REBUILDING CIVILIZATION

Water and sanitation

Obtain, purify, distribute water, and manage excreta and wastewater.

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1 of 5 articles translated; the rest are available in Spanish.

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Contents

Water purification

Remove pathogens and contaminants from water: heat, filtration, chemicals and sun, from household to industrial scale.

WATER AND SANITATION › WATER PURIFICATION

Boiling water

Boil water to kill pathogens, with time adjusted for altitude, safe cooling and storage, and fuel consumption.

N1 · Pottery and farming · Draft · Machine translation · civilizationrebuild.org/en/01-agua-y-saneamiento/potabilizacion/hervido-del-agua/

> **Machine translation.** Its structure and figures have been automatically checked against the Spanish original, but no person has reviewed it.

> **Draft without technical review.** It may contain errors: double-check figures and procedures before applying them. It contains 6 figures marked “verificar” (to be verified).

Summary

Boiling water destroys practically all the bacteria, viruses and protozoa (including their cysts and oocysts) that cause disease, using only fire and a container. It is the most reliable biological purification method and the easiest to verify by eye (just seeing it at a rolling boil) when there is no chlorine, certified filters or laboratory available. Expected, measurable result: starting from water with no visible turbidity, a batch of up to ~10 L becomes microbiologically safe in 15-35 minutes (lighting the fire, heating and boiling), plus 30-60 minutes of cooling before it is comfortable to drink, at a cost of between 1.5 and 2.2 kg of dry firewood (or 0.4-0.6 kg of charcoal) per 10 L over an open fire. Boiling does **not** remove chemical products, heavy metals or turbidity, and boiled water is not protected against later recontamination: safety depends as much on how the water is boiled as on how it is cooled and stored.

Prerequisites

- **Knowledge:** none is essential to carry out the procedure as described here. It helps to have already decided how the water is collected (the clearest source available) and, if the goal is to reduce fuel use, to compare with solar disinfection (SODIS) and with filtration, articles planned for this same folder.
- **Materials:**
  - Water to be treated, as clear as possible: 2-3 L per person per day just for drinking (more in heat or with physical work).
  - Fuel: dry firewood (moisture <20 %, it snaps with a crack instead of bending), or charcoal, or any other sustained heat source (gas, electric stove, embers).
  - A tightly woven cotton cloth (a sari-type cloth folded 4-8 times works; see “How it works”) to pre-filter the water if it is turbid.
  - A clean, narrow-mouthed container with a lid and, if possible, a tap, kept exclusively for drinking water, for later storage.
  - A thick cloth or oven mitt to handle the hot container.
- **Tools:**
  - An open-air fire or a hearth (N0: three stones and firewood are enough).
  - A container that can be set directly over the flames and withstand repeated boiling without cracking or releasing toxic substances. **This is where this article's technological level is decided:** it is set at `nivel: 1` because the main procedure (container placed directly over the fire) requires fired ceramic (N1 minimum) or metal (N2); a purely N0 container — raw hide, bark, waterproofed basketry, wood — burns, warps or loses its seal if brought near direct fire. A genuine N0 route does exist, slower and with greater losses: heating stones red-hot in the bonfire and dropping them into water held in a container that resists water but not direct fire (“hot-rock boiling”). Because it is less efficient and carries a greater risk of burns, it is documented as a lower-resource variant (see “Variants”), not as the main procedure.

  - A thermometer and/or a WAPI indicator are optional (needed only for the lower-temperature pasteurization variant, see "Variants").
- **Time and people:** one person is enough. Per batch of up to 10 L: 5-10 min to prepare the fire, 10-20 min to bring the water to a boil (depending on fire strength and volume), 1-3 min of sustained boiling, and 30-60 min of cooling before it is comfortable to drink (it can be drunk warm before that, already safe, if there is urgency).

How it works

Why heat kills pathogens

Heat denatures the proteins and enzymes of microorganisms and damages their nucleic acids; above a certain temperature, sustained for long enough, the pathogen stops being viable or infectious. Thermal sensitivity varies by type of organism:

- **Bacteria in vegetative form** (*E. coli*, *Vibrio cholerae*, *Salmonella*, *Shigella*): inactivated in seconds from about 60 °C upward; at boiling temperature, destruction is practically instantaneous.
- **Enteric viruses** (rotavirus, norovirus, hepatitis A): somewhat more resistant than bacteria, but likewise inactivated in under 1 minute at boiling temperature.
- **Protozoan cysts and oocysts** (*Giardia*, *Cryptosporidium*): the most heat-resistant organisms of sanitary concern among those commonly transmitted by water. *Cryptosporidium* oocysts are inactivated in under 1 minute above 70 °C, and *Giardia* cysts almost instantly from that same temperature.
- **Bacterial spores** (e.g. *Bacillus*, *Clostridium*): boiling at 100 °C does **not** reliably destroy them; autoclave temperatures (~121 °C under pressure) or very long times are needed. In practice, however, they are not the usual cause of waterborne illness, which is why boiling remains the reference method for household use, with this honest caveat.

Taken together, a sustained rolling boil comfortably exceeds the temperature and time that any common enteric pathogen needs to be inactivated.

Boiling versus pasteurization

It is not necessary to reach 100 °C to kill pathogens: pasteurization uses lower temperatures (60-72 °C) for longer to achieve the same effect with less fuel. The reference study (Ciochetti and Metcalf, 1984) found that fecal coliforms in river water were inactivated from 60 °C upward, and that keeping water above 65 °C leaves it, for at least one hour, above the pasteurization temperature of milk (62.8 °C), considered sufficient to inactivate the enteric pathogens of concern. Boiling (100 °C, 1-3 min) is simpler to verify without a thermometer — just seeing it bubble is enough — and gives a wider safety margin against variations in altitude, turbidity or uneven heat distribution in the container; that is why WHO/UNICEF and the CDC recommend it as the default method. Lower-temperature pasteurization (the WAPI variant, see "Variants") is preferable when fuel is the scarcest resource.

Altitude adjustment

Water boils when its vapor pressure equals atmospheric pressure; at lower atmospheric pressure (higher altitude), water boils at a lower temperature. This does not invalidate the method — even at high altitude the boiling temperature stays well above the 70 °C that suffice for the pathogens mentioned above — but it reduces the safety margin, which is why WHO/UNICEF and the CDC recommend extending the boiling time above 2000 m (~6500 ft):

Altitude (m)	Boiling point (°C)	Rolling-boil time
0 (sea level)	100.0	1 minute
610	97.8	1 minute
1219	95.7	1 minute
1829	93.6	1 minute
~1980 (6500 ft, WHO/CDC threshold)	~93.0	**3 minutes** from here on
2438	91.6	3 minutes
3048	89.6	3 minutes
4572	84.7	3 minutes

Rule of thumb: **1 minute of rolling boil below 2000 m; 3 minutes from 2000 m upward.**

Why settle and filter before boiling

Heat does not remove turbidity or suspended matter, and sediment can shelter pathogens protected from the heat inside it (larger particles take longer to reach the lethal temperature at their core), besides wasting fuel by heating matter that is not water. Filtering through a tightly woven cotton cloth also has a documented effect of its own: a field study in Bangladesh (Colwell et al., 2003) showed that a sari-type cloth folded 4-8 times forms a filter with an effective mesh of about 20 microns, able to retain the zooplankton and phytoplankton that *Vibrio cholerae* usually attaches to, and cut cholera cases by 48 % in the villages where it was used. Settling and filtering before boiling is therefore a step that reduces fuel use and adds an extra barrier, not a substitute for boiling.

What boiling does NOT remove

- **Dissolved chemicals:** pesticides, solvents, nitrates, excess arsenic or fluoride are not destroyed or meaningfully evaporated by boiling; if the water is boiled for a long time, letting a significant fraction of it evaporate, the concentration of what does not evaporate (salts, heavy metals) can even rise slightly.
- **Heavy metals** (lead, mercury, cadmium, arsenic): not removed by boiling.
- **Turbidity, color, salty taste or mineral off-odor:** boiling does not clear the water or remove salty tastes; only settling, filtration or distillation act on this.
- Because of the above, if the water is suspected of contamination by fuel, solvent or industrial chemicals, **it must not be boiled for drinking**: another source must be found.

Procedure

1. **Prepare the water.** If there is visible turbidity, let it settle undisturbed in a container for 30-60 min and pour off only the clear water from the top without stirring up the sediment, or filter it through a tightly woven cotton cloth folded 4-8 times (sari-type, effective mesh of ~20 microns) tied over the mouth of another clean container. *Success criterion:* the water looks transparent (text is legible through a 10 cm layer of it) and leaves no visible sediment after 10 minutes at rest in a glass.
2. **Choose the container.** Fired ceramic without lead glaze, or metal, with a capacity of at least 1 L per person per serving, with no cracks or leaks, and that has never held fuel, paint or pesticides. *Success criterion:* after filling it with water and leaving it for 5 min, no drips appear and no rust stains rub off to the touch.
3. **Fill the container between 2/3 and 3/4 of its capacity**, leaving room for the boil without overflowing. *Success criterion:* a gap of at least 5 cm between the water surface and the rim.
4. **Cover** with a lid or a flat object that does not release substances (another pot, a clay plate) and place over the fire at maximum power. *Success criterion:* no continuous jet of steam is seen escaping from the sides before it starts to boil (covering it saves fuel, see “Calculations”).
5. **Heat until it reaches a rolling boil**: large bubbles rising continuously from the bottom that do not stop when stirred. *Success criterion:* visible bubbling across the whole surface (not just at the edge) for at least 10 consecutive seconds.
6. **Keep it at a rolling boil** for 1 minute if the site's altitude is below 2000 m; 3 minutes if it is at or above that. *Success criterion:* time it from the moment step 5's criterion is met; the boil does not stop at any point during the interval.
7. **Remove from the fire** with a thick cloth or tongs (the container and any metal handle are above 90 °C) and uncover it while keeping face and hands away from the jet of steam. *Success criterion:* no one makes direct contact with the container or gets hit by the steam.
8. **Cool** it covered, out of children's reach, until it is comfortable to drink. *Success criterion:* the outside of the container is lukewarm (≤ 35-40 °C to the touch), not hot.
9. **Aerate to improve the taste (optional).** Pour the water back and forth between two clean containers 5-10 times from a height of ~30 cm. *Success criterion:* fine air bubbles appear and the water loses the “flat” taste typical of boiled water (caused by the loss of dissolved air during boiling).
10. **Store** it in the narrow-mouthed container, covered, with a tap if possible, without putting hands, cups or ladles into the water. *Success criterion:* the water is only served by pouring directly or through the tap, never by dipping a utensil in.

Verification

- **Visual:** the water is transparent, with no sediment or film on the surface, and the only smell or taste that differs from the original is the “flat” taste typical of boiling (which aeration in step 9 fixes).
- **Process-based, not product-based:** there is no simple field test that can confirm afterward that boiled water is free of pathogens; the guarantee comes from having met the time and temperature requirements (steps 5-6), not from a later check. If a thermometer is available, it can confirm that a rolling boil (not just hot water) was reached before timing starts.

- **Important:** unlike chlorination, boiling leaves no protective residual. Correctly boiled water can be contaminated again 5 minutes later if it is served with dirty hands or in a dirty container; the real verification that it is still safe to drink is that it has been handled following step 10 at every moment since it was boiled.

Common mistakes

Symptom	Likely cause	Solution
Someone who drinks “boiled” water still gets sick	Recontamination during cooling or storage (hands, ladle, dirty container)	Use a narrow-mouthed container with a lid/tap; serve without dipping utensils in; wash the container daily
The water tastes “flat” or unpleasant	Loss of dissolved air during boiling	Aerate it by pouring between two containers before drinking (step 9)
Much more fuel is used than expected	Uncovered container, fire exposed to wind, damp firewood	Cover the container; shield the fire from wind; use firewood with under 20 % moisture or an efficient stove
The water is still turbid after boiling	Water with sediment was boiled without settling or filtering it first	Settle and/or filter with cloth before boiling (step 1); boiling does not clear the water
Strange or metallic taste after using a certain container	Unsuitable container: plastic not rated for heat, lead-glazed ceramic, or a container that held fuel/pesticide	Use only fired ceramic without lead glaze, or metal kept exclusively for water (see “Safety”)
The boil does not give enough safety margin at high altitude	Time was not adjusted for altitude	Boil for 3 minutes instead of 1 above 2000 m (see altitude table)

Safety

- **Burns and scalds (the main hazard of this procedure):** steam at 100 °C causes deeper burns than liquid water at the same temperature, because it releases a large amount of extra heat as it condenses on the skin. Always use a thick cloth or oven mitt to move the container; uncover it while keeping face and hands away from the jet of steam; make sure the container sits stable over the fire and cannot tip over; keep children out of reach of the fire and the hot container at all times, including during cooling.
  - **What to do for a burn:** cool it immediately with lukewarm or cold (not iced) running water for 10-20 minutes; do not apply ice directly, toothpaste or home remedies to the burn; do not pop blisters; cover with a clean, non-stick cloth. Seek medical attention if the burn is bigger than the palm of the hand of the person who suffered it, if it affects the face, hands, skin folds or genitals, or if extensive blisters appear.
- **Smoke poisoning:** if firewood or charcoal is used to boil in a closed or poorly ventilated space, there is a risk of carbon monoxide poisoning, which is odorless and can be fatal. Always boil outdoors, under a smoke outlet, or with assured cross-ventilation.
- **Valid containers:** fired ceramic without lead or cadmium glazes (some old or handcrafted glossy glazes contain them, and heat and acidity make them more likely to leach into the water), or metal (stainless steel, aluminum, iron) kept exclusively for food use.
- **Invalid containers:**
  - Plastic not certified for direct contact with heat: it can warp, burn or release compounds into the water.
  - Any container that has held fuel, solvent, paint or pesticide: boiling does not remove those chemical residues even if the water ends up free of pathogens.
  - Ceramic with lead or cadmium glaze.
  - Galvanized metal for repeated, prolonged boiling: the zinc coating can degrade with continued use and leach into the water in excess (verificar: the size of the risk depends on the condition of the coating and how many times it is reused).
- **Stones for the hot-rock boiling variant (see “Variants”):** never use river stones, porous stones, or ones that have been wet on the inside: steam trapped in their pores can make them explode violently when heated, throwing off fragments. Use dense, dry stones with no visible cracks, and always heat them well away from the face.
- **Reminder:** boiling does not protect against chemicals or heavy metals (see “What boiling does NOT remove” in “How it works”); if that kind of contamination is suspected, boiling alone is not enough.

Variants

- **With fewer resources (N0, no ceramic or metal): hot-rock boiling.** Dense, dry, non-porous stones are heated red-hot in the fire for 20-30 min, and dropped in one at a time with green-wood tongs or a forked stick into the water, which is held in a container that withstands water but not direct fire (raw hide, sewn tree bark, a very tightly woven basket waterproofed with clay or resin, a hollowed-out log). Roughly 3-5 fist-sized stones (~0.5 kg each) are needed per liter of water to reach a boil, replacing stones as they cool (verificar: exact figure depends a great deal on the type of stone and the size of the fire). It is a technique with a documented history of use in cultures that had no fire-resistant containers. *What is lost:* energy efficiency (a lot of heat stays in the stones that never fully submerge), more time and labor, and a higher risk of burns from splashing and of porous stones exploding. *What is gained:* not depending on fired ceramic or metal.
- **With more resources (N2 upward):** a metal kettle with a tight-fitting lid and a heat-insulated handle; a gas or electric stove with power control, which reaches the boil sooner and without smoke; from N3 onward, an electric kettle with automatic shutoff at boiling (less supervision needed); at industrial scale (N3-N4), continuous-flow pasteurizers with a heat exchanger that recovers part of the heat from the already-treated water to preheat the incoming water, cutting fuel use per liter considerably.
- **Lower-temperature pasteurization variant with an indicator (WAPI):** instead of bringing the water to a boil, it is heated (over a fire, in a box-type solar cooker, or over embers) and held at 65 °C using a WAPI indicator — a polycarbonate tube with a wax plug calibrated to melt at that temperature, developed by Fred Barrett and Dale Andreatta for Solar Cookers International — or, without a WAPI, with a thermometer. The basis for this (Ciochetti and Metcalf, 1984) is that fecal coliforms are inactivated from 60 °C upward, and that keeping the water above 65 °C comfortably exceeds the pasteurization temperature of milk (62.8 °C), sufficient for the enteric pathogens of concern. *Advantage:* it saves a significant part of the fuel compared with boiling, since there is no need to reach 100 °C or sustain a boil. *Disadvantage:* it requires controlling the temperature more precisely than just "seeing it boil"; it does not destroy heat-resistant bacterial spores (of little relevance in drinking water); making a WAPI requires N3-N4-level materials and calibration, although an already-made WAPI can be reused thousands of times. Recommended when fuel is the scarcest resource and there is a reliable way to control temperature.
- **Scaling up to a village:** boiling in communal cauldrons of 20-200 L over a shared fire or in a community kitchen, in shifts. The larger the cauldron, the smaller its surface-to-volume ratio, which reduces relative heat losses and fuel use per liter compared with boiling in small batches. In exchange, the risk of recontamination rises (more people dipping ladles or containers into the same cauldron), and it becomes necessary to organize distribution into individual narrow-mouthed containers and to ensure a centralized fuel supply, which is usually the real bottleneck: WHO/UNICEF point to the high cost and fuel consumption as the main limitation of large-scale boiling compared with centralized chlorination, which works out far cheaper per liter. Where possible, reserve communal boiling for those without access to chlorine, and treat it as a transitional solution.

Calculations

Theoretical energy to boil 10 L of water

Data: specific heat of water c = 4.186 kJ/(kg·°C); mass of water m = 10 kg (10 L); initial temperature 20 °C, final 100 °C (at sea level); ΔT = 80 °C.

Minimum energy the water must receive (not counting losses or the time of sustained boiling):

```
Q = m × c × ΔT = 10 kg × 4.186 kJ/(kg·°C) × 80 °C = 3349 kJ ≈ 3.35 MJ
```

In practice, most of a fire's heat is lost to the air and surroundings rather than passing into the water, so considerably more fuel is needed than this theoretical figure.

With an open three-stone fire (real thermal efficiency 10-15 %, verificar)

```
Firewood energy needed = 3.35 MJ / 0.10 to 0.15 = 22.3 to 33.5 MJ
```

With air-dried firewood (calorific value ≈ 15 MJ/kg):

```
Firewood mass ≈ 22.3/15 to 33.5/15 = 1.5 to 2.2 kg per 10 L (≈ 150-220 g per liter)
```

With an improved rocket-type stove (efficiency 25-40 %)

```
Firewood energy needed = 3.35/0.25 to 3.35/0.40 = 8.4 to 13.4 MJ
Firewood mass ≈ 0.56 to 0.9 kg per 10 L (≈ 56-90 g per liter)
```

That is, between 2 and 3 times less firewood than with an open fire, consistent with fuel savings on the order of 40-60 % cited by field comparisons between three-stone fires and rocket stoves (verificar: exact figure varies by study).

With charcoal (28-30 MJ/kg) and a "jiko"-type stove (efficiency 20-30 %, verificar)

```
Energy needed = 3.35/0.20 to 3.35/0.30 = 11.2 to 16.75 MJ
Charcoal mass ≈ 0.37 to 0.6 kg per 10 L (≈ 37-60 g per liter)
```

Effect of the lid

Covering the container reduces fuel use for boiling by 20-35 % compared with boiling uncovered (a general estimate from cooking physics, not specific to water purification). Applied to the open three-stone fire, this could bring consumption down to approximately 1-1.8 kg of firewood per 10 L.

Honesty note: all the fuel-mass figures in this section are order-of-magnitude estimates based on published efficiencies for different fire/stove types; actual consumption depends heavily on the moisture of the firewood, wind, fire size, the shape of the container and the experience of the person tending it. They are marked as estimates, not as an exact, reproducible value.

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