GUIDE TO APPROPRIATE RURAL WATER SUPPLY DISINFECTION AND DEVELOPING AN ACTION PLAN FOR EMERGENCIES

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PREFACE

The purpose of this guide is to provide governments, health officials, municipal officers and nongovernmental organizations in developing countries with simple, low-cost methods for disinfecting rural supplies during emergencies and guidance to formulate a model plan of action for governments during emergencies. This guide is not appropriate for disinfection of a public system or a network for a village. However, households in the community could use it, if public water disinfection is not in place.

The guide provides instructions and alternative methods for water disinfection in concise and simple language so that non-technical as well as technical people can use it in order to minimize health risks associated with waterborne diseases.

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1. CHAPTER I

INTRODUCTION

Contaminated water and lack of sanitation are the cause of many waterborne diseases in developing countries. It is estimated that one billion people does not have access to safe drinking water and that about two billion does not have adequate sanitary services. It is estimated that about a quarter of the world population does not have safe drinking water or adequate sanitary services, especially in rural areas. Dehydration; resulting from diarrhoea due to drinking polluted water or due to unsanitary house conditions, or inadequate sanitation are the reasons behind the death of 1.7 million children annually world wide. Diarrhoea is also the most common cause of child malnutrition, which can lead to death or permanently impaired mental and physical development. [1,2]

The relationship between water disinfection and waterborne diseases is inversely proportional. Poor water disinfection can be responsible for the outbreak of cholera and other diarrhoeal diseases. The cost in terms of treatment or death is very high when compared with the routine prevention measures, such as sanitation, personal hygiene and safe water, that can be put in place.

Methods of disinfection vary in efficiency with regard to pathogen deactivation, removal and die off. Plain sedimentation is rated at medium effectiveness, slow sand filtration at high effectiveness. Coagulation with rapid sand filtration and disinfection with chlorine are rated as excellent. With respect to taste, odour and pathogen removal, chlorine is rated the highest after removal (by aeration or other methods) of excess chlorine odour. [4]

Organisms such as bacteria, rotaviruses and *Giardia* are killed when 5 mg/L of free available chlorine is maintained for 30 minutes at 5 ° C and a pH of 6 to 7. [6] The chlorine dose should be sufficient to satisfy the chlorine demand which is required to destroy organic and inorganic matter and produce an excess chlorine (residual chlorine) after 30 minutes of contact time (the required time to kill organisms and to react with other organic matter present in the water). Residual chlorine (disinfectant) is of prime importance in maintaining water quality. Since the amount of organic matter varies from one source to another, the required dose for disinfection will also vary, depending on the characteristics of the water source.

The ability of pathogens to survive in water is dependent on many variables, such as type of pathogen, water temperature, availability of nutrients, pH and chemical constituents of the water. Some water-related disease pathogens can survive for years in regular water, others for only a few days. It should always be assumed that the water has the potential to carry a pathogen and requires disinfection.

In recent decades new types of waterborne disease have been discovered. The possibilities are very high that more new pathogens will develop over time with the collective introduction of various biological entities caused by human activity and/or the natural development of biological entities. Another potential threat is the introduction of new chemicals into the body of water that could alter the genetic structure of a pathogen. As a result, a new strain of pathogen could be produced and then introduced to humans and other living creatures. Thus, every now and then, we will discover or observe the outbreak of new diseases never heard of before.

Tables 1 and 2 show diseases related to water and sanitation, morbidity and mortality rates of some important water-related diseases. [3]

Table 1. Diseases related to water and sanitation

Group	Disease	Route leaving host	Route of infection
Diseases which are often water-borne	Cholera	Faeces	Oral
	Typhoid	Faeces/urine	Oral
	Infectious hepatitis	Faeces	Oral
	Giardiasis	Faeces	Oral
	Amoebiasis	Faeces	Oral
	Dracunculiasis	Cutaneous	Percutaneous
Diseases which are often associated with poor hygiene	Bacillary dysentery	Faeces	Oral
	Enteroviral diarrhoea	Faeces	Oral
	Paratyphoid fever	Faeces	Oral
	Pinworm (*Enterobius*)	Faeces	Oral
	Amoebiasis	Faeces	Oral
	Scabies	Cutaneous	Cutaneous
	Skin sepsis	Cutaneous	Cutaneous
	Lice and typhus	Bite	Bite
	Trachoma	Cutaneous	Cutaneous
	Conjunctivitus	Cutaneous	Cutaneous
Diseases which are often related to inadequate sanitation	Ascaris	Faecal	Oral
	Trichuriasis	Faecal	Oral
	Hookworm (ancylostoma/necator)	Faecal	Oral/percutaneous
Diseases with part of life cycle of parasite in water	Schistosomiasis	Urine/faeces	Percutaneous
Diseases with vectors passing part of their life cycle in water	Dracunculiasis	Cutaneous	Percutaneous
	Malaria		

Source: [3]

Table 2. Morbidity and mortality rates of important water-related diseases

Disease	Cases per year (thousands)	Deaths per year (thousands)
Cholera	384	11
Typhoid	500	25
Giardiasis	500	Low
Amoebiasis	48 000	110
Diarrhoeal Disease	1 500 000	4000
Ascariasis	1000	20
Trichuriasis	100	Low
Ancylostoma	1500	60
Dracunculiasis (Guinea worm)	> 5000	–
Schistosomiasis	200 000	800
Trachoma	360 000 (active)	9000 (blind)

Source: [WHO, 1993]

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2. CHAPTER II.

DISINFECTING RURAL WATER SUPPLIES IN AN EMERGENCY

A. Introduction

Disinfection of water is the process of treatment which results in the killing of any bacteria present and oxidization (burning up) of organic materials, which serve as food for bacteria. Disinfection methods include heat, ultraviolet radiation, silver ions, acids, alkali, chemical oxidants and others. Chemical oxidants include potassium permanganate, ozone and halogens. Halogen oxidants include bromide, iodine, chlorine dioxide and chloramines. Disinfection used to be thought of as an oxidation process only. However, oxidizing agents similar to chlorine are not as effective as chlorine in attacking disease-causing organisms because hypochlorous acid specifically, destroys the cellular membranes and attacks the enzymes essential to organisms, in this way rendering them non-functional. Chlorine, ultraviolet radiation and ozone are the most common disinfectants. There has been recent interest in combining two or more of these methods to reduce the by-products of disinfection and achieve higher efficiency. Ultraviolet radiation, ozone and chlorine derivatives are combined in this methodology, which is called advanced oxidation processes (AOPs). Even though chlorine has the potential to produce harmful by-products, it is still the most appropriate disinfectant for most countries for continuous use and during emergencies. The chlorine compounds that are most widely used during emergencies are calcium hypochlorite and sodium hypochlorite. [6,7]

There are several other simple low-cost methods for water disinfection. These include chemical methods, such as chlorine or iodine, and physical methods such as pasteurization, boiling and radiation.

At the household level, if there are visible foreign materials or turbidity in the water it should be clarified before disinfection. Many simple methods exist that can be used to clarify water. Clarified water is much more acceptable to people from an aesthetic point of view, but is also important to ensure effective disinfection. Water can be clarified by physical means such as settling and filtration, or by chemical means, such as flocculation, where chemicals are used to cause suspended matter to cling together and form a mass that can settle easily.

B. Summary of disinfection methods

The following summarizes the various methods of simple low-cost disinfection, the purpose of which is to make it easier to choose the most appropriate method to suit the circumstances. The user can then consult the detailed method for final evaluation.

If using chemicals as a disinfectant and the container's label is not clear enough, then handle these chemicals with care. They are potentially hazardous and poisonous. Store them in a dark dry place away from moisture, light and children. Read the information and expiry date on the container carefully. If the information is not clear or if there is no information or instructions on the container, ask the seller or call the manufacturer, or the nearest health centre, the nearest pharmacist, the nearest medical doctor, or a chemist for any question regarding the use, safety requirements, or any missing information.

1. **Boiling.** If a heat source is available, boil the water for 3 minutes. Let it cool and then pour it back and forth between two containers to improve its taste. Boiling is the most effective way to destroy all pathogens.

2. **Water disinfection tablets.** Tablets containing chlorine or iodine can be bought from a pharmacy, chemical supplier, swimming pools supplies merchant, or water equipment supplier. Health departments at central or municipal level may also hold a stock for emergency. Follow the manufacturers' instructions for use.

3. **Chlorination** (household bleach solution). Water can be disinfected with a household bleach solution. Make sure that the type of bleach solution used is the sodium hypochlorite type and does not contain additives, such as scent.

4. **Chlorine compounds.** Dry chlorine compounds are the most commonly used disinfectants. They are the most practical disinfectants during an emergency and will kill cysts.

5. **Iodine.** Ordinary tincture of iodine can be used to purify water. Tincture of iodine is not an efficient oxidant for large-scale water disinfection. However, it is useful for emergency situations and for individual use where other methods are not available.

6. **Lemon or lime juice.** If lemon/lime juice is available, using it is an inexpensive method of disinfection.

7. **Solar water disinfection.** Solar radiation and pasteurization should only be used as a last resort for water disinfection, when no other methods are available. Weather conditions, time restraints and verification issues are limiting factors, particularly in an emergency.

8. **Combined ultraviolet radiation and thermal disinfection.** If economically feasible, combined ultraviolet and thermal disinfection is a very effective method. This method can eradicate any life form provided that high ultraviolet and temperature intensities are achieved. However, if the climate and water quality are suitable, this method may be the best in the long run.

C. Disinfection selection criteria

The factors affecting the choice of the method of disinfection are not limited to cost only. Water quality, the nature of water constituents and contaminants, pollution status and the purpose of water use are other factors. The nature and type of emergency, climate, the availability of chemicals and equipment and time restraints will influence the selection of a process. Water disinfection is influenced also by the nature of chemicals, concentrations, organisms, contact time, temperature, pH and organic matter content. Since all these factors are so varied in nature, it is not possible to recommend a certain procedure. It is the responsibility of health professionals in each community to study the existing conditions and recommend to the public the most appropriate method for use in an emergency.

Basically, if chlorine tablets or compounds are available locally in shops, or are stocked by the government, then this will be the first choice. Boiling is the second choice. If lemon or lime is available inexpensively, then this will be the third choice, especially during a cholera epidemic. If iodine is the only choice available, then this is the final choice. Low-income communities can also use any of these methods permanently, if no central systems are available.

Table 3 is a suggested and not an absolute ranking of methods. The actual ranking depends on the kind of emergency at hand and the availability of the materials needed for disinfection, in addition to climate at that location. It is also preferable that health officials or the users in the area decide and inform people of what should be done.

Table 3. Selection criteria for water disinfection during emergencies

Disinfectant	Residual	Time	Giardia	Reliability	Verification	Rank
Chlorine compounds	Yes	30 min.	Killed	Excellent	Easy	**1**
Chlorine tablets	Yes	30 min.	Killed	Excellent	Easy	**2**
Chlorine bleach	Yes	30 min.	Killed	Excellent	Easy	**3**
Boiling	No	20 min.	Killed	Excellent	Easy	**4**
Lemon/lime	Yes	30 min.	Unknown	Excellent	Easy	**5**
Iodine	Yes	30 min.	No	Good	Easy	**6**
UV-thermal	No	Hours	Killed	Poor	Not easy	**7**
UV-solar	No	6 hours	No	Poor	Not easy	**8**

D. Water Clarification

Before disinfection, water has to be clarified if it is turbid, i.e. cloudy. Turbidity is caused by a large amount of dissolved, suspended and settleable solids. Suspended solids are those solids that carry negative charges, which cause them to stay in suspension (colloidal matter is sometimes positive), and settleable solids are those solids that can settle easy by gravity. Clarification increases the efficiency of disinfection by removing suspended matter that can protect and harbour pathogens and reduce the efficiency of the disinfectant. Suspended solids require filtration or chemical coagulation to remove them from water. Sand filtration and chemical coagulation are the two main methods for water clarification. Positively charged ions such as aluminium, iron, silver, sodium, etc. will combine with negatively charged particles to form settleable solids.

Note. Although clarification of water is very important, in an emergency, when the means and time may not be available, water may be disinfected without clarification. However, the disinfectant dose should be increased depending on the amount of contamination or turbidity in the water.

Method 1. Settling

Pour the water to be disinfected into a deep container and let it stand. The water will become clear after a while (about ½ to 1 hour). Remove or siphon off the clear portion of water into another clean container for disinfection.

Method 2. Simple filtration

Hold the material to be used in place (cloth or paper) on top of a container, then pour the water slowly through the material. The water in the container is considered to be filtered.

- **Sheets of paper.** Use several layers of porous paper, such as clean paper towel or similar, to filter the water into a clean container. Similar materials may be available in the local environment that could be used to accomplish the same result.

- **Cloth materials.** Use several layers of clean towels, of very tightly woven synthetic materials, or of cotton. Other materials may be available in the home or local environment that would accomplish the same result.

Method 3. General sand filtration method

Choose a relatively deep container (about 1 m) to make a sand filter. A plastic or galvanized metal drum is the best choice. Make a hole about the size of a tap just above the bottom of the container or drum. Place the drum at an elevated level so that another container can be placed below it to catch the filtered water. Fill the drum with layers of sand and gravel as follows: (6)

1. Fill the bottom with 5 cm of pea size gravel (3 to 6 mm in diameter).

2. Cover the first layer with 5 cm of coarse sand (0.7 to 1.4 mm).

3. Cover the second layer with 40 cm of fine sand (0.02 to 0.3 mm).

4. Cover the third layer with 5 cm of humus clay.

5. Cover the fourth layer with 5 cm of activated carbon or coarse charcoal.

6. Place another container below the hole in the drum to catch the filtered water.

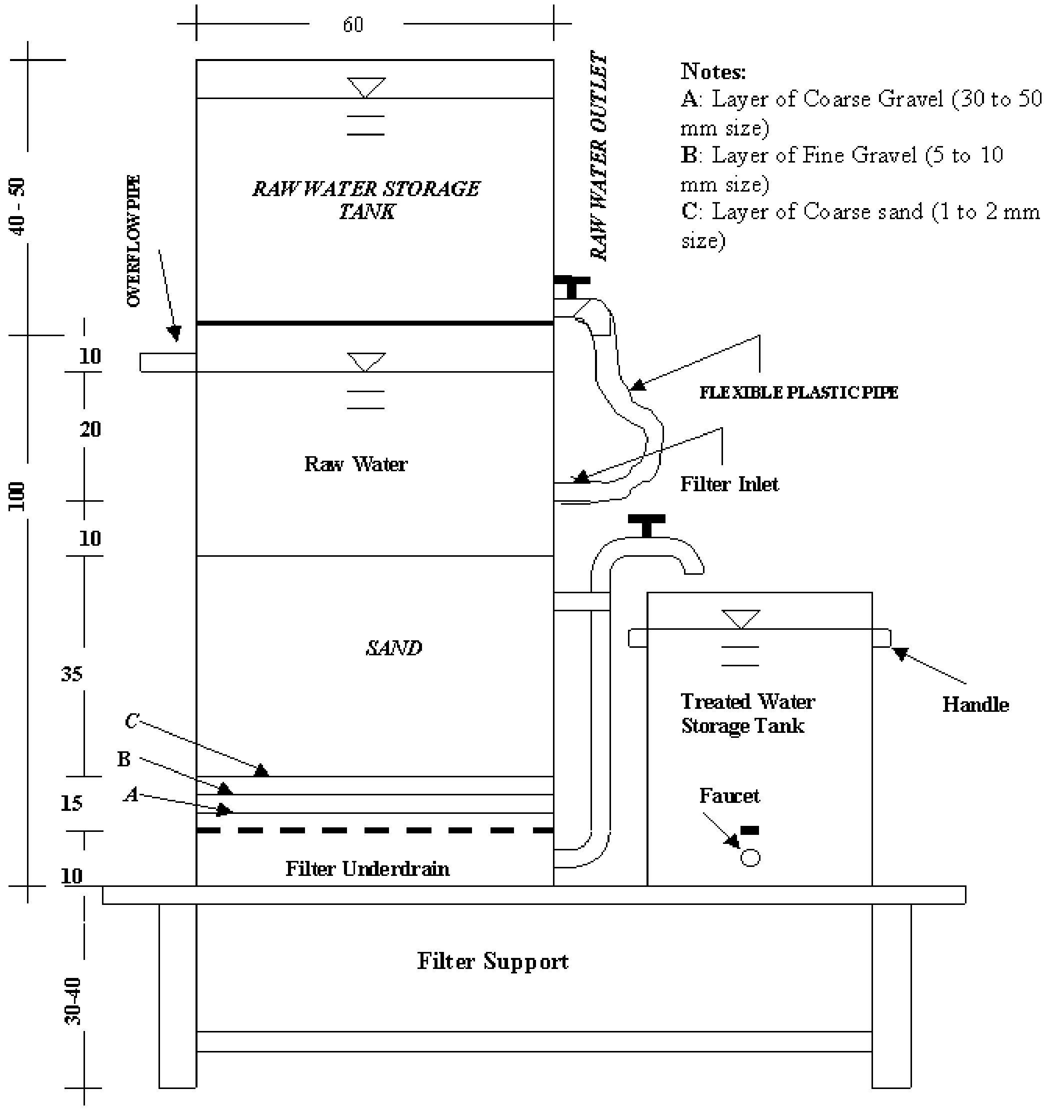
Note 1. Ensure that the final sand filter has about 40 cm of space left above the filter media, i.e. enough space to pour a good amount of water into.

Note 2. Ensure that all materials used are clean and from a non-polluted source.

Method 4. WHO/Afghanistan filtering method

This method is similar to Method 3 above, but does not use layers of carbon and clay. The diagram below shows the method used for a family size filter unit. This filter is a 1.5 X 0.6 m barrel, where gravel and sand are at the bottom with piping installation to easy up the filtration process, as shown in the drawing below:

Sketch –1 - FAMILY SIZE FILTER UNIT
WHO/Afghanistan



Method 5. Filter for heavily contaminated water

If the water is heavily contaminated with unknown contaminants, the following chemical method is recommended, provided chemicals and other necessary materials are easily accessible.

For every 25 litres of water:

1. Add 167 g of activated carbon.

2. Add 11 g of soda ash (sodium carbonate).

3. Stir for 20 minutes.

4. Add 11 g of pre-dissolved alum (potassium aluminium sulphate), and gently mix.

5. Allow it to coagulate and clarify by sedimentation for 30 minutes.

6. Siphon, if possible through a filter medium, the clear portion of the water into another (clean) container.

7. Disinfect the filtered water.

Alternative materials

- If activated carbon is not available, add 1 Kg of finely crushed charcoal.

- If soda ash is not available, use 32 g of baking soda (sodium bicarbonate), or 64 g of fine white ash from a wood or charcoal fire. Mix for 20 minutes.

- If alum is not available, add 64 g of baking soda (sodium aluminium sulphate). Mix gently.

- Then follow steps 5 through 7 above.

Note. The above method should be used when the amount and type of contamination is unknown. It should only be used for a short period of time and for a maximum of one week. The choice is between whether to dehydrate or get a little bit sick.

E. METHODS OF DISINFECTION

1. Boiling

Boiling was the classical method of pathogen inactivation before the discovery of chlorine. It kills all pathogens but it requires a lot of energy and is more expensive than chlorination. It is efficient and simple if sources of energy are cheap and available (firewood, gas, petroleum fuels and electricity are the main sources of energy). Boiling will destroy pathogen cellular membrane and structure. Boiling is suitable for small-scale disinfection of water during emergencies when other technologies are not available. It can also be used if the quality of water received from an outside source is uncertain. Boiling is effective even if the water is turbid. [6, 8,17]

Safety. Pressure cookers, enclosed water boilers and microwave ovens are safer than using an open pan on an open fire. If there is no alternative, however, ensure due care is taken in handling fire and hot water and that children are kept at a safe distance.

1. Clarify the raw water

2. Fill a pan or container suitable for the source of energy available with water.

3. Bring the water to the boil and keep it boiling for at least 3 minutes.

4. Let the water cool down and then transfer to a clean closed container.

Note 1. The flat taste of boiled water can be improved by pouring it back and forth from one container to another (called aeration), by allowing it to stand for a few hours, or by adding a small pinch of salt for each quart of water boiled.

Note 2. With use, white residues will accumulate inside the pot due to minerals dissolved in the water. These are not harmful. They can be removed by filling the pot with vinegar and letting it stand overnight. The minerals will dissolve again and the liquid can then be discarded.

Note 3. To cook food, the raw water can be clarified and used directly. Let the food boil until it is well cooked.

Verification. Boiling for 3–10 minutes, depending on water quality and the extent of contamination, kills most bacteria and viruses. Boiling for 20 minutes sterilizes water by killing every living entity. [17]

Efficiency. Disinfection will reach 100% after 20 minutes. Water should be brought to a rolling boil for 2 or 3 minutes, or even longer if the water is not clear.

Cost. Boiling water is more expensive than all other methods. The main cost involved is the source of energy used. Approximately 1 kg of wood is required to boil 1 litre of water. For example, if 1 kg of wood costs US$ 0.032 then each cubic metre of water will cost US$32. At this rate, a family of seven consuming 730 litres (0.730 m^3) of drinking-water per person per year will spend US$ 163.5 per year (0.73 × 7 × 32). Obviously final cost depends on location. In many situations the cost is not an issue if other methods are not available and not practical for the specific situation. [18]

Note. A wide variety of inexpensive solar cookers are available and can be made locally or at home, and these can be used for boiling water if the weather is appropriate. [11]

2. Chlorine compounds

Chlorine compounds are salts. Hypochlorites are salts of hypochlorous acid (HOCL); calcium hypochlorite ($Ca(OCl)_2$) is the dry form most commonly used. Chlorine compounds are found in many forms. Dry chlorine compounds are the mostly commonly used disinfectants and are the most practical in an emergency. Municipalities use gaseous chlorine, but this cannot be used on a small scale as it requires expensive equipment, installation etc.

Dry compounds are available commercially in granular, powdered or tablet form, dissolve readily in water and contain 70% available chlorine. Sodium hypochlorite (NaOCl) is commercially available in liquid form at concentrations of between 5% and 15% available chlorine. Chlorine combines with water to form hypochlorous acid, which in turn can ionize the hypochlorite ion. Below pH 7 the bulk of HOCl remains un-ionized. [5]

Safety. Handle all forms of chlorine with care. They are poisonous and potentially hazardous. Store them in a cold, dark, dry place away from moisture, light and children. Read the information and expiry date on the container carefully. If the information is not clear or if there is no information or instructions on the container, a health centre, pharmacist, medical doctor or chemist can answer questions regarding use and safety requirements.

All chemicals should be used with great care. If possible also much safer, wear rubber or plastic gloves to protect hands, glasses to protect eyes and coats or aprons. Hypochlorite solutions attack the skin, eyes, mucous membranes and other tissues. Dry hypochlorites are oxides that react with organic matter releasing heat and producing oxygen and chlorine. They will cause fire if they come into contact with heat, acids, organic matter or other oxidizable substances.

If household bleach is used, make sure that it is not scented. The additives could be toxic. If in doubt about the product, contact the manufacturer or other specialists to check that the bleach is safe to use for drinking-water disinfection.

Make sure that the life of the chemical to be used has not expired. If in doubt, test its results by available methods. Always rely on end-product testing such as residual chlorine or chlorine smell tests. Read label instructions carefully. The label will indicate concentration, warnings, date of expiry, hazards, etc.

Note. For eye and skin contact, irrigate the eye and flush the skin with water for at least 15 minutes then seek medical attention. For inhalation, move the patient into fresh air and seek medical attention. Over-exposure may cause severe burns.

Verification. The disinfected water should only be used after a specific contact time (30 minutes) or after a positive verification test of chlorine residual. Colorimetric chlorine residual test kits such as those used for swimming pools can be used for verification. The colour comparator kit is easy to use. The strength of the pink colour indicates the strength of residual chlorine in the water. Some of the colours are numbered from 0.1 mg to 5 mg per litre. Verification can be accomplished by measuring a chlorine residual of 3 mg/L for at least

50 minutes or 5 mg/L for at least 30 minutes. A slight smell of chlorine after 50 minutes can also be used as verification that disinfection is 100 % complete. [6,8]

Efficiency. A chlorine residual of 3 mg/L after 50 minutes is indicative that the disinfection is 100 % (i.e. including for cysts). Chlorine compounds are 100% efficient for killing bacteria and viruses provided that a chlorine residual of 3 mg/L is maintained for at least 30 minutes; and 100% efficient for *Giardia*, provided that a chlorine residual of 3 mg/L is maintained for 50 minutes or of 5 mg/L is maintained for 30 minutes. Chlorine is more effective in warm water. [6,8]

WHO guidelines require at least 0.1 mg/L residual at the end of the distribution line for an urban community service where water has to travel for a long distance from the treatment facility.

Cost. The estimated annual cost of using a chlorine compound to disinfect water is about US$ 1 per person per year, based on the assumption of 730 litres of drinking water per year.

Method 1. Chlorine bleach

Chlorine bleach, chlorinated lime, stabilized bleaching powder and tropical chloride of lime are different names for bleaching powder. This product is a white powder commercially available at 30%–35 % available chlorine.

1. Clarify the raw water.

2. Make a disinfectant stock solution (1% strength) by adding 35 g of chlorine bleach (chlorinated lime) to 1 L of water. Mix well.

3. Add 3 drops (0.6 mL) of the 1% stock solution for each litre of water to be disinfected. Thus, for 10 litres add 6 ml (1 teaspoon and 6 drops) of the stock solution. For 100 litres add 60 ml (12 teaspoons) of the stock solution.

4. Mix well. Wait 10 minutes then test the water for chlorine residual or chlorine smell.

5. If chlorine residual is less than 5 mg/L after 10 minutes, or there is no smell of chlorine, repeat step 3, i.e. double the stock solution added.

6. If the chlorine residual is at least 5 mg/L, after 10 minutes, or you can smell the chlorine, wait an additional 20 minutes before drinking.

Verification. A slight smell of chlorine after 30 minutes is a sign that the water is safe to drink. If chlorine residual cannot be verified by this method, do not drink the water; the bleach solution may have become too weak. Repeat the process or use new powder recently manufactured.

Method 2. Calcium hypochlorite

Calcium hypochlorite comes in a powder or granular form. High-test calcium hypochlorite (HTH) forms contain 70%–75% available chlorine. It contains the highest available chlorine for compounds. All chlorine compounds are poisonous and hazardous; this compound is the most hazardous. Hypochlorites are classified as poisonous, strongly oxidant and hazardous materials.

1. Clarify the raw water.

2. Make a calcium hypochlorite disinfectant stock solution (1% strength) by adding 15 g of the dry calcium hypochlorite to 1 L of water.

3. Proceed as in method 1.

Verification. See method 1.

Method 3. Chlorine tablets

Chlorine tablets are another form of dry hypochlorite with various concentrations of available chlorine. Depending on the manufacturer, they come in small containers with various sizes for different applications. The label on the container will specify the concentration and the instructions for application. These tablets are sold in pharmacies, chemical supply stores and water equipment stores. Check carefully the expiry date before purchase. Ask the seller or other professionals for instructions if they are not shown on the label. In emergencies, tablets can often be obtained from health centres.

1. Clarify the raw water.

2. Read the label for instructions and expiry date.

3. Follow the instructions by adding one tablet to the amount of water specified on the label, or less than one tablet if the quantity of water required is smaller than that specified.

4. If the water is still very turbid after clarification, or very cold, add two tablets to the specified amount (i.e. double).

5. Wait 5 minutes and stir the water well to dissolve the tablet(s).

6. Mix well, wait 10 minutes then test the water for chlorine residual or chlorine smell.

7. If chlorine residual is less than 5 mg/L after 10 minutes or there is no smell of chlorine, repeat steps 3–6.

8. If the chlorine residual is at least 5 mg/L after 10 minutes or there is a smell of chlorine, wait an additional 20 minutes before drinking the water.

Verification. If the chlorine residual is at least 5 mg/L after 10 minutes, and at least 0.5 mg/L after 30 minutes or there is a smell of chlorine after 30 minutes, then the water is disinfected. The slight smell of chlorine after 30 minutes is a sign that the water is safe to drink.

Method 4. Sodium/calcium hypochlorite solution (bleach solutions)

Industrial grade sodium and calcium hypochlorite solutions are commercially available at a concentration of 3.5%–15% available chlorine. Make sure that these solutions are not scented. If in doubt, contact the manufacturer or other specialists to confirm its safety for drinking-water disinfection.

Hypochlorite solutions should be stored in a dark dry place away from other chemicals or fuels. Hypochlorite solutions will lose their strength if exposed to light.

4.A. Household bleach solution (3.5 % strength)

1. Clarify the raw water.

2. Make a sodium or calcium hypochlorite disinfectant stock solution (1% strength) by adding and mixing well two parts of the 3.5% bleach solution to ten parts of water (i.e. a ratio of 2:10).

3. Proceed as in method 1.

Verification: See method 3.

4.B. Household bleach solution (5% strength)

1. Clarify the raw water.

2. Make sodium or calcium hypochlorite disinfectant stock solution (1% strength) by adding and mixing well 3 parts of the 5% bleach solution to 12 parts of water.

3. Proceed as in method 1.

Verification: See method 3.

Method 5. Portable chlorination unit

Chlorine gas (Cl_2), disinfects water by oxidizing organic matter, such as bacteria, etc. Sodium hypochlorite, which contains free chlorine equivalent to gas chlorine, is generated from the following final reaction of common salt and electricity:

$ClNa + H_2O + e- >> NaOCl + H_2$

One litre of 0.6% (6000 ppm) sodium hypochlorite solution mixed into 6000 litres of water will produce a 1 mg/L concentration. Likewise, to produce a 2 mg/L concentration, add 2 litres of 0.6% sodium hypochlorite solution to 6000 litres of water etc.

Simple small portable units that can be used for chlorination for small communities are available. See Photo below.

On-site sodium hypochlorite generators, for example, require only common salt, water and electricity (A/C or D/C from solar panels) and are simple to operate and maintain, without need for special training. [7]

3. Iodine

There are two forms of iodine for disinfection: liquid and dry. Iodine is more expensive than chlorine and does not kill all pathogens. Chlorine is more effective against all germs and *Giardia*. [9]

Cost. For example, the annual cost of iodine tablets per person in the USA is about US$ 3.65, based on a water consumption of 2 L per person per day. This would cost a family of seven about US$ 26 per year. [8]

Method 1. Tincture of iodine

Common household iodine from the medicine chest or first aid kit may be used to disinfect water. Tincture of iodine (7% available free iodine) is most commonly sold. Iodine is not used widely because of its ineffectiveness against cysts, which may be present in surface waters, and because some people are allergic to it. Its efficiency is temperature sensitive, and its health effects if used on a continuous basis unknown. [9] There is some suspicion concerning risks in pregnancy.

Make sure that it is the pure tincture of iodine that is used and that it does not have additives. Read the expiry date on the bottle and if in doubt call the manufacturer to verify its use for drinking-water disinfection.

Tincture of iodine is not an efficient oxidant for large-scale water disinfection. However, it is useful for emergency situations and for individual use where other methods are not available.

1. Clarify the raw water.

2. For water that is not very cold and is drawn from a tap or spring, add 2 drops of 7% tincture of iodine per litre (or 5 drops of 2% (USP) tincture of iodine). If it is very cold double the number drops.

3. If the water is raw surface water, very turbid or very cold, add 9 drops per litre. [8]

4. Mix well, cover the container, and wait for an additional 30 minutes before drinking.

Verification. Disinfection is complete after 30 minutes contact time. The slight taste and colour of iodine in water is a good sign that the water is safe to drink.

Method 2. Iodine tablets

Iodine tablets can be bought from a pharmacy or a chemical/medical supplier. The instructions on how to use the tablets will be on the bottle. Check the expiry date before purchase and use. If in doubt, a doctor, chemist, pharmacist or health centre should be able to verify if the product is safe to use for drinking-water disinfection. If instructions are not available, use one tablet for each litre of water to be purified.

Cost. Based on a consumption of 2 litres per person per day, the estimated annual cost of iodine tablets is US$ 3.65 per person.[8]

1. Clarify the raw water.

2. Follow the instructions by adding one tablet to the specified amount of water, or less than one tablet if the quantity of water required is smaller than that specified.

3. If the water is very turbid or very cold, add two tablets to the specified amount (i.e. double).

4. Wait 5 minutes and stir the water to dissolve the tablets.

5. Cover the container and wait for an additional 30 minutes before drinking.

Verification. Disinfection is complete after 30 minutes contact time. The slight taste and colour of iodine in water is a good sign that the water is safe to drink.

4. Lemon juice

Lemon juice is an effective disinfectant and can also be used for raw surface water. The pathogen *Cholera vibrio* does not survive below a pH of 4.5. Lemon juice contains 5%–8% citric acid. 5 ml (1 teaspoon) of lemon or lime juice added to 1 litre of water kills *Cholera vibrio* after 30 minutes of exposure. The effectiveness of lemon juice on *Giardia* is unknown. The cost is variable. Availability is seasonal. [10]

1. Prepare a stock of lemon/lime juice in a clean closed container.

2. Clarify the raw water.

3. Add 1 teaspoon (5 ml) of lemon/lime juice for each litre of water.

4. If the water is very turbid or very cold, saline or hard, double the amount of lemon. For raw surface water use 7 mL for each litre.

5. Stir the water well.

6. Cover the container and wait for 30 minutes before drinking.

Verification. The stronger the taste of lemon or lime after 30 minutes the safer the water. Verification is by contact time. If possible, test the pH with any available pH indicator. A pH around 4.5 is a verification of bacterial disinfection.

5. Solar radiation

Provided that weather conditions are good (sunny), solar radiation can be used to disinfect drinking water. Solar radiation in the UVA range 320 nm to 400 nm is effective for water disinfection. If the water temperature is above 50 °C, the synergetic effect on pathogenic germs will be 3 times higher. However, solar radiation is not effective against *Giardia* and viruses, unless accompanied by heat.

Solar disinfection requires direct exposure to sunlight. It requires over 500 Watt per square metre of solar radiation for a six-hour exposure. Solar radiation disinfection is most effective between the latitudes of 15° and 35° in both the northern and southern hemispheres, where over 90% of radiation comes directly from the sun and there is over 3000 hours of annual sunshine. [11,13]

Solar radiation disinfection is the least expensive method, but it is not reliable. It is not recommended except for emergencies when other resources are exhausted or as the last resort. It is weather-dependent and a radiation meter, if available, does the verification. However, if the climate and water quality are suitable, it could be the best method in the long run.

Solar radiation disinfection methods comprise solar bottle, solar puddle, solar cooker, solar reactor and solar distillation.[11]

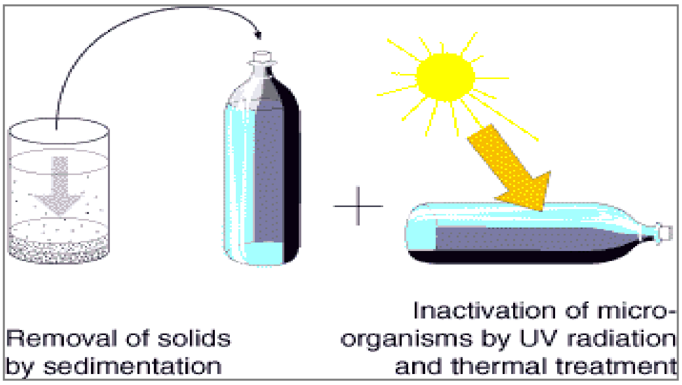
Water disinfection efficiency in clear plastic bags is 90%, plastic bottles 75% and glass bottles 70%. [11,12]

Method 1. Basic method

1. Clarify the raw water.

2. Pour the clarified water into clear plastic bags, clear or bluish plastic containers, or clear or bluish glass bottles. Tie the plastic bag(s) closed or screw on the caps.

3. Choose a sunny location that receives continuous sun from 10 in the morning until 4 in the afternoon. Place the transparent containers on its side, as shown in diagram, in the chosen location.



4. Next morning, pick up the containers and replace them with a new batch. [11]

Note. This method does not kill cysts. It is not suitable in rainy or cloudy locations. If the weather is cloudy, rainy or overcast, use another method for disinfection.

Method 2. Solar reactor

This method is basically the same as method 1 above. The reactor shown in the photos consists of a shallow water container made of plastic, aluminium or similar material, covered with a plastic or glass sheet. The dimensions are usually 1.2 × 0.6 × 0.1 m with 5 cm depth. It has an inlet and outlet for water, and is held together by an aluminium or timber frame or similar. It can be carried easily and could be made in other sizes too. The reactor is placed horizontally on the ground and exposed to direct sunlight for the longest period possible as in method 1 (Item 3 & 4). The photos illustrate how the solar reactor is used for water disinfection.[11,12]

Method 3. Solar water pasteurisation

Solar water pasteurization uses solar radiation to heat the water to a certain temperature and hold it at that temperature for a specific period of time. Solar pasteurization is based on the characteristic ability of a black body to absorb solar radiation and convert it into heat energy. There are many techniques and methods that can be used for pasteurization.

Pasteurization using solar radiation can be accomplished by raising the water temperature to 65 °C for 15 minutes or to 62 °C for 30 minutes. Some strains of bacteria will be killed at 60 °C. Pasteurization-resistant bacteria do not cause disease in people. If water is heated to 65 °C for about 6 minutes all the germs, viruses and parasites that cause disease in humans are killed, including cholera, *Giardia* and hepatitis A and B. This is the same principle as that applied to treat milk and other beverages. It is not necessary to boil the water. [14]

The general process is accomplished by exposing a container painted black to solar radiation for a sufficient period of time to raise the water temperature to pasteurization level 65 °C. One approach is to expose black painted plastic or metallic containers to direct sun. Other more sophisticated methods use solar panels with black painted copper, aluminium or steel tubing enclosed in insulated glass. Thermostats and insulated storage tanks for both raw and treated water are usually packed with such systems.

1. Clarify the raw water.

2. Pour the clarified water into black plastic bags, black painted plastic containers, or black painted glass bottles, or any small black painted container. Tighten the plastic bags, screw on the caps or cover the containers.

3. Before 10 in the morning, place the containers, standing up, in a sunny location that receives continuous sun from 10 in the morning until 4 in the afternoon.

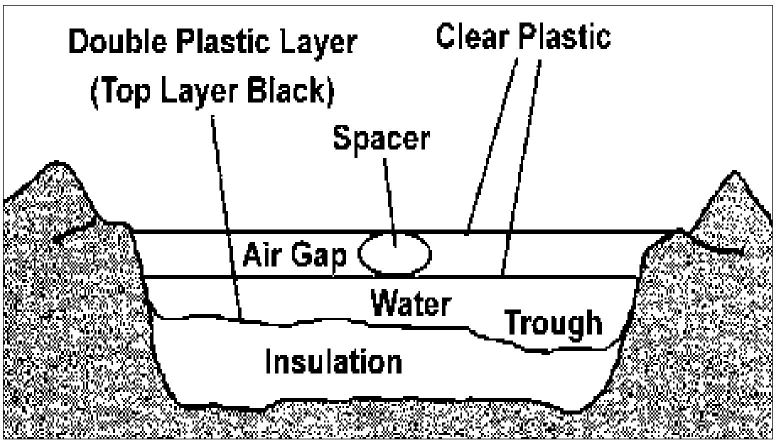
4. If reflective material and thin clear plastic are available, make a reflector and cover the containers with thin clear plastic. Place the container inside the reflector such that the radiation will be directed towards the container.

5. Starting at 12 noon, choose one container and measure its temperature every 15 minutes. If three consecutive temperatures are above 62 °C, the water is being pasteurized. Stop taking readings and leave the containers till 4 p.m. and then it will be safe to drink. If a thermometer is not available: if it is possible to hold the container with bare hands for 10 seconds or more, then the water temperature water is less than 62 °C

6. If three consecutive readings above 62 °C were not observed, try to pasteurize it next day or use another method to disinfect the water.

Method 4. The solar puddle pasteurization process

Pasteurization is not the only way to disinfect drinking-water, but pasteurization is particularly easy to scale down so the initial cost is low. Another low-cost device that pasteurizes water is called a solar puddle. One form of the solar puddle is sketched in the figure, though many variations are possible. [14]



1. Dig a shallow pit about 10 cm deep and 1 m × 1m; the pit can be larger or smaller. If the puddle is larger there is more water to pasteurize, but there is also proportionately more sunshine collected.

2. Fill the pit with 5–10 cm of solid insulation, such as wadded paper, straw, grass, leaves or twigs. Flatten this layer of insulation, except for a low spot (trough) in one corner of the puddle (see Figure).

3. Put a layer of clear plastic and then a layer of black plastic over the insulation with the edges of the plastic extending up and out of the pit. Two layers are used in case one develops a small leak. Use inexpensive polyethylene, although special UV- stabilized plastic will last longer.

4. Put some water in (Depth 3-8 cm) and flatten out the insulation so that the water depth is even to within about 1.25 cm throughout the puddle, except in the trough, which should be about 2.5 cm deeper than the rest. Put more water in so that the average depth is 2.5 to 7.5 cm depending on how much sunshine is expected. Preferably, place a pasteurization indicator [18] (which can be built locally) in the trough since this is where the coolest water will collect. Place a layer of clear plastic over the water, again with the edges extending beyond the edges of the pit. Form an insulating air gap by putting one or more spacers on top of the third layer of plastic (large wads of paper will do) and putting down a fourth layer of plastic, which must also be clear. The depth of the air gap should be 5 cm or more. Pile dirt or rocks on the edges of the plastic sheets to hold them down.

5. To siphon the water out, place a siphon in the trough and holding it down with a rock or weight. If the bottom of the puddle is flat, over 90% of the water can be siphoned out. Once the puddle is built, water can be siphoned out and more added each day, either by folding back the top two layers of plastic in one corner and adding water by bucket, or by using a fill siphon. The fill siphon should NOT be the same siphon that is used to drain the puddle, as the fill siphon is re-contaminated each day. The drain siphon MUST REMAIN CLEAN. Once in place, the drain siphon should be left in place for the life of the puddle. [14]

The only expensive materials used to make the puddle are a pasteurisation indicator (about $2 for the size tested). All the items needed are easily transportable, so solar puddles might be an excellent option for a refugee camp if the expertise were available for setting them up.

On days with good sunshine the required temperature can be achieved with 64 L of water (depth 6.5 cm). With thinner water layers higher temperatures can be reached.

The device seems to work even under conditions that are not ideal. Condensation in the top layer of plastic does not seem to be a problem, but if a lot of condensation accumulates the top layer should be pulled back to let the condensation evaporate. The device works in wind, or if the bottom insulation is damp. Water temperature is uniform throughout the puddle to about 1°C

After some months the top plastic layers weaken under the combined effects of sun and heat and have to be replaced, but avoiding hot spots can minimize this. Another option would be to use a grade of plastic that is more resistant to sunlight. The two bottom layers of plastic tend to form tiny tears unless care is taken in handling them (that is why there are two layers on the bottom). A tiny hole may let a little water through and dampen the solid insulation, but this is not a big problem.

There are many variations of the solar puddle. The top layer of plastic can be arranged like a tent that sheds rain. Adding a second insulating layer of air makes the device work even better, though this adds the cost of an extra layer of plastic.

Verification. Disinfection can be verified by checking the temperature with a thermometer or thermal indicator, such as bees wax or soybean paste.

F. Removal of radioactive contamination from water

Although boiling or chemical treatment will kill germs and chemical treatment might remove chemicals, they will not remove radioactive contamination from water.

Only surface water or exposed open containers would be contaminated during a "radioactive" disaster. If possible during such emergencies, use only water from sealed sources and not water exposed to ambient air. If surface water supplies, such as rivers, lakes and open reservoirs are suspected of being contaminated with radioactive matter and need to be used, coagulation, sedimentation and filtration will remove most of the contamination. Water softeners or ion exchange systems used in buildings and homes will remove most of what little is of dissolved chemical and radioactive contaminants. It should not be necessary to decontaminate water stored in enclosed containers, as it will not have been affected. [16]

G. Disinfection of Shallow wells and Water Ponds or Reservoirs

This manual is basically intended for emergencies and households. However, certain homes or small communities use wells, ponds, storage tanks or similar.

Health officials in the area are best equipped to handle disinfection of large wells or ponds. However, if an individual or a house needs to disinfect their small well, then it is recommended during emergencies to disinfect small quantities of water for drinking as needed, in accordance with any of the methods described.

A large quantity of water needs continuous dosing of chemicals and monitoring, which should be done by a professional. However, the following procedure is intended for general use if health officials are not available. [16]

1. Small wells and reservoirs require a dose of 50 to 100 mg/L (50 g to 100 g per cubic metre).

2. Calculate the volume of water to be disinfected in cubic metres. Then apply 1 litre (5% to 10% strength) chlorine bleach for each cubic metre of water.

3. If the well or the reservoir is connected to a piping system, turn the pump on and open all taps so chlorinated water can reach the ends of the lines. Turn the taps off when a strong smell of chlorine is noticed. Allow the water to stay in the lines for 12 hours (over night).

4. Next day there should be a slight smell of chlorine. If not, repeat the treatment with the same amount of bleach.

Alternatively for a well, a small plastic bag can be filled with chlorine solution. Make a small hole in it, and it will then drop chlorine into the well to keep it disinfected. The quantity of water in the well has to be calculated in order to decide on the quantity of disinfectant needed. Health officials can provide guidance. Another practical method is to use a rope or line with a drop controller attached to a bleach bottle to provide continuous dosing to the well as needed. Slow-dissolving tablets can also be used.

It is always advisable to smell the water before using it; a slight smell of chlorine verifies that the water is disinfected.

3. CHAPTER III

GUIDE TO SETTING UP AN ACTION PLAN FOR EMERGENCY WATER SUPPLY

Safe drinking-water is one of the most important supply items during emergencies, and public health officials should ensure that every community and family knows how to treat water during emergencies to ensure its safety for drinking. A person can survive on 1 litre of water per day for drinking, while 2 litres per day per person will also allow for food preparation and essential cleansing. WHO considers seven litres of water per capita per day (lpcd), as the minimum required over a short period of time, after which at least 20 lpcd should be ensured. Health facilities need 40 to 60 litres per person per day. Generally, the more disinfected water is available the better the health situation will be.

For 14 days of emergency, a householder should allocate about 1 cubic metre of water storage per every 50 square metre of his home living space or at least 2 cubic meters of drinking water storage for a family of seven individuals. [15] For more details, see the list of selected WHO references.

A national plan of action for water disinfection during emergency should be a part of the national disaster and contingency control plan, which itself should be a part of the national disaster preparedness and response plan (Electricity, Communications, Transportation, Nuclear Radiation, Earthquakes, Energy etc.). The details for each plan require that each operating agency in the country assign their district or regional offices the primary responsibility to develop their own procedures and operational plan for emergency response. They should also provide them with technical help if needed. Each plan should be coordinated with other related agencies with similar interests. The media (television, radio, newspapers) and non-governmental and women's organizations or similar can also play an important role and should be involved in the planning. An approach to help in implementing strategy planning is to make water disinfection a part of the educational curriculum in the country and tailor it to the local community needs. Every district, community and even individual plots have their own unique water features. Administrative regulations and financial limitations play a vital role in this regard. A general emergency plan should be drawn up at all levels, with the involvement of the government, municipality and village council, and should be tailored to suit the community and the existing conditions in that area or location.

The most important aspects are to ensure the ability to coordinate efficiently and quickly between all agencies concerned and to be prepared for any event or requirement in an emergency. The following considerations should be taken into account in drawing up an emergency plan.

1. An emergency plan for water supply should provide for a water reserve storage capacity of at least 14 days under severe emergency status, without resort to outside water sources. Emergency supplies may then be available from governmental sources. The next priority is water for washing hands. The emergency plan should be drawn up and tested under various emergency scenarios. It should be reviewed by all levels of government, by municipalities and by nongovernmental organizations. Schools, health centres and hospitals are important assets during emergencies.

2. Highly trained professional emergency teams should be established. The team members will carry the responsibility of emergency mitigation. The professional background of. the team members will be defined by the nature of potential emergencies. These are dependent on the environmental setting of the country and its resources. For example, a town that has chemical factories will require a team structure different from a town that has no industry (such as only agriculture).

3. The national emergency operation plan should include a back-up strategy for provision and storage of both water and power supplies. The normal water supply system might be damaged or affected totally or partially by power failure, contamination, natural or man-made disease. If designed as a network of subsystems, the water supply system will not be as vulnerable as a single major water supply system. If one subsystem fails, another subsystem can take its place.

4. The potential for nuclear, biological and chemical contamination scenarios should be considered individually and in combination. For example, if a toxic chemical enters the water system due to an accident in a major factory in one area and at the same time the water treatment plant suffers damage due to an earthquake, the emergency response team should be prepared to deal with both water decontamination and disinfection on one hand and treatment and management of casualties on the other hand. Manuals and guidance for all scenarios as well as disease vector surveillance, field sanitation and communicable disease control should be prepared by the relevant government agencies to suit the existing conditions in a country or community.

   Every civil service/defence department should have an annex in the national response plan pertaining to the services it renders. The annex will define the responsibilities and the actions that it will take during emergencies to save life and property. The department of health for example will deal with casualties while the waterworks will deal with water disinfection, maintenance and repair. These responsibilities should be well defined and not overlap between departments.

5. Every water source and water supply system requires an individual assessment of its vulnerability to contamination or damage during disaster. The health risks, impact and methods of mitigation associated with the vulnerabilities should be addressed. The location of the system and the nature of the surroundings will define its vulnerability to

contamination. For example, a water treatment plant receiving water from farm runoffs will always have a potential for chemical and biological contamination.

6. Any government should build confidence between itself and the public. Media response to emergencies should be well planned and well coordinated with governmental agencies and actions. Television, radio and newspapers should be aware of exactly what is going on, the government should be very frank in explaining to the public and the media what is happening. This will prevent rumours that can cause panic among the public and lessen the effectiveness of any plan of action during emergencies.

7. Immediate action should be taken by government to include appropriate means for disseminating information and disinfection-related material and instructions to the general public on how to disinfect water and how to recognize the symptoms of an illness from water-borne diseases. The guidelines contained in this publication can provide useful source material for developing suitable public information brochures.

Annual Actions

The following actions should be evaluated and reviewed annually:

1. Define the type and frequency of water surveillance and establish surveillance reporting requirements and quality control programmes. This should include how, what, when and how often to sample and inspect the premises of waterworks and water sources, including quantity and quality of water sources. Define the data that should be collected, how often reports should be made and disseminated, and the quality of data to be reported.

2. Establish emergency status requirements, procedures and activation methods. This means when, who, and how a state of emergency is declared and who will declare it.

3. Medical supplies and equipment should be inspected and updated periodically. Emergency equipment and medical teams should be trained and given refresher courses from time to time.

4. Communities should be kept regularly informed and trained in procedures with regard to water supply in emergencies and action that may need to be taken at the household level.

5. Optimize detection, operational support, environmental surveillance and assessment, decontamination and sanitation before and during emergencies. All resources (human, mechanical and supplies) should be used in the most effective manner in order to get the best out of what is available at the time.

Surveillance and Assessment

The purpose of surveillance is to recognize, prevent and/or reduce potential problems before they occur and to be prepared to take counter measures when necessary.

1. The potential risks should be identified through detailed environmental assessment and routine surveillance. The specific risks should be evaluated, quantified and qualified so that each can be managed and the potential harm that they could impose reduced. Results should be reported regularly to the next level.

2. Appropriate control measures should be identified and implemented to reduce the harm or the potential for harm to people and environment. Training will be needed to handle such emergencies.

3. The chosen control measures should be tested to ensure appropriateness and effectiveness and to allow modifications as necessary.

Information for the Public

Appropriate information material should be developed for the public so that people know what to do in the event of an emergency that may affect water supplies. Information material should address the following issues.

1. The waterworks supply system might be affected during emergency by power failure, damage or contamination. People should be alert and prepared for such contingencies. If they suspect that the waterworks supply is a potential health hazard by observing a greenish or a brownish colour in the water, they should immediately take action by reporting it to the local authority and disinfecting it. If the water source is a community waterworks, people should have an emergency reserve supply of water. The amount of reserve water required will depend on the length and type of emergency but in general a reserve of 2 cubic metres should be planned for every seven people.

2. Glass jugs and polyethylene plastic containers are good for water storage provided they have been thoroughly washed with soap and water, filled and sealed. Water that has been carefully stored for a long period of time will be as safe to drink as fresh water, but may not taste “fresh”. Some may want to test their stored water for smell every three months, but it is not necessary for health. Odorous as it may become, it will still be usable for emergencies. There may be several other sources of drinking water available that people do not think of, for example the hot water storage tank, the flush tank of the toilet, and the household water pipes. A well and a pump are a desirable emergency source of water for drinking, food preparation and sanitation, particularly for large families.

3. If the water is contaminated or there is damage to the community water supply system, households should close the main water shut-off valve to prevent contaminated water from mixing with the safe water inside the house. It is very important to know the location of the shut-off valve in the home, and to make sure that it is in good working order.

4. In the event of an emergency, people should use the safe water they have stored first and make it last as long as possible. Other water should not be used unless it becomes absolutely necessary, and then it should be disinfected before use.

5. After all stored safe supplies of water within the house have been used up, households may have to purify and disinfect water obtained from other sources. Such sources should be identified as early as possible, before they are required. Outside sources of water should never be used during emergencies without purifying, unless the local authorities say it is safe to do so.

6. Cooperation with neighbours in order to find the most efficient solutions in an emergency is essential.

ABBREVIATIONS

°C	degrees Centigrade
cm	centimetres
g	Gram, = 1/1000 of a kilogram
Kg	Kilogram = 1000 grams
L	Litres
L/cap/day	litres/person/day
lpcd	litres/person/day
m	metre(s)
m^3	cubic metre(s)
mg	milligram or milligrams
mg/L = ppm	milligrams per litre = ppm
mL	millilitres
mm	millimetres
nm	nanometre
ppm	parts per million = mg/L
1 teaspoon	1 teaspoon of a liquid = 5 mL. If the chemical is in solid form, it depends on its granularity, density & if the spoon is flat or heaped; it varies between 5 – 11 grams for most chlorine compounds. If the chemical is known; usually a coin or a measuring device or similar is given to villagers as a reference. Better use weight.

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