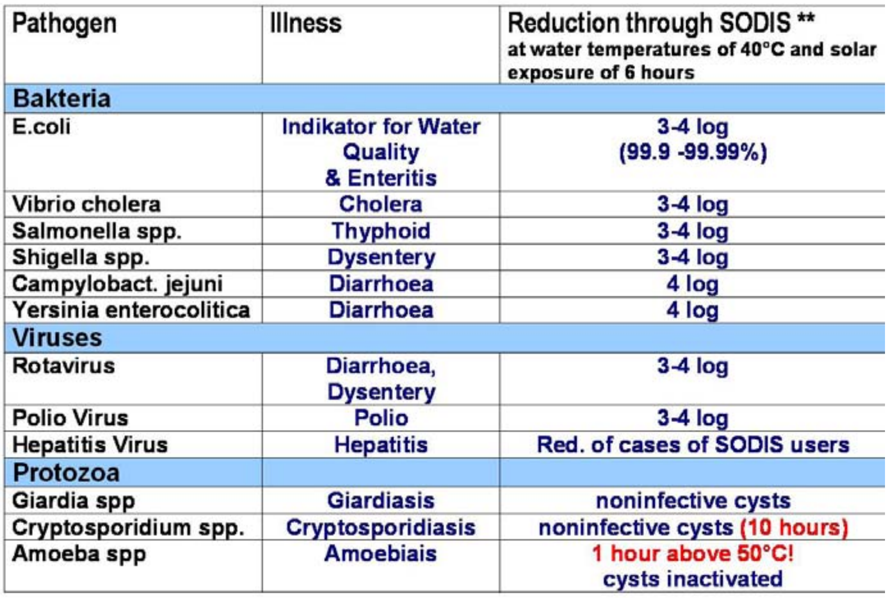
Water turbidity test

Place the water-filled bottle upright on the SODIS logo on top of a table in the shade. Look through the bottle opening to the bottom of the bottle. Water turbidity is less than 30 NTU if you can read the letters of the SODIS logo through the water. If you can still see the sunrays of the logo, turbidity is less than 20 NTU.

Figure 12: SODIS logo and instructions for turbidity test.

- **Oxygen.** SODIS works more efficiently if water contains high levels of oxygen: sunlight produces highly reactive forms of oxygen (oxygen free radicals and hydrogen peroxides) in the water. These molecules react with cell structures and kill the pathogens.
- **Bottle material.** Various types of transparent plastic materials are good transmitters of light in the UV-A and visible range of the solar spectrum. Plastic bottles are made of either PET (polyethylene terephthalate) or PVC (polyvinyl chloride). Both materials contain additives like UV-stabilisers to increase their stability or to protect them and their content from oxidation and UV radiation. Use of bottles made of PET instead of PVC is recommended as PET contains much less additives than PVC bottles.
  Transmission of UV radiation through glass is determined by its iron oxide content. Since ordinary window glass of 2-mm thickness transmits almost no UV-A light, it cannot be used for SODIS. However, glass bottles can be used for SODIS. Specific glass types (Pyrex, Corex, Vycor, Quartz) transmit significantly more UV-light than the ordinary window glass.
- **Shape of containers.** UV radiation is reduced with increasing water depth. At a water depth of 10 cm and moderate turbidity of 26 NTU, UV-A radiation is reduced by 50 %. Therefore, the containers used for SODIS should not exceed a water depth of 10 cm.
- **Replacement of bottles.** Ageing plastic bottles leads to a reduction of UV transmittance that can, in turn, result in a less efficient inactivation of microorganisms. Transmittance losses may be due to mechanical scratches or photoproducts. Heavily scratched, old or blind bottles should be replaced.

(Meierhofer et al., 2002)



Pathogen	Illness	Reduction through SODIS ** at water temperatures of 40°C and solar exposure of 6 hours
Bakteria		
E.coli	Indikator for Water Quality & Enteritis	3-4 log (99.9 -99.99%)
Vibrio cholera	Cholera	3-4 log
Salmonella spp.	Thyphoid	3-4 log
Shigella spp.	Dysentery	3-4 log
Campylobact. jejuni	Diarrhoea	4 log
Yersinia enterocolitica	Diarrhoea	4 log
Viruses		
Rotavirus	Diarrhoea, Dysentery	3-4 log
Polio Virus	Polio	3-4 log
Hepatitis Virus	Hepatitis	Red. of cases of SODIS users
Protozoa		
Giardia spp	Giardiasis	noninfective cysts
Cryptosporidium spp.	Cryptosporidiasis	noninfective cysts (10 hours)
Amoeba spp	Amoebiais	1 hour above 50°C! cysts inactivated

Table 7: Microorganisms eliminated by SODIS. (Meierhofer et al., 2002, p. 12)

the northern or southern hemisphere. In Beirut for example (latitude: 33 °N), the UV-A radiation intensity reaches a peak level of 18 W/m2 in June and decreases to 5 W/m2 in December. The seasonal differences of solar radiation are important factors for solar water disinfection. Seasonal radiation intensities need to be assessed prior to SODIS implementation in a specific area. The solar radiation intensity is also subject to daily variations. Less radiation energy is available with increasing cloudiness. During completely overcast days, the UV-A radiation intensity is reduced to one third of the intensity recorded during a cloudless day. (Meierhofer et al., 2002, p. 14)

Effectiveness and health impact

At a water temperature of 30 °C and a fluence of 555 W*h/m2 (350 – 450 nm, a dose of solar radiation corresponding to approximately five hours of mid-latitude, midday summer sunshine) is required to achieve at least a 3-log (99.9 %) reduction of faecal coliforms. Under these conditions, only the effect of UV-A radiation is present. However, the die-off rate of faecal coliforms exposed to sunlight increases significantly when two stress factors, UV-A radiation and increased water temperature, are present, thus causing the so-called synergetic effect (cf. Fig. 13). (Meierhofer et al., 2002, p. 11)

SODIS is highly effective in improving the microbiological water quality at household level. However, it cannot always guarantee a 100 % reduction of bacteria and viruses as SODIS efficiency also depends on climatic conditions and user's handling practice. (cf. Table 7). <www> (SODIS)

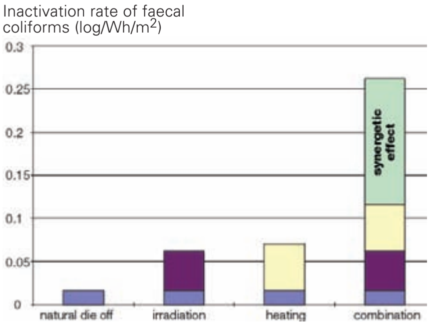


Figure 13: Synergetic effect of heat and radiation. (Meierhofer et al., 2002, p. 12)

SODIS is also effective in eliminating Giardia and Cryptosporidium, but a higher radiation intensity is required to destroy cysts of cryptosporidium. Cysts of amoeba only need a water temperature of at least 50 °C for one hour to be destroyed.

In four randomized, controlled trials, SODIS reduced diarrhoeal disease incidence among users from 9 – 86 %. (Conroy et al., 2001, 1999 and 1996, Rose et al., 2006, Hobbins, 2003, <www> CDC, 2008)

Sustainability of SODIS: A personal report

"My expectations were quite high when we travelled again to Melikan, a small rural village in Indonesia (...). Right in the centre of Melikan is a small lake and the most important water source for the community. People wash themselves and their clothes in the lake, lake water is also used for watering cattle, and the inhabitants also draw their drinking water from it. For lack of firewood, this water was not always boiled before consumption four years ago. Children playing outside could also not be dissuaded from drinking the raw water. As a consequence, both children and adults frequently suffered from diarrhoea. SODIS was well accepted by the inhabitants of Melikan who had carefully been trained in the use of this new water treatment method (...). Three years ago, I met many people who praised the different advantages of SODIS. Two girls were smiling at me and showed me how simple it is to apply SODIS. But has this enthusiasm for SODIS lasted, did the people also replace the broken bottles? We drove through the village and stopped at the house of the community leader who informed us that the women are responsible for SODIS application. After this visit, we walked through the village and discovered many bottles exposed to sunlight either on the roof or on special stands. My heart started to beat faster when we approached the house of my small friends. Near the house we saw SODIS bottles laid down on a wooden stand much higher than the one used three years ago. We talked to a woman breastfeeding a baby. She was the mother of the two girls. At our request, she called her daughters, and around the corner came two healthy teenagers instead of the small girls I met three years ago. Not only the wooden stand had become taller since my last visit but also the girls had grown up considerably. They were again smiling at me, especially when I gave them the SODIS poster with their photo showing how simple it is to apply SODIS. Their continuous use of the water treatment method reveals that SODIS is sustainable in Melikan as it could be in other places around the world".

Martin Wegelin, Sandec.

Photos 5: Two Indonesia girls using SODIS as children (left), and the same girls as teenagers (right). (Source: Eawag/Sandec)

Advantages of SODIS

- Simple application
- Recontamination is unlikely as water is served directly from the small, narrow-necked and capped bottles in which it is treated
- Proven reduction of bacteria, viruses and protozoa
- Proven health impact
- No change in water taste
- Use of local resources
- Reduction of energy demand
- Meeting other needs (transport, safe storage)
- Low cost

(Lantagne et al., 2005, p. 27, Meierhofer et al., 2002, p. 9)

Drawbacks of SODIS

- Requires relatively clear water
- Dependence on climatic conditions
- Long-term treatment (some hours to two days)
- Treatment of limited water volume
- Requires a large supply of intact, clean and adequately sized bottles
- No change in chemical water quality

(Lantagne et al., 2005, p. 27, Meierhofer et al., 2002, p. 9)

Further questions

▸ Is it possible to increase the effect of SODIS?

▸ Up to which contamination level with faecal coliforms does SODIS work?

▸ Can slightly coloured bottles be used for SODIS?

▸ How should old and damaged SODIS bottles be dealt with?

Additional info

▸ Meierhofer, R. and Wegelin, M. (2002): Solar water disinfection - a guide for the application of SODIS. Eawag/Sandec, Dübendorf. www.sodis.ch/Text2002/T-EducationMaterials.htm (last accessed 28.07.08)

Download available on the CD of Sandec's Training Tool and from the Internet.

3.2 What are slow sand filters?

- **If properly constructed, operated and maintained, slow sand filters are capable of removing up to 99 % enteric pathogens.**
- **A biological layer on top of the sand, the so-called "Schmutzdecke", eliminates bacteria and other pathogens.**
- **A minor removal of arsenic, iron or manganese through adsorption and filtration also occurs.**

Filtration in general

A number of processes occur during filtration, including mechanical straining, absorption of suspended matter and chemicals and, particularly in slow sand filters, biochemical processes. Depending on the size, type and depth of the filter media as well as on the flow rate and physical properties of the raw water, filters can remove suspended solids, pathogens, certain chemicals, tastes, and odours. Straining and settlement are treatment methods, which usefully precede filtration to reduce the amount of suspended solids entering the filtration stage. This extends the operating period of a filter prior to cleaning. Larger pathogens (e.g. parasite worm eggs) are more readily removed by filtration than smaller pathogens (e.g. viruses). (Skinner et al., 1999)

Method

In slow sand filtration, the water passes slowly (flow velocity of 100 – 200 l/m²/h) downwards through a bed of fine sand. For the filter to perform well, sudden changes in the flow rate should be avoided and the water should not be very turbid (cloudy with suspended solids), otherwise the filter will quickly clog. The raw water should contain a fair amount of oxygen to promote the useful biological activity both in the biological layer called "Schmutzdecke" and further down in the filter bed. Appropriate slow sand filters can produce a good drinking water quality. (Skinner et al., 1999)

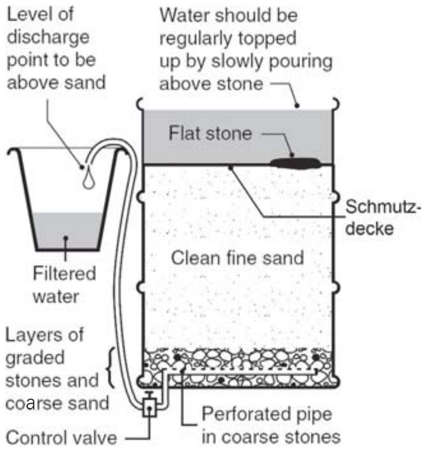


Figure 14: A simple slow sand filter. (Adapted from Skinner et al., 1999)

Four processes remove pathogens and other contaminants:

1. Mechanical trapping: Sediments, cysts and worms are removed from the water by becoming trapped in the spaces between the sand grains. The spaces become smaller over time, enabling the filter to trap smaller particles sooner in the sand bed. The filter can remove some inorganic compounds and metals if they are attached to other materials or to each other.
2. Adsorption or attachment: Viruses are adsorbed or become attached to the sand grains. Once attached, they are metabolised by the cells or inactivated by antiviral chemicals produced by the organisms in the filter. Certain organic compounds are also adsorbed in the sand and thus removed from the water.
3. Predation: The microorganisms within the "Schmutzdecke" or biological layer consume bacteria and other pathogens found in the water, thereby providing highly effective water treatment.
4. Natural death: Food scarcity, less than optimal temperatures and a relatively short life span will cause pathogens to die off and become nutrients for other microorganisms.

<www> (CAWST)

Since it takes several days for the biological layer to build up after filter construction, removal of pathogens and nutrients is limited. An alternative treatment option or a second filter will therefore be necessary.

To prevent filter clogging, the top sand layer has to be replaced periodically, depending on the amount and turbidity of the water filtered. The sand may be washed and used again. After washing

BioSand Filter

The BioSand Filter (BSF) is a slow sand filter suited for home use. The most widely used version of the BSF is a concrete container approximately 0.9 metres tall and 0.3 metres square filled with sand. The water level is maintained at 5 – 6 centimetres above the sand layer by adjusting the height of the outlet pipe. This shallow water layer allows a bioactive layer to grow on top of the sand that helps reduce disease-causing organisms. A perforated plate is placed on top of the sand to prevent disruption of the bioactive layer when water is added to the system. To use the system, users simply pour water into the BSF and collect the filtered water from the outlet pipe in a bucket. (Lantagne et al., 2005, p. 24).
Compared to slow sand filters, BioSand Filters have an intermittent water flow and a higher flow rate.

Advantages:

- Proven removal of protozoa and approximately 90 % bacteria
- One-time installation with few maintenance requirements
- Long life
- High user acceptability due to ease of use, including improved look and taste of water
- High flow rate – up to 36 litres per hour (0.6 L per minute)
- Durable and robust
- Removes turbidity, some iron, manganese, and arsenic
- Water quality improves with time
- Sells for US$ 10 – 30
- Opportunity for local businesses

(Lantagne et al., 2005, <www> CAWST)

Drawbacks:

- Low rate of virus inactivation
- Lack of residual protection and removal of less than 100 % bacteria
- Current lack of studies proving health impact
- Difficult to transport and high initial costs, which makes scalability more challenging
- Periodic use of the filter required
- Can be difficult to move (weight: ~ 80 kg)
- Cannot remove colour or dissolved compounds (same as all other filters)

(Lantagne et al., 2005, <www> CAWST)

the sand, the biological performance of the filter will again be reduced for some days. This also occurs if some substances in the raw water kill the organisms in the biological layer. (UNICEF, 2008, p. 4)

Effectiveness and health impact

Slow sand filters, which remove suspended solids and microbes by means of a slime layer (Schmutzdecke) that develops within the top few centimetres of sand, are capable of removing up to 99 % enteric pathogens if properly constructed, operated and maintained. (UNICEF, 2008, p. 4)

Other studies reveal the following removal efficiencies:

- 83 % E. coli reduction in 83 filter samples
- 96 % faecal coliforms
- 95 – 98 % E. coli in a ripened filter
- 98.5 % E. coli
- 83 % heterotrophic bacterial populations
- 100 % Giardia spp.
- 99.98 % cryptosporidium oocysts
- 50 – 90 % organic and inorganic toxicants.
- All or part of suspended sediments

(<www> CAWST, Lantagne et al., 2005, p. 24)

Advantages of slow sand filters

- Use of locally available material for filter construction
- No material needed for operation
- Improves physical, chemical and bacteriological parameters

Drawbacks of slow sand filters

- Maintenance is crucial for removal efficiency and delivery rate: owners of such filters need to be motivated to operate the filters, to carefully and correctly clean them and to carry out the time-consuming and periodic task of renewing the sand bed. (Skinner et al., 1999)
- Requires raw water of low turbidity (water of > 100 NTU will cause the filter to clog and thus require more maintenance)
- Reduced efficiency until build up of the biological layer (biological layer takes three weeks to develop to maturity)
- Biological layer is destroyed if sand dries out
- Large space requirements, some (simple) construction materials needed

Further questions

- Considering the high reproduction rate of bacteria in tropical climates, is a 90% removal of bacteria sufficient? Is it possible to store the treated water or should it be consumed directly after treatment?
- Considering the laborious and complicated construction and maintenance of the slow sand filter, is this technology appropriate for use at household level or should it better be used at community level?

Additional info

- Lantagne, D., Quick, R. and Mintz, E. (2005): Household water treatment and safe storage options in developing countries: A review of current implementation practises. www.irc.nl/page/37316 (last accessed 15.09.08)

Download available on the CD of Sandec's Training Tool and from the Internet.

- CAWST. Centre for Affordable Water and Sanitation Technology. <www> www.cawst.org (last accessed 25.4.2008

3.3 What is ceramic and terracotta (clay) filtration?

- **This filtration method is suitable for removal of solid particles and some pathogens (depending on pore size of the filter).**
- **Ceramic filtration is most appropriate in areas where quality ceramic filter production is available, including a distribution network for replacement of broken parts and training of users on correct filter maintenance and use. <www> (CDC, 2008)**

Method

Water is filtered through a candle made of porous material, usually unglazed ceramic. Ceramic filters are appropriate only for fairly clear water as they rapidly clog if the water contains suspended particles. Their effectiveness depends on the size of the pores in the clay. Filters with very small pore sizes can remove all pathogens. The impurities are deposited on the surface of the candle. Filters need to be scrubbed off when the candles are blocked and the flow rate is reduced. Boiling the filter after it has been cleaned is also recommended to kill off the pathogens trapped in the pores. Some filters are impregnated with silver to kill microorganisms. Since scrubbing wears down the ceramic material, the candle needs to be replaced periodically before it becomes too thin to guarantee the removal of all pathogens. (Skinner et al., 1999)

Most ceramic filters for HWTS systems are based on a filter/receptacle model. To use the ceramic filters, families fill the top receptacle or the ceramic filter with water that flows through the ceramic filter or filters into a water storage receptacle. The treated and stored water is then accessed via a spigot on the water storage receptacle. <www> (CDC, 2008)

Ceramic filters have traditionally been used for water treatment throughout the world. Currently, the most widely distributed ceramic filter is the Potters for Peace (PFP) filter, which is shaped like a flowerpot and impregnated with colloidal silver. Colloidal silver — tiny silver particles suspended in liquid — is a disinfectant, preventing bacterial growth in the ceramic filter and enhancing inactivation of the bacteria in the filter. (Lantagne et al., 2005, p. 25)

(a) Manufactured unit (b) Candle with jars (c) Using candle with siphon (d) Porous jar

Figure 15: Design option for candle filters. Manufactured filter units as illustrated in (a) are available but costly. If filter candles are available, they can be fitted into earthenware pots (b); an alternative arrangement to avoid watertight connections through the jars is the use of a siphon pipe (c); open porous-clay jars (d) can also be used. (Skinner et al., 1999)

Effectiveness and health impact

The effectiveness of ceramic filters at removing bacteria, viruses and protozoa depends on the production quality of the ceramic filter. Most ceramic filters are effective at removing the majority of the larger protozoal and bacterial organisms but not the smaller viral organisms. Studies have shown significant removal of bacterial pathogens in water filtered through high quality, locally produced and imported ceramic filters in developing countries. <www> (CDC, 2008)

Higher quality ceramic filters treated with bacteriostatic silver have revealed their effectiveness in the lab at reducing waterborne protozoa by more than 99.9 % and bacteria by more than 4 logs. Their potential usefulness as a public health intervention has been shown in development and emergency settings. The effectiveness of the filters in removing viruses is limited. (Clasen et al., 2006 and 2004 in UNICEF, 2008, p. 3)

A 60 – 70 % reduction in diarrhoeal disease incidence has been documented in users of these filters. Studies have also shown significant bacterial contamination when poor-quality, locally produced filters are used or when the receptacle is contaminated at household level. For lack of residual protection, it is important for users to be trained on proper operation and maintenance of the ceramic filter and receptacle. <www> (CDC, 2008)

Advantages of ceramic and terracotta filters

- Long life if the filter remains unbroken
- Proven reduction of bacteria and protozoa
- Proven reduction of diarrhoeal disease incidence in users

<www> (CDC, 2008)

- Neither chemicals nor fossil fuels are required
- Simple installation and operation
- Turbidity is removed
- Local production of low-cost units is possible
- No change in water taste or odour

Drawbacks of ceramic and terracotta filters

- Low filtration rate (1 – 3 litres per hour with non-turbid water)
- Candles are fragile: frequent filter breakages and difficult transport from producer to consumer
- Low effectiveness against viruses
- Small fissures and cracks may lead to reduced removal of pathogens
- No residual disinfection effect (risk of recontamination)

(<www> CDC, 2008, Lantagne et al., 2005)

- Removal efficiency is highly dependent on candle type (variability in quality control of local producers)
- Regular cleaning of the filter and receptacle is necessary, especially when turbid source water is used (otherwise the filter is blocked)
- Not applicable with extremely turbid water.

Photo 6: Example of a ceramic filter. (Source: www.picasaweb.google.com)

Further questions

▸ What is the difference between ceramic and clay filtration? Which material is the best?

Additional info

▸ CDC (2008): Environmental Health - Bibliography on Point-of-Use Water Disinfection 2008 CDC Fact Sheets and Other Documents on Household Water Treatment. www.ehproject.org/ehkm/pou_bib2.html, (last accessed 21.4.2008)

▸ Lantagne, D., Quick, R. and Mintz, E. (2005): Household water treatment and safe storage options in developing countries: A review of current implementation practises. www.irc.nl/page/37316 (last accessed 15.09.08)

Download available on the CD of Sandec's Training Tool and from the Internet.

3.4 What are household defluoridation filters?

- **A filter consisting of bone char can be used for fluoride removal. A combined filter has been developed for additional elimination of heavy metals and microorganisms.**
- **Before purchasing a combined filter, the fluoride concentration of the raw water should be measured to assess the treatment requirements and lifespan of the filter**

Method

The aim of these filters is to decrease the fluoride concentration in water at household level. Fluoride in groundwater and surface water is mostly of geological origin, and elevated concentrations can lead to health effects, such as dental and skeletal problems (cf. Module 2). Defluoridation filters remove fluoride from the water. The filters are designed to supply a household (5 – 12 persons) with water for drinking and cooking. Two types of defluoridation filters are used at household level: a simple defluoridation bucket which removes only fluoride from drinking water and a combined filter, which also eliminates heavy metals and microorganisms from the water. The latter is presented hereafter.

The combined filter consists of two filter processes within the same system. Since the upper bucket for raw water storage is transparent, the water level is visible without opening the lid. The raw water passes through a ceramic candle filter containing silver nitrate and activated carbon. Two different processes lead to the removal of microorganisms: filtration through the ceramic candle and toxic silver nitrate kills the microorganisms flowing through the filter. Moreover, activated carbon adsorbs chemical impurities, such as dissolved organic material and/or heavy metals.

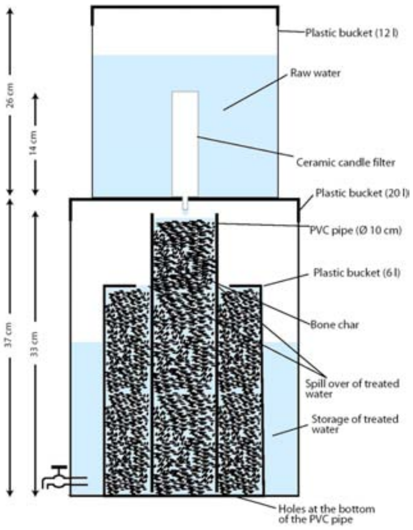


Figure 16: Schematic illustration of a combined defluoridation filter. (CDN et al., 2007)

The water then flows first top-down, then bottom-up through a PVC pipe filled with bone char (6 L). The treated water spills over to the 20-L water bucket, where it is stored and ready for withdrawal.

Before purchasing the combined filter, the fluoride concentration of the raw water is measured to determine the treatment requirements and lifespan of the filter. After purchasing the filter, the first few litres of treated water have to be discarded due to elevated turbidity and colour. Thereafter, the treated water is colourless and tasteless. The upper bucket is refilled with raw water. The users can withdraw treated water at any time as contact time in the bone char filter is regulated by the flow around the candle filter. The surface of the ceramic filter needs to be washed regularly as soon as the flow rate decreases. Washing should be carried out with clean water and a soft cloth. If the fluoride concentration in the outlet exceeds 1.5 mg/L the saturated filter medium has to be replaced.

Effectiveness and health impact

Studies on fluoride removal efficiency of defluoridation filters of CDN WQ (Catholic Diocese of Nakuru, Water Quality section) conducted by Mavura et al. (2002) in Kenya exhibited very high F removal efficiencies ranging between 97.4 % and 99.8 % (in general > 99 %). According to CDN WQ's laboratory research, about 200 bedvolumes of water containing 6 mg F/L can be treated at a flow rate of 10 bedvolumes/day before the F concentration in the treated water exceeds the national Kenyan standard of 1.5 mg F/L.

As fluoride is invisible, tasteless and odourless, regular sampling and analyses in the laboratory or on-site are necessary to ensure fluoride removal. Monitoring studies of households carried out in October 2006 revealed that saturated bone char is often not properly regener-

Photos 7: A combined defluoridation filter (above and middle) and the ceramic candle (below). (Source: CDN et al., 2007)

Advantages of defluoridation filters

- Bone char is a suitable filter medium with a high fluoride removal efficiency. The raw material required is locally available and production costs are low.
- The candle filter regulates the flow through the bone char filter (users do not have to be concerned about the required contact time).
- Optimal use of the adsorption capacity of the bone char due to column design.
- The filter medium never dries up as water flows bottom-up into the inner bucket containing bone char.
- The combined filter removes fluoride as well as microorganisms and heavy metals (no additional treatment required).

(CDN et al., 2007)

Drawbacks of defluoridation filters

- Maintenance of the candle filter requires regular washing
- Ceramic candles may break if not handled carefully
- Raw water with elevated turbidity cannot be treated with this filter design due to clogging of the candle filter
- If treated water is not withdrawn and only raw water is added, the water may overflow from the defluoridation bucket
- The combined filter is more expensive than a simple defluoridation bucket

(CDN et al., 2007)

ated either for lack of knowledge or finances. (CDN et al., 2007)

Due mainly to the chronic nature of fluorosis, studies on the health impact of defluoridation treatment are still lacking. Such studies are important but challenging, as several years are required to obtain satisfactory data.

Further questions

▸ Is it more effective to use a combined filter or to combine two different methods (e.g. SODIS + simple defluoridation bucket) to obtain safe drinking water?

▸ Is it realistic to expect users to regularly control and replace their filters?

Additional info

▸ CDN and Müller, K. (2007): CDN's defluoridation experiences on a household scale. Catholic diocese of Nakuru, Water quality/EAWAG. www.eawag.ch/organisation/abteilungen/sandec/publikationen/publications_ws/downloads_ws/ws_household_scale.pdf (last accessed 15.09.08)

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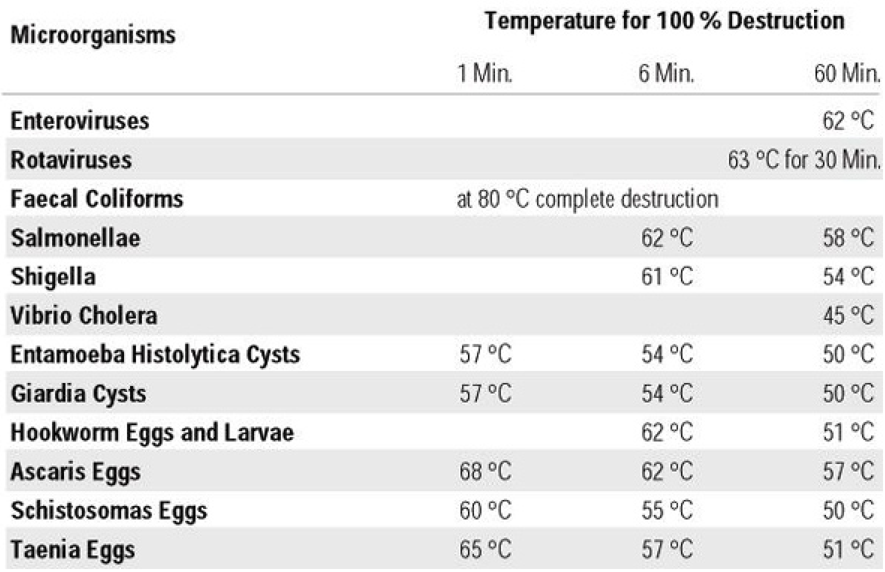
3.5 What is water boiling and pasteurisation?

- **The boiling of water is a simple method for sterilisation of small quantities of drinking water. Even heating to pasteurisation temperatures (60 °C) for a few minutes will kill or deactivate most pathogens.**
- **The cost and time required to procure fuel, the increased risk of fire, indoor air pollution, and questions related to the environmental sustainability of boiling are all realistic drawbacks.**

Methods

Microbiologically contaminated water is filled in a heat-resistant vessel (cooking pot, steel drum) and brought to boil. At sea level, the boiling point is at 100 °C. As a rule of thumb, water should be kept boiling for one minute at sea level, and one minute boiling time added for every 1000 metres of elevation. Ideally, the water is cooled and stored in the same vessel in order to minimise the risk of recontamination.

Boiling or heat treatment of water with fuel is effective against the full range of microbial pathogens and can be employed irrespective of water turbidity or dissolved constituents in the water. While WHO and others recommend bringing water to a rolling boil for one



Microorganisms	Temperature for 100 % Destruction		
	1 Min.	6 Min.	60 Min.
Enteroviruses			62 °C
Rotaviruses			63 °C for 30 Min.
Faecal Coliforms	at 80 °C complete destruction		
Salmonellae		62 °C	58 °C
Shigella		61 °C	54 °C
Vibrio Cholera			45 °C
Entamoeba Histolytica Cysts	57 °C	54 °C	50 °C
Giardia Cysts	57 °C	54 °C	50 °C
Hookworm Eggs and Larvae		62 °C	51 °C
Ascaris Eggs	68 °C	62 °C	57 °C
Schistosomas Eggs	60 °C	55 °C	50 °C
Taenia Eggs	65 °C	57 °C	51 °C

Table 8: Effect of heat on selected pathogens. (Adapted from Feachem et al., 1983)

Chulli
To pasteurise water, a simple flow-through system has been developed, which makes use of waste heat generated in traditional clay ovens or "chullis" in Bangladesh. A hollow aluminium coil is fitted into the clay chulli and water is passed through the coil during normal cooking events. By adjusting the flow rate, effluent temperature can be maintained at approximately 70 °C. Laboratory testing, along with over 400 field tests on chulli systems deployed in six pilot villages, showed that the treatment completely inactivated thermotolerant coliforms. The chulli system produces up to 90 litres of treated water per day at the household level without any additional time or fuel requirement. The technology, which was developed to provide an alternative source of safe drinking water in arsenic-contaminated areas, may also be widely applied wherever people consume microbiologically contaminated water. However, it does not remove arsenic but allows the use of microbiologically contaminated but arsenic-free surface water sources.

(Fakhrul Islam et al., 2006, p. 356)

Photo 8: Construction of a flow-through system in a traditional Bangladeshi clay oven. (Source: Richard Johnston, UNICEF in Fakhrul Islam et al., 2006)

minute, it is mainly intended as a visual indication that a high temperature has been achieved; even heating to pasteurisation temperatures (60 °C) for a few minutes will kill or deactivate most pathogens. However, the cost and time used in procuring fuel, the potential aggravation of indoor air quality and associated respiratory infections, the increased risk of fire, and questions associated with the environmental sustainability of boiling have led to other alternatives. (UNICEF, 2008, p. 4)

Effectiveness and health impact

Table 8 lists temperatures and exposure times required to eliminate microorganisms. As shown, water does not have to be boiled in order to kill 99.9 % of the microorganisms. Heating the water up to 50 – 60 °C for one hour has the same effect. (Meierhofer et al., 2002, p. 11)

Advantages of water boiling and pasteurisation
- Common technology
- Complete disinfection (if applied with sufficient temperature and time)
- Can be combined with cooking and tea boiling

Drawbacks of water boiling and pasteurisation
- Boiled water has a flat taste
- Operation might be expensive (fuel, fire wood, gas etc.)
- Method is time consuming (physical presence needed during the heating process, long cooling down time)
- Chemicals are not removed
- Water boiling is often not performed in practice because:
  - energy is scarce and expensive
  - electricity and kerosene are frequently not available
  - firewood is generally used for cooking only

Further questions
▸ Gas stoves currently often replace traditional ovens. Could these also be used in the same way as the chullis for water pasteurisation?

▸ How could people learn about the exact time and temperature needed for pasteurisation? How can they control it to render the water treatment process as energy saving as possible?

Additional info
▸ Meierhofer, R. and Wegelin, M. (2002): Solar water disinfection - a guide for the application of SODIS. Eawag/Sandec, Dübendorf. www.sodis.ch/Text2002/T-EducationMaterials.htm (last accessed 28.07.08)

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3.6 What is chemical disinfection?

- **Chemical disinfection of water leads to the destruction and inactivation of pathogens, especially bacteria and viruses. The effect on parasites is limited.**
- **It is most appropriate in areas with an available and consistent supply of hypochlorite solution, with water of relatively low turbidity as well as in urban, rural and emergency situations, where educational messages promoting the correct and consistent use of the hypochlorite solution can reach users. <www> (CDC, 2008)**

Method

The disinfecting substance, such as chlorine, is added to the contaminated water, often as sodium hypochlorite (liquid bleach, Javel) or calcium hypochlorite (bleaching powder). The pathogens are destroyed after a defined reaction time. If applied in the right amount, the substances provide a disinfecting residual that helps to prevent recontamination. Commonly used disinfectants are:

- Sodium hypochlorite (liquid bleach, Javel water)
- Calcium hypochlorite (chlorinated lime, bleaching powder)
- High test hypochlorite (HTH)
- Potassium permanganate
- Bromine in different chemical forms
- Iodine (iodine and bromine are not recommended for long-term application)
- Silver in different chemical forms

All of the above agents are commercially available in different strengths. Dosing has to be adjusted according to water quality and strength of a solution (or powder). In turbid water, chlorine is absorbed by organic and inorganic matter and no longer available for disinfection. This leads to dosing difficulties if the raw water source is subject to turbidity variations. (Turbidity is the amount of organic and inorganic substances dissolved in the water).

Apart from boiling, chlorination is the most widely practised means of treating water at community level. Chlorine must be added in sufficient quantities to destroy all the pathogens but not so much that taste is adversely affected. Appropriate dosage leads to a concentration of 0.5 mg/L free chlorine in the water (WHO, 2006a). In addition to sodium hypochlorite solution packaged in bottles, the tablets formed from dichlorisocyanurate (NaDCC), a leading emergency treatment of drinking water, and novel systems for on-site generation of oxidants, such as chlorine dioxide, also play a role in household water treatment. (UNICEF, 2008, p. 3)

Advantages of chemical disinfection
- proven reduction of most bacteria and viruses
- proven health impact
- low cost
- scalability

<www> (CDC, 2008)
- Wide range of products commercially available
- Residual effect prevents recontamination to a certain degree
- Wide range of microorganisms are removed
- No energy required at household level

Drawbacks of chemical disinfection
- Relatively low protection against parasites
- Lower disinfection effectiveness in turbid waters contaminated with organic and inorganic compounds
- Concern about the potential long-term carcinogenic effects of chlorination by-products

<www> (CDC, 2008)
- Dosage of the different chemicals is difficult at household level
- Storage of different disinfectants is difficult.
- Contact time is essential for disinfectants to react
- Strong taste and odour of the treated water

Overall, sodium hypochlorite, the active ingredient in commercial laundry bleach solutions, appears to be the safest, most effective and least expensive chemical disinfectant for point-of-use treatment. A dilute solution of sodium hypochlorite can be produced on-site through electrolysis of salt water or commercially manufactured by a private company. (Mintz et al., 2001, p. 1566)

The sodium hypochlorite solution is packaged in a bottle with directions instructing users to add one full bottle cap of the solution to clear water (or two caps to turbid water) in a standard-sized storage container, agitate and wait 30 minutes before drinking. (Lantagne et al., 2005, p. 19)

A Safe Water System (SWS) was developed by the Centres for Disease Control and Prevention (CDC) and the Pan American Health Organisation, combining the hypochlorite water treatment with safe storage and hygiene. <www> (CDC, 2008)

Effectiveness and health impact

At concentrations used in HWTS programmes, the hypochlorite solution is effective at inactivating most bacteria and viruses that cause diarrhoeal disease. However, it is not effective at inactivating protozoa, such as cryptosporidium and amoeba. Numerous studies have shown complete removal of bacterial pathogens in hypochlorite-treated water in developing countries. In seven randomized control trials, the SWS reduced diarrhoeal disease incidence in users from 22 – 84 %. These studies, conducted in rural and urban areas, include adults, children, poor, HIV positive, and/or people using highly turbid water. <www> (CDC, 2008)

SWS has been used to improve the safety of oral rehydration solutions, street-vended beverages, and as an emergency response measure for persons displaced by natural disasters and threatened by epidemic cholera. (Mintz et al., 2001, p. 1566)

Initial research shows that water treated with SWS does not exceed WHO guidelines for disinfection by-products, which are potentially cancer-causing agents. Since the concentration of the chlorine solution used in SWS programmes is low, the environmental impacts of the solution are minimal. (Lantagne et al., 2005, p. 19)

Further questions

▸ How can parasites be removed to obtain completely safe drinking water?

▸ Is there a long-term carcinogenic risk if the hypochlorite solution is "overdosed"?

Additional info

▸ CDC (2008): Environmental Health - Bibliography on Point-of-Use Water Disinfection 2008 CDC Fact Sheets and Other Documents on Household Water Treatment. www.ehproject.org/ehkm/pou_bib2.html, (last accessed 21.4.2008)

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3.7 What is flocculation and sedimentation?

- **Method used for the treatment of turbid water.**
- **Should be followed by one of the aforementioned treatment systems to eliminate microbial or chemical contamination.**

Turbidity

Turbidity in drinking water is caused by inadequately filtered particulate matter present in source water or from resuspended sediments in the distribution system. It may also be caused by inorganic particulate matter present in some groundwaters or due to sloughing of the biofilm within the distribution system. Water with less than 5 NTU is usually acceptable to consumers; however, this may vary according to the local context. (WHO, 2006a, p. 219)

High turbidity is a particular challenge for most household-based water treatment technologies. Solids can use up free chlorine and other chemical disinfectants, cause premature clogging of filters and block UV radiation essential for solar disinfection. Particulates can even stimulate bacterial growth. While turbidity can often be managed by pretreatment or even simple sedimentation, flocculation/coagulation using common substances, such as alum, can be an effective and relatively low-cost option. Such forms of assisted sedimentation have been shown to reduce the levels of certain microbial pathogens, especially protozoa, which may otherwise present a challenge to chemical disinfectants. (UNICEF, 2008, p. 4)

In any case, where water is disinfected, the turbidity must be low so that disinfection can be effective. No health-based guideline value for turbidity has been proposed; ideally, however, median turbidity should be below 0.1 NTU for effective disinfection, and changes in turbidity are an important process control parameter. (WHO, 2006a, p. 219)

Also the disinfection efficiency of SODIS is reduced in turbid water. Suspended particles in the water reduce the penetration of solar radiation into water and protect microorganisms from being irradiated. SODIS requires relatively clear raw water with a turbidity of less than 30 NTU. If water turbidity is higher than 30 NTU, the water needs to be pretreated before being exposed. Larger particles and solids can be eliminated by storing the raw water for one day, letting the particles settle to the bottom prior to decanting the water.

Methods

Turbidity can be reduced by:

- Coagulation/flocculation/sedimentation (e.g. using aluminium sulphate or crushed Moringa oleifera seeds)
- Filtration (e.g. using a sand layer or a cloth)

(Meierhofer et al., 2002, p. 15)

Conventional coagulation/flocculation/sedimentation practices are essential pretreatments for many water purification systems, especially for filtration treatments. These processes agglomerate suspended solids together into larger bodies so that physical filtration processes may remove them more easily. Particulate removal by these methods renders subsequent filtration processes far more effective. The process is often followed by gravity separation (e.g. sedimentation) and is always followed by filtration.

A chemical coagulant, such as iron salts, aluminium salts or polymers, is added to source water to facilitate bonding of particulates. Coagulants create a chemical reaction and eliminate the negative charges that cause particles to repel each other.

The coagulant-containing source water mixture is then slowly stirred in a process known as flocculation. This water churning induces particles to collide and clump together into larger and more easily removable clots or "flocs". The process requires chemical knowledge of source water characteristics to ensure the use of an effective coagulant mix. Inadequate coagulants make these treatment methods ineffective. The ultimate effectiveness of coagulation/flocculation is also determined by the efficiency of the filtering process with which it is paired. <www> (GHEF)

Moringa. Using natural materials to clarify water is a long-standing technique. Of all the materials used, seed powder of the Moringa tree seems the most ef-

Advantages of Moringa

- Moringa oleifera trees are hardy and drought-resistant, fast growing and a source of large numbers of seeds.
- Moringa oleifera seeds are non-toxic and effective coagulants useful for removing turbidity and bacteria from water.
- The cost of seed treatment is very low, in most cases negligible.

<www> (Clearinghouse)

Drawbacks of Moringa

- Plant seeds may not be readily available.
- Moringa treatment is suitable to reduce turbidity but not highly effective in removing pathogens.

<www> (Clearinghouse)

Photos 9: Moringa tree and seeds. (Source: www.treesforlife.org)

fective. With a 60 % protein content, the seed pressed cake left over from crushing seeds to obtain oil can be used as soil fertiliser, fuel for cooking and to clear dirty water. The Moringa seeds are crushed and mixed with the water, as a natural coagulant to remove water turbidity.

Storage and settlement. Storing water for just one day can result in the die-off of more than 50 percent of most bacteria; conditions in storage vessels are usually not conducive to their survival. Longer periods of storage will lead to further reduction. Cercariae, intermediate hosts in the lifecycle of schistosomiasis, can only live for 48 hours after leaving a snail if they do not reach a human or animal host. Storing water for more than two days thus effectively prevents the transmission of this disease. Suspended solids and some of the pathogens in any water left in a container will begin to settle at the bottom. After a period of several hours, the water collected from the top of the container will be relatively clear, unless the solids are very small (e.g. clay particles). Although this clear water will still contain some pathogens, many others will have settled to the bottom, often attached to the surface of particles. (Skinner et al., 1998). This is the cheapest and simplest but not very effective water treatment and storage system.

PūR

Several systems include both a chemical coagulation step for particle removal (flocculation) and a chlorination step for disinfection. This dual approach produces high-quality water. A HWTS option, the so-called PūR (Purifier of Water), was developed for sale to users and NGOs at production cost. The small sachet containing ferrous sulphate (a flocculant) and calcium hypochlorite (a disinfectant) powder has a dual effect of particle removal and disinfectant. (Lantagne et al., 2005, p. 29)

Effectiveness and health impact

The flocculant/disinfectant powder PūR proved its ability to remove most bacteria, viruses and protozoa, even in highly turbid waters. PūR has also been documented to reduce diarrhoeal disease from 16 to over 90 % incidence in five randomized controlled health intervention studies. Moreover, PūR eliminates heavy metals from water, such as arsenic, and chemical contaminants, such as pesticides. Studies on the efficiency of PūR have been conducted in the laboratory, in developing countries, in rural and urban areas as well as in refugee camps, with poor adults and children using highly turbid water. <www> (CDC, 2008)

Advantages of PūR

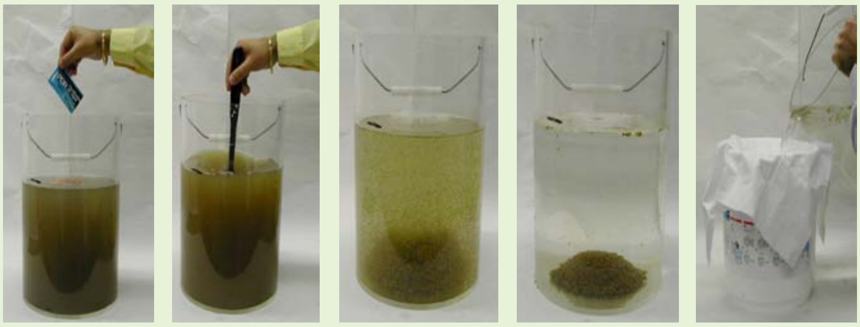
- Removal or inactivation of viruses, bacteria, parasites, heavy metals, and pesticides even in highly turbid waters;
- Residual protection;
- Proven health impact;
- Ease of scalability or use in emergency situations as the sachets are centrally produced and easily transported (due to their small size, long shelf life and classification as a non-hazardous material for air shipment).

Drawbacks of PūR

- Multi-step process requiring demonstrations for new users and a time commitment for water treatment from the users;
- Requires two buckets, a cloth and a stirring device; and
- High relative cost per litre of water treated.

(Lantagne et al., 2005)

PūR (Purifier of Water™) was developed by Procter & Gamble (P&G) in collaboration with the Centres for Disease Control and Prevention. PūR sachets are now centrally produced in Pakistan and sold to NGOs worldwide at a cost of US cent 3.5 per sachet. <www> (CDC, 2008)



Photos 10: Use of PūR: open the sachet, add the contents to an open bucket containing 10 litres of water, stir for five minutes, let the solids settle to the bottom of the bucket, strain the water through a cotton cloth into a second container, and wait 20 minutes for the hypochlorite to inactivate the microorganisms. (Lantagne et al., 2005, p. 29). (Source: UNICEF, 2008)

Further questions

▸ How can the need for water pretreatment be determined? Is there a simple turbidity test valid for all HWTS systems?

▸ Is there a risk for water contamination through turbidity treatment if, for example, the cloth used as filter is not clean or the Moringa seeds contain pathogens on their surface?

Additional info

▸ CDC (2008): Environmental Health - Bibliography on Point-of-Use Water Disinfection 2008 CDC Fact Sheets and Other Documents on Household Water Treatment. www.ehproject.org/ehkm/pou_bib2.html, (last accessed 21.4.2008)

▸ Lantagne, D., Quick, R. and Mintz, E. (2005): Household water treatment and safe storage options in developing countries: A review of current implementation practises. www.irc.nl/page/37316 (last accessed 15.09.08)

Download available on the CD of Sandec's Training Tool and from the Internet.

▸ Clearinghouse Clearinghouse for low-cost household water treatment technologies. <www> www.jalmandir.com (last accessed 25.4.2008)

3.8 What HWTS system should be chosen?

- **There is no "best" HWTS system. The choice depends on local criteria, such as water quality at the source, cultural preferences or financial possibilities.**
- **To entirely remove microbiological and chemical contamination as well as turbidity, a combination of different systems might be necessary.**

Choice of the best HWTS option in a given area is a challenge for implementers. Important criteria to consider when selecting a HWTS option include:

- Community or user specific needs and preferences. For example, if turbidity of the source water is high, users should pretreat water by filtration or coagulation prior to disinfection and safe storage or, if users prefer a current practice, such as storing water in ceramic pots, the project should include this practice;
- Mechanisms to prevent recontamination of the treated water: a number of HWTS options include some form of residual protection (SWS, SODIS, P□R). Safe storage or other mechanisms to prevent post-treatment contamination should form part of every HWTS project; and
- Mechanisms (financial or other) providing sustained availability: long-term access to the HWTS option requires not only activation of some type of supply chain but also ensuring that once activated, access is uninterrupted.

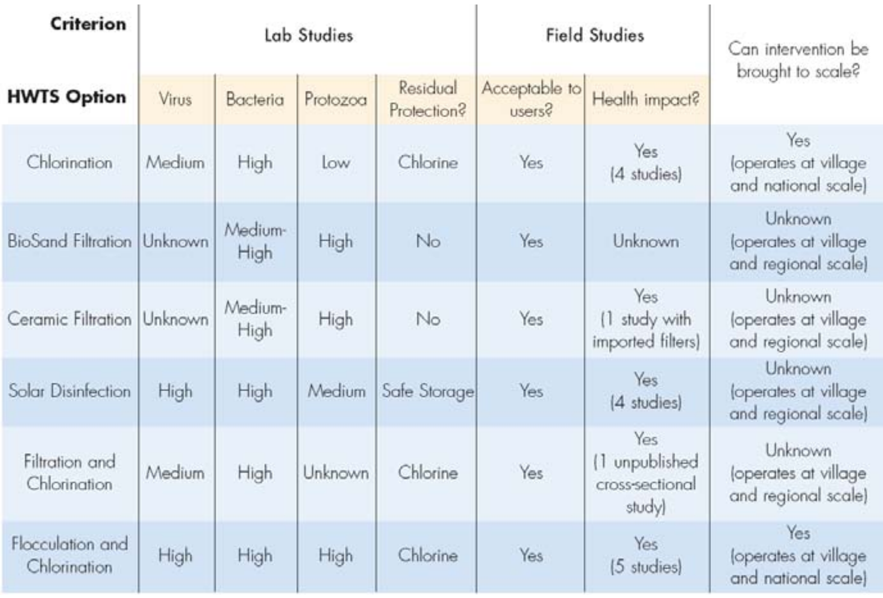
(Lantagne et al., 2005)

Combining the treatment methods

Many HWTS systems require pretreatment as they function only with water of low turbidity. Furthermore, methods used to remove chemicals do not necessarily also remove pathogens or vice versa. Therefore, a combination of two water treatment methods might be necessary to produce microbiologically and chemically safe drinking water.

Sometimes the choice of a HWTS intervention is not systematic

"We examined a BioSand Filter installation operating in a peri-urban slum with access to piped and processed municipal water – and intervention, which is not the most cost-appropriate or effective for this setting. An investigation of source water quality prior to implementation would have revealed that a potentially more appropriate intervention, such as improving the local water supply, educating users on safe water storage to prevent recontamination or using chlorination alone, should have been implemented." (Lantagne et al., 2005, p. 31)



Criterion	Lab Studies				Field Studies		Can intervention be brought to scale?
HWTS Option	Virus	Bacteria	Protozoa	Residual Protection?	Acceptable to users?	Health impact?	
Chlorination	Medium	High	Low	Chlorine	Yes	Yes (4 studies)	Yes (operates at village and national scale)
BioSand Filtration	Unknown	Medium-High	High	No	Yes	Unknown	Unknown (operates at village and regional scale)
Ceramic Filtration	Unknown	Medium-High	High	No	Yes	Yes (1 study with imported filters)	Unknown (operates at village and regional scale)
Solar Disinfection	High	High	Medium	Safe Storage	Yes	Yes (4 studies)	Unknown (operates at village and regional scale)
Filtration and Chlorination	Medium	High	Unknown	Chlorine	Yes	Yes (1 unpublished cross-sectional study)	Unknown (operates at village and regional scale)
Flocculation and Chlorination	High	High	High	Chlorine	Yes	Yes (5 studies)	Yes (operates at village and national scale)

Table 9: Different HWTS options and their performance criteria. (Adapted from Lantagne et al., 2005, p. 19)

Further questions

- Who decides on the appropriate combination of methods?
- Should a community or family concentrate on one HWTS system or should different systems be available to react to possibly rapid water quality changes?
- What is the health impact of routine versus sporadic use of HWTS options in the home? (Lantagne et al., 2005)
- Which HWTS system is the most appropriate for disaster situations?

Additional info

- Lantagne, D., Quick, R. and Mintz, E. (2005): Household water treatment and safe storage options in developing countries: A review of current implementation practises. www.irc.nl/page/37316 (last accessed 15.09.08)

Download available on the CD of Sandec's Training Tool and from the Internet.

3.9 What is safe storage?

- **Safe storage of drinking water includes appropriate vessels and correct handling of the stored water.**
- **The properties of household water collection, treatment and storage vessels must be compatible with the intended uses (collection, treatment and storage), meet the daily water volume needs of the household, be practical and manageable for the users (women, men or children), and be socio-culturally acceptable.**

Water from potable sources or water turned potable by boiling, chemical treatment or solar disinfection remains susceptible to the introduction of contaminants during collection, transport and storage. The risk of diarrhoea from contamination of drinking water during household storage, first noted in the 1960s, has since then been repeatedly observed. Safe water storage vessels with tight-fitting lids and narrow mouths, allowing users to remove water by pouring or through spigots but not by dipping, have been included in both chemical and solar water treatment programmes. The great challenge is to create water storage vessels that correspond to traditional cultural standards and still meet the requirements of adequately protecting treated water from recontamination. (Mintz et al., 2001, p. 1568)

Since ancient times, water for household use is collected by a variety of methods and stored in a variety of containers. In developing countries, many of the traditional types of water storage methods employing vessels of various materials and sizes are still widely used today. These include traditional pots or urns fashioned from natural materials (e.g. gourds or wood) or fabricated from clay, copper, brass, and other impervious materials, as well as flexible bags or other vessels made of animal hides, other animal parts or fabrics treated to seal and prevent leakage. Today, metals, such as aluminium, steel and iron, as well as other materials, primarily plastics, have come into widespread use for water collection and storage in the form of buckets, jerry cans, picnic coolers, and other vessel types and shapes. (Sobsey, 2002, p. 8)

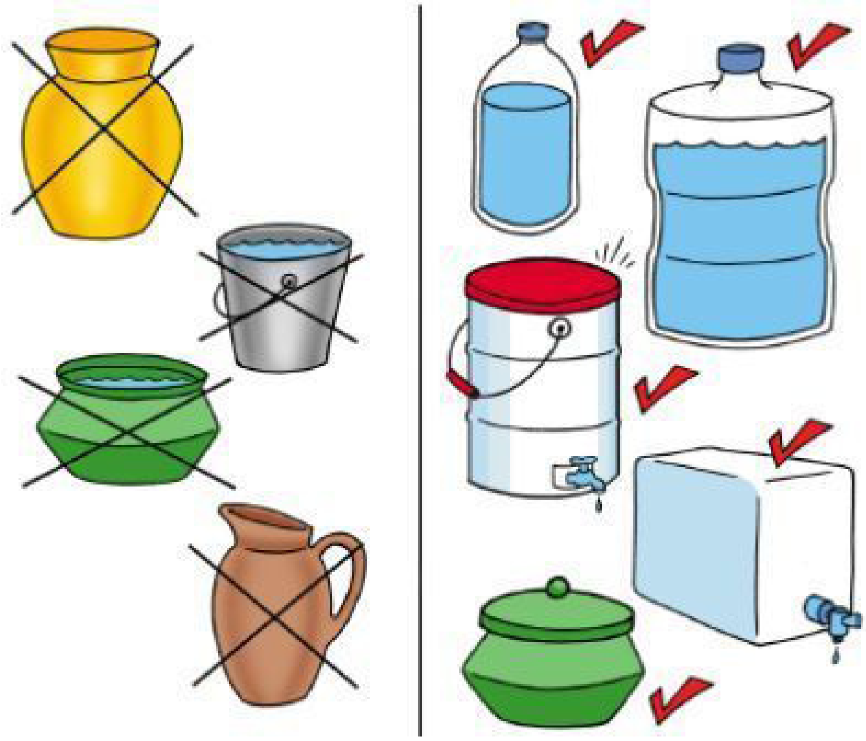


Figure 17: Some examples of good and bad storage containers. <www> (CAWST)

Some of the key factors influencing the impact of storage vessels and conditions on household water quality are:

- Handling and ease of use based on capacity, size, shape, weight, presence of handles;
- Durability, weight and other properties related to resistance and longevity;
- Presence of a coverable (preferably screw-cap) opening for filling and cleaning access but small enough to reduce the potential for recontamination by contaminated hands, dipping utensils and other vehicles (e.g. airborne dust), vectors or other sources;
- Ability to withdraw water in a sanitary manner, such as via a tap, spigot, spout or other narrow orifice; and
- Presence and accessibility of documentation on the proper use of the container for water treatment and sanitary storage.

(Sobsey, 2002, p. 8)

A properly designed safe storage system should meet the following requirements:

- The storage vessels must be affordable. Locally available buckets, pots, urns, jerry cans, barrels, used beverage containers, flexible bags, and flagons are usually of low cost and readily available.
- Beside storage, the vessel should be suitable for water collection and transport.
- The vessel should be compatible with household water treatment methods. Multiple containers are needed in some household water treatment systems. For example, one for raw, untreated water and another for treated water. The vessel materials must be compatible with the physical and chemical agents used for water treatment. In case of chemical use, such as disinfectants (e.g. chlorine), the vessel material must not require excessive oxidants or result

in chemical reactions leading to high concentrations of toxic disinfection by-products. In case of solar or heat treatments, the vessel must be capable of withstanding high temperatures, and depending on the type of solar treatment, they must allow penetration of UV radiation and/or absorption of heat energy.

(Sobsey, 2002, p. 9)

The most appropriate water storage vessels for many household treatment and storage options are:

- Between 10 – 25 litres capacity, rectangular or cylindrical with one or more handles and flat bottoms for handling and ease of storage;
- Made of lightweight, oxidation-resistant plastic, such as high-density polyethylene or polypropylene for durability and shock resistance;
- Fitted with a 6 – 9-cm screw-cap opening to facilitate cleaning, but small enough to discourage or prevent the introduction of hands or dipping utensils;
- Fitted with a durable, protected and easily closed spigot or spout for dispensing water; and
- Provided with pictorial and/or written instructions for use affixed permanently to the container, as well as an affixed certificate of approval or authenticity.

(Sobsey, 2002, p. 9)

Effectiveness and health impact

By simply replacing unsafe with safe water storage vessels resulted in lowering the rates of cholera transmission in Calcutta's households. (Mintz et al., 2001, p. 1567)

A study was conducted among a Malawi refugee population, which experienced repeated outbreaks of cholera and diarrhoea, and where water contamination in the homes was found to be a significant cause of cholera. The water in the source wells had little or no microbial contamination, however, the water collectors rapidly contaminated the water, primarily through contact with their hands. One fourth of the households were supplied with the improved water collection container. Analysis revealed a 69 % reduction in faecal coliform levels in household water and 31 % less diarrhoeal disease among children under the age of five in the group using the improved bucket. (Roberts et al., 2001)

Further questions

▸ Which is the best storage vessel overall?

▸ How long should water be stored? Is there a time limit for water use? Or, regarding water quality as a function of storage time, is there a maximum water quality peak?

Additional info

▸ CAWST. Centre for Affordable Water and Sanitation Technology. <www> www.cawst.org/index.php?id=120 (last accessed 15.09.2008)

4.1 What are the quantitative water aspects?

- **In developing countries, 20 litres are used on average for household purposes, compared to 150 litres in industrialised countries.**
- **Not all of this water has to be of excellent quality, merely the amount used for drinking or preparing food consumed uncooked should be treated, i.e. generally less than five litres per person and day.**
- **Ready access to water is essential as it leads both to an increased quantity of water used for hygiene purposes and improved health. (The amount of water used per person and day depends on the distance to the source).**
- **Furthermore, ready access to water results in time saving: typically half an hour to an hour per day and household. The time saved benefits mainly women and is a significant contribution to their emancipation.**

The drinking water needs is estimated at about two litres per day for a 60-kg person and one litre per day for a 10-kg child. <www> (WHO)

However, water is not only required for drinking but also for cooking, cleaning or personal hygiene. The table contains the average household water needs in industrialised and developing countries.

Not all the water a person uses during a day needs to be of perfect microbiological and chemical quality. Usually less than five litres/person/day are needed for drinking or preparing food eaten uncooked. Treating only this amount of water will be much easier than treating all the water used in the house. If the raw water looks reasonably clear, it will usually not require treatment before use for other domestic purposes. Water may sometimes need treatment for:

- bathing – if it contains pathogens which penetrate the skin (e.g. cercariae, which transmit schistosomiasis);
- cooking – if excessive iron or manganese cause taste or colour problems, or if harmful chemicals are transferred from the water to the food; and
- laundry – if it contains so much iron or manganese that it stains the clothes.

(Skinner et al., 1998)

Experience reveals that the quantity of water used per capita depends on the accessibility of the water source. Those people with access to a house or yard connection or to a well inside the property will use larger quantities of water than those having to fetch water outside, even if such a source is only a few minutes' walk from the house. (WHO/UNICEF, 2000, p. 12)

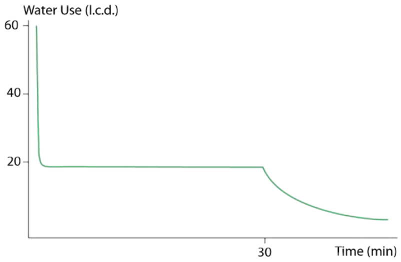


Figure 18: Typical relationship between water collection time and mean household water use. (l.c.d. = litre consumed daily per person). (Cairncross et al., 2003, p. 17)

A number of studies from developing countries have pointed to the importance of ready access to water an resulting increases in the quantity used for hygiene, rather than water quality improvements alone, in determining the health benefit. A complicating factor is that the quantity of water used is related in a nonlinear way to the distance of the household from the water source. When water is provided closer to the home, water use increases until a plateau is reached at about 1 km (cf. Fig. 18). When water is provided closer than that, there is very little further increase unless on-plot taps are provided, when water use doubles or trebles. A number of studies in the last two decades failed to find any health benefit when water quality alone was improved, while a large proportion of the classical studies, which detected significant health benefits, compared groups using in-house piped water with others using public taps or wells. The negative studies usually surprised their authors, but the results were quite comprehensible when it came to be understood that a significant percentage of diarrhoeal disease is not waterborne but transmitted from person-to-person on hands, food and other fomites because of poor hygiene practices. (Cairncross et al., 2003, p. 17)

Water supply is about much more than health. It offers other benefits to which a money value can be attributed more easily than its health effect, and which often figure larger in the consumer's eyes. The saving in time spent by a household collecting water is typically half an hour to an hour per day. Mainly women profit from this time saving, which significantly contributes to their emancipation. It allows women to devote more time to child-care, and there is evidence that this affects the children's nutritional status. (Cairncross et al., 2003, p. 15)

Further questions

- What are the per capita water use differences between the developing countries?
- If there is not enough safe water available for a family, what "priority ranking" is given to the different uses? (e.g. drinking water for children under five, cooking for babies, drinking for working adults etc.).

Additional info

- Cairncross, S., O'Neill, D., McCoy, A. and Sethi, D. (2003): Health, environment and the burden of disease; A guidance note. DFID, London. www.dfid.gov.uk/Pubs/files/healthenvirondiseaseguidenote.pdf (last accessed 15.09.08)

Download available on the CD of Sandec's Training Tool and from the Internet.

	Industrialised countries (multiple taps)	**Developing countries (communal tap)**
Toilet flushing	60 l/person/day	Unknown
Shower and cleaning	60 l/person/day	5 – 10 l/person/day
Cooking/washing	30 l/person/day	3 – 5 l/person/day
Drinking	3 l/person/day	2 – 3 l/person/day
Total	**Approx. 150 l/person/day**	**Approx. 20 l/person/day**
% drinking water of total consumption	2 %	10 %

Table 10: Water used at household level.

4.2 What are the political and institutional aspects?

- **To increase coverage and uptake of a HWTS approach, all stakeholders have to be engaged in a collaborative effort.**
- **To design a pilot project, it is necessary to perform a feasibility study, to create awareness and change behaviour.**

Scaling up HWTS

Successful scaling up requires leveraging existing commercial structures, donor funding for campaigns (but not product subsidies), Ministry of Health support, community-based approaches, and collaboration by all partners. Most importantly, HWTS is not about products and technologies but community mobilisation, social marketing and behavioural change. It is therefore important to have a rigorous communication plan in place, involving all partners and channels of communication. A recent report (Clasen, 2008) identified some of the challenges of scaling up HWTS and emphasised the need to engage all stakeholders in a collaborative effort to increase coverage and uptake. It also identified some of the opportunities for scaling up HWTS, including government commitment to promote awareness and generate demand; the use of schools, clinics and NGOs to encourage uptake and behavioural change; and partnerships with social marketing organisations and the private sector to expand access and coverage. Like most other household-based water interventions, however, the provision of facilities/products must be accompanied by an extensive behavioural change programme to stimulate adoption and continued utilisation by householders. Effective and robust implementation strategies for rolling out the adopted HWTS approach are very important for successful scaling up. (UNICEF, 2008, p. 5)

The following are some suggested actions to scale up HWTS in a country programme:

- Find out about existing initiatives and experience in your country or in neighbouring countries.
- Organise a learning and planning seminar on how the country office will roll out HWTS with support from the regional WASH (water, sanitation and hygiene) campaign adviser, professional institutions and/or NGOs experienced in social marketing.
- Work with the WHO office in the country, government ministries (ministries of health and water resources), national and international NGOs, private sector, and other stakeholders to organise a national stakeholders' forum/advocacy meeting on household water management to advocate for national support for HWTS. Involve all stakeholders in a collaborative effort to increase coverage and uptake.
- Join and engage in the Home Water Treatment and Safe Storage Network (www.who.int/household_water).
- If applicable, carry out a pilot project with partners identified above.
- Identify and leverage existing commercial structures, donor funding for campaigns (but not product subsidies).
- Promote partnerships with social marketing organisations and the private sector, even if they are partners with whom you have not worked before.

(UNICEF, 2008, p. 7)

Community training in Uzbekistan

Since good health depends both on access to clean drinking water and on the right hygiene behaviour, the SODIS team in Uzbekistan provided the promoters with two complete information outlines for training sessions: one for SODIS and one for hygiene. Each team was expected to adapt these outlines to the particular conditions in their village. During community meetings, the promoters introduced the SODIS method by explaining the effect of sunrays and pointing out how diarrhoea is transmitted. In some cases, hygiene rules were taught along with the SODIS method. During the agricultural peak season (cotton harvest in autumn), it was not possible to organise community meetings as the villagers were busy in the fields. The community village leaders were first contacted and the promotion teams were introduced to the interested families. Through the village health posts, the promoters were informed about families whose members had recently suffered from diarrhoea and those with small children. These families are the ones most interested in learning and applying the SODIS method. The promoters were able to build a good relationship with many of the interested households. They visited them once a week to answer their questions and find solutions to their problems. Project evaluation revealed that these people applied SODIS most consistently.

About 20 – 40 adults and often a substantial number of children attended the meetings. The villagers followed the meetings with interest and were even willing to participate. For example, after the promoters had presented the SODIS method with the help of pictures, someone from the audience was asked to repeat the preparation of a SODIS bottle. As a reward for his participation, he was given a painted SODIS bottle. Villagers who were already applying SODIS shared their experiences and encouraged the audience to follow their example. The technical resource persons in Uzbekistan put emphasis on participatory teaching methods, including role games. The promoters, however, rejected the latter and explained that this would make SODIS look ridiculous. Instead, the promoters decided to design their own posters with hygiene rules.

(Meierhofer et al., 2002, p. 42)

Design of a pilot project

1. Feasibility study for a sustainable application. Before a sustained introduction and establishment of HWTS methods in a household, a feasibility study should be performed in a community or a region to determine the following points:

- Is water treatment needed? (Diarrhoea incidence, quality of water at the source, what water treatment methods are already practised).
- Are needed resources available? (Which methods can be practised with the available resources).
- Is the method applicable?
- Is the method socially acceptable?
- Is the method economically feasible?

2. Create awareness and achieve behavioural change. Secondly, awareness about the importance of safe drinking water for family or community health should be created. Thus, promotion of systems and technologies has to be accompanied by education programmes aiming at changing behaviour. For a successful introduction of HWTS methods, choice of the right trainers is of key importance, including the relationship between trainer and community to establish behavioural change.

Training of users:
- training through promoters (health workers, NGO staff, community volunteers)
- awareness building (participatory methods)
- locally adapted training materials (posters, flyers, calendars)
- training during group and community gatherings
- regular household visits (once a month during 12 months)
- promotion through schools

Information campaign:
- promotion through mass media
- public exhibitions and demonstrations (health centres)
- street plays, songs, puppet plays
- public display of posters and prompts

Advocacy:
- involving and convincing opinion leaders
- exchange with local authorities
- involve stakeholders (NGOs, health, education and water supply sector)
- networking activities
- health impact and water quality tests

Further questions

▸ Who should initiate a HWTS project? Wouldn't it be more promising for the project if the initial effort originated from a community, an NGO or the government?

▸ What are the most sustainable and cost-effective approaches of reaching rural and remote areas? (Lantagne et al., 2005, p. 33)

Additional info

▸ WHO. WHO Network for the promotion of household water treatment & safe storage. <www> www.who.int/household_water/en/ (last accessed 15.09.08)

4.3 What are the socio-cultural aspects?

▸ **Initiatives in HWTS must include community participation, education and behavioural change.**

A number of studies and considerable field experiences have revealed that the introduction of a water treatment technology is unlikely to be successful or sustainable without the inclusion of the socio-cultural aspects of the community and without behavioural, motivational, educational, and participatory activities within the community. Therefore, initiatives in water, hygiene and sanitation must include community participation, education and behavioural changes. A number of systems have been developed and successfully implemented for this purpose. (Sobsey, 2002, p. 50)

Some previous efforts to introduce and promote similar practices of household water chlorination and safe storage in an improved vessel have possibly failed or achieved poor results due to inadequate participatory education, behavioural modification, motivational communication, social marketing, other community-based participation, and responsibility. (Sobsey, 2002, p. 50)

Positive messages for hygiene education

An hour before the SODIS presentation in Viña Perdida, Doña Ricarda was already present in the community room and said "I have just enough time to get water for my pigs before the presentation starts," "Can I accompany you?" I asked. "Of course". Doña Ricarda brought a large and two smaller jerry cans as well as a cloth for carrying the load. Together we went down to the irrigation canal running through Viña Perdida. The water was clear and cool. Downstream I saw people washing their clothes and children playing in the water. In the meantime, Doña Ricarda had filled her jerry cans with water. She gave me the large jerry can of 25 litres and took the two small ones. With an effort, I placed the jerry can on my back and followed Doña Ricarda who was already on her way to her house on top of the hill. I had difficulties following her fast steps and started to work up a sweat. As we arrived, I asked Doña Ricarda if she usually carries all this water by herself. "Of course", she said "Every day, I carry the big jerry can on my back and the two small ones in each hand. If the weather is very hot, I even go twice. I do not want the pigs to go to the irrigation canal and make everything dirty there. You have seen women do their laundry there and also fetch water for the kitchen from the canal".

Shortly afterwards, my local partners started introducing SODIS to the people of Viña Perdida now gathered in the community room. The first topic addressed were hygiene practices in the village. When answering the question on the kind of hygiene practices common in Viña Perdida, only negative answers were given: "We drink dirty water from the canal, we have no latrines, we do not wash our hands, we live together with animals, we are altogether unhygienic". The general atmosphere in the room following this discussion was not really bad but rather strange. This prompted me to tell the people the experience I just had with Doña Ricarda. The steps Doña Ricarda takes to water her pigs are nothing else than hygiene practice. Every day she carries about 40 litres of water uphill to prevent the pigs from messing around in the irrigation canal and dirtying the water others use further downstream for washing and cooking. Doña Ricarda is making an enormous effort every day to prevent the water from being contaminated and to protect her neighbours and their children from possible diarrhoea illnesses. "We have to be grateful to Doña Ricarda for her attitude, and I am convinced that every day all of you take many similar hygienic measures, maybe even without being aware". Doña Ricarda was visibly touched when I told her story to the community gathering, and the atmosphere in the room changed all of a sudden. I had learned that traditional hygiene is practiced everywhere. When discussing and praising these positive behaviours, people are far more motivated to learn and adopt new strategies.

(Stephan Indergand-Echeverria, STI, in Meierhofer et al., 2002, p. 47)

Further questions

▸ Do programmes promoting HWTS systems exist that include community participation, education and behavioural change?

▸ What motivates users to purchase and use a HWTS option? (Lantagne et al., 2005)

Additional info

▸ Wood, S., Sawyer, R. and Simpson-Hébert, M. (1998): PHAST step-by-step guide: a participatory approach for the control of diarrhoeal disease. WHO. www.who.int/water_sanitation_health/hygiene/envsan/phastep/en/index.html (last accessed 15.09.08)

Download available from the Internet.

4.4 What are the financial and economic aspects?

- **Chlorination and SODIS were found to be the most cost-effective HWTS technologies.**
- **However, other HWTS technologies should not be neglected as the context of other criteria must also be considered.**

Costs / benefit effects of different HWTS options

Cost is a critical factor in any development programme. Costs are highly programme-specific, they vary according to location, implementation strategy, desired endpoint, and cannot be generalised. Programme planners must evaluate both the costs and treatment requirements of a community to determine the most cost-effective and appropriate intervention. When reviewing cost data, it is important to compare them to the costs of other water and sanitation improvements. According to a recent cost-benefit evaluation, all the water and sanitation improvements analysed were cost-beneficial in all regions of the world, with returns of US$ 1.92 – 15.02 on each US$ 1 invested, depending on region and type of improvement (Hutton et al., 2004). However, disinfection at point-of-use (the only HWTS option considered in the analysis) had the lowest cost per person when compared to all non-HWTS interventions to provide improved water supply or sanitation. This initial work indicates that HWTS options are cost-effective mechanisms for providing improved water to households. (Lantagne et al., 2005, p. 32)

The point estimate for household-based interventions in Figure 19 represents the best available estimate of the true annual cost per person covered by the intervention, while the range reflects certain variations in such cost. (Clasen et al., 2008, p. 16)

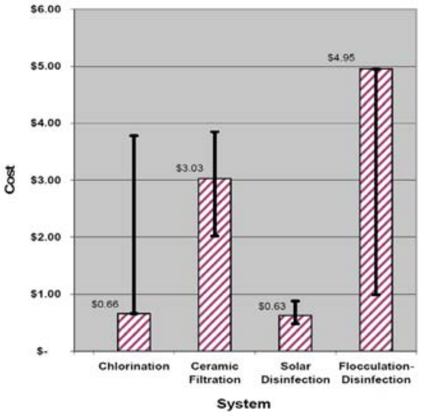


Figure 19: Annual cost per person and range of annual cost (narrow bars) for household-based interventions to improve water quality. (Clasen et al., 2008, p. 17)

Among all water quality interventions to prevent diarrhoea, chlorination is the most cost-effective. Solar disinfection is only slightly less cost-effective owing to its almost identical cost but lower overall effectiveness. Ceramic filters represent an opportunity to avert higher levels of DALYs with additional investment. This represents additional costs and benefits beyond household-based chlorination, and reflects a potential debate over the resources that individual householders or the public sector may want to deploy in order to achieve health returns. Combined flocculation / disinfection was strongly dominated by all other interventions, except under an assumption in which it can be implemented at its minimum cost. (Clasen et al., 2008, p. 24)

Social marketing in Zambia

The NGO Population Services International (PSI) is the largest social marketing NGO in the world, with offices in more than 70 countries. PSI designs a brand name and logo for health products, sells them at low prices, distributes them through wholesale and retail commercial networks; and generates demand for the products through behavioural change, communication, such as radio and TV spots, mobile video units, point-of-sale materials, theatre performances, and person-to-person communication. In October 1998, PSI launched its Zambian SWS product, a bottle of sodium hypochlorite solution branded as "Clorin". This programme is one of the oldest PSI/CDC collaborations. Sales steadily increased from 732 bottles per month in October 1998 to 132,000 bottles per month in November 2003. A cholera epidemic in 1999 increased demand for Clorin; while sustained social marketing and promotion in health centres and door-to-door visits stimulated further sales. A population-based, cross-sectional study conducted by an independent agency reported that 42 % of households said they were currently using Clorin and 22 % reported using it in the past. However, only 13 % of households had residual chlorine in their water at the time of the unannounced visit, indicating a discrepancy between reported and actual use. The study did not find a lower rate of reported diarrhoea among users of Clorin as compared to non-users. However, using large cross-sectional studies to assess the efficacy of household water treatment options requires further refinement. The limitations of this study, which was the first large cross-sectional population study (as opposed to a randomized study with a controlled population), impacted the results. The Clorin product is subsidised by USAID; the full cost of the 250-millilitre bottle, including production, marketing, distribution, and overhead, – amounts to US$ 0.34, and the retail price is set at US$ 0.12. The total programme cost per person/month of protection from diarrhoea is US$ 0.045. Increasing the price to recover full costs could have a negative impact on demand, particularly in a country like Zambia, which ranks 164th out of 177 on the Human Development Index. The programme, which needs studies on the price elasticity of demand for this product, is currently implementing options to significantly lower costs. The PSI of Zambia project is an example of a successful social marketing intervention that creates demand for a product and makes it widely available through the commercial sector. Interested NGOs can readily incorporate Clorin into their own programme. The two major challenges this programme faces are achieving financial self-sufficiency while maintaining access to the product and increasing demand among the highest-risk populations. With its wide Clorin use and distribution, Zambia is an ideal location for future research on programme effectiveness in disease prevention, cost-effectiveness and interventions to reduce economic and behavioural barriers to utilisation. (Lantagne et al., 2005, p. 21)

Cost-effectiveness in the context of other criteria

Cost and cost-effectiveness, though important for setting health priorities, must be considered in the context of other economic and non-economic criteria, especially if the goal is to achieve a sustainable solution by having some or all of the cost of safe drinking water borne by the beneficiaries. Affordability and perceived value are among the other economic criteria. A point-of-use water treatment product, which may improve water quality at a lower cost per unit (person, household, day, litre etc.) than some alternative product, may be important to government planners, donors and policy-makers. But to consumers asked to pay for the product, the overriding consideration may be whether they have enough money on hand that day to buy it. Such "ability to pay" may depend not on the cost as determined by economic analysis but on the price the householder must pay at that time and place. A bottle of dilute sodium hypochlorite for US$ 1.50, which can last a family for six months, has a significantly lower unit cost than a sachet of flocculant/disinfectant priced at US$ 0.10 and lasting less than a week. Nevertheless, as companies who market to the poor have frequently found, consumers with limited cash may nevertheless prefer the sachets because they find them to be more affordable given their limited cash. The minimum purchasable unit and minimum purchase price can sometimes influence the choices of poor consumers more than the unit price. Similarly, consumers' "willingness to pay" depends largely on their current cash position, other priorities, assessment of the risk to be avoided, perceived utility of the proposed solution etc. – all economic factors not strictly related to cost. Non-economic factors, such as compatibility, complexity and ease of handling, also influence consumer attitudes and practices with respect to adoption of an innovative product. Cultural preferences also play a role. Policy-makers and programme implementers must consider these factors in addition to basic cost and cost-effectiveness if they expect to secure some measure of cost recovery in scaling up household water treatment. (Clasen et al., 2008, p. 27)

Cost example of ceramic filters

Locally manufactured ceramic PFP-design filters range in cost from US$ 7.50 – 30. Distribution, education and community motivation can add significantly to programme costs. Ceramic filter programmes can achieve full cost recovery (charging the user the full cost of product, marketing, distribution, and education), partial cost recovery (charging the user only for the filter and subsidising programme costs with donor funds) or can be fully subsidised such as in emergency situations. If a family filters 20 litres of water per day (running the filter continuously) and the filter lasts for three years, then the cost per litre water treated (including cost of filter only) is US$ 0.034 – 0.14. Commercially available ceramic filter systems range in cost from tens to hundreds of US dollars, depending on where they are manufactured and purchased and on the quality of the ceramic filters. The economics and sustainability of commercial product-based projects depend on donor funding and subsidy as well as on follow-up to ensure replacement parts are accessible to the population using the filters. <www> (CDC, 2008)

Further questions

- What are the current rates of purchase and use of HWTS in different demographic, socio-economic and cultural groups? How do these correlate with water-related disease prevalence rates? (Lantagne et al., 2005)
- Combined flocculation / disinfection belongs to the less cost-effective HWTS technologies; however, it can be the most appropriate in certain situations. When could that be the case?

Additional info

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Download available on the CD of Sandec's Training Tool and from the Internet.

Bold: The key readings (additional info) are available on the CD of Sandec's Training Tool. They are open source products. The user must always give credit in citations to the original author, source and copyright holder.

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