HY-02 Safe water without a utility: boiling, solar disinfection, sand filters, chlorine and the evidence for each

HEALING after the FALL, research library, HY-02

Researched 10 October 2026 by Claude Opus agent for THRIVING after the FALL, Book Four. Library document, unverified.

A note on method. More than 30 searches were run. Read in full or in large part: the Cochrane review by Clasen and colleagues (2015), the Wilderness Medical Society water guideline (Backer et al. 2024), the SODIS manual (Meierhofer and Wegelin 2002), Colwell and colleagues on sari cloth (2003), the Orissa blinded chlorine trial (Boisson et al. 2013), Clasen and Boisson (2016), Clasen and colleagues on boiling in Vietnam (2008), the CAWST biosand fact sheet (2009), the CDC turbidity fact sheet (2009), Dorris and colleagues (2025) and García-Gil and colleagues (2021). Most other trials were read as abstracts, and each reference says which. Schmidt and Cairncross (2009), Sobsey (2002) and the WHO drinking-water guidelines could not be opened. My own sums are marked [VERIFY]. A log reduction value (LRV) of 1 removes 90 per cent, 2 removes 99 per cent, 3 removes 99.9 per cent and 4 removes 99.99 per cent.

Findings by section

1. What the trials say, and why the numbers shrink

The Cochrane review by Thomas Clasen and seven colleagues pooled 45 cluster-randomised trials, 2 quasi-randomised trials and 8 controlled before-and-after studies, with more than 84,000 participants (Clasen et al. 2015).

Intervention	Risk ratio for diarrhoea (95% CI)	Trials	Participants
Filtration, all types	0.48 (0.38 to 0.59)	18	15,582
Ceramic filters	0.39 (0.28 to 0.53)	8	5,763
Biosand filters	0.47 (0.39 to 0.57)	4	5,504
Solar disinfection	0.62 (0.42 to 0.94)	4	3,460
Chlorination	0.77 (0.65 to 0.91)	14	30,746
Flocculant-chlorine sachets	0.69 (0.58 to 0.82)	4	11,788
Improved storage alone	0.91 (0.74 to 1.11)	2	1,871
Source improvement	Too little evidence		

These look like a halving of diarrhoea. They are not. More than 80 per cent of studies were unblinded and asked mothers whether children had diarrhoea, and a family that has been given a filter has reasons to report less. Clasen and Boisson (2016) pooled open trials at 0.55 (0.44 to 0.68) and blinded trials, with a placebo tablet or sham filter, at 0.94 (0.84 to 1.06). All four adequately blinded chlorine trials found no effect. Adjusted for blinding, chlorination

moved from 0.72 to 0.80, filtration from 0.48 to 0.62 and SODIS from 0.68 to 0.80, borderline (Clasen et al. 2015, Table 23). No trial longer than 12 months showed an effect of chlorination or filtration, and no trial reported adverse events.

The blinded nulls have explanations. They were run where diarrhoea was rare (the United States, Australia), where people did not use the product (only 32 per cent of Orissa households had chlorine in their water, Boisson et al. 2013), or where the "sham" filter itself removed more than 90 per cent of coliforms (Clasen et al. 2015, Table 24). Four review authors had consulted for water-product makers, as the review declares. The honest reading is that the methods clean the water, that the health effect is real but smaller than open trials say, and that daily use is the bottleneck.

Wolf and colleagues for WHO also found filtration strongest (0.50), with chlorination at 0.66 and SODIS at 0.63 (Wolf et al. 2022, secondary). In the WASH Benefits and SHINE trials chlorination cut diarrhoea by about a third in Bangladesh, where promoters visited about six times a month, and did nothing in Kenya and Zimbabwe, where visits were monthly and fewer than half of Kenyan households had chlorine in their water (Pickering et al. 2019, secondary). A method people stop using protects no one.

2. Boiling

What it kills. Heat kills every waterborne pathogen that matters, including Cryptosporidium, and turbidity does not shelter them. Protozoan cysts die at 55 °C in 5 minutes, Cryptosporidium at 64 °C within 2 minutes, bacteria at 65 °C in under a minute, most viruses at 56 to 60 °C in 20 to 40 minutes and hepatitis A at 85 °C in a minute or less. Pasteurisation at 60 to 70 °C for 30 minutes is enough (Backer et al. 2024, Table 1). Bacterial spores survive but are not a meaningful cause of diarrhoea (Dorris et al. 2025).

How long. WHO says water is safe once it reaches a rolling boil (WHO 2015, summary only). The CDC says 1 minute, and 3 minutes above 6,500 feet, about 2,000 metres (CDC 2024). Dorris and colleagues (2025) found agency advice ranged from "bring to a boil" to 20 minutes without scientific basis, and modelled 3 to 5 log reduction of all pathogens within about a minute at the boiling point up to 10,000 feet. The 10-minute rule is obsolete (Backer et al. 2024).

Altitude. Water boils about 0.5 °C lower per 150 metres (Dorris et al. 2025): 95 °C at 1,524 metres, 90 °C at 3,048 metres and 86 °C at 4,267 metres (Backer et al. 2024, Table 2). All are above the killing temperatures, so boiling works wherever people live.

Fuel. In rural Vietnam, 50 households heated 3 litres in about 18 minutes and boiled for a mean of 1.9 minutes, used about 22 kg of wood a day for all purposes, and wood collectors spent 1.57 hours a day gathering it. The authors assumed an open-fire efficiency of 8 per cent (Clasen et al. 2008). Heating a litre from 20 °C to boiling needs about 335 kJ, so at 8 per cent and about 15 MJ per kg of air-dry wood it takes roughly 0.28 kg of wood per litre, and about 0.09 kg on a stove of 25 per cent efficiency (my arithmetic, energy values from Engineering ToolBox) [VERIFY]. Humanitarian rules of thumb run to 1 kg per litre [VERIFY]. Gilman and Skillicorn (1985, cited in Clasen et al. 2008) estimated that boiling would cost the poorest quarter of Bangladeshi households 22 per cent of their income.

After the boil. In Vietnam boiling cut thermotolerant coliforms by 97 per cent, yet 60.5 per cent of stored boiled samples still contained them (Clasen et al. 2008). In Cambodia over 90 per cent of 60 households said they boiled, but only 31 per cent had boiled water when visited. Boiling cut E. coli by 98.5 per cent on average and covered storage did better (Brown and Sobsey 2012, abstract). Boiling leaves no residual protection.

3. Heat short of boiling

Heating water to the first simmer and covering it for 30 minutes holds it in the pasteurising range and saves fuel. "Too hot to touch" is not a reliable test (Backer et al. 2024). Wrapping the pot in hay or sawdust should hold heat longer, but I found no measured data [VERIFY]. Solar cookers can reach pasteurising temperatures, and a wax indicator

that melts at about 65 to 70 °C shows the target was reached. In a Kenyan study an indicator raised households with coliform-free water from 10.7 to 43.1 per cent (cited in Clasen et al. 2008). Beeswax melts at about 62 to 64 °C, too low for a reliable indicator [VERIFY].

4. Solar disinfection (SODIS)

Dose. UV-A and violet light and heat above about 45 °C kill microbes in clear bottles. The EAWAG manual sets the dose at about 555 Wh per square metre of UV-A and violet light, about 6 hours of mid-latitude summer sun, giving 3 log of faecal coliforms at 30 °C. At 50 °C a quarter of the light, about an hour, suffices (Meierhofer and Wegelin 2002).

Rules. Six hours if the sky is clear or at most half cloudy, two consecutive days if more than half cloudy, and not at all in continuous rain. Bottles of 1 to 2 litres, no more than 10 cm deep, of PET rather than PVC, unscratched. Fill three-quarters, shake 20 seconds, fill to the top. Lay on a dark or reflective surface. The best latitudes are 15 to 35 degrees. Overcast skies cut UV-A to about a third, and in Beirut UV-A falls from 18 W per square metre in June to 5 in December (Meierhofer and Wegelin 2002, Backer et al. 2024).

Turbidity. Above 30 NTU SODIS fails. At 26 NTU and 10 cm depth UV-A is halved. Cloudier water must be settled, filtered or flocculated first, or boiled (Meierhofer and Wegelin 2002). A field rule is that a printed headline readable through the bottle from above means below 30 NTU [VERIFY].

What it kills. In Latin American field samples, 81 per cent reached more than 3 log and 5 per cent less than 1 log (Meierhofer and Wegelin 2002). Best and typical LRVs are 5.5 and 3 for bacteria, 4 and 2 for viruses, and 3 and 1 for protozoa (Backer et al. 2024, Table 9). Cryptosporidium, enteroviruses and amoebae are more resistant than E. coli. Drink within 24 hours because bacteria can regrow (Luzi et al. 2016, cited in García-Gil et al. 2021).

Trials. Conroy and colleagues gave bottles to 206 Maasai children aged 5 to 16 in Kenya and found an odds ratio of 0.66 for diarrhoea over 12 weeks (Conroy et al. 1996, cited in Clasen et al. 2015). In a later cholera outbreak, children under 6 in SODIS households had 3 cases among 155 against 20 among 144 controls, with no difference in older people (Conroy et al. 2001). In Nakuru, Kenya, in 2007 to 2009, about 1,100 children were compared and dysentery fell (rate ratio 0.55, 0.42 to 0.73), while a South African trial with compliance below 35 per cent found a non-significant 0.64 (du Preez et al. 2011). In 22 Bolivian communities, Mäusezahl and colleagues compared 376 children in 225 households with 349 in 200. Only 32.1 per cent of households used SODIS regularly, episodes were 3.6 against 4.3 a year, the risk ratio was 0.81 (0.59 to 1.12), and the authors advised caution (Mäusezahl et al. 2009).

Scale and plastic. Drinking water for a family needs a handful of bottles, but cooking water too would need up to 25 (García-Gil et al. 2021). After 17 hours of sun, plasticisers reached levels similar to bottled water, and antimony exceeded limits only at 80 °C (Schmid et al. 2008). The WHO guideline value for antimony is 20 micrograms per litre (WHO 2022). SODIS works in cold climates because the light does the work (Backer et al. 2024). After the Fall, PET bottles are a finite stock, and I did not confirm how much less UV-A ordinary glass passes [VERIFY].

5. Chlorine

What it kills and misses. The dose is concentration times time (CT, mg per litre times minutes). For 99.9 per cent inactivation E. coli needs 0.016, enteric viruses 2.5 to 30, hepatitis A 0.5 to 2.3 and Giardia 77 to 153 in cold water. Cryptosporidium needs 10,400 to 15,300, which is 20 mg per litre held for 8 to 13 hours (Backer et al. 2024, Table 4, CDC 2008). At household doses chlorine does not kill Cryptosporidium. Cold slows chlorine sharply:

Free chlorine, Giardia contact time	5 °C	15 °C	30 °C
2 mg/L	240 min	180 min	60 min
4 mg/L	180 min	60 min	45 min

Free chlorine, Giardia contact time	5 °C	15 °C	30 °C
8 mg/L	60 min	30 min	15 min

Doses and residual. WHO advises at least 0.5 mg per litre of free chlorine after 30 minutes at pH below 8, at least 0.2 at the point of use, and a health guideline value of 5 mg per litre (INERIS, citing WHO). The CDC Safe Water System uses 1.875 mg per litre for clear water and 3.75 for turbid water with 30 minutes' contact. In a study of 158 sources in 22 countries, the high dose on unimproved sources kept a residual in 83 per cent of samples at 8 hours but only 65 per cent at 24 (secondary summary). Drink chlorinated turbid water within 8 hours and clear water within 24.

Drops per litre at 20 drops per mL (Backer et al. 2024, Table 7):

Product	About 2 mg/L (clear)	About 5 mg/L (cloudy or cold)
Bleach 5%	1 drop per litre	2 drops per litre
Bleach 8.25%	1 drop per 2 litres	1 drop per litre (about 4 mg/L, arithmetic) [VERIFY]
1% stock	4 to 5 drops per litre	8 to 10 drops per litre

The guideline advises 3 to 4 mg per litre for clear surface water and double for cloudy water. Taste is distinct above about 2 to 3 mg per litre. A pinch of vitamin C in the cup removes the taste but also the residual. For a 20 litre jerrycan, 4 mL of 1 per cent stock gives 2 mg per litre (my arithmetic, matching the CDC doses).

Turbidity. Particles shelter microbes and use up chlorine. WHO aims for below 1 NTU and accepts below 5 NTU (secondary), MSF accepts up to 20 in emergencies (MSF, summary), and direct chlorination above 100 NTU is advised against (secondary). Settle or filter first.

Bleach is not what it says. Lantagne tested 32 bleaches from 12 countries and found strength differed from the label by 35 per cent on average, from 45 per cent weaker to 100 per cent stronger (Lantagne 2009). Bleach weakens with heat, light and age.

Calcium hypochlorite. HTH at 65 to 70 per cent available chlorine is best for large volumes (Backer et al. 2024). A 1 per cent stock needs about 14 g of 70 per cent HTH per litre (arithmetic following the MSF method) [VERIFY]. MSF renews 1 per cent solutions daily and forbids mixing NaDCC and HTH (MSF).

Chlorine from salt. Direct current through brine makes hypochlorite. The WATA devices of the Antenna foundation use 25 g of salt per litre and make about 6 g of active chlorine per litre. The 10 W mini-WATA makes 0.5 litres in 3 hours, and the 180 W WATA-Plus 15 litres in 4 hours (WATA information via SSWM, secondary). Half a litre holds about 3 g of chlorine, enough for about 1,500 litres at 2 mg per litre, one day's drinking water for 300 people (my arithmetic) [VERIFY]. A solar-powered cell in a University of the Western Cape thesis made about 20 g of chlorine a day from under 80 g of salt (Key 2010). The chemical minimum is 1.65 kg of salt per kg of chlorine ($2 \times 58.44 \div 70.9$). The Wilderness Medical Society gives electrolytic oxidants a strong recommendation on moderate evidence (Backer et al. 2024). Electrodes must resist corrosion (coated titanium or graphite, not steel) [VERIFY], and the cell gives off hydrogen.

By-products and iodine. The risk of trihalomethanes is far smaller than the risk of infection. Iodine must not be used in pregnancy or thyroid disease or for more than a few weeks (Backer et al. 2024).

6. Settling and coagulation

Settling. Standing water for 2 to 24 hours and pouring off the top lowers turbidity and chlorine demand (CDC 2009). The three-pot method, where only water stored for a day or more is drunk, appears in humanitarian manuals, but I found no trial of it [VERIFY]. Settling alone does not make water safe.

Alum. About 1 mL (an eighth of a teaspoon) per 4 litres, stirred fast 1 minute and slowly 5, settled at least 30 minutes, filtered through cloth and then disinfected. Coagulation removes 60 to 98 per cent of microbes (Backer et al. 2024). The right dose varies, alum lowers pH, too much tastes bitter, and it lowers chlorine demand (CDC 2009).

Moringa. The seed of the drumstick tree, *Moringa oleifera* Lam. (Moringaceae), contains proteins that coagulate clay. The part used is the dry seed kernel, shelled and crushed. In Sudan, where women clarified Nile water this way, Madsen and colleagues found turbidity fell 80 to 99.5 per cent and bacteria 1 to 4 log within 1 to 2 hours, concentrated in the sediment. Within 24 hours Salmonella, Shigella and sometimes E. coli regrew in the clear water (Madsen et al. 1987). The CDC suggests about 2 g of crushed kernel per 20 litres (about 100 mg per litre), stirred 5 minutes and settled 24 hours. Moringa adds organic matter and raises chlorine demand, so the CDC does not recommend it with chlorine (CDC 2009). The WEDC brief gives 10 to 50 mg per litre below 50 NTU and up to 200 mg per litre above 150 NTU (Folkard et al. 1999, secondary). After Moringa, boil or use SODIS. The root and root bark are reported to be toxic and must not be used [VERIFY]. The related *Moringa stenopetala* is also reported as a coagulant [VERIFY].

Other coagulants. In Haiti a cactus called raket (an *Opuntia* species) is stirred in for 10 minutes and the water strained (CDC 2009). The Indian clearing nut, *Strychnos potatorum* L.f., has a reported tradition [VERIFY], but its genus includes the strychnine tree, *Strychnos nux-vomica* L., and the book should not recommend it without a primary source.

7. Cloth: the sari study

In Matlab, Bangladesh, Rita Colwell and colleagues compared 65 villages with about 133,000 people. In 27 villages women filtered water through old sari cloth folded to 8 layers, in 25 through nylon mesh, and 13 were controls. From January 2001 to July 2002, cholera incidence per 1,000 people per year was 0.65 with sari, 0.79 with nylon and 1.16 in controls, a 48 per cent reduction with sari (P below 0.005) (Colwell et al. 2003).

Vibrio cholerae clings to plankton larger than 20 μm. One layer of sari has pores of 100 to 150 μm, but folded 4 to 8 times the pores close to about 20 μm. In the laboratory the folded cloth removed more than 99 per cent of plankton-attached vibrios, and old cloth worked better than new. About 90 per cent of villagers kept up the practice. The study was not randomised and the water was not cultured.

Cloth does little against free bacteria, viruses or most protozoa. Improvised media such as cloth cut bacteria and viruses by 50 to 85 per cent and large parasites by 99 per cent, and a double cloth removes Guinea worm larvae and schistosome cercariae (Backer et al. 2024). Cloth lowers turbidity but not chlorine demand (CDC 2009).

8. Ceramic filters

A ceramic pot filter is fired clay mixed with sawdust or rice husk that burns out to leave pores, usually painted with colloidal silver and set in a lidded bucket with a tap. It removes bacteria and protozoa by size. Viruses (about 0.03 μm) are much smaller than bacteria (0.2 to 0.5 μm) or Cryptosporidium (2 to 6 μm) (Backer et al. 2024, Table 3). Best and typical LRVs are 6 and 2 for bacteria, 4 and 0.5 for viruses and 6 and 4 for protozoa (Table 9). Flow is about 1 to 3 litres an hour [VERIFY].

Ceramic filters pooled at 0.39 (Clasen et al. 2015). In Cambodia, Brown, Sobsey and Loomis found a prevalence ratio of 0.51 (0.41 to 0.63) over 18 weeks (Brown et al. 2008). But use fell about 2 per cent a month, mainly from breakage (Brown, Proum and Sobsey 2009, abstract seen through search) [VERIFY]. A cracked filter can look whole.

After the Fall, filters need clay, a kiln, a press and a flow test for every batch [VERIFY]. Without silver they still remove bacteria by size, but bacteria may grow on the clean side [VERIFY].

9. Biosand and slow sand

The household filter. Developed by David Manz in Calgary [VERIFY] and spread by CAWST, the biosand filter is a concrete or plastic box of fine sand over gravel with about 5 cm of water above the sand. A biological layer, the schmutzdecke, grows at the top. CAWST reports removal of bacteria up to 96.5 per cent in the laboratory and 87.9 to 98.5 per cent in the field, viruses 70 to over 99 per cent, protozoa over 99.9 per cent, and turbidity to below 1 NTU (CAWST 2009). Best and typical LRVs are 3 and 1 for bacteria, 3 and 0.5 for viruses and 4 and 2 for protozoa (Backer et al. 2024, Table 9). After 30 days' use, E. coli fell 0.3 to 4 log, geometric mean 1.9 (Elliott et al. 2008).

Operation. The biolayer takes up to 30 days to ripen, and output should be disinfected meanwhile. Batches of 12 to 18 litres give 24 to 72 litres a day, with pauses of 1 to 48 hours, ideally 6 to 12. Flow should be no more than 0.4 litres a minute. Inlet water should be below 50 NTU. When flow slows, "swirl and dump" the top of the sand. The filter must never dry out (CAWST 2009).

Cost. A concrete filter weighs 70 to 135 kg, lasts more than 30 years and costs 12 to 40 US dollars. Running costs are nil, but casting needs a steel mould made by a welder (CAWST 2009). Sand must be fine and sieved, about 0.7 mm or less [VERIFY].

Trials. In Bonao, Dominican Republic, Stauber and colleagues found an odds ratio of 0.53 for 75 households against 79 (Stauber et al. 2009). A plastic biosand trial in Kandal, Cambodia, in 2008, with 1,147 people, found 0.41 (Stauber et al. 2012, cited in Clasen et al. 2015). All were unblinded. A 20 litre bucket with 10 cm of gravel under 23 cm of sand cut turbidity from 6.2 to 0.9 NTU and removed 99 per cent of bacteria (Backer et al. 2024).

Slow sand filters apply the same process to a town, the technology that protected Altona in 1892. They need a trained operator, and design figures should be taken from WHO or CAWST manuals, which I did not read [VERIFY].

10. Safe storage

In the Nyamithuthu camp in Malawi, Roberts and colleagues gave a quarter of 400 Mozambican refugee households a covered bucket with a spout. Over 4 months faecal coliforms fell 69 per cent and diarrhoea in under-fives 31 per cent ($P = 0.06$) (Roberts et al. 2001). The two storage trials in the Cochrane review pooled at 0.91, and 0.69 in under-fives, neither significant (Clasen et al. 2015). The container needs a narrow mouth or a tap and a lid (Backer et al. 2024).

11. Springs, wells and the sanitary survey

Springs. Kremer and colleagues randomised protection of 200 springs in Busia, Kenya. A concrete box and pipe cut faecal contamination 66 per cent at the spring, less at home, and child diarrhoea by about a quarter, at about 1,000 US dollars a spring (Kremer et al. 2011). It is the best randomised evidence for a source improvement.

Wells. A protected dug well has a raised headwall, a sanitary seal at the top of the lining, a cover, a drainage apron and a fence (Reed et al. 2013). The apron should be at least 1 metre wide [VERIFY]. Cloudiness after rain means surface water is entering. Latrines are usually sited at least 30 metres from water and 1.5 metres above the water table (Sphere standards through an IFRC guide, secondary). This is a convention: in fissured rock or gravel bacteria travel further [VERIFY].

Shock chlorination after flooding or repair is commonly 50 mg per litre for at least 12 hours (Lifewater, and New Jersey guidance, summaries), though Connecticut guidance allows 3 hours and warns that strong chlorine attacks the grout of dug wells. WHO asks for turbidity below 5 NTU first and warns that disinfection without removing the source of contamination protects only briefly (Reed et al. 2013).

The sanitary survey is a walk round the source with yes-or-no questions: a latrine within 30 metres or uphill, standing water, a broken apron, a cracked seal, animals, a bucket on the ground. The number of "yes" answers ranks what to fix first [VERIFY]. It needs no laboratory.

Trials. Source improvements had too little evidence to judge. Piped water in South Africa gave 0.43, wells in China 0.45 and hand pumps in Bangladesh 0.83, while a well trial in Afghanistan found no difference (Clasen et al. 2015).

12. Rainwater

Rain is nearly clean when it falls, but roofs collect droppings, dust and leaves. A first-flush diverter discards the first water. Advice varies: 1 mm of rain is 1 litre per square metre, Brazil's standard discards 2 mm, and other guides give 0.4 to 2 litres per square metre [VERIFY]. Diverters reduce but do not remove E. coli. Tanks should be covered, screened against mosquitoes and fitted with a tap. Avoid roofs with lead flashing or lead paint [VERIFY]. Treat rainwater before giving it to infants.

13. The historical record

Hamburg and Altona, 1892. Hamburg drew unfiltered Elbe water above the city. Altona drew water below it, after Hamburg's sewage, but passed it through slow sand filters. In the cholera epidemic Hamburg had about 17,000 cases and roughly 8,600 to 10,000 deaths, and Altona was largely spared (Museum-digital, secondary). Robert Koch identified the vibrio. Evans' *Death in Hamburg* (1987) is the standard history, which I did not read.

Lincoln, 1905, and Jersey City, 1908. A typhoid epidemic in Lincoln linked to a faulty sand filter caused 1,045 cases and 131 deaths by late April 1905, and Alexander Houston then dosed the supply with hypochlorite at about 1 part per million. In 1908 John L. Leal and George W. Fuller began dosing 40 million gallons a day from Jersey City's Boonton Reservoir with chloride of lime at 0.2 to 0.35 parts per million, after a court case (Wikipedia).

The mortality decline. Cutler and Miller (2005) estimated that filtration and chlorination explained nearly half the fall in mortality in large American cities between 1900 and 1936 and three-quarters of the fall in infant mortality. Anderson, Charles and Rees (2022) found transcription errors and, with corrected data, much smaller effects. Cutler and Miller accepted the errors.

Milwaukee, 1993. Turbidity in treated water from the southern plant rose between 23 March and 9 April. Cryptosporidium passed the filters and survived the chlorine. An estimated 403,000 people fell ill (MacKenzie et al. 1994), and between 69 and over 100 died (Wikipedia). Chlorine is not a complete answer, and rising turbidity is a warning.

14. The decision table: which method for which water

Water	First choice	Second choice	Avoid
Clear rainwater, covered tank	Chlorine 2 mg/L or SODIS	Boil	Untreated for infants
Clear protected spring or well, below 5 NTU	Chlorine 2 mg/L, 30 min	SODIS, biosand, ceramic	Dipping into storage
Clear river or pond, below 30 NTU	Biosand or ceramic, then chlorine	SODIS 6 h, or boil	Chlorine alone where animals or people defecate upstream
Cloudy, 30 to 100 NTU	Settle or alum, cloth, then chlorine 4 to 5 mg/L or boil	Moringa, then boil or SODIS	SODIS without clearing
Floodwater, over 100 NTU	Settle, alum, cloth, then boil	Settle, biosand, then chlorine	Direct chlorination, SODIS

Water	First choice	Second choice	Avoid
Near-freezing water	Boil	Chlorine at double dose, 2 h or more	Normal chlorine contact time
Rainy or cloudy season	Boil, or rainwater plus chlorine	SODIS over 2 days	SODIS for 6 h only
Cholera in the village	Chlorine 4 to 5 mg/L or boil, folded sari on all raw water	Flocculant-chlorine	Raw water, even for washing food
Outbreak continuing despite chlorine	Boil	Ceramic filter, or pasteurise at 65 °C or more	Chlorine as the only barrier
Water for infants and the sick	Boil, cool covered, use same day	Chlorine plus SODIS	Water kept overnight uncovered
Smell of fuel or chemicals, mine or dump upstream	Find another source	None at home	Boiling, which concentrates chemicals

15. The household routine

1. Fetch from the best source in a covered container used only for drinking water.
2. If cloudy, let it stand overnight and pour off the top, or clear it with alum or Moringa, then strain through folded cloth.
3. Treat it every day by one method from the table, adding a second when there is an outbreak or an infant.
4. Store it covered, with a tap or narrow mouth, off the floor.
5. Pour, never dip. Each person has a cup washed with soap.
6. Drink chlorinated turbid water within 8 hours and other treated water within 24.
7. Wash the container weekly with a little chlorinated water [VERIFY].
8. Keep the latrine 30 metres away and downhill, and wash hands with soap (HY-01).

Evidence grades

Grades follow the brief: A for trials or systematic reviews, B for consistent observational series and the historical record, C for convergent tradition with plausible mechanism, D for a single tradition or theory, X for ineffective or harmful.

- **Boiling. B.** Tradition: boiled water and tea are long-standing norms in China and much of Asia [VERIFY]. Record: large falls in E. coli in Vietnam and Cambodia, no randomised trial on diarrhoea. Science: heat inactivation is unambiguous.
- **Simmer and cover, solar pasteurisation. B.** Laboratory thresholds and the Kenya indicator study.
- **SODIS. A**, weak and inconsistent: pooled 0.62, Bolivia null with 32 per cent use.
- **Household chlorination. A** for the water, uncertain for diarrhoea (open 0.77, blinded null). Municipal chlorination B. Fails against Cryptosporidium.
- **Electrolytic hypochlorite.** B for commercial devices, D for improvised cells.
- **Flocculant-chlorine sachets. A**, but unavailable after the Fall.
- **Ceramic filters. A** (0.39, open trials), with falling use.
- **Biosand filters. A** (0.47, open trials).
- **Community slow sand filters. B** (Hamburg and Altona).
- **Folded sari cloth against cholera. B** (one large non-randomised study). As the only treatment for other pathogens: X.

- **Alum. B** (utility practice and laboratory data).
- **Moringa seed. C.** Tradition: Sudan and reportedly elsewhere [VERIFY]. Record: turbidity and 1 to 4 log of bacteria removed in the laboratory. Science: cationic proteins, regrowth within 24 hours, no health trial. As a disinfectant: X.
- **Raket cactus. D. Three-pot settling. D** [VERIFY].
- **Safe storage. A**, borderline effect.
- **Spring protection. A** (Kremer et al. 2011). **The 30 metre distance. D** (convention).
- **First-flush diversion. D.**
- **Ten-minute boil. X** for the claim that it is needed. **"Too hot to touch". X. "Clear water is safe". X.**
- **Copper or silver vessels. D** at best. I found no measured effect [VERIFY].

Means ledger

Method	Hands alone	Hearth	Garden and still	Village of 300	District of 3,000	Before the Fall
Source	Pick the cleanest source, move latrines, fence animals	Clear drains, mend aprons	Spring boxes and well covers in stone and lime	Sanitary survey and map, shock chlorination after floods	Protected source per village, gravity pipe	Piped treated water (0.43 in South Africa)
Boiling	No	Rolling boil, simmer and cover	Efficient stoves, hay boxes, wood lots	Boil for infants and the sick	Fuel plantations, boiling stations in outbreaks	Not needed
SODIS	Bottles in sun	With cloth pre-filter	Bottle stock and racks	Teach, check, replace bottles	Glass or plastic supply	Not needed
Chlorine	No	Salvaged bleach by drops	Scale, HTH, 1% stock	Daily stock, dosing at the source, smell or residual test	Brine electrolysis, residual testing	Automated dosing
Coagulation	Settle overnight	Strain through cloth	Moringa trees, alum	Jar tests for dose	Alum for town tanks	Full treatment works
Filters	Folded cloth	Bucket sand filter	Biosand moulds, ceramic kiln	Filter per household	Slow sand filter, batch-tested ceramics	Multi-barrier treatment
Testing	Look and smell	Headline test		Microscope for eggs only, hydrogen sulphide strips if salvaged [VERIFY]	Coliform counts with an incubator [VERIFY]	Full laboratory

What each rung changes. Hands alone can choose a source and stop dipping. The hearth adds boiling and SODIS, which kill nearly everything, and is the rung that changes outcomes most. The garden and still adds filters, efficient stoves and chlorine by weight, which make daily treatment cheaper. The village adds organisation: surveys, dosing at the source, outbreak control. The district adds chlorine from salt, which ends reliance on salvage, and testing, which replaces guessing with counts. Only the utility before the Fall delivered treated water to every tap.

Harm test

- **Boiling.** Scalds, especially to toddlers near floor-level pots. Smoke harms lungs, and charcoal indoors can kill by carbon monoxide [VERIFY]. Fuel gathering takes hours, mostly from women and children, and district-wide boiling on open fires strips woodland. Boiling concentrates nitrate, a risk for infants fed formula from shallow wells near latrines or manure [VERIFY]. Stored boiled water is often recontaminated (60.5 per cent in Vietnam).
- **SODIS.** The harm is false confidence: too short, too cloudy, too turbid, scratched bottles. Chemical leaching from PET is negligible (Schmid et al. 2008). Never use bottles that held fuel or pesticide.
- **Chlorine.** Concentrated bleach and HTH burn eyes, skin and gut. Keep stock locked and labelled. A child who swallows it should be given water or milk, not made to vomit [VERIFY]. Bleach mixed with vinegar or other acid releases chlorine gas, and with urine or ammonia releases chloramines. HTH can ignite with fuel or oil [VERIFY]. Overdosing drives people to stop, underdosing protects no one, labels are often wrong. Electrolysis gives off hydrogen. Chlorine alone leaves Cryptosporidium alive.
- **Coagulants.** Alum overdose makes water acid and bitter. Moringa raises chlorine demand and bacteria regrow. Never use Moringa root [VERIFY], and never substitute unknown seeds, especially *Strychnos* species.
- **Filters.** Unripe or dried biosand filters, cracked ceramics and filters cleaned with dirty water pass pathogens.
- **Wells.** Diggers die in collapses and in bad air at the bottom [VERIFY]. Strong chlorine damages dug-well grout.
- **Rainwater.** Open tanks breed mosquitoes, and dead animals contaminate the whole store.
- **Who must not.** Iodine is unsuitable in pregnancy and thyroid disease. Infants under six months should have breast milk, and any water they get should be boiled.

Red flags (with honest comfort)

See HY-03 for rehydration, IN-11 for the infections, and HY-04 and HY-05 for related hygiene. OR-06 covers the organisation of village services.

- **Large rice-water stools in more than one household.** Cholera can kill within hours. Start oral rehydration (HY-03), chlorinate or boil all water, strain raw water through folded sari, stop washing food in raw water.
- **Bloody diarrhoea with fever.** Shigella or amoebae. Give fluids and food and isolate the stool.
- **Fever for more than a week, confusion, a swollen belly.** Typhoid. Perforation is fatal without surgery. Give fluids, food and cooling, and boil all household water.
- **Yellow eyes after nausea or diarrhoea.** Hepatitis A or E, dangerous in pregnancy [VERIFY].
- **Watery diarrhoea spreading despite chlorinated water.** Suspect Cryptosporidium and switch to boiling.
- **A blue-grey infant fed on well water, without breathing difficulty.** Nitrate poisoning [VERIFY]. Change the source.
- **Water smelling of fuel or chemicals.** No home method removes them. Find another source.
- **A well that clouds after rain.** Stop using it until cleaned and shock-chlorinated.

Honest comfort. Most diarrhoea is short and self-limiting, and it is the lost fluid, not the germ, that kills. A household that treats and covers its water, washes hands and starts rehydration early will prevent most deaths, even if not every illness. When a child dies of cholera or typhoid where there is no doctor, the family has not failed.

The case against

The trials are biased. Wolf-Peter Schmidt and Sandy Cairncross (2009) argued that the evidence did not justify scaling up household treatment, because open trials with self-reported outcomes invite reporting bias. Their argument has held. The Orissa double-blind chlorine trial, with 2,163 households and 2,986 children, found prevalence of 1.69 against 1.74 per cent, a ratio of 0.95 (0.79 to 1.13) (Boisson et al. 2013). Blinded trials pooled at 0.94 (Clasen and Boisson 2016), and Engell's review found no effect once blinding was considered (Engell 2013, cited in Clasen et al. 2015). Paul Hunter (2009) modelled the benefits of SODIS and chlorination as nearly vanishing by 12 months, with ceramic filters holding up best.

People stop. SODIS use in Bolivia was 32 per cent, chlorine use in Kenya under half, and ceramic filter use fell about 2 per cent a month. In Bangladesh the chlorine effect vanished when visits stopped.

The history is weaker than told. Anderson, Charles and Rees (2022) corrected the data behind the claim that water treatment explained half of American urban mortality decline and found smaller effects.

Treatment is not a supply. The largest single effect in the Cochrane review was piped water in South Africa (0.43), and diarrhoea also spreads by hands, food and flies.

The rebuttal. Blinded trials were in low-risk or low-use settings, and in Orissa a 2017 Emory University thesis found an odds ratio of 0.69 among confirmed adherers (secondary, not peer-reviewed) [VERIFY]. The laboratory evidence for boiling, chlorine against bacteria and filtration is not in doubt, and Hamburg and Altona is a natural experiment no trial will match. The case against is a case against overclaiming and against programmes that hand out products and leave, not against treating water.

Both romances. The herbal romance says Moringa purifies water. It clears water, bacteria regrow, and chlorine works less well. The hospital romance says only a utility makes water safe. A household with a pot, a fire, a bottle and the sun can make water safer than most people drank before 1900.

Today and after the Fall. Today a commercial filter or chlorine tablets are the best household choice. After the Fall, tablets and sachets run out within months, commercial filters break and bleach decays. Fire, sun, sand, clay, salt and a salvaged solar panel remain. A district that makes its own chlorine, casts its own biosand filters and fires its own ceramic pots has secured its water for a generation.

10-line summary

1. A rolling boil kills every waterborne pathogen at any inhabited altitude. One minute adds a margin, three above 2,000 m.
2. Boiling's limits are fuel, about 0.3 kg of wood per litre on an open fire [VERIFY], and recontamination (60.5 per cent in Vietnam).
3. SODIS needs 6 hours of sun, 2 days if cloudy, clear PET bottles and water below 30 NTU. Use tends to fall.
4. Chlorine at 2 mg/L, 4 to 5 for cloudy water, with 30 minutes' contact, kills bacteria and viruses and protects storage, but not against Cryptosporidium.
5. Filters show the largest effects: ceramic 0.39, biosand 0.47. Biosand needs 30 days to ripen and must not dry.
6. Folded old sari cloth cut cholera by 48 per cent in Matlab, but does little against other pathogens.
7. Alum and Moringa clear water but do not disinfect it, and Moringa weakens chlorine.
8. Blinded trials found 0.94 where open trials found 0.55. The methods clean water, but the health gain is smaller and depends on daily use.
9. A covered container with a tap, never dipped, protects all treated water.
10. A protected source, latrines 30 m away and downhill, and a sanitary survey prevent what treatment must otherwise fix.

Open questions

- The true health effect of household treatment where risk and adherence are both high. No blinded trial has measured it.
- Whether any method keeps its effect beyond 12 months.
- Real fuel use per litre on post-Fall hearths: estimates run from 0.09 to 1 kg.
- Field data on simmer-and-cover and hay-box pasteurisation.
- SODIS in glass, at high latitude in winter, and in maritime cloud.
- Whether improvised electrolysis cells make stable, measurable hypochlorite, and from which electrodes.
- Moringa dose by water type, and whether chlorine can safely follow at a higher dose.
- How long a ceramic filter without silver stays safe.
- Safe latrine distances by soil and rock type, and first-flush volumes by climate.

Sources to read in full

1. Clasen et al. 2015. Interventions to improve water quality for preventing diarrhoea. Cochrane review, for every effect size.
2. Backer, Derlet and Hill 2024. Wilderness Medical Society guidelines on water treatment, for doses, LRVs and improvised methods.
3. Meierhofer and Wegelin 2002. The SODIS manual.
4. CAWST biosand filter construction manual (not read here, fact sheet only).
5. Colwell et al. 2003. Reduction of cholera in Bangladesh villages by simple filtration.
6. Clasen and Boisson 2016, on blinded trials.
7. Reed, Shaw and Chatterton 2013. WHO and WEDC technical notes on water in emergencies.
8. WHO Guidelines for Drinking-water Quality, 4th edition (not read here).
9. Evans 1987. Death in Hamburg.
10. Sobsey 2002. Managing Water in the Home (WHO, not read here).

At the bedside after the Fall

Household. Minimum: one covered container with a tap kept for drinking water, a pot, a few clear 1 to 2 litre PET bottles, folded old cloth, and bleach or HTH while it lasts. Settle, strain, then boil, sun or chlorinate, and store covered. First failure to expect: someone dips a cup into the treated water, or the family stops treating when no one is ill.

Village of 300. Minimum: a sanitary survey of every source in the first month, with latrines moved 30 m away and downhill. One protected spring or well with apron, cover and fence. A named person who makes 1 per cent stock daily and doses each jerrycan at the source (4 mL per 20 litres clear, 8 mL cloudy). Biosand filters for every household with infants, cast in a shared mould. Moringa trees and an alum store. Records of doses, turbidity and diarrhoea cases. Needs: a welder, fine sand, a scale, salvaged chlorine, a teacher. First failure to expect: weak or old chlorine stock that nobody notices without a residual test, then an outbreak. Second: filters left to dry in the dry season.

District of 3,000. Minimum: a brine electrolysis cell on a salvaged solar panel supplying every village, with a residual test or colour standard. A potter's workshop making flow-tested ceramic filters. A slow sand filter for any town on river water. A bench with a microscope and, if possible, an incubator. An outbreak plan: boiling stations, sari cloth for raw water, chlorination at every source. Needs: salt, electricity, electrodes, clay, a kiln, a trained operator, a register of sources. First failure to expect: the cell or panel fails with no chlorine in reserve. Keep a month's stock.

Protocols

Protocol 1. Boil

1. Settle and strain cloudy water first.
2. Bring to a rolling boil, with bubbles breaking across the whole surface.
3. Boil 1 minute, or 3 minutes above 2,000 m.
4. Cool covered. Pour into storage without dipping. Use within 24 hours.
5. Tolerance: once the boil rolls, the water is safe. A boil that never rolled is a failure.

Protocol 2. Simmer and cover

1. Heat until bubbles rise steadily from the bottom.
2. Take off the fire, cover tightly and wrap in a blanket or hay.
3. Leave 30 minutes before opening (Backer et al. 2024).
4. Not for infants or at altitude. Boil instead.

Protocol 3. SODIS

1. Clear PET bottles, 1 to 2 litres, unscratched, labels off.
2. If a headline cannot be read through the full bottle from above, clear the water first [VERIFY].
3. Fill three-quarters, shake 20 seconds, fill to the top, close.
4. Lay flat on corrugated iron or a dark roof in full sun by mid-morning.
5. Six hours if clear or at most half cloudy. Two days if more cloudy. Not in constant rain.
6. Drink from the bottle or a clean cup within 24 hours.

Protocol 4. Bleach

1. Read the strength. If unknown, assume 5 per cent.
2. Clear water: 1 drop of 5 per cent bleach per litre, or 1 mL (20 drops) per 20 litres.
3. Cloudy, cold or river water: 2 drops per litre, or 2 mL per 20 litres.
4. Stir and wait 30 minutes, or 2 hours in cold water.
5. Sniff. A faint chlorine smell means a residual. If none, dose again and wait 30 minutes more [VERIFY].
6. Drink cloudy chlorinated water within 8 hours, clear within 24.
7. Tolerance: up to 5 mg/L is within the WHO guideline. Strong taste fades if the water stands open for a few hours.

Protocol 5. Make a 1 per cent stock

1. From 5 per cent bleach: 1 part bleach to 4 parts clean water [VERIFY].
2. From 70 per cent HTH: about 14 g per litre of clean water. Settle and pour off the clear liquid [VERIFY].
3. Label “POISON, 1% CHLORINE” with the date. Store cool, dark and locked.
4. Dose 4 mL per 20 litres clear, 8 mL cloudy.
5. Make HTH stock fresh daily (MSF). Never mix NaDCC and HTH.

Protocol 6. Hypochlorite from salt

1. Dissolve 25 g of salt per litre of clean water.
2. Run the cell outdoors, away from flames, for the maker’s time (mini-WATA: 0.5 litres in 3 hours).
3. The product holds about 6 g/L. Keep dark and closed, and use within a few days [VERIFY].
4. Dose about 7 mL per 20 litres for 2 mg/L (40 mg ÷ 6 mg per mL) [VERIFY]. Confirm by smell or test.

Protocol 7. Alum

1. Dissolve about 1 mL of alum per 4 litres of raw water in a little water and add it.
2. Stir fast 1 minute, slowly 5 minutes.
3. Settle at least 30 minutes.
4. Pour off through folded cloth, leaving the sludge.
5. Disinfect. If still cloudy, try a stronger dose in another bucket. If bitter, use less.

Protocol 8. Moringa

1. Shell dry seeds of *Moringa oleifera* and crush the white kernels to powder.
2. Use about 2 g per 20 litres, mixed to a paste with clean water.
3. Stir fast 30 seconds, then slowly 5 minutes.
4. Settle 1 to 24 hours and pour off through cloth.
5. Boil or SODIS. Do not rely on normal chlorine doses. Use within 24 hours.

Protocol 9. Sari cloth

1. Use old, soft, washed cotton.
2. Fold to 8 layers and pour the water through, always the same side up.
3. Rinse in filtered water and dry in the sun after use.
4. Disinfect afterwards whenever possible.

Protocol 10. Biosand filter

1. Fill with gravel and fine sieved sand so that about 5 cm of water stands above the sand.
2. Disinfect the output for the first 30 days.
3. Pour 12 to 18 litres once or twice a day, with 1 to 48 hours between batches, best 6 to 12.
4. Collect into a covered container. If flow exceeds 0.4 litres a minute, the sand is wrong or disturbed.
5. When flow slows, swirl the top sand, scoop out the dirty water, wash hands, and disinfect output for a few days.
6. Never let it dry. Never feed it water above about 50 NTU.

Protocol 11. Storage

1. Narrow mouth or tap, with a lid, raised off the floor.
2. Wash weekly with a few drops of bleach in water, dry upside down.
3. Pour or use the tap. Never dip.

Protocol 12. Protect and survey a well or spring

1. Note latrines within 30 m or uphill, standing water, droppings, rubbish, a broken apron or seal, a bucket on the ground.
2. Fix the worst first: move latrines, build an apron at least 1 m wide sloping to a drain, raise a headwall, cover and fence.
3. After floods or repairs, shock-chlorinate at about 50 mg/L for at least 12 hours, then bail until the smell fades. A well 1.5 m across with 3 m of water holds about 5,300 litres and needs about 265 g of chlorine, roughly 380 g of HTH or 5.3 litres of 5 per cent bleach [VERIFY].
4. Repeat every season and after floods, and record the results.
5. Never enter a well alone or without testing the air [VERIFY].

Protocol 13. Rainwater

1. Collect from clean metal or tile roofs, not lead-painted [VERIFY].
2. Divert about 1 to 2 litres of first flush per square metre of roof, and empty the diverter after rain.
3. Cover and screen the tank, fit a tap, clean yearly.
4. Treat before drinking, and always before giving to infants.

Numbers to carry

1. **Rolling boil: 1 minute, 3 above 2,000 m. Short of fuel: simmer, cover 30 minutes.**
2. **SODIS: 6 hours of sun, 2 days if cloudy, below 30 NTU, bottles of 2 litres or less.**
3. **5 per cent bleach: 1 drop per litre clear, 2 cloudy. Wait 30 minutes. Smell for chlorine.**
4. **1 per cent stock: 4 mL per 20 litres clear, 8 mL cloudy.**
5. **Chlorine does not kill Cryptosporidium. Boil if an outbreak continues despite chlorine.**
6. **Biosand: 30 days to ripen, 5 cm of water on top, never dry.**
7. **Latrine 30 m from water and downhill. Apron 1 m wide.**
8. **Chlorinated cloudy water within 8 hours, other treated water within 24.**
9. **About 0.3 kg of wood per litre on an open fire [VERIFY].**
10. **Blinded trials 0.94, open trials 0.55. A method works only if used every day.**

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