THE INTERNATIONAL MOUNTAINEERING AND CLIMBING FEDERATION
UNION INTERNATIONALE DES ASSOCIATIONS D'ALPINISME

Office: Monbijoustrasse 61 • Postfach
CH-3000 Berne 23 • SWITZERLAND
Tel.: +41 (0)31 3701828 • Fax: +41 (0)31 3701838
e-mail: office@uiaa.ch

RECOMMENDATION

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Water Disinfection in the Mountains

Intended for Doctors, Interested Non-Medical Persons
and Trekking or Expedition Operators

C. Albanus, L. Timmermann, V. Schoeffl, J. Milledge, Th. Küpper

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1 Introduction

Travellers' diarrhoea is one of the most common and important health problems affecting travellers. The syndrome occurs in up to 70% (in some regions up to 90% [1]) of people travelling to less developed regions, resulting in a significant impairment of the victim's activities, with nearly 40% of travelers changing their itinerary [1], [2], [3], [4]. Although contaminated food may be a more important risk factor for travellers' diarrhoea than water [1], the availability of safe water and knowledge of how to obtain it, is a must for mountaineers worldwide to balance (high altitude) dehydration, to improve performance, and to minimise risks (e.g. frostbite, altitude diseases). In most cases obtaining and purifying water will be the mountaineer's responsibility when safe community based water resources are not available. This UIAA MedCom recommendation summarises advantages and disadvantages of several procedures with special regard to the situation in the mountains or at high altitude and will advise mountaineers on how to prepare safe water while minimising environmental damage.

It should be noted that natural surface water may also be contaminated with organic or inorganic material from land and vegetation and with industrial chemical pollutants [5]. It should also be noted that microorganisms with a small infectious dose (e.g., Giardia, Cryptosporidium, and Shigella species; hepatitis A virus, enteric viruses, and enterohemorrhagic Escherichia coli) may cause illnesses even when a small volume of contaminated water is inadvertently swallowed during water-based recreational activities [6]. Both, industrial pollutants and water-based recreational activities are beyond the scope of this recommendation but need some attention by the traveller.

Of special interest for mountaineers is that most enteric organisms, including Shigella species and Salmonella typhi, hepatitis A virus, and Cryptosporidium species, can survive for weeks to months when frozen in water [7], [8].

2 Definitions

- **"Safe water"** does not mean that water needs to be absolutely sterile. Water is safe (=potable) when the concentration of pathogenic germs is too low to expect any damage to human health (infection). International standards of water testing define water as safe or potable when free of E. coli or thermotolerant coliform bacteria (0 colony forming units (CFU)/100ml), independent of the sampling point (water entering the distribution system or at any point of use) [9].
- **"Disinfection"** is the killing, inactivation, or removal of germs which can induce infectious diseases.
- **"Sterilisation"** means that all germs are eliminated.
- **"Conservation"** describes procedures which prevent microbiological recontamination of previously "safe" water.
- We define **"regular methods"** for water disinfection as methods providing water which is accepted to be safe.

- **"Improvised methods"** do not guarantee safe water. These methods should only be used if no regular method is available.

3 Pathogens in water

Pathogenic germs occurring in water include bacteria, viruses, and protozoa with distinct behaviour in terms of survival time or resistance against disinfection methods. Travellers' diarrhoea is mainly caused by bacteria (50-80 %), followed by viruses (5-25 %), and protozoa (< 10 %) [10], [11]. Among the bacterial species, ETEC (enterotoxigenic E. coli) is the most frequent cause of travellers' diarrhoea worldwide [12]. Bacterial spores, which are much more resistant than vital bacteria, do not belong to the primarily relevant waterborne pathogens [9]. Also most helminth diseases are rather associated with food than with drinking water, although there are exceptions. Pathogens differ in their environmental resistance. Generally viruses and protozoa (cysts) tend to be more resistant against several disinfection methods than bacteria. Survival of pathogens in water is difficult to measure and compare due to the distinct methodic design of the studies. Most water hygiene projects make use of Escherichia coli (E. coli) representing a reliable indicator of fecal contamination. However, the absence of E. coli may not be interpreted as potable for certain because environmental conditions might favour survival of intestinal enterococci more than coliform bacteria [13].

Some species can survive for long periods of time in water, especially at cold temperatures [14]. For example, Campylobacter can survive for several weeks at 4 °C [15]. In nutrient-rich waters some types of bacteria are even able to replicate. Host-dependent viral and protozoan species are, however, not capable of replication in water.

It should be noted that there are significant regional differences in germs and risk. Independent from any kind of water disinfection travelers going to the Himalayas should be aware of typhoid fever since Nepal is among the regions with the highest incidences worldwide, also in the tourist regions of Kathmandu [16], [17], [18], [19], [20], [18]. A vaccination is strictly recommended although Salmonella typhi can be easily killed b yall methods mentioned below. Generally, the goal is a 3 to 5 log reduction (99.9e99.999%), allowing a small risk of enteric infection [21], [22].

4 Principles for avoiding waterborne diseases

- Maintaining good standards of hygiene when handling any kind of water, beverage, food, or human waste is the "gold standard"!
  - Do not fill any other substances in containers used for drinking water, beverages, or food! Severe poisoning has been reported, e.g. when fuel was carried in beverage bottles.
  - Keep any equipment clean, which may be in contact with food, water or beverage! Wash your hands before handling food, water, or beverage! Recent research indicates the advantage of additional hand disinfection [23]

  - o Human waste needs to be buried at least 30 m from any water source to avoid further contamination of surface water.
- Minimising the amount of safe (treated) water needed!
  - o Determine which procedures can be done using untreated water (e.g. cleaning equipment, cleaning hands from heavy dirt etc.)
  - o Nevertheless, preparation of 4-5 litres of safe water per person per day should be expected.
- If several procedures of water treatment are available, always use the safest option!
  - o Having good quality raw water to disinfect improves the safety of any procedure and preserves the equipment. Collecting rainwater may be an option to obtain good quality raw water.
  - o "Improvisation methods" (see below) should be used only if "regular methods" cannot be performed for any reason. These methods do not provide safe water, but they reduce the concentration of germs significantly and therefore they statistically reduce the risk of waterborne diseases.
- Do not fill containers used for drinking water with any other substances
- Preconditions essential for water treatment in groups:
  - o Only trained persons should act and decide which procedure of those available should be used. Group infections may be the consequence of water disinfection by incompetent individuals!
  - o A demonstration to all group members should be performed by those in charge of water disinfection. This should be followed by the group's supervised participation in water disinfection procedures before water disinfection at one's own risk is performed.

5 Regular methods of water disinfection

In the mountains, there is no method available which is absolutely free of any failure. Thus, sound knowledge of a variety of water disinfection methods is essential. While some sources provide relatively safe water (e.g. water directly obtained from a high volume spring), most waters do need some sort of treatment before consumption, even if optically clear. If it is planned to store disinfected water for more than one day, a procedure for conservation should follow disinfection (see below).

5.1 Thermal disinfection

Principles: Although the temperature of boiling water at high altitude is lower than at sea level (boiling point reduced about 0.3°C (6°F) every 100 meters of altitude, Table 1), boiling kills virtually all waterborne enteropathogenic germs rapidly. In fact, most relevant species are killed at temperatures above 70°C within one minute [24]. Previously the thermal sensitivity of Hepatitis A virus (HAV) was discussed. However, even though the results of studies vary, a sufficient inactivation of HAV in a watery environment is provided at temperatures >80°C in less than one minute [25]. Nevertheless, to be on the safe side, travellers should be vaccinated against it. Bacterial spores show an even higher resistance against heat, requiring temperatures above 100°C to become inactivated. However, as mentioned above, spores do not belong to the pathogens that are particularly relevant to drinking water hygiene.

Table 1: Boiling temperature of water at several altitudes

Altitude [m]	°C	°F
0	100.0	212
1000	96.7	206
2000	93.3	200
3000	89.9	194
4000	86.6	188
5000	83.2	182
6000	79.9	176
7000	76.5	170
8000	73.2	164

Procedure: To add a margin of safety, water should boil with bubbles in it for at least one minute. Then temperature above 70°C is kept up long enough to ensure an adequate disinfection.

Advantages: Simple method, (nearly) no failure.

Disadvantages: Time and fuel consuming procedure with 1 kg wood necessary to boil 1 litre of water. Fuel must be carried to the mountains or taken locally which contributes to deforestation. Therefore, other procedures are preferred in any situation where liquid water (as opposed to ice) is available. Note that water is not conserved and recontamination is possible.

Additional remarks: To optimise procedure safety, all expedition members should be vaccinated against Hepatitis A.

5.2 Chemical disinfection

There are numerous chemical disinfection products available which are sold as tablets, liquids or powder. The most common purification substances are based on the oxidising effects of halogens. Chlorine and iodine are the halogens used in water disinfection. According to European guidelines, iodine should not be used because of possible side effects especially in the case of a non-diagnosed thyroid problem, making chlorine the recommended substance in chemical field water disinfection. Therefore, this recommendation focuses on a detailed description of chlorine-based products below. Another method is the production of mixed oxidants species by electrolysis of a salt solution which will also not be described in detail because up to now it is not very common in field use. Further techniques of chemical water disinfection include hydrogen peroxide and potassium permanganate which are, however, not recommended anymore (see chapter "Insufficient methods" below). Ozone is used to disinfect water on a larger scale. These systems are too heavy and too big to be carried along while travelling or climbing. But they provide safe water for tourists and locals in several regions of the world (e.g. Annapurna Circuit).

5.2.1 Chlorine (Hypochlorites)

Principles: Sodium hypochlorite, calcium hypochlorite, and NaDCC (sodium dichloroisocyanurate = sodium troclosene) belong to the most important chemical compounds available for field water disinfection. In Germany NaDCC is marketed e.g. as Micropur® forte, in the U.K. it is distributed e.g. as "Oasis Water Purification Tablets". Certisil combina® consist of sodium hypochlorite and ChloroSil® contains calcium hypochlorite. Efficacy of these substances is based on the formation of hypochlorous acid (HOCl) in water [26], [27]. HOCl oxidises and thereby destroys structural proteins and metabolic enzymes of the microorganism which causes cell death. All drinking water relevant bacteria and viruses are susceptible to disinfection with hypochlorites. However, there is a limited effect on protozoa. Also, eggs and larvae of several helminths show an increased resistance against hypochlorous acid.

Chemical oxidation neutralises some tastes and odors of water and removes colour to a certain extent. Oxidation of dissolved manganese and iron forms trivalent compounds that can be filtered from water [28]. If water contains larger amounts of organic material (e.g. algae), chlorine reacts with these substances to form chlorinated disinfection by-products (e.g. chloramines, trihalomethanes). This results in a strong chlorinous taste and odour of the water and can irritate mucous membranes. Furthermore, chlorine atoms which react with organic material cannot contribute to disinfection anymore, resulting in an increased chlorine demand.

Procedure: A sufficient amount of disinfectant must be added to the water (as indicated in the product's instruction manual). Shake well for homogeneous distribution of the disinfectant. Wait for an appropriate amount of time as given by the instructions. In cold water disinfection takes longer (about 2-4 times for every 10°C). Careful warming of the water (to about 20°C) shortens the time necessary for disinfection. Turbid water should be pre-filtered to reduce the amount of chlorine used up by organic substances and to minimise the formation of chemical by-products. **Note:** It is often recommended that at the end of the time necessary for disinfection the water should taste a bit of chlorine. Otherwise there was not sufficient disinfectant added before. In this case add the same amount of disinfectant as before and wait the same time for disinfection. However, since the threshold to smell chlorine is very individual and varies over a significant range this often referenced advice seems to be not reliable and therefore not recommended by UIAA MedCom.

Advantages: Can be used immediately at any place and any time where liquid water and disinfectant is available. Effective against most waterborne pathogens. No fuel necessary, therefore no contribution to deforestation. No heavy equipment required. Chemicals are relatively cheap and easy to obtain in larger towns and cities.

Disadvantages:

- Chemical disinfection is a method susceptible to environmental influences (e.g. water temperature, pH, organic contamination).
- Treatment is time consuming (30 minutes to 2 hours, depending on product, water temperature, turbidity, and expected germ spectrum). In cold water disinfection time needs to be increased (e.g. quadrupled for water <5°C). Alternatively, disinfectant can be added to water in higher concentrations. However, this impairs the taste and odour of the water. However, chemical disinfection is susceptible to errors concerning the correct dosage or certain species not being covered.
- Disinfection with hypochlorites is only safe if the pH of water is less than 7.5. Be careful in limestone regions! You may double the concentration of disinfectant, but at pH >8.5 there is virtually no disinfecting effect anymore [27].
- Chlorine compounds have a limited effectiveness against protozoa like Giardia lamblia and Cyclospora. Higher dosages or longer contact times are required in this case. There is no effectivity against Cryptosporidium parvum at practical dosages and contact times. Also eggs and larvae of several helminths show an increased resistance against hydrochlorous acid.
- Organic contamination of water results in the formation of disinfection by-products which may lower disinfection capacity, impair taste/odour of water and (in larger quantities) constitute a health risk. If only water with organic compounds is available the amount of disinfectant should be increased (doubled).

Additional remarks:

- The taste of water is impaired by chemical disinfection, especially if high concentrations were used to cope with cold conditions or organic material. It can be neutralised by adding one knife point of vitamin C (ascorbic acid) powder per litre or commercial neutralisation drops after disinfection is completed. Note that after neutralisation there is no disinfecting effect anymore!
- Chlorine products lose their effectiveness when exposed to certain environmental influences like sunlight and air. Thus, they have limited capability of conserving the water for longer periods of time. For this purpose, some chlorine products contain silver ions which prevent recontamination. Note: There are also water treatment products that only contain silver with no chlorine component (e.g. Micropur® *classic)*. Even though silver has a weak disinfection power itself, these products are intended for conservation of water that has already been disinfected and not for initial treatment!
- Trihalomethanes (chloroform) have carcinogenic potential which is why there are defined limits for these substances in communal drinking water supplies. The risk to health of travellers applying chemical field water disinfection remains unknown. However, it can be reasonably assumed that pathogens in water are of far more importance to human health than the levels of trihalomethanes that form at common chlorine dosages during a limited exposure time while travelling [24].

- There is evidence presenting certain advantages of using NaDCC over sodium and calcium hypochlorite for water treatment at individual level, even though the mode of action is the same. NaDCC is delivered in form of tablets making handling easier and safer than liquid NaOCl which presents the risk of under- or overdosage [29]. NaDCC tablets have a shelf life of 5 years while NaOCl liquid should be used up within 6 months. Due to its chemical composition NaDCC produces less by-products and has a slight buffering capacity for higher pH values. However, there is no official recommendation yet indicating a preference for NaDCC.

5.2.2 Chlorine dioxide

Note: Due to similar names, chlorine and chlorine dioxide (ClO_2) can easily be confused. When talking about water disinfection, the term “chlorine” usually refers to hypochlorites (including NaDCC) or chlor gas. Chlorine dioxide is a totally different substance with distinct properties and until recently ClO_2 was not available for individual use by travellers. As a volatile and explosive gas, its scope included facilities where large amounts of water are processed like municipal water plants or swimming pools. At present time, chlorine dioxide is also available as a field product in form of a 2-component solution or tablets. It is marketed under different trade names: Katadyn Micropur MP-1, Potable Aqua Chlorine Dioxide Water Purification Tablets, Aquamira and Pristine [24].

Principles: Chlorine dioxide is formed when sodium chlorite comes in contact with acid [27]. This reaction is initialised only when the tablet comes in contact with water or when the two components of the liquid solution are mixed. Chlorine dioxide gas dissolves in water but does not react with water molecules to form hypochlorous acid [30]. It is a free radical which has a high oxidising capacity without transferring chlorine atoms to organic molecules. Thus, in contrast to the hypochlorites described above, there is virtually no formation of chlorinated disinfection by-products. Chlorine dioxide kills bacteria and viruses within 15 minutes [31]. Inactivation of cysts and Cryptosporidium parvum depends on water temperature: At 20 °C disinfection requires 30 minutes while cold or dirty water needs 4 hours to be purified.

Procedure: For treatment of 1 litre of water add 1 tablet. As for the liquid, preparation includes two steps: First mix the two components to initiate reaction according to the instructions. After that, mix with water. Avoid exposure to sunlight when unpacking the tablet and during treatment time because UV light breaks down chlorine dioxide [24]. Keep water bottle closed while disinfections takes place because otherwise ClO_2 molecules can escape from solution [24]. Recommended contact times are 15 minutes against bacteria and viruses and 30 minutes to 4 hours against protozoa (depending on water temperature and degree of contamination). Reaction time can be reduced by pre-filtering and slightly warming the water where possible. Note: Warm water also causes a faster degradation of chlorine dioxide!

Advantages: Chlorine dioxide is a potent water disinfectant requiring less concentration and contact times than hypochlorites. It is effective against all relevant waterborne pathogens, even Cryptosporidium parvum. In contrast to hypochlorites, chlorine dioxide is also effective in alkaline water (pH 8-9). After disinfection, chlorine dioxide leaves less chlorine taste/odour. On the contrary, it even neutralises bad tastes and odours of water. No chlorinated by-products like trihalomethanes are formed.

Disadvantages: In the outdoor setting, disinfection by chlorine dioxide is a time consuming procedure (as is the case with the hypochlorites) and requires protection against light [31]. Some authors favour the solid form of chlorine dioxide because imprecise amounts of liquids and delay in mixing cannot guarantee a certain dosage of ClO_2 making disinfection uncertain [31]. Since no residuals are formed, recontamination is possible. Disinfected water should be used up quickly, the storage of water disinfected by chlorine dioxide is not recommended since the substance is relatively volatile (keep bottles closed whenever possible).

Additional remark: The breakdown products of chlorine dioxide are chlorite and chlorate which in higher doses can have adverse health effects. As it is the case with trihalomethanes, however, the risk of infectious waterborne diseases during travel is most likely of far more importance as compared to the short-time exposure to chlorine dioxide in the usual dosages. This assumption is supported by results of animal experiments [32].

5.2.3 Iodine

Principles: Like chlorine, iodine belongs to the chemical group of halogens, destroying microorganisms by oxidation. Elemental diatomic iodine (I_2) andhypoiodous acid (HOI), which forms when I_2 hydrolyses in water, are the primary microbicidal agents. The efficacy of disinfection with iodine is subject to the same environmental influences as chlorine: pH, water temperature, turbidity and type of microorganism (see description above). Given adequate dosages and contact times, the disinfecting effect of chlorine and iodine is comparable [24]. However, there are some differences: Iodine shows greater chemical stability and is less volatile than chlorine. Also, effectiveness is slightly less affected by pH. Since iodine has a lower reactivity than chlorine, there is less halogen demand through organic contamination. This makes iodine more suitable for poor-quality water. On the negative side, iodine can have adverse health effects, especially on the thyroid gland. Excess intake of iodine can cause hyper- as well as hypothyroidism and goiter. This results in a higher risk for thyreotoxicosis, a disruption of reproductive function and impaired development in fetuses. Also, a higher incidence of thyroid cancer and thyroid autoimmune diseases have been reported [33]. Thus, iodine is not recommended as a primary disinfectant by the WHO and should only be used if there is no other suitable option [34].

For iodine-based water disinfection there are two different categories: (1) iodine tablets / solutions that can be added to water, (2) iodine resins, i.e. solid-phase iodine matrices through which water is filtered while pathogens are killed by coming into contact with the resin’s surface. With the latter procedure only small amounts of iodine are released into the water and filter systems often contain a carbon element to remove residual iodine from solution. This way, the resulting drinking water is not “contaminated” with excess iodine but there is also no residual disinfecting effect.

Procedure: In the case of tablets or solution, add to water according to the instructions and wait for the time specified in the manual. In cold water, allow for a longer reaction time. Turbid water should be pre-filtered before adding the disinfectant. As for the resin filters, stick to product specific instructions (resins need to be primed before first use!). Keep track of the number of disinfection cycles applied because the filter cartridge has a limited lifetime and needs replacement after a certain volume of water filtered. Turbid water results in faster clogging of the filter.

Advantages: Can be used immediately at any place and any time where liquid water and disinfectant is available. No fuel necessary. In case of tablets/solutions no heavy equipment required. Effective against most waterborne pathogens. Resin filters that are equipped with a pre-filter are effective against protozoa as well.

Disadvantages: Like chlorine, disinfection with iodine tablets / solution is dependent on water condition (pH, temperature and turbidity). Time consuming procedure. Effectiveness against protozoa is limited, no effect on Cryptosporidium in practical dosages and contact times. In contrast to chlorine there are potential adverse health effects, especially regarding thyroid dysfunction. In case of resin filters regular exchange of filter cartridge required.

Remarks: Because of the health concerns described above, the following application restrictions are acknowledged by the WHO: Iodine is not suitable for long-term disinfection. If application for more than 1 month is intended, thyroid function should be checked beforehand. Iodine is not recommended for pregnant women, infants and young children, persons with hypersensitivity against iodine, pre-existing thyroid dysfunction or a family history of thyroid disease as well as residents of areas with severe iodine-deficiency [34].

In Nepal iodine tablets are available. Their iodine content differs and therefore they should be used strictly according to the respective procedure. The same for Lugol solution: It is cheap and easily available in any pharmacy, but again there are various concentrations on the market from 1% to 15% (sometimes even more) which needs caution when used to disinfect water. When other procedures for water disinfection are not available the use of Lugol solution for a limited time is o.k. For a 2% iodine solution put 5 drops in one liter of clear water (or 1 drop of 10% solution). Disinfection time, its temperature dependence and the need for higher concentrations when organic substances (e.g. algae) are in the water are similar as described for chlorine.

5.3 Filtration

Principles: The process of filtration refers to the physical removal of germs from water (not killing them as with chemical disinfection). Germs are eliminated by several physical characteristics like their size in relation to the filter's pores or hydrophobic or electrostatic interaction between the germ's surface and the filter material. Small particles (e.g. viruses) will be partially removed due to agglomeration. Depending on the filter type, there are construction-dependent advantages and disadvantages. Therefore, detailed knowledge about the filter type used is essential for any user. Read the specifications of the product carefully to be aware of the pore size!

Procedure: Water passes through the filter material, driven by either gravity or by applying pressure or suction manually or electrically. Pore size should not be larger than 0.2 µm to achieve an adequate removal of pathogens. For the removal of viruses a pore size of 0.02 µm is required. Use the filter according to the instructions.

If more and more pressure is required to press water through the filter increases, the filter unit needs to be cleaned. This should be performed only by persons trained with the system to avoid damage. Clean according to the instructions in the manual (some filters like ceramic need to be brushed, others like hollow fibre filters can be backwashed). Do not forget to dispose the first cup of water filtered after the system was maintained to be sure that the “safe side” of the filter system is clean.

Types of filters: There are many different types of filters on the market, differing in material, pore size, or the presence of an additional adsorbing (e.g. activated carbon) or antibacterial (e.g. silver) component. In the following, we describe the most widely used categories of outdoor filters. Note that there are also products in which these filter elements are combined.

- **Textile filters:** Improvised or commercially available textile elements with lager pore sizes, used to pre-filtrate water to reduce turbidity or under emergency conditions (see chapter 6.4).
- **Ceramic filters:** Up to now, microporous ceramic is the most common material of outdoor water filters, with or without an activated carbon component or silver impregnation. The filter element is a cylindrical ceramic block. Ceramic filters of good quality have a pore size of 0.2 µm and are usually operated by a hand pump, pressing the water through the filter element.
- **Activated carbon:** Retains particles and microorganisms in its pore matrix by electrostatic adhesion. Available as compressed filter block or as granulate. Often combined with mechanical filters like ceramic filters. Note that gradually the binding sites within the carbon become saturated and the cartridge has to be replaced.
- **Hollow fibre filters:** These filters are based on the functional principle of semipermeable membrane filtration, similar to dialysis. The filter element consists of a bundle of hollow fibres which results in a large filtration surface. This reduces the pressure needed to bring water through the unit. Pore size differs significantly depending on the model and ranges from 0.2 (“filter”) to 0.02 µm (“purifier”). Purifiers with 0.02 µm pores are able to remove even viruses. The driving force for water flow is usually either suction (in form of a tube used like a very large straw or integrated into a bottle), gravity (in form of a bag that hangs from an elevated point), hand pump, or squeezing a water bag or bottle with attached filter. Examples of manufacturers are the companies LifeStraw and Sawyer, which sell filters as well as purifiers, so read the specifications of the product carefully to be aware of the pore size!
- **Glass fibre filters:** Pleated matrix of glass fibres with pore sizes down to 0.2 µm. Often combined with ceramic or other pre-filter element to avoid fast clogging. Examples: Katadyn “Vario” (hand pump glass fibre filter combined with ceramic and activated carbon), Katadyn “Gravity Camp” and “Base Camp Pro” (water bags using gravity drip for larger quantities of water).
- **Nanocomposite filters:** This category comprises a variety of different materials and constitutes the most recent development in the field of personal water treatment equipment. The idea behind these filters is a functionalisation and enlargement of the filter surface by coating it with different kinds of nanoparticles which have distinct physico-chemical properties (adsorbing, microbicidal, or catalytic). Depending on the material it is also possible to remove toxins like

heavy metals or chemicals from water. Companies selling these products usually do not reveal the exact structure and composition of their filters. The results of laboratory tests commissioned by the manufacturers are positive. However, currently there is a lack of independent data. The commission will keep these systems under review (e.g. “water-to-go” or “Sawyer select filters/purifiers”).

- **Others:** The company “Water-to-go” markets a filter integrated into a bottle using a NASA-developed three-component nanotechnology filter element. The manufacturer does not reveal the exact structure and composition of the filter and only states that it contains nano alumina, activated carbon and “other filtration ingredients” (https://www.watertogo.eu/filter-facts). He claims that the device removes 99.9% of bacteria, protozoa and viruses as well as diverse metals and chemicals. The results of laboratory tests commissioned by the manufacturer are positive, however, currently there is a lack of independent data. UIAA MedCom will keep the system under review.

Advantages: Relatively simple procedure, also suitable for producing larger quantities of water for groups. Depending on the pore size removal of all relevant waterborne pathogens can be achieved. Improves also optical quality of the water by reducing turbidity. No bad taste or smell as with chlorine. Some materials (adsorbing substances like activated carbon or nanocomposites) even remove bad tastes/ smells and toxins / chemicals. Modern filter materials like hollow fibre filters or nanocomposite filters are lighter than classical ceramic filters. Therefore, these types of filters are more suitable for use in the mountains, where luggage capacity is limited.

Disadvantages:

- Most filters do not remove viruses (except for e.g. hollow fibre filters with a pore size of 0.02 µm or nanocomposite filters). Therefore, combine filtration with chemical disinfection to profit from the advantages of both methods.
- Clogging is a frequent problem. The smaller the pores the safer the water, but also the bigger the problem of clogging. If possible use clear water. Do not increase pressure of filtration! This may press germs through the system and contaminate your water. In the case of membrane filters, the filter material may be damaged by applying too much pressure. If the pressure required to press the water through the filter increases, the surface of the filter unit needs to be cleaned. This should be performed only by persons trained with the system to avoid damage. Clean according to the instructions in the manual (some filters like ceramic need to be brushed, others like hollow fibre filters can be backwashed). Do not forget to dispose the first cup of water filtered after the system was maintained to be sure that the “safe side” of the filter system is clean.
- Depending on the material, filters are breakable (especially ceramic), so handle the equipment with care. Most filters are damaged when freezing containing water remnants, resulting in microscopic cracks compromising disinfection. With some filters the need for replacement is only indicated by gradually requiring increasing filtration pressure. However, if the filter is damaged filtration pressure remains low in spite of an urgent need for replacement! Other filters (e.g. some nanocomposite filters) show no sign of being “used up” at all, so the user has to keep track of how many litres have been treated until a defined volume has been reached.

- Water is not conserved, so recontamination of treated water is a risk. Also the filter itself may become contaminated. For this reason some filters are impregnated with silver ions. Another issue is a possible contamination of the mouthpiece of devices which provide clean water by sucking water through the filter unit.

Additional remarks: The clearer the water to be filtered, the longer the filter can be used without the need for maintenance or replacement. If no clear water is available, it is useful to let the water "rest" in a bucket for the particles to settle before filtering. A simple coffee filter reduces turbidity and should eliminate eggs and larvae of helminths. Therefore, combination of a coffee filter and chlorine, which might not readily inactivate these germs, but bacteria and viruses, can be a suitable method to produce safe water. Any filter system without activated carbon or other adhesive substances will not remove toxins. Avoid water which might be polluted by industry (old mines in the mountains) or agriculture (pesticides) where the approach to the mountain passes is farmland!

5.3.1 Gravity filtration by the ultrafilter "LifeStraw Family 1.0"

Principles: Recently this system was controversial discussed although more and more in use, also in international projects. Therefore it is also a topic for occupational and social medicine. This ultrafilter is designed for drinking water treatment in households of low-income settings rather than to be applied during travel or in the mountains. But it may be expected that mountaineers and travellers will get their water from households (lodges) which use such systems. Since it is able to provide large volumes of water it may be expected that more and more expeditions or trekking groups will use it in future. Therefore it is included in this recommendation as a new, low-cost method working without power source. The unit cost would be USD $ 0.005 per litre treated [35]. One filter may provide enough water for a 5-person family for three years.

Procedure: In a two-step procedure water passes through a pre- and an ultrafilter of 80 µm and 20 nm (0.02 µm), respectively, removing protozoa, bacteria and viruses.

Advantages: An easy to operate method for water treatment providing enough water for a household (9 L/h) without electricity or batteries. As the filters work by gravity, no pumping is needed. As two filters are included, it can handle even very turbid water. There is no need to combine this method with other chemical disinfectant because the ultrafilter is small enough to eliminate viruses.

Disadvantages: The gravity filter was not designed to be used by travellers in the mountains due to its size and weight (680 g). By this weight-efficacy-relation it may be used by groups or in base camps or by lodges en route. The apparatus has to be cleaned regularly to prevent biofilm formation. Recontamination is an observed problem in rural households with pets and poor hygiene. As the system is a hollow fibre technology it should not freeze while wet. For mountaineers this could cause a significant risk because such micro-breaks are not visible and it is not easy to decide whether the filter is dry (and then frost resistant) or not.

Additional remarks: Only few data exist on this new method. LifeStraw has designed other devices which include a LifeStraw 2Go (in a bottle) for travellers. In contrast to the Family filter, it lacks the ultrafilter of 20 nm eliminating protozoa and bacteria, but not viruses. UIAA MedCom will keep the system under review.

Note: The commission is keeping matrix filters under review. These are filters combining different materials, with or without additional chemical compounds. The same for hollow fibre filters (e.g. LifeStraw®, Water to go®). A problem may arise here how to keep the system clean during the trip.

5.4 Improvised filtration methods

Mountaineers or trekkers may be confronted with situations where the disinfectants wanted are out of stock or water treatment equipment is broken. In these situations they need to improvise as well as the circumstances allow. Note: Any improvisation in the process of water disinfection should be used only in case regular methods are not available ("survival situation"). It must be pointed out that these methods do not guarantee safe water, but by reducing the number of germs they significantly decrease the risk of waterborne diseases.

5.4.1 Sand

Principles: This simple filter method can reduce the number of larger germs like Giardia cysts and eggs or larvae of several parasites (helminths). It should be (relatively) effective against Vibrio cholerae as well, because this germ tends to agglomerate with organic material [36]. Also other bacteria and viruses can be reduced significantly [24]. Efficacy of sand filters depends on the height of the sand column (the higher the better), the flow rate of water (the slower the better) and the grain size of the sand (the smaller the better).

Procedure: Cut a very small hole (4-5 mm in diameter) into the bottom of a container (plastic bag, bucket…) and fill it with fine sand. The water passes through the sand and exits the container through the hole.

Advantages: Simple method, can be used for larger amounts of water (e.g. for groups).

Disadvantages: Due to many variables involved, an overall effectiveness of this survival method cannot be given, but compared to charcoal filtration (see below) a pure sand filtration is less effective.

Additional remarks: A minor water flow rate will improve the filtration effect. This can be achieved by a smaller bottom hole and / or finer sand. If possible, sand filters, as well as any other method described below, should be combined with chemical disinfection.

5.4.2 Charcoal

Principles: Combines the effects of physical removal of germs due to pore size and extraction of smaller particles through adhesive forces. By this it is possible to (at least partially) remove chemical contamination as well, e.g. toxins, heavy metals or substances which cause a bad taste or smell.

Procedure: A container (plastic bag, bucket…) can be filled with charcoal obtained from a camping fire and then crushed. The water passes through the charcoal and exits the container through a small hole at the bottom (about 4-5 mm in diameter). As is the case with the sand filter, a low flow rate (accomplished by a smaller hole) will improve the filtration effect. The charcoal should be replaced every several days.

Advantages: Simple method, can be used for larger amounts of water (e.g. for groups).

Disadvantages: As mentioned for pure sand filters, an overall effectiveness of charcoal filtration cannot be given.

5.4.3 Optimized sand-charcoal-filter

Principles: Combination of sand and charcoal filtration.

Procedure: Several layers combine their filter effects and prevent the charcoal from floating. The system is shown in Figure 1.

Advantages: Compared to pure sand or charcoal filtration, the combination improves efficacy and safety. Simple method, can be used for larger amounts of water (e.g. for groups).

Disadvantages: Several components are required. As mentioned above an overall effectiveness cannot be given.

Additional remarks: The system can also be used for pre-filtering turbid water to prevent clogging of ceramic filters (see above). As mentioned for pure charcoal filtration, the system should be replaced every few days to keep the procedure as safe as possible. If some small pebbles are placed in the bottom of the container, followed by a layer of fine sand, no pieces of the charcoal will be carried into the filtered water. Some fine sand followed by a layer of pebbles on top of the charcoal will prevent the charcoal from "floating" when water is added to the container.

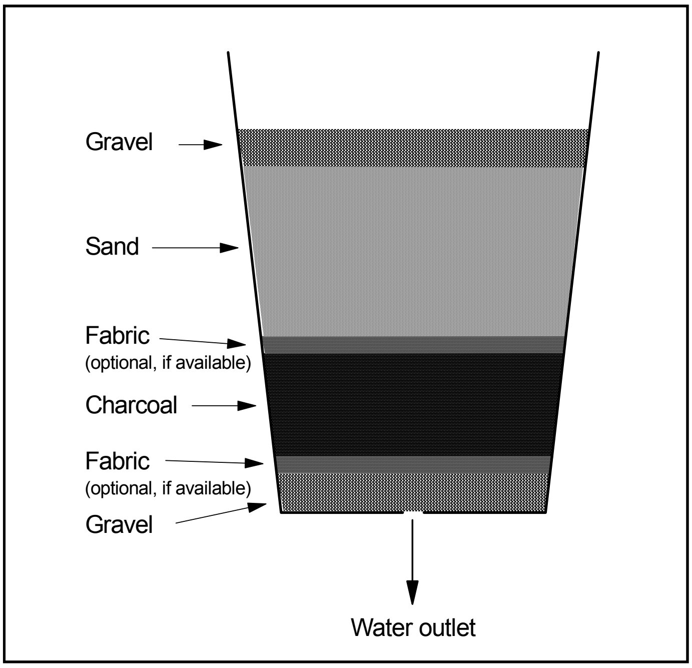

Figure 1: Optimized layering of charcoal – sand – filter

5.4.4 Textile filters ("Sari filter")

Principles: The procedure can reduce the number of larger germs like Giardia cysts and eggs or larvae of several parasites (helminths) [37], [38]. It was proven to be (partially) effective against Vibrio cholerae as well, because this germ tends to agglomerate with organic material and the particles exceed the critical diameter of the textile's pores [39], [40], [36]. Also the counts of other bacteria and viruses can be reduced [24]. Furthermore, aesthetic quality of water is improved by reducing turbidity.

Procedure: Filter water through several layers of tightly woven textile material.

Advantages: Simple method. Can be used for larger amounts of water (e.g. for groups).

Disadvantages: As mentioned for pure sand filters, an overall effectiveness of textile filtration cannot be given. For V. cholerae a reduction of 99% of the germs was reported [36].

Additional remarks: The tighter the textiles, the better the filtration effect. Therefore, older textiles, which are matted, are more effective than new ones. The procedure is of special importance in community based health projects in developing countries. It can also be used to pre-filter the water in order to reduce turbidity before applying a ceramic filter, chemical or UV disinfection.

5.5 Other methods

5.5.1 Ultraviolet Light

Ultraviolet radiation leads to cell damage causing not only skin lesion in humans, but also destroying germs in drinking water. This principle has been made use of in municipal water treatment plants for almost 100 years but only recently became available for individual use while travelling. The effective component of the UV spectrum is **UV-C** (100-380nm) with maximal antimicrobial efficacy at 250 and 270 nm [41]. UV-C rays disrupt the DNA of the microorganism primarily by causing the formation of dimers between bases. As a consequence, the DNA strands cannot be copied and replicated anymore. This way the microorganism is unable to multiply and cause an infection. Also solar **UV-A** radiation can be used to disinfect water (see chapter 6.5 Solar disinfection). Here the mode of action is quite different in that cell damage occurs mainly indirectly via the formation of reactive oxygen species in water.

5.5.1.1 SteriPen®

The first and currently most widely spread product for point-of-use UV-C water disinfection is the SteriPEN®. Its general effectiveness has recently been validated by an independent study, which also underlined the risk of incorrect application [42].

Principles: The SteriPEN® is a handheld device emitting mainly UV-C radiation with a wavelength of 254 nm. Effectiveness of this method depends on characteristics of the water (e.g. turbidity, germ concentration) and handling of the device. In general, all microorganisms are susceptible to UV-C radiation. However, bacterial spores and some strains of viruses show a higher resistance to UV light than vital bacteria and protozoa [43].

Procedure: In one disinfection cycle, the SteriPEN® can treat 1 litre of clear water in 90 seconds. For the user's safety the device is equipped with a water sensor, so the UV lamp will only turn on when submerged in water. During irradiation the water has to be agitated continuously by stirring with the device or by swaying the bottle. Proper water agitation is essential for achieving a reliable disinfection [42]! After the time cycle is complete the device will switch off automatically. While the SteriPEN® is in use, dry off any water remnants in the bottle cap, neck (if possible) and around the device to prevent them from getting back into the bottle!

Advantages: Water disinfection with the SteriPEN® is an easy and fast method to achieve safe drinking water. With about 160 g, the SteriPEN® is lighter than a ceramic filter (about 430 g) and disinfects water in less time than chemical treatment (90 seconds vs 0,5-2 hours). UV light does not change the water's aspect, smell or taste in contrast to chemical by-products.

Disadvantages: Fragility of the lamp and limited lifetime of batteries (four AA lithium batteries are necessary for 100 disinfection cycles) make an extra set of batteries and a backup method necessary. Rechargeable SteriPEN® models require an external power source after 20-50 litres. An additional filter has to be applied prior to disinfection when dealing with turbid water since particles in water scatter UV radiation. Droplets in the cap and neck of the water bottle are not disinfected and pose a risk of recontamination making water storage not advisable. Disinfection with the SteriPEN® does not remove toxins or heavy metals from the water. Turbid water limits the effect of any light. Therefore the use of clear water is a must!

Additional remarks: Common bottle materials (glass and plastic) are opaque for UV-C light, thus there is no risk to the user. However, when applying the SteriPEN® in larger containers like cooking pots, a part of the UV radiation exits the water surface. It has not yet been examined whether this constitutes a risk for the user.

5.5.1.2 Solar disinfection (SODIS)

Principles: Solar disinfection (known as SODIS) is recognised by the WHO and UNICEF as a possible method for treating water intended to drink. Exposure to sunlight for several hours reduces pathogenic germs in water. The mode of action is a combination of **UV-A** irradiation causing the formation of reactive oxygen species (ROS) in water and thermal disinfection [44]. Susceptibility of germs to SODIS depends on the pathogens' characteristics. While most waterborne pathogenic bacteria are inactivated within 6 hours of sun exposure (555 W*h/m^2 at 30°C water temperature = mit-latitude midday summer sunshine [45]), some viruses and protozoa are less amenable to SODIS [44]. The sensitivity against higher temperature also plays an important role: While Vibrio cholerae will not survive above about 45°C others are more resistant [45] Temperatures above 50°C are sufficient to obtain potable water within 1 hour, independently of UV radiation [24]. However, since it is difficult to measure the temperature of SODIS correctly in the mountains it is not recommended to shorten disinfection time and stay at 6 hours of exposure.

Procedure: A plastic (PET) or other commonly available bottle (size up to 2 litres) is filled with water and then exposed to sunlight for at least 6 hours according to the standard method. If the sky is clouded disinfection can be achieved by exposing the bottle for 2-3 days with a risk of some germs surviving [46]. A black (increase of temperature) or reflective (increase of radiation) surface underneath the bottles enhances the effect [44]. Shake the bottle for 30 seconds before exposing to the sun to increase the level of dissolved oxygen, favouring the formation of ROS [44].

Advantages: If applied correctly viable pathogenic germs are reduced significantly to non-detectable levels after exposure time. Apart from PET or glass bottles, which are distributed worldwide, SODIS requires no further equipment. The use of sunlight is probably the cheapest and easiest method to disinfect large quantities of water.

Disadvantages: There is a plurality of influencing factors like temperature, water turbidity, and intensity of UV radiation on disinfection time and efficacy. People make use of SODIS without any instruction on disinfection time according to the local circumstances. This makes SODIS an uncontrolled, not reliable method. Water needs to be clear for SODIS to be effective and bottles have to be in a good condition (no scratches which scatter the UV radiation). Only where high temperatures can be achieved these preconditions are not mandatory.

Additional remarks: SODIS is mainly applied for point-of-use water disinfection where resources are limited. However, the concept of SODIS can also be transferred to the survival or back country setting [47]. To prevent recontamination, water should be consumed within 48 hours [44]. Standard plastic and glass bottles can both be used for SODIS [48]. Both materials are relatively opaque for UV-B (and UV-C which is however already filtered out by the atmosphere) but penetrable for UV-A radiation. UV rays are weakened depending on thickness and composition of the material. Usually, plastic bottles (PET) are made use of because they are easily obtained in many regions, lighter and less breakable than glass bottles [44].

6 Insufficient chemical methods

6.1 Potassium permanganate

Potassium Permanganate ($KMnO_4$) is not suitable to produce safe water or food. If used in concentrations which do not change the taste of the product, its disinfection capacity is insufficient so that it simply cannot be recommended anymore. An additional side effect is that it changes the colour of the tongue and teeth to brown.

6.2 Hydrogen peroxide

Hydrogen peroxide (H_2O_2) is effective against bacteria. However, the substance is very unstable and disintegrates quickly. Therefore, adequate concentrations cannot be guaranteed when used in the mountains. Viruses require higher dosages and there are limited data on its potential against protozoa [24].

7 Conservation of safe water

Any stored water can become contaminated and unsafe again if it is stored for hours or days (depending on the temperature) and if there is no residual disinfectant. Therefore, a conservation method is necessary when the water is not consumed shortly after disinfection. **Silver ions** which inactivate some germs and block bacterial growth preserve clean water for up to 6 months [24]. Compared to silver ions, chlorination is less stable and provides conservation only for a few days, depending on water temperature as well as exposition to sunlight and air. Some disinfection products contain both, hypochlorite and silver, and therefore they fit with any water problem in the mountains, except for cysts and eggs of some parasites, which can be easily filtered (see above). Of course, clean containers are a prerequisite for the conservation of safe water.

Note: In contrast to common belief pure silver ions are not sufficient to disinfect water! For initial disinfection, always use products containing a halogen component (or other disinfection method). Silver ions are recommended for conservation only! Be careful: Too high concentrations of silver ions cause pitting corrosion in aluminium containers.

8 Special recommendations for commercial mountaineering or guided groups

While mountaineers are responsible for themselves, any organisation offering mountaineering, trekking tours, or expeditions will have special responsibility for their clients. This responsibility is defined by law. The following principles are according to European law, but other countries have similar or nearly identical regulations.

In case of organised mountaineering, trekking, or expeditions the production of safe water is in the responsibility of the trekking organisation. It should be an integral part of the organisation's safety concept, e.g. as standard operation procedure (SOP). The most important regulations the organisation must know and respect are as follows:

- Water, which is indented for human use, may not contain pathogenic germs in concentrations, which might cause an impairment of human health.
- Water, which does not meet the quality criteria for safe water, must be processed until it meets these criteria.
- The law forbids and will prosecute those individual/s who produce drinking water for other people in a way that human health may be impaired. Any entrepreneur or owner of a water supply installation, who provides water as drinking water for others, which does not fulfil the criteria, can be prosecuted in terms of imprisonment for up to two years or fined according to the laws of the country. Any entrepreneur or owner of a water supply installation can be prosecuted as well, if he adds additives like chlorine above the concentration stated by law. Note: In contrast to U.S. regulations it is forbidden by European law to add iodine to water which shall be used for drinking!

"Water supply installation" in the meaning of the laws is any apparatus or procedure from which drinking water will be obtained, including any point-of-use system, i.e. any system used during the trip.

9 Overview of the procedures

Procedure	Safe for				Remarks
	viruses	bacteria	cysts (Giardia, amoebic) & eggs of helminths	Cryptospo-ridium	
Boiling	+	+	+	+	Fuel consuming / deforestation
Chemical disinfection[6]	+	+	(+)[5]	(+)[1]	May be critical if water is very cold or contains organic substances[7]
Ceramic filter	(+)[2]	+	+	+[3]	Type specific failures / limitations
Chemical disinfection + filtration	+	+	+[5]	+[1,3]	The only absolutely safe procedure at high altitude
Hollow fibre filter	(+)	+	+	+	Removal of viruses depends on pore size
Sand filter	-	(+)[2]	(+)[4]	n.d.	Fine sand and low flow necessary
Charcoal filter	-	(+)[2]	(+)[4]	n.d.	Low flow necessary
Sand + charcoal filter	-	(+)[2]	(+)[4]	n.d.	Fine sand and low flow necessary
Textile filter	-	(+)[2]	(+)[4]	n.d.	The tighter the textiles, the better the filter effect
Gravity filter Life Straw	+	+	+	+	
SODIS	(+)[6]	+	(+)	+	Dependent on weather, water clarity and condition of the bottle
SteriPEN®	(+)[6]	+	+	(+)[6]	Limited data on viruses and protozoa available

+: safe; (+): safe with some limitations (see footnotes)

Footnotes:

[1]: only chlorine dioxide achieves disinfection of Cryptosporidium in practical dosages and contact times

[2]: only filters with pore sizes of 0.02 µm (or additional adsorbing component) are effective against viruses

[3]: pore size < 1 µm necessary

[4]: "nearly safe" (> 99% elimination of germs possible but cannot be guaranteed)

[5]: longer disinfection time or higher concentration of disinfectant necessary

[6]: certain types of viruses (e.g. adenovirus) or cyclosporidium require very high UV dosages

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Members of UIAA MedCom

Agazzi, G. (Italy), Alemdar, E. (Turkey), Andjelkovic, M. (Serbia), Angelini, C. (Italy), Basnyat, B. (Nepal), Behpour, A.R. (Iran), Bouzat, P. (France), Brugger, H. (Italy), Dhillon, S. (UK), Dikic, N. (Serbia), Gurtoo, A. (India), Hefti, U. (Switzerland), Hillebrandt, D. (UK), Hilty, M. (Switzerland), Holmgren, J. (Sweden), Horakova, L. (Czech Republic), Jean, D. (France), Kamikomaki, N. (Japan), Kanazawa, H. (Japan), Koukoutsi, A.(Greece), Kuepper, T. (Germany), Masuyama, S. (Japan), Mateikaite, K. (Lithuania), McCall, J. (Canada), Meijer, H. (Netherlands), Morrison, A. (UK), Nogueira Garrigos Vinhaes, E. (Brazil), Paal, P. (Austria), Peters, P. (Luxembourg), Reis E Silva, M. (Portugal), Rodway, G. (USA), Roi, G.S. (Italy), Rosier, A. (USA), Rotman, I. (Czech Republic), Schoeffl, V. (Germany), Shahbazi, J. (Iran), Sherpa, N.N. (Nepal), Sherpa, S.Z. (Nepal), Trevena, D. (Australia), van der Spek, R. (Netherlands), van Vessem, M. (Netherlands), Von Delft, E. (South Africa), Wichardt, E.L. (Norway)

Invited guest authors:

C. Albanus and L. Timmermann, both from the Institute of Occupational & Social Medicine, RWTH Aachen Technical University, Aachen / Germany

History of this recommendation paper

As many mountaineers have deficiencies in their knowledge of this topic, or have expressed a desire to learn more, the UIAA MedCom decided to establish a special recommendation on this topic at the meeting at Snowdonia in 2006. The first version was approved at the UIAA MedCom Meeting at Adršpach – Zdoňov / Czech Republic in 2008. The recommendation was updated in 2012 and approved at the annual meeting at Whistler / Canada in July 2012. However, since several new data were published the commission decided to make a complete revision which is presented here. It has been accepted by written consent in lieu of a meeting March 2021.