

Water quality and analysis

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Water quality is defined by physical, chemical and biological parameters, but also on the characteristics of the water resource, the supply system and the final utilisation.

Water quality standards depend on the intended use of the water: human consumption (for drinking, cooking, domestic and personal hygiene), food production (crops or livestock), industry and the environment.

However, in humanitarian programmes, water-quality aspects related to human consumption are the most important, because of their implications for health.

Different sets of standards exist, and many countries have their own reference standards, but the most widely recognised worldwide guidance on water-quality standards is provided by the World Health Organisation (WHO).

Respecting water-quality standards may be difficult and may require the development of non-sustainable systems for a community. In these cases, a system that produces less than perfect quality water may be appropriate, and certain critical quality parameters should be met to cope with major health risks. Having water in a sufficient quantity must be the first priority, to allow water consumption, food production and hygiene activities to be undertaken.

Not all situations have the same health risks. A crowded refugee camp with no water and sanitation facilities has a high health risk, and programme implementation must pay special attention to water quality. Attention to water-quality standards is more necessary at nutritional or health centres than at community water points.

1 Water quality and programme strategy

1.1 Water quality and public health

A sufficient quantity of good-quality water is essential for health. An important proportion of water-related diseases is directly linked to poor water quality, characterised by chemical or microbiological contamination (Table 4.I).

Diarrhoea is one of the major global health problems, with around 4 billion cases each year (WHO 2000). Lack of access to clean water is one of the main factors of transmission routes of diarrhoea. Many infectious diseases are transmitted by pathogens in human faeces via the faecal-oral route, which is the main link between water quality and public health. The aim of most water and sanitation programmes is to block potential disease-transmission routes, using water-quality surveillance to monitor these routes and assess the effectiveness of the programme.

Table 4.I: Disease groups related to water quality.

Group	Example of diseases
Water-borne diseases (caused by consumption of biologically contaminated drinking water)	Cholera Typhoid Infectious hepatitis Giardiasis, Amoebiasis
Water-based diseases	Schistosomiasis, Dracunculiasis (guinea worm)
Diseases caused by consumption of chemically contaminated drinking water	Fluorosis (fluoride), Skin cancer (arsenic) Lead poisoning

1.2 Water quality and programme profile

1.2.1 EMERGENCY PROGRAMMES

Emergency contexts are normally characterised by a high vulnerability of the population and a high risk of epidemics. Therefore, rapidly and efficiently covering the basic needs of the population is the priority. This is the case in the setting up of camps for refugees or displaced persons.

In these contexts, microbiological water quality is a major issue, considering that numerous outbreaks are related to water quality. Treatment of water is therefore highly recommended, and the most common process employed is chlorination.

When water is clear, chlorination removes faecal contamination (though it is less effective against most viruses, protozoa cysts, and helminth ova than against bacteria). Turbid water needs pre-treatment before chlorination, and it is usual practice to flocculate it with chemicals. Residual chlorine will protect water from further bacteriological contamination during a limited period of time after the initial disinfection. Monitoring of residual chlorine must be done on a daily basis at the distribution points.

Water-quality monitoring should be systematic and properly reported:

- daily monitoring of the water treated through the measurement of free residual chlorine (with a pool tester) at the water distribution sites (taps) and therapeutic feeding centre/ health centre storage containers;
- if chlorination is not done, regular random checking of microbiological contamination (faecal coliform counts);
- if chemically-assisted sedimentation is done, daily chemical analysis (to measure the quantity of flocculants necessary and to check the water treated).

Note. – The short-term nature of emergency programmes (limited to several months in general) means that risks of developing chronic diseases through ingestion of chemical contaminants is limited and not considered a priority. Verification of organoleptic parameters (taste, smell – including chlorine – and colour of the water) and physicochemical parameters (especially conductivity) is of little use and should be considered only if the population to be served find the water unacceptable.

1.2.2 LONG-TERM PROGRAMMES

These programmes have a more community-focused approach, and are therefore directed towards the self-reliance of the population in both the use of the water source and the maintenance of water quality throughout the distribution chain (water point to household water storage).

In this context, the appropriate selection of the water source (and its use) should ensure that:

- the chemical quality of the water does not have a negative impact on public health (special attention must be paid to the potential risks of chronic diseases due to toxic chemicals like arsenic, fluoride etc.);
- the population accepts to drink the water delivered (no problems regarding taste – including chlorine – salinity, smell or colour);
- the use of the water source should include sustainable control of the risk of biological contamination (proper design of water points, participation of the community and institutions in the maintenance of the infrastructure, and water-quality-monitoring).

Ensuring biological quality (protection of the water source from re-contamination, and proper use of the water) will depend on water-point management and hygiene-promotion programmes through training of trainers. The sustainability of water-quality monitoring for these programmes must be sought through a proper partnership with relevant institutions (e.g. Ministry of Rural Development) or local partners (local NGOs, local community groups etc.).

1.3 Water quality through programme steps

During a standard water-supply programme, water-quality analysis should be taken into account in the selection, validation and monitoring steps, and will be carried out on the water resource, at the water point, at the water distribution process and on stored water at the household level (Tables 4.II & 4.XV).

Water-quality parameters, especially microbiological parameters, can significantly fluctuate, as demonstrated in the following examples, and therefore should be regularly monitored:

Table 4.II: Water-quality analysis purpose according to programme steps.

Water chain	Water quality analysis purpose
Water resource	To confirm the water quality of the resource and identify (through its characteristics) its vulnerability to contamination To ascertain the need for treatment. To gather information for the study of the water source: water flow etc.
Catchment (surface-water intake, well etc.)	To check the effectiveness of the catchment, to protect against contamination (or re-contamination)
Treatment system	To adjust treatment activity To check the efficiency of the treatment
Supply system	To detect possible sources of contamination and corresponding causes (maintenance, cleanliness, technical failures etc.). To monitor the use of the water at the distribution point.
Transport and storage in the household	To study people's habits regarding the uses of the water (transport and storage) To define hygiene promotion messages in order to promote proper use of the water

– In a refugee camp, or any area with a high concentration of people using the same source of water, limited quantity of water available may have an impact on the *microbiological quality* of the water at water points that are over-used. Where sanitation is inadequate, the water source itself is at risk of contamination.

– The seasonal variation of the water resource, including the water table, springs, and rivers, may have a direct impact on the *chemical quality* of the water. High concentrations of salts, indicated by a high conductivity, are observed at the end of the dry season, or at the beginning of the rainy season, with the release of chemicals in the aquifers via mineral leaching or during floods.

1.3.1 SELECTION OF THE WATER RESOURCE

1.3.1.1 *The quality of water resources at regional level*

In many situations it is very difficult to modify the chemical quality of the raw water in a sustainable way, and therefore, chemical parameters must be assessed carefully before starting a programme, especially for long-term interventions where chronic diseases are a real risk (e.g. skin cancer linked to high free arsenic concentrations in the water).

While assessing the hydrological parameters of the water resource (e.g. by a random survey of different existing water points), the chemical aspects of water quality are checked, to establish the technical feasibility of the project and its sustainability (the water resource could be potentially affected by natural pollution). This survey may influence technical choices for development of the future water points and it is fundamental for the choice of the water source (e.g. prefer shallow wells to boreholes if there is potential mineral toxic contamination with arsenic or fluoride).

Some parameters can present a geographical variability, so this data must be reported on maps presenting each of the main chemical forms (major parameters, conductivity and, possibly, toxic minerals). On the other hand, chemical parameters are subject to seasonal variation (conductivity, toxic minerals) and must be monitored at selected sites (stations) clearly registered and identified through mapping.

Water-quality surveys should be cross-checked with medical data (e.g. dental fluorosis rates, figures for skin cancer due to free arsenic in the water etc.) in order to define the major risks related to water quality.

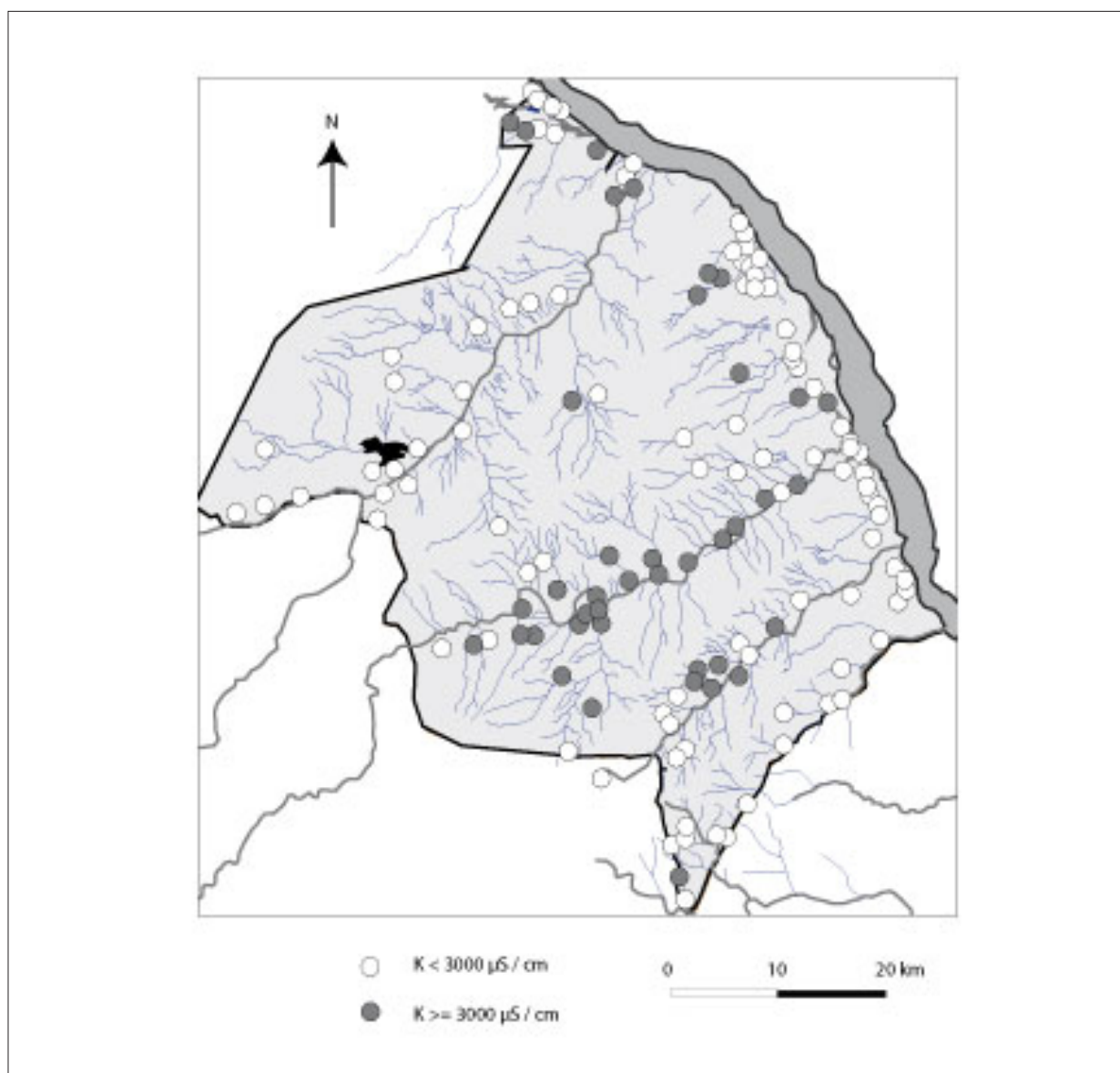


Figure 4.1: Conductivity mapping (ACF Mozambique, 1999).

If the only available water resource is dangerous for human consumption (most of the time, surface water or rainwater are an alternative when groundwater resources are affected by chemical pollution), and treatment is not affordable, the agency may decide to cancel the programme, applying the principle of precaution. This critical decision should be taken after discussions at the highest level and be accompanied by lobbying of relevant national or international institutions to raise awareness of the risks and encourage a search for other solutions.

The map shown in Figure 4.1 was drawn during a feasibility study. It aims to identify zones where conductivity is $>3000 \mu\text{S}/\text{cm}$ (dark spots), with a serious risk of acceptance problems. In these places, an alternative water source, such as rainwater or surface water was recommended.

1.3.1.2 Water-quality checking at the water point

After completion of the technical work, chemical and microbiological parameters are analysed to confirm water quality (partly for contractual purposes vis-à-vis local institutions or the community) before the installation is handed over.

In the case of rehabilitation of a water point or network, two microbiological quality checks (*E. coli*) must be done (before and after the technical intervention) in order to measure the impact of the activity.

Note. – During the construction of water points, some parameters can be checked in order to anticipate problems. For example, regular conductivity measurements are done during drilling. In case of suspicion of the presence of toxic substances, more specific analysis can be undertaken (for example, arsenic, which is a potential problem in countries along the Mekong Delta and in Nepal, is now checked by ACF during drilling in Cambodia).

1.3.2 WATER-QUALITY MONITORING

1.3.2 1 Monitoring the quality of delivered water

Monitoring the quality of delivered water concerns the risk of re-contamination in the system. The purpose is to detect the source of contamination and its causes, and it must be conducted at all the stages of the system (catchments, storage, pipelines and distribution points).

Contamination can be due to technical faults or lack of maintenance (e.g. microbiological contamination by re-infiltration of the water that has been drawn, through faults in a well's apron, or inadequate sealing around the upper part of a borehole, absence of perimeter fence etc.). Contamination of a water point / distribution network may also be linked to problems in the surrounding environment, such as inadequate sanitation, use of fertilisers on nearby fields, industrial activity in the catchment area etc.

Parameters to be monitored at the water point / distribution network are mainly biological (algae etc.) and microbiological (faecal coliforms), and the monitoring can be done through:

- Routine monitoring of microbiological water quality. The frequency of the analysis depends on the likelihood of specific risks (outbreaks) and the condition of the system.
- Sanitary inspection of the water point / distribution network: this activity, to be developed together with the relevant local institution, is an overall checklist for each type of water supply to check the state, use and maintenance of the installation (e.g. is the apron cracked or damaged? etc., See Annex 7B). The water committee responsible must be involved in these tasks.

In case of a regional toxic risk, monitoring of the major chemical parameters is carried out twice a year (after the end of the dry and rainy seasons) to check the suitability of the water source.

1.3.2 2 Monitoring at household level

This is the most important aspect because it directly affects the health of the targeted population. It is also the most difficult to check; it concerns the entire distribution chain, from the point where water is delivered, to the homes of consumers (in practice, a sample of households is chosen); it may change from one household to another (depending on water-transport or water-storage practices, hygiene behaviour etc.); it may also change over time (for instance, during the rainy season, people may use water from unprotected sources such as seasonal pools and streams, and the quality of this water needs to be monitored too).

The main parameter to take into account is *faecal pollution* (indicated by faecal coliform counts), which must always be checked by a *sanitary survey* (cleanliness, domestic water storage conditions, hygiene practices etc.).

The interventions to preserve the quality of water at the household level are mainly hygiene promotion, and providing the means to practice good hygiene, e.g. proper drinking-water storage or proper sanitation facilities.

1.4 Water resources and water quality

1.4.1 RAINWATER

General remarks on quality

The main advantages of rainwater for human consumption are:

- Very low risk of biological contamination.
- Very low conductivity.
- Very low turbidity.

Long-term reliance on rainwater alone may cause health problems due to its low mineral content.

Pollution factors

- Particles of dirt from roofs and gutters.
- Direct surface pollution and animal contamination in open harvesting systems.
- Biological contamination (algae, parasites, bacterial) of the major storage tank.
- Development of an turbidity in the case of lack of maintenance of the tank, rain catchment surfaces, gutters (mainly at the beginning of the rainy season).
- Creation of alkalinity through reaction of the water with the internal plastering of new tanks.
- Possible presence of combustion residues, factory emissions and dust, from the atmosphere, including high NO and SO₂ concentrations (acid rains in India). This risk is minimal in most areas.

Even if the quality of the rainwater itself is good, harvesting and storage systems are easily contaminated and the quality of water supplied is usually poor, therefore they are principally used at household level.

Other disadvantages

- Development of mosquito larvae and insects in water-storage tanks, pose a potential risk of vector-related diseases (malaria etc.).

Recommended analyses

- Regular microbiological monitoring at the main water-storage tank and at the distribution point.
- NO, SO₂ and pH should be checked at the beginning of the programme and once a year thereafter.

1.4.2 SURFACE WATER (RIVERS)

General remarks on quality

The main characteristics of surface water include the following (see also Box 4.1):

- Microbiological contamination is usually severe, particularly if the river flows through inhabited areas.
- There is a limited risk of toxic levels of mineral elements. This means that surface waters represent a suitable alternative to naturally contaminated groundwater (e.g. with arsenic or fluoride).
- They provide a quick and short-term solution to a temporary pollution problem.
- A range of biological indicators (fish, plants, algae) facilitate the identification of pollution.
- Turbidity is usually high, with the risk of adsorption of pathogens on suspended particles.

Pollution factors

- Weak protection from direct contamination risks (e.g. human or animal faecal pollution).
- Presence of organic matter (the degradation of which causes decreased dissolved oxygen levels).
- Presence of plant nutrients (e.g. from agricultural pollution) may cause eutrophication of the water.
- Possible presence of pesticides (organochlorides, organophosphates, carbamates etc.), if their use is common in the area.

Box 4.1

Specific phenomena of surface-water quality.

The natural evolution of surface-water quality

The water quality of a river undergoes a natural evolution from the source to the mouth:

- Profile evolution through regressive erosion: the upstream reaches transport coarse material, the downstream reaches carry finer particles, and finally deposits.
- Physicochemical evolution and mineralisation: concentrations of organic matter and dissolved minerals increase from upstream to downstream, with a lowering of dissolved oxygen and an increase in water temperature.
- Biological evolution: increase in biological activity, and of bacterial presence in particular, from upstream to downstream, with involvement in the decomposition of organic matter.

Pollution of surface water with organic matter

The introduction of organic matter in a river course will provoke a modification of its natural environment downstream.

- Lowering of dissolved oxygen, due to aerobic degradation of the organic matter: this represents a phenomenon of auto-purification under specific conditions.
- Modification of physicochemical parameters: temperature, pH and ammonia (NH₃) increase.
- Sedimentation of anaerobic mud, with the release of methane gas (CH₄) and iron sulphide (iron pyrites).
- Increased mineralisation that may cause eutrophication.

Eutrophication

- The phenomenon is the same whether caused by natural processes (e.g. seasonal algal blooms in lakes) or artificial events (pollution, excess of mineral elements, phosphates due to detergents etc.).
- The steps are: increase of the phytoplankton population, increase of turbidity, concentration of algae in the upper layers and sudden death of vegetation (due to high temperature) followed by settlement of the organic matter, decrease of the oxygen levels, and diagenesis.
- Eutrophication leads to a significant increase of pH, linked to a release of toxic substances such as NH₃ that impair drinking-water quality.

Recommended analyses

- Regular biological analyses, turbidity, and conductivity, which is an indicator of occasional pollution.
- Complete checking of major elements and toxic minerals when starting the programme, and then twice a year (end of rainy and dry seasons to account for any concentration / dilution phenomena).
- Regular analysis of PO₄, NO₃, K, mainly for the risk of agricultural pollution, including pesticides or fertilisers, or if the monitoring of conductivity shows an unexpected increase.

1.4.3 STATIC SURFACE WATER (VILLAGE PONDS)

General remarks on quality

The biological and chemical characteristics of the pond water include the following:

- The presence of parasites that may represent a health risk through consumption, e.g. contamination of drinking water by the *Fasciolopsis* intestinal fluke, or through contact, e.g. *Schistosoma cercariae* penetrating the skin.
- The presence of bacteria (possibly pathogenic, e.g. *Salmonella* spp.) depends on the natural conditions and on the pond's fresh water supply. Where ponds are filled by surface run-off, there is a high risk of faecal contamination.
- A limited concentration of natural toxic minerals (ponds may represent a useful alternative to mineralised groundwater).
- Active anaerobic mineralisation involving a rapid recycling of organic matter (auto-purification).

- A whole range of biological indicators (fish, plants, algae) facilitating the identification of pollution.

Contamination factors

- Faecal contamination of the village pond, especially due to domestic animal presence and water-sharing with cattle.
- In the case of floods or cyclones, ponds, in addition to wells, are especially vulnerable to any surface contamination.
- In the case of agricultural pollution, ponds (and lakes) may concentrate toxic elements (as is the case of the Aral sea and the related lakes of Karakalpakstan).

Recommended analyses

- Direct observation of biological indicators, parasites, mosquito larvae.
- Direct observation of possible faecal contamination (dung, animal tracks).
- Regular bacteriological analyses (faecal contamination indicators).

Negative factors

- These areas may contribute to the general insalubrity of the area (malaria, mosquitoes, swamp gas (CH₄)).

Note. – Ponds are different from lakes, because of their limited depth, and they have specific environmental characteristics:

- sunlight can reach the bottom, allowing colonisation by rooted vegetation;
- the water temperature is homogeneous (no thermocline, which is present in lakes);
- the presence of dissolved mineral elements is homogeneous.

1.4.4 GROUNDWATER

General remarks on quality

Generally, groundwater is of good microbiological quality and is not vulnerable to external pollution. Exceptions to this include karst systems with rapid water infiltration, or where there is insufficient filtration of surface pollution in surface-soil layers.

This good microbiological quality, especially with abstraction through boreholes, makes groundwater ideal for human consumption. The main risk is one of natural chemical contamination, such the abundance of toxic minerals (e.g. As and F) in very specific contexts.

Note. – The excellent biological quality of groundwater is due to:

- the filtration and fixation of biological elements by the soil (see Chapter 13, Section 3.5);
- the anaerobic conditions that limit the bacterial (and organic) presence;
- the lack of light that limits the presence of phototroph bacteria;
- the low and stable temperature and generally very low concentration of nutrients that limit bacterial growth.

Pollution factors

The good biological quality of groundwater may be threatened by contamination from the surface, mainly linked to an inappropriate exploitation of the resource (improper water-point design and lack of protection).

– The aquifer's vulnerability is closely linked to the possibility of transit of surface pollution through the non-saturated zone, and the behaviour of the pollution 'cloud' in the saturated zone (related to the transmissivity of the aquifer).

– Water flowing through mineral deposits (such as sulphate dolomites and Triassic facies, gypsum) may develop a high dissolved-solids concentration, rendering it unpalatable.

– The presence of naturally-occurring toxic minerals, due to leaching of specific rock-types or geological formations (quartzite or meta-sediments containing high fluoride concentrations, and

sulphide deposits releasing arsenic). The concentrations of dissolved elements is often linked to redox reactions: an oxidation and precipitation of elements in the upper, oxidised area of the aquifers (e.g. toxic As(III) becomes As(V)) leading to a decrease in concentration, and a reduction reaction (causing increased solubility and therefore greater availability, in the case of As) in deeper parts of the aquifer. This leads to the creation of an As-contaminated zone 20-70 m deep in the recent deltaic sediments of the Mekong River, in Cambodia.

Recommended analyses

- Complete analysis of the major elements and the main toxic minerals, to validate the resource and the water point.
- Conductivity and pH must be checked in the site-validation process.
- Microbiological monitoring of water points, to identify the main risk: biological contamination (faecal).
- Monitoring of potassium, phosphates and particularly nitrate (NO₃) and pesticides (atrazine) in intensive agricultural areas (e.g. in Tajik and Uzbek cotton fields).

2 Standards and guidelines

2.1 The concept of pollution

Pollution consists of all direct or indirect factors that may affect water quality. This definition must take into account the concept of pollutant flow (evolution of the ‘quantity’ of pollution with time) and pollution potential (for example, the construction of latrines in a shallow water-table area).

Pollution can be the result of human activities or natural phenomena (including animals and plants) and can be responsible for the poor quality of water and non-compliance with quality standards in relation with water use.

There are various types of pollutant:

- *Domestic*: faecal pollution is the main domestic cause of water pollution. Abundance of organic matter and high concentrations of mineral salts (nitrogen compounds, phosphates etc.), detergents and organochlorides must also be considered.
- *Agricultural and livestock*: pesticides and fertilisers are the main cause of agricultural pollution. Water may also contain pathogenic *E.coli* and other pathogens, from animal faecal pollution.
- *Industrial*: factory effluents (hydrocarbons, chemical products, high temperature waters) are limited risks in humanitarian intervention contexts.
- *Natural*:
 - geological pollution, caused by the release of soluble elements, such as arsenic or fluoride, into water via leaching of specific minerals (fluoroapatite, Pb-Zn sphalerite, arsenopyrite and others). These elements may be spread during specific events (river floods), by thermo-mineral springs, and natural naphtha. These processes are complex and contextual, and greatly dependent on the chemical environments of groundwater;
 - microbiological and biological pollution (bacteria, virus, fungi, protozoa, helminths);
 - physical pollution (turbidity, temperature of the water, radioactivity).

The principal source of water pollution for humanitarian programmes is related to human activities and to the faecal-oral disease-transmission cycle, mainly due to poor sanitation, contamination of the water source, improper design of water points, bad maintenance of installations and poor hygiene practices (linked to either lack of knowledge or resources to apply hygiene principles).

In other cases, specific chemical pollution due to natural toxic minerals may also appear, and, more seldom, pollution is due to the use of pesticides (e.g. in intensive agricultural activities in some Central Asian countries).

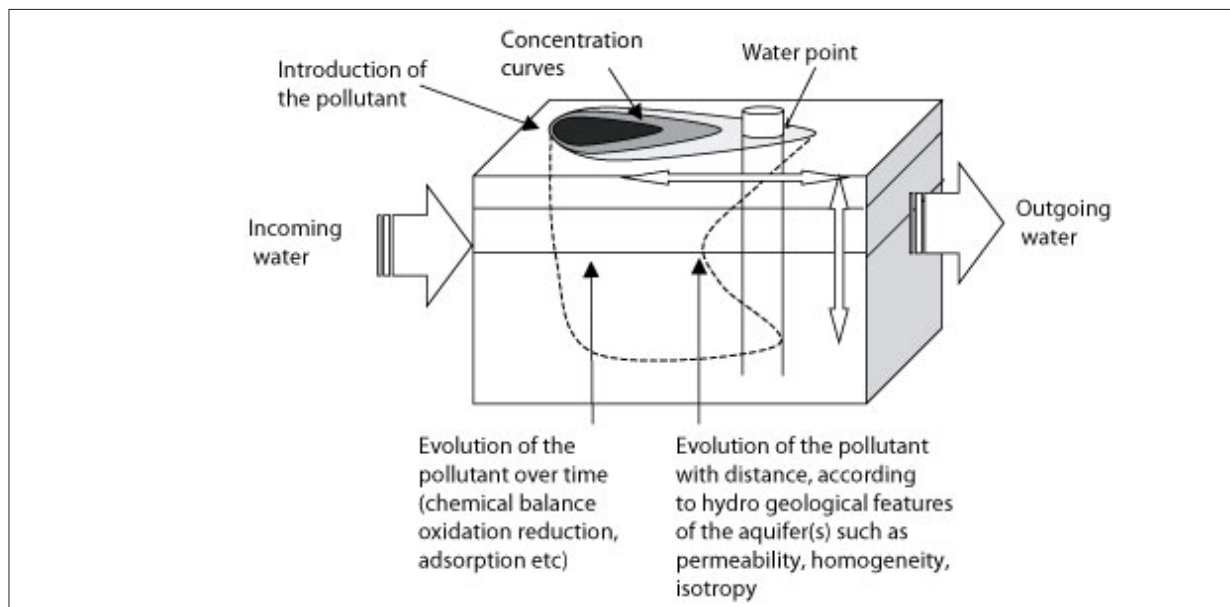


Figure 4.2: Diffusion evolution of a pollutant in an aquifer.

Pollution is described in terms of its spatial and temporal distribution (it can be described as a mathematical differential system where the water reservoir is represented as a ‘black box’ with pollutant concentration determined by the balance of pollutants entering and leaving it - see Figure 4.2). The main parameters of pollution to be considered are; its intensity (acuteness), its physical distribution (diffuse or localised pollution, vertical variability etc.), and its evolution over time.

Pollution can be chronic (continuous addition of pollutant), occasional, or cyclical (for example, pollution flow linked to amount of rainfall). Pollution is often specific to a type of water resource (surface water or groundwater).

2.2 The concept of toxicity

An element becomes toxic in water above a specific concentration, but may be beneficial or even essential for human health at lower concentrations, as illustrated in the Misterlich diagram, below (Figure 4.3).

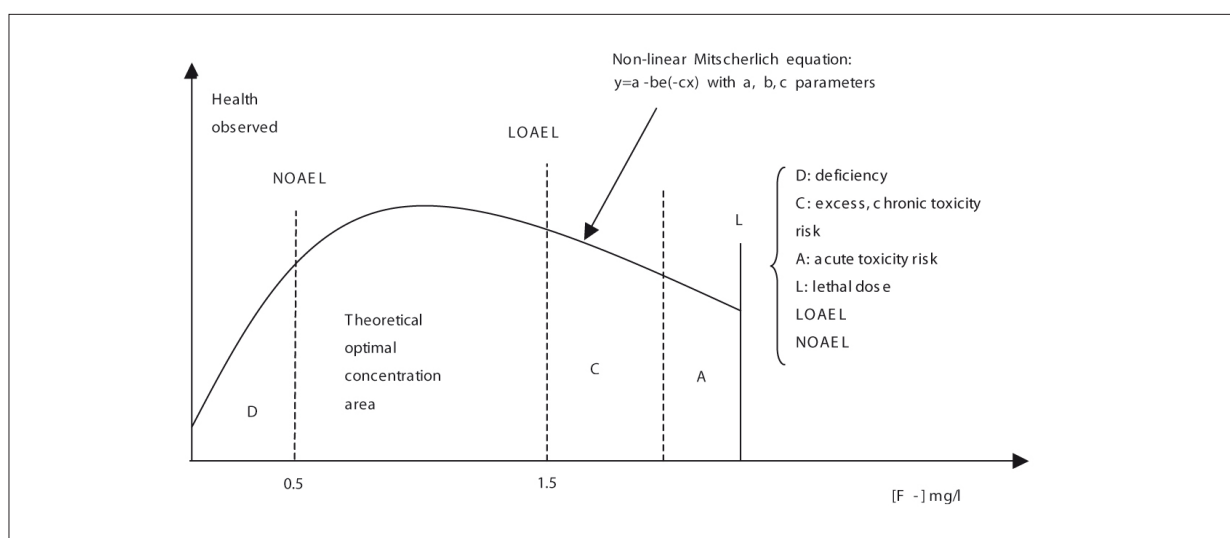


Figure 4.3: Misterlich diagram.

This type of diagram explains the case of fluoride, illustrated by the ACF program in the east of Sri Lanka. The lack of fluoride, below a concentration of 0.5 mg/l (zone 'D' on the diagram) increases the risk of dental caries. However, above 1.5 mg/l (WHO guideline, 2003), fluoride causes fluorosis, with mottling of tooth enamel and impaired development of the skeleton, through a chronic toxicity process mainly affecting children under 8 years old. Values like the Tolerable Daily Intake (TDI), the No Observed Adverse Effect Level (NOAEL) and Lowest Observed Adverse Effect Level (LOAEL) are defined by WHO, and vary with the weight of each individual.

Toxicity has different consequences, depending on the concentration of the chemical in the water:

- *acute toxicity*: violent and immediate sickness/death;
- *sub-acute toxicity*: only a certain percentage of the population is affected;
- *chronic toxicity*: the consequences appear after a long-term exposure to limited concentrations, with a cumulative effect in the organism (as in the case of fluoride and arsenic).

The main chemical elements affecting human health that may appear in water can be grouped as follows:

- *essential elements*: Na, Mg, K, Ca, Si, P, S, Cl, H, C, O;
- *toxic elements*: As, Pb, Cd, Al, Ag, Sb, Hg, U, Rn;
- *essential elements that are toxic at high levels*: N, F, Cr, Mn, Fe, Co, Ni, Cu, Zn, Se, Mo, Ba, Be.

2.3 Quality standards, guidelines and indicators

2.3.1 PRACTICAL USE OF WATER-QUALITY STANDARDS

Water-quality standards refer to substances and parameters that may have some health importance or that may affect acceptability. Nevertheless, in the comments made by WHO (see Box 4.2), it is stressed that drinking-water quality guidelines must be used bearing in mind the local context or the level of local service (average quality of water distributed, national standards, drinking-water coverage). Exceptional circumstances (war, natural disasters etc.) may prevent guidelines being strictly observed.

It is therefore essential to follow standards with common sense, making enquiries about local regulations, and comparing the quality of traditionally-consumed water with the quality of water to be supplied. Having enough reasonably clean water is preferable to having an insufficient quantity of high-quality water; lack of water to ensure a minimum level of hygiene may present more health problems than having water of medium quality.

This flexibility applies particularly to biological contamination: faecal coliforms are an indicator of faecal contamination, consequently their presence indicate only a potential risk of water contamination by pathogens (see Section 3.2.2). As the standard of 0 faecal coliforms/100ml may be impossible to reach for many water supplies (e.g. open wells), a binary approach (polluted / non-polluted water) has limited relevance. Assessing the risk of pollution, e.g. in order to determine further sanitary measures, is the most useful approach (see Section 4.3.3). This approach is also recommended by WHO (see Box 4.2).

Box 4.2

Practical use of standards according to WHO 2003.

“In many developing and developed countries, a high proportion of small-community water-supply systems fail to meet local or national quality standards. However, it should be recognized that to condemn a large number of supplies is not particularly useful and may be counterproductive. In such circumstances it is important that realistic goals for progressive improvement are agreed with the suppliers and subsequently implemented. Recognizing that achieving the Guideline may be difficult in some emergency situations it is practical to classify water quality results in terms of an overall grading for water quality linked to priority for action. Sophisticated grading schemes may be of particular use in community supplies where the frequency of testing is low and reliance on analytical results alone is especially inappropriate.”

The level of risk for the presence of pathogens, linked to faecal contamination of water, can be considered as follows, bearing in mind that the presence of specific pathogens and the susceptibility of a population to infection also need to be taken into account when considering sanitary risk:

PATHOGEN RISK FAECAL COLIFORMS /100 ML

– low risk	0 to 10*
– significant risk	10 to 50
– high risk	50 to 100
– very high risk	> 100

* *Some pathogens are not linked to faecal risk (e.g. some viruses, some protozoa, guinea worm etc.).*

A sanitary survey must complement bacteriological analysis to qualify the sanitary risk.

2.3.2 WHO GUIDELINES, THIRD EDITION (2003)

Tables 4.III to 4.V are based on the WHO nomenclature. The guidelines cover the main parameters of importance for drinking-water quality. WHO guidelines are divided into health-related guidelines, and non-health related guidelines, referring to chemical elements whose harmfulness has not been proved: for those elements, WHO makes recommendations regarding the maximum acceptable value. In some countries, those elements are covered by standards issued from official directives (See Annex 7A) e.g. the French *Alimentation en eau potable* (AEP), directives (1989).

Parameters that are difficult to measure and that do not cause frequent problems are not mentioned in this chapter (e.g. cadmium). It is however necessary to remain vigilant, particularly in urban or industrialised areas, and to contact specialists to deal with particular problems: it is also important to refer to the various guidelines for materials hazardous to health not covered by this book.

The application of the WHO guidelines for drinking-water quality should be the reference in water programmes, paying particular attention to those related to the major risks to health. In cases where the WHO guidelines cannot be applied, actions should be guided by the principle of precaution (see Section 1.3.1.1).

2.3.2.1 Health-related guidelines

Table 4.III: Microbiological quality of drinking water.

O: origin. H: health.

Parameters	WHO guideline values	Interpretation (see following section)
<i>E. coli</i> or thermotolerant coliforms	0 colonies /100 ml	O, H: indicators of faecal pollution (see note in Section 2.3.1)

Note. – According to WHO, the most definite indicator of faecal pollution is the presence of *Escherichia coli*, a member of the thermotolerant (or faecal) coliform group. In practice, the detection of faecal coliform bacteria as a whole is an acceptable and easier alternative.

Table 4. IV: Chemical substances that have some sanitary relevance for drinking water.
O: origin. H: health. NH: non-health.

Parameters	WHO guideline values	Interpretation (see following section)
Arsenic (As)	0.01 mg/l	O: rocks, industrial waste (iron and steel, precious-metal processing industry) H: proven carcinogenic effect (skin cancer)
Chlorine (Cl ₂)	5 mg/l	O: water disinfection products
Copper (Cu ⁺⁺)	2 mg/l	O: corrosion of copper pipes, agricultural NH: colour and bitter taste if > 5mg/l
Fluorides (F ⁻)	1.5 mg/l	O: rocks, fertiliser, food (fish), industrial pollution (aluminium manufacture) H: dental and bone fluorosis
Lead (Pb)	0.01 mg/l	O: natural (galena), chemical industry, lead pipes corrosion, surface treatment H: cumulative neurological toxicity
Manganese (Mn)	0.4 mg/l	O: iron-bearing rocks H: toxic effect on nervous system when > 20 mg/l NH: turbidity and taste when > 0.3 mg/l
Nitrates (NO ₃ ⁻)	50 mg/l	O: faecal contamination, organic matter, soil leaching, fertiliser, wastewater H: child methaemoglobinaemia
Nitrites (NO ₂ ⁻)	3 mg/l	O: organic matter H: child methaemoglobinaemia

2.3.2.2 Non health-related guidelines (recommendations)

Table 4.V: Drinking water substances and parameters that may lead to acceptability problems.
O: origin. H: health. NH: non-health.

Parameters	WHO recommendations	Interpretation (see following section)
<i>Organoleptic parameters</i>		
Colour	15 TCU	Nil
Conductivity	1000 mg/l 1400 µS/cm	O : dissolved solids NH: taste
Turbidity	5 NTU	O: matter in suspension, colloids, dissolved matter H: can involve bacteria presence in water through onto particles adsorption
<i>Inorganic substances / parameters</i>		
Aluminium(Al)	0.2 mg/l	O: coagulants used in water treatment, industry, natural NH: colour and acceptability problem when > 0.2 mg/l
Ammonia (NH ₄)	1.5 mg/l	O: nitrogenous organic matter (waste, wastewater, plants etc.) NH: taste and smell when >1.5 mg
Chloride (Cl ⁻)	250 mg/l	O: natural (salty contexts), human (urine), industrial H: laxative effect NH: brackish taste when >250 mg/l, pollution indicator
Hardness	200 mg/l	O: presence of Calcium and Magnesium NH: taste threshold, excess use of soap to achieve cleaning
Hydrogen sulphide (H ₂ S)	0.05 mg/l	O: rock, organic matter under anaerobic conditions H: no problem if swallowed, fatal if inhaled at high doses
Sodium (Na ⁺)	200mg/l	O: natural, industrial H: can indicate pollution (Na is present in urine) NH: taste threshold
Sulphates (SO ₄ ²⁻)	250 mg/l	O: natural (rocks), industry H: laxative effect, taste problem, NH: water aggressive to concrete when >250 mg/l
Iron (Fe ⁺⁺)	0.3 mg/l	O: rocks, coagulants (ferric sulphate/ferric chloride) NH: aesthetic (red colour, metallic taste, rotten fish smell) ferruginous bacteria can block pipes.
Zinc (Zn)	4mg/l	O: industrial, pipe corrosion NH: becomes an agricultural pollution when concentrated in soil

2.3.3 THE SPHERE PROJECT 2004

The Sphere project defines standards to be used in emergency contexts (see Chapter 2). Sphere water-quality standards are based on WHO guidelines for drinking water, but also include some comments and specifications useful for emergency contexts. Extracts from the Sphere project are presented in Box 4.3.

Box 4.3

Extracts from Sphere standards related to water quality.

Water quality standard

Water is palatable, and of sufficient quality to be drunk and used for personal and domestic hygiene without causing significant risk to health.

Key indicators

- a) A sanitary survey indicates a low risk of faecal contamination.
- b) There are no faecal coliform per 100 ml at the point of delivery.
- c) People drink water from a protected or treated source in preference to other readily available water sources.
- d) Steps are taken to minimise post-delivery contamination.
- e) For piped water supplies, or for all water supplies at times of risk or presence of diarrhoeal epidemic, water is treated with a disinfectant so that there is free chlorine residual at the tap of 0.5 mg per litre and turbidity is below 5 NTU.
- f) No negative health effect is detected due to short-term use of water contaminated by chemical (including carry-over of treatment chemicals) or radiological sources, and assessment shows no significant probability of such an effect.

Guidance notes

Microbiological water quality: faecal coliform bacteria (>99% of which are *E. coli*) are an indicator of the level of human/animal waste contamination in water and the possibility of the presence of harmful pathogens. If any faecal coliforms are present, water should be treated.

– Post-delivery contamination

Water should be routinely sampled at the point of use to monitor the extent of any post-delivery contamination.

– Water disinfection

In order for water to be disinfected properly, turbidity must be <5 NTU.

– Chemical and radiological contamination

Those risks should be assessed rapidly by carrying out chemical analysis. A decision that balances short-term public health risks and benefits should then be made. A decision about using possibly contaminated water for longer-term supplies should be made on the basis of a more thorough professional assessment and analysis of the health implications.

– Palatability

Although taste is not in itself a direct health problem (e.g. slightly saline water), if the safe water supply does not taste good, users may drink from unsafe sources and put their health at risk. This may also be a risk when chlorinated water is supplied, in which case promotional activities are needed to ensure that only safe supplies are used.

– Water quality for health centers

All water for hospitals, health and feeding centers should be treated with chlorine or another residual disinfectant.

Table 4.VI: Sphere indicators.

Test	Sphere Standards (2004): key indicators
Turbidity	5 NTU (for purpose of disinfection)
Faecal coliforms	0 col. /100ml at the point of delivery (see note in Section 2.3.1)
Chloride, fluoride, iron (FeII), manganese, nitrates, nitrites, sulphates, arsenic	No negative health effect is detected due to short-term use of water contaminated by chemical or radiological sources A guidance note on chemical and radiological contamination
Residual disinfectant products (chlorine)	For piped water and all water supply in case of diarrhoea epidemic, water is treated with free residual chlorine = 0.5 mg/l, and turbidity <5 NTU. A guidance note on water quality for health centres on chlorine and other residual disinfectant

3 Quality indicators

The primary method for assessing water quality in the field is to conduct sanitary surveys, including sanitary inspections (see Section 3.1), which are complemented by bacteriological and physicochemical analyses. The type of analysis is chosen on the basis of the following objectives:

- identify possible pollution of the water (mainly bacteriological);
- characterise water before treatment, or determine the efficiency of the treatment;
- characterise the context or the resource before its exploitation;
- characterise a water point by a risk assessment approach.

The main parameters measured for reaching these objectives are listed in Table 4.VII.

3.1 Sanitary surveys and risk assessments regarding water quality

Sanitary inspections of water systems and resources regard the ongoing status of the water supply and the potential risks of contamination in the long term. They are useful to identify what interventions are required and they are a tool that can be used by water-point committees to be able to monitor their water supply.

Three main types of risk factor are included in sanitary inspections:

- a) hazard factors: these are sources of faeces in the environment (e.g. pit latrines, sewers, solid-waste dumps and animal husbandry);
- b) pathway factors: these are factors that allow microbiological contamination to enter the water supply, but that are not direct sources of contamination (e.g. leaking pipes, eroded catchment areas and damaged protection works);
- c) indirect factors: these are factors that enhance the development of pathway factors, but do not directly allow contamination of the supply and are not a source of faeces (e.g. lack of fencing, faulty surface-water diversion drainage).

Sanitary inspections can be done with standardised forms depending the water system as shown in Annex 7B. These forms can be adapted to specific situations and contexts.

In the majority of cases, a sanitary inspection on its own can provide a reasonable idea of the bacteriological quality of the water and its vulnerability to pollution, but it is important to complement this information with water-quality analyses. Sanitary information can be crossed with water-quality information through risk analysis as Annex 7B also shows. Annex 7B represents an example of risk analysis adapted from the *Guidelines for drinking-water-quality, Volume 3*, WHO 1997. To implement this kind of tool requires testing and adaptation to local conditions.

Table 4.VII: Principal indicators of water quality.

Objectives	Indicators
General analysis of the resource	Complete water analysis
a) Characterisation of a groundwater environment	Conductivity Temperature pH Cations (calcium, magnesium, potassium, sodium, trace metals) Anions (halides, sulphate, carbonate, nitrate, alkalinity) Trace elements (manganese, fluoride, arsenic)
b) Characterisation of a surface-water environment	Conductivity Temperature Turbidity pH Cations (liquid ammonium, potassium) Anions (nitrate, nitrite) Trace elements (iron, manganese) Oxidability and BOD Dissolved oxygen Biological index
Major risks to health	Sanitary survey Agricultural and industrial assessment: usages and possible pollutants (i.e. pesticides: carbamates, organophosphates, organochlorides etc.)
Faecal pollution test	Sanitary survey Bacteriological analysis
Analysis prior to treatment (filtration, chlorination, flocculation)	Bacteriological analysis Chlorine demand pH Turbidity Conductivity
Analysis after treatment	Bacteriological analysis Residual chlorine Aluminium pH Turbidity Conductivity
Analyses aimed at defining fitness for irrigation	Conductivity Cations (calcium, magnesium, sodium)

A sanitary survey is a larger exercise that includes sanitary inspection, but also analysis of factors such as disease prevalence, hygiene practices etc. that may have an impact on health. The sanitary survey offers a complete and meaningful approach to the situation. It reveals the vulnerability of water to pollution and keeps its value over time.

Sanitary surveys serve to:

- identify sources of contamination in order to define remedial actions;
- validate the water-supply system;
- assess the seriousness of a situation by analysing risks;
- compare different sources and systems in order to prioritise actions;
- identify recurrent problems in order to adapt strategies and methodologies.

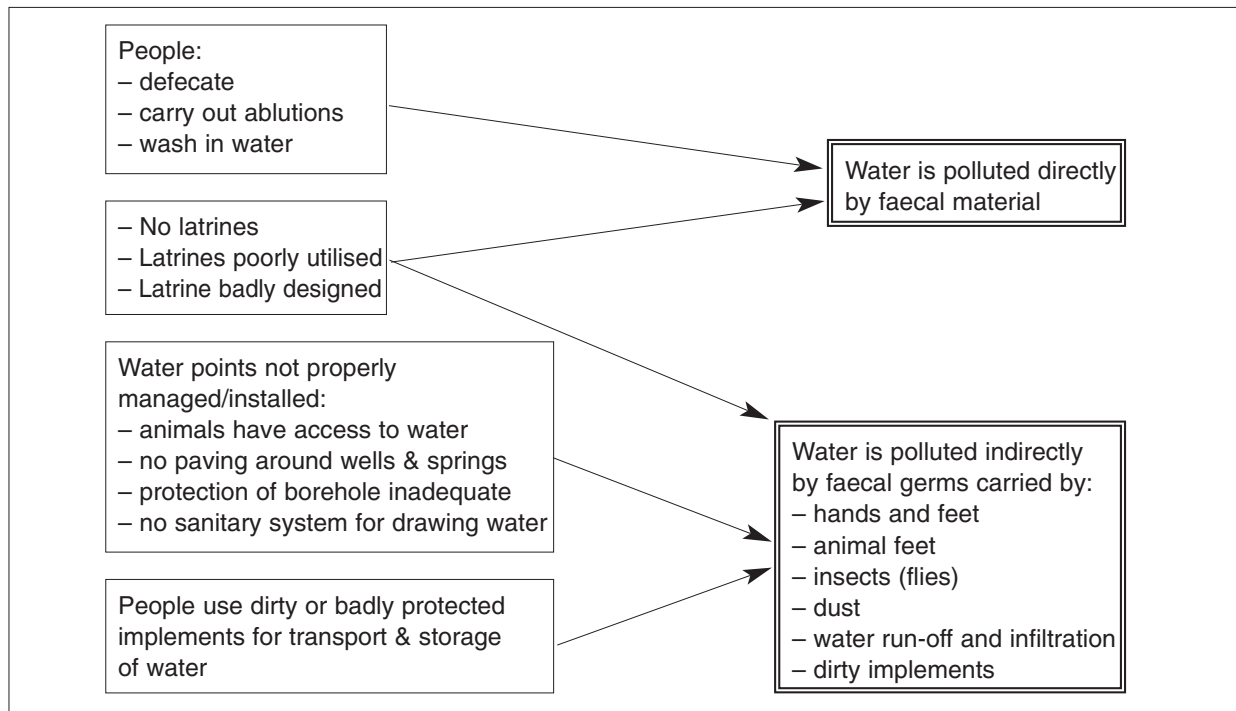


Figure 4.4: Faecal risk.

All situations that allow faeces to come into contact with water (directly, as in defecation into water, or indirectly, as in transport by run-off) represent a potential source of pollution. The sanitary survey investigates these risk situations (Figure 4.4). It must be carried out throughout the water system, from the water point to the users' homes.

3.2 Biological analysis

Bacteriological analysis indicates faecal pollution of water but is also a valuable check on the efficiency of the protection or treatment measures, and is a complementary tool for the sanitary survey and sanitary inspections. It is an indicator of water quality only at the time of sampling, and does not retain its value over time, so needs to be interpreted in the light of the sanitary survey.

3.2.1 PATHOGENIC ORGANISMS PRESENT IN WATER

Pathogenic organisms that may be present in the water are very numerous and varied, Table 4.VIII presents the most important. The faecal-oral infections can be transmitted by either water-borne or water-washed mechanisms. Truly water-borne transmission occurs when the pathogen is in water which is drunk by a person or animal that may become infected. But all water-borne diseases can also be transmitted by any other route which permits faecal material to pass into the mouth (for example via contaminated food).

3.2.2 BACTERIOLOGICAL ANALYSIS

There are very many pathogens (see Table 4.VIII) that may be found in water. It is not feasible (or feasible only through expensive and time-consuming methods) to test for pathogens directly. As most pathogens in water are derived from faeces (human and animal), the approach is therefore to analyse the water for bacteria that show human and animal faecal contamination has occurred. These are called 'indicator bacteria'. Their presence in water does not prove the presence of pathogenic organisms, but provides a strong indication of it.

Table 4.VIII: Main faecal–oral (water-borne or water-washed) water-related infections (from Cairncross & Feachem 1990).

Infection		Pathogenic agent
Diarrhoeas and Dysenteries	<i>Campylobacter enteritis</i>	Bacterium
	Cholera	Bacterium
	<i>E. coli</i> diarrhoea	Bacterium
	Salmonellosis	Bacterium
	Shigellosis (bacillary dysentery)	Bacterium
	Yersiniosis	Bacterium
	Rotavirus diarrhoea	Virus
	Giardiasis	Protozoon
	Amoebic dysentery	Protozoon
	Balantidiasis	Protozoon
Enteric fevers	Typhoid	Bacterium
	Paratyphoid	Bacterium
Poliomyelitis		Virus
Hepatitis A		Virus
Leptospirosis		Spirochaete
Ascariasis		Helminth
Trichuriasis		Helminth

The most definite indicator bacteria (according to WHO) used in routine assessment of the risk of faecal contamination is *Escherichia coli*. This species is present in the faeces of warm-blooded animals, including humans, and is part of the normal intestinal flora of healthy individuals. It is abundant in human faeces (up to 1 billion bacteria/gram of fresh matter), and persistent enough to be detected (its detection duration in water at 20°C varies from 1 week to 1 month). *E. coli* is the most common species in the group of *thermotolerant coliforms*, or *faecal coliforms* (more than 99% of faecal coliforms in water are *E. coli*). In practice, faecal coliforms are commonly used to identify faecal contamination.

Results of bacteriological analysis do not provide definite information on the presence or absence of pathogens. Some virus and protozoa may be found in drinking-water supplies when faecal coliforms are absent, so water that contains no faecal coliforms should be seen as low risk, rather than safe. On the other hand, faecal coliform presence indicates faecal contamination, but does not prove the presence of pathogenic organisms, even if this may be strongly suspected (see risk estimation in Section 2.3.4).

Generally, faecal coliforms are not pathogenic. However, some serotypes of *E. coli* (O157:H7) may cause serious diseases: pathogenic strains of *E. coli* are responsible for urinary tract infections, bacteraemia, meningitis and diarrhoeal disease in humans. Animals, primarily cattle and, to a lesser extent, chickens, goats and pigs, are the main reservoir for pathogenic *E. coli*.

Note. – Total coliforms are a much larger group of coliform bacteria that are present in cold- and warm-blooded animal and human faeces, but not all total coliforms have a faecal origin, and many are present in most non-treated water sources in tropical regions, particularly in water enriched with organic matter. They are not systematically identified, as their presence does not necessarily indicate a sanitary risk, but they can be used to measure the effectiveness of treatment processes.

3.3 Physicochemical characteristics

Choice of parameters to be identified is based on the objective of the analysis.

3.3.1 ACIDITY (pH)

The pH (hydrogen potential) measures the concentration of H⁺ ions in the water, representing the balance between acidity and alkalinity on a scale of 0 to 14, with 7 being neutral.

Table 4.IX: Classification of the water according to its pH.

pH < 5	Strong acidity (Coca Cola® pH = 3 ; orange juice pH = 5) Presence of mineral or organic acids in natural water
pH = 7	Neutral pH
7 < pH < 8	Most surface water (approaching neutrality)
5.5 < pH < 8	Most groundwater
pH > 8	Alkalinity, intense evaporation

It characterises a large number of physicochemical equilibriums and depends on many factors, including the origin of the water (Table 4.IX).

It can have a direct influence on the toxicity of other elements: sulphur is present as toxic H₂S under acidic conditions, but as a harmless precipitate of S₂ at pH>13. pH also has an influence on chlorination efficiency (best results are achieved in acidic waters, below pH 7, and chemically-assisted flocculation (aluminium sulphate is most effective between pH 6 and 8).

Analyses to be done *in-situ* with pH-meter or colorimeter.

WHO recommendation: 6.5 – 8.

3.3.2 ALKALINITY

Alkalinity corresponds to measurement of constituents from the group of weak acid anions capable of reacting with H⁺. The alkalinity of water is a measure of its capacity to neutralise acids. This parameter plays a major role in the buffer-effect of water. It determines the way in which pH is modified by the addition of weak acids or bases, particularly during treatment processes (flocculation and disinfection).

3.3.3 BOD, COD AND OXIDABILITY

These parameters enable estimation of the quantity of organic matter present in water.

BOD (biochemical oxygen demand) expresses the quantity of oxygen necessary for the breakdown of biodegradable organic matter in the water by the development of micro-organisms under certain given conditions. The conditions most commonly assumed are 5 days (partial degradation occurs by then) at 20 °C, in the absence of light and air: this is known as BOD₅. This measurement is widely used for monitoring sewage-treatment-plant effluent, because it provides an estimate of the loading of biodegradable organic matter. It is expressed in mg/l (mg of O₂ consumed per litre).

COD (chemical oxygen demand) shows the quantity of oxygen necessary to oxidise the organic matter (biodegradable or not) in the water, using an oxidant (potassium dichromate). The result is expressed in mg/l.

Oxidability is a measurement similar to COD, and is used in the case of low concentrations of organic matter (COD < 40 mg/l). The oxidant used is potassium permanganate.

3.3.4 CONDUCTIVITY AND TOTAL DISSOLVED SOLIDS

Most matter dissolved in water occurs as electrically-charged ions, with ion concentrations dependent on the pH and EH (redox potential) of the water, and the composition and concentration of different negatively- and positively-charged ions that may react to form inert solids. Total dissolved solids (TDS) is defined as the quantity of dissolved material in water, and depends mainly on the solu-

Table 4.X: Classification of water according to its conductivity χ .

χ ($\mu\text{S/cm}$)	Type of water	
0.005	Demineralised water	
$10 < \chi < 80$	Rainwater	Normally no acceptance problems for human consumption in this range
$30 < \chi < 100$	Slightly mineralised water, granitic context	
$300 < \chi < 500$	Fairly well-mineralised water, carbonated context	
$500 < \chi < 1\,000$	Mineralised water	
$1\,000 < \chi < 1\,500$	Highly mineralised water	
$1\,500 < \chi < 3\,000$	Brackish water	
$\chi > 20\,000$	Seawater	

bility of rock and soil minerals in contact with waters within normal pH and EH ranges. For instance, water that flows through limestone or gypsum dissolves calcium, carbonate, and sulphate, resulting in high levels of total dissolved solids.

Conductivity is a measure of the capacity of water to pass an electrical current and is affected by the presence of dissolved solids. As the level of TDS rises, the conductivity will also increase. Conductivity changes may indicate contamination. For instance, contamination of a water supply with sewage can raise the conductivity because of the presence of chloride, phosphate, and nitrate. Intensive use of fertilizers will have similar consequences.

Conductivity also increases with water temperature, so measurements must be presented in terms standardised at either 20 or 25 °C. Normally the measuring devices used in the field automatically make this conversion. Conductivity differences, like temperature variations, may indicate zones of pollution, mixture or infiltration. Surface-water conductivities are normally below 1 500 $\mu\text{S/cm}$. In practice, acceptance problems for consumers appear above 1 500 $\mu\text{S/cm}$ (Table 4.X), but this factor depends a lot on the habits of the population concerned (the value of 1.5 g/l of TDS, which is equivalent to around 2 000 $\mu\text{S/cm}$, is the drinking-water standard in France). Conductivity is measured in micro-siemens per centimetre ($\mu\text{S/cm}$), and TDS in milligrams per litre. The relation between the two parameters is not linear.

Analysis should be done *in situ* with an electrical-conductivity meter.

WHO recommendation: <1000 mg/l (~1400 $\mu\text{S/cm}$).

3.3.5 DISSOLVED OXYGEN

Dissolved oxygen is affected by the presence of organic matter. Water absorbs oxygen to the point where partial pressure in air and water are in equilibrium. The solubility of oxygen in water depends on atmospheric pressure (and therefore on altitude), and on the temperature and mineralisation of the water: saturation with O_2 decreases as temperature and altitude increase.

This parameter is used essentially for surface water. At sea level, at 20 °C, the concentration of oxygen in equilibrium with atmospheric pressure is 8.8 mg/l of O_2 , or 100% saturation. Highly aerated water (e.g. in mountain streams) is generally supersaturated with oxygen, whereas water charged with organic matter degradable by micro-organisms is sub-saturated. A significant presence of organic matter in a water body, for example, allows micro-organisms to develop and consume the oxygen. Dissolved oxygen is therefore a useful parameter in the biological diagnosis of the aquatic environment.

Analyses should be done *in-situ*.

3.3.6 HARDNESS

Water hardness is created by dissolved calcium and magnesium, and is commonly expressed in mg/l CaCO_3 , or degrees of hardness.

$$1 \text{ French degree of hardness (TH)} = 10.3 \text{ mg/l } \text{CaCO}_3$$

Hardness is never a problem for human consumption, but high hardness may lead to encrustation of pipes, and low hardness (soft) waters may be corrosive.

AEP standard lower limit 15 TH (155 mg/l CaCO_3).

WHO recommendation: 100 to 300 mg/l.

3.3.7 TEMPERATURE

The variations in water temperature in an environment provide indications regarding the origin and flow of the water. Water temperature is usually linked with other parameters, especially conductivity and pH (Box 4.4).

Note. – Analysis should be done *in situ* with a thermometer.

Box 4.4

Groundwater temperature.

Temperature gradients

It is generally considered that the geothermal temperature gradient is 1 °C per 33 m. This means that the deeper the groundwater is, the hotter it is.

Generally, the following classification can be established:

- depth between 2 and 5 m: zone of daily temperature variation;
- depth between 15 and 40 m: zone of annual temperature variation;
- depth greater than 40 m: constant temperature zone.

Classification

Particular causes, such as volcanic or thermal effects, have a significant influence on water temperature. There are three types of water source, depending on the difference between the average annual temperature of water and air:

- $t_{\text{water}} > 4 \text{ °C}$ more than t_{air} – thermal source;
- $t_{\text{water}} = t_{\text{air}}$ – normal source;
- $t_{\text{water}} > 4 \text{ °C}$ less than t_{air} – hypothermal source.

3.3.8 TURBIDITY

Turbidity characterises a cloudy condition in water caused by particles in suspension (organic residues, clays, microscopic organisms etc.). Problems for users caused by turbidity are related to acceptance. High turbidity allows micro-organisms to become fixed (adsorption) to particles in suspension: the bacteriological quality of turbid water is therefore suspect as strong turbidity can also protect micro-organisms fixed on particles from disinfection.

Turbidity is a major constraint for chlorination, as pathogens associated with particles are protected from oxidation. Another concern is the formation of organochlorides that are toxic. Sphere recommends turbidity below 5 NTU to enable effective chlorination.

Analysis to be done *in situ* (recommended) with a turbidity meter:

Units: 1 NTU (Nephelometric turbidity unit) = 1 JTU (Jackson TU) = 1 FTU (Formazin TU).

WHO recommendation: <5 NTU and <0.1 NTU for effective disinfection.

3.4 Major ions

The mineral content of most kinds of water is dominated by several elements, commonly called major ions. These elements are in general not linked to public health problems (except nitrate, see Table 4.IV). Values from the French standards (AEP) are provided here, as most of the major ions are not covered by WHO guidelines.

Cations (positive charge): calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), and potassium (K^+), iron (Fe^{2+} , Fe^{3+}), manganese (Mn^{2+}), ammonium (NH_4^+)

Anions (negative charge): chloride (Cl^-), sulphate (SO_4^{2-}), nitrate (NO_3^-), nitrite (NO_2^-), phosphate (PO_4^{3-})

3.4.1 CALCIUM AND MAGNESIUM

Calcium Ca^{2+} and magnesium Mg^{2+} are present in crystalline and sedimentary rocks (calcite (CaCO_3), dolomite (CaMgCO_3), magnesite (MgCO_3), gypsum (CaSO_4), apatite ($\text{Ca}_5(\text{PO}_4)_3$) and fluorite (CaF_2) plus sandstone and detrital rocks with carbonated cement): they are very soluble substances, present in most types of water. Their concentration and the Ca/Mg ratio provide information about the origin of the water and the nature of the reservoir. The calcium ion is sensitive to base-exchange phenomena. Total hardness is the concentration of Ca^{2+} and Mg^{2+} . Carbonated hardness is the concentration of bicarbonate/carbonate (HCO_3^- , CO_3^{2-}).

Due to its laxative effect, the French AEP standard upper limit for Mg is 50 mg/l. No AEP standard exists for Ca.

3.4.2 CHLORIDES

The Cl^- ion is present in small quantities on Earth. The main source of chloride in water is solution of sedimentary rocks deposited in a marine environment, which have not been completely leached, and evaporites. Ingress of seawater (where Cl^- is present in great quantities) and evaporation phenomena in endoreic basins are also possible sources of chlorides (the smaller the distance from the sea, the more significant the contribution made by precipitation). Human contributions (e.g. from urine) are minor.

AEP standard upper limit is 200 mg/l.

WHO recommendation (taste): <250 mg/l.

3.4.3 IRON

The presence of iron in groundwater has several origins: in the form of pyrites (FeS_2), it is usually associated with sedimentary rocks deposited in a reducing environment (marls, clays) and metamorphic rocks. It is usually found in strong concentrations in the water of weathered bedrock. The following concentrations in groundwater are reported by ACF:

- sedimentary (Cambodia, 1998): 3–15 mg/l;
- bedrock (Uganda, 1996): 0.5–1.5 mg/l.

When present in reduced (ferrous) form (Fe^{2+} or Fe(II)), iron is oxidised by atmospheric oxygen and precipitates in oxidised (ferric) form (Fe^{3+} or Fe(III)) when water is pumped. This produces rust stains on the slabs of boreholes or wells, and users may not find the water acceptable, because it stains laundry and has a pronounced taste when consumed directly or in hot drinks.

Treatment to remove iron involves aeration of the water in order to oxidise the dissolved Fe^{2+} to Fe^{3+} , which then precipitates and can be removed by filtration.

AEP standard upper limit is 0.2 mg/l Fe (in-situ analysis is recommended).

WHO recommendation: <0.3 mg/l.

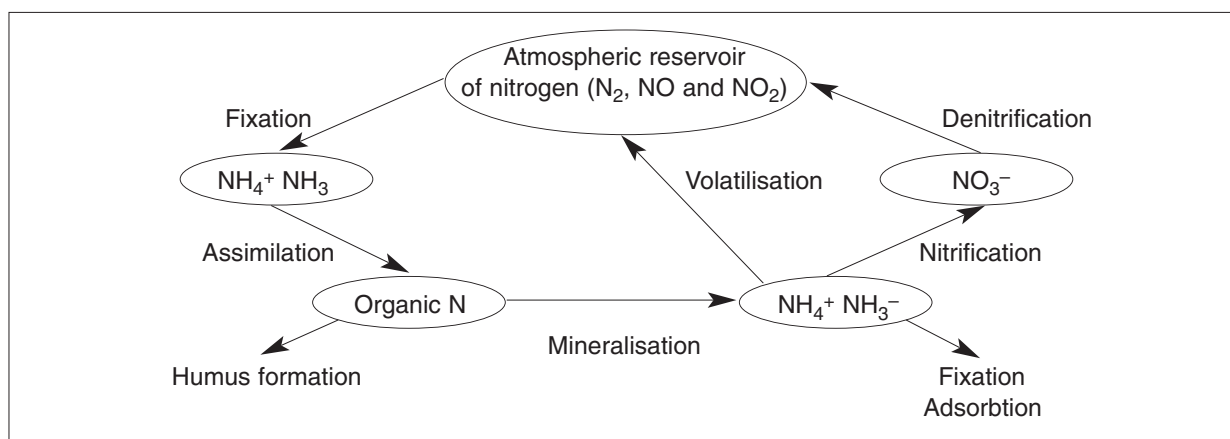


Figure 4.5: The nitrogen cycle.

3.4.4 NITRATES AND NITROGEN COMPOUNDS

Nitrates (NO₃⁻) are part of the nitrogen cycle. The main nitrogen reservoir is the atmosphere. In natural water, nitrogen comes essentially from rain (1-3 mg/l) and from soil drainage.

Micro-organisms decompose organic matter present in the soil, and the mineral nitrogen thus produced is then transformed into nitrates by aerobic bacteria. This transformation, called nitrification, has two stages: nitrification, which produces nitrites (NO₂⁻), and nitratation, which transforms the nitrites into nitrates (NO₃⁻). If the conditions of the environment permit it, the nitrates are used as a source of energy by anaerobic bacteria, and transformed into gaseous nitrogen. Nitrates can also be adsorbed and become fixed on clays and humus.

The content of nitrates in soil, and later in water, is strongly linked to the quantity of organic matter and to environmental conditions. Contributions from human activities (use of nitrate fertilisers and manure) are therefore significant. Also, waste from sewage-treatment plants, latrines and septic tanks contribute organic matter capable of producing nitrates.

Nitrates and nitrites are considered dangerous to health. Nitrates ingested with water are reduced to nitrites in the intestines and become fixed to haemoglobin, thus decreasing oxygen transfer: this is known as methaemoglobinaemia, which affects children in particular (especially under 6 months).

The scale of nitrate concentration in water is very wide. Groundwater, with an environment that facilitates denitrification, can be nitrate free, whereas water 'polluted' by a significant contribution of organic matter, fertilisers or residual water may contain up to several hundreds of mg NO₃ /litre.

AEP standard upper limits are 50mg/l for NO₃⁻ and 0.1 mg/l for NO₂⁻.

WHO guidelines (health related) are 50 mg/l (nitrate) and 3mg/l (nitrite).

3.4.5 PHOSPHATE

The main sources of phosphates are rock-leaching (carbonated contexts), faecal contamination, domestic pollution (detergents) and agricultural pollution. They are not toxic, but may lead to acceptance problems (taste and colour). They may also participate in germ proliferation (providing a nutrient salt) and are essentially useful as an indication of faecal contamination.

AEP standard upper limit is 5 mg/l of P₂O₅.

3.4.6 SODIUM AND POTASSIUM

Sodium (Na⁺) is very abundant on Earth and occurs in crystalline and sedimentary rocks (sands, clays, evaporites). Halite, or rock-salt, is common salt (NaCl), highly soluble in water. In

Table 4.XI: Scale of sodium and potassium concentration.

Context	Na ⁺ (mg/l)	K ⁺ (mg/l)
Groundwater in calcareous formations	1 < C < 4	0.3 < C < 3
Groundwater in crystalline formations	2 < C < 15	1 < C < 5
Seawater	C > 10 000	380

contrast, sodium does not normally occur in carbonated rocks (Table 4.XI). Clays can be saturated in Na⁺ by the process of base exchange.

Potassium (K⁺) is quite abundant on Earth but not in water. It is easily adsorbed and recombined in the soil (particularly in clays). Its origin is crystalline rocks (but in minerals less susceptible to weathering than those that contain sodium), evaporites (sylvinite) and clays (Table 4.XI).

AEP standards for sodium and potassium are 150 mg/l Na and 12 mg/l K.

WHO recommendation: <200 mg/l Na.

3.4.7 SULPHATE AND HYDROGEN SULPHIDE

The natural origins of sulphate are rainwater and solutions of sedimentary evaporitic rocks, particularly gypsum (CaSO₄), but also pyrites (FeS₂) and, more rarely, igneous rocks (galenite, blende, pyrite). Human origins are mainly the use of chemical fertilisers and detergents. In general, the presence of sulphate in non-polluted natural water indicates the presence of gypsum or pyrites. In anaerobic conditions, sulphate is transformed by bacteria into hydrogen sulphide that is toxic and corrosive. Presence of sulphur in waters may lead to acceptance problems. Hydrogen sulphide (H₂S) is a gas recognisable by its rotten egg smell at low concentrations. In higher doses, it becomes odourless and very dangerous if inhaled, causing frequent fatal accidents among sewer workers and possible problems in wells (Laos, ACF 1996) when gypsum is present.

AEP standard upper limit is 250 mg/l SO₄.

WHO recommendation: <250 mg/l for SO₄.

3.5 Trace-elements and toxic minerals

3.5.1 ARSENIC

Natural arsenic is mainly found in recent sedimentary contexts associated with large deltas (Burkina Faso, Cambodia, India, Bangladesh, Nepal, Vietnam, Zimbabwe). Other sources of arsenic are insecticides and chemical industries. Arsenic is a cumulative poison (causing skin cancers, liver cancers, leukaemia). It exists in water as the reduced As(III) form, which is free and toxic, or the oxidised As(V) form, which is less soluble and not toxic.

The presence of As is mainly in groundwaters: in the Cambodian Mekong alluvial basin, the highest concentrations in the aquifer are between 20 and 70m of depth: the upper layers of the aquifers present less free arsenic (oxidation), as well as the deep layers (precipitation). This vertical variability depends on both geological and hydrological conditions, but must be checked to find alternative water resources for long-term projects.

Arsenic concentrations may vary with seasonal events (floods, dry season) and also presents a huge geographical variability (in the same village, some boreholes may be contaminated and others not). The diseases caused by arsenic are generally linked to 10 to 15 years of water consumption.

WHO guideline value is 0.01 mg/l maximum (some national standards may differ a lot, e.g. Cambodia: 0.05 mg/l). In-situ analysis is recommended.

3.5.2 CHLORINE

Chlorine is a water-disinfection product. Laboratory tests show that chlorine ingestion corresponding to a concentration of 5 mg/l over 2 years does not cause health problems; above this threshold, there is no evidence as yet but WHO proposes a health-related guideline. Chlorine taste threshold: 0.3-0.6 mg/l; odour threshold: 2 mg/l.

WHO guideline value: 5 mg/l.

3.5.3 FLUORIDE

The main sources of fluoride in groundwater are sedimentary rocks (for example, fluoroapatite from phosphate basins), but also igneous rocks (granites) and veins. Thermal areas are also frequently involved. Rock-groundwater contact time and chemical interactions determine the concentration of free F^- . Even though these concentrations are extremely variable, they can reach 5 to 8 mg/l in sedimentary basins (Senegal, Travi).

Fluoride is recognised as an essential element for the prevention of tooth decay (fluoride toothpaste). However, regular ingestion of water with a fluoride concentration greater than 1.5mg/l can cause problems such as bone and dental fluorosis (brown colouring of the teeth which can lead to their loss): children are particularly vulnerable to this problem.

WHO guideline value is 1.5 mg/l maximum of fluoride (F^-).

3.5.4 LEAD

Lead is frequent in rocks (galena) and in the chemical industry (explosives), and is a cumulative poison, causing neuropsychological disorders and cardio-vascular diseases. It can be measured with a colorimeter.

The WHO guideline value is 0.01mg/l maximum. In-situ analysis is recommended.

3.5.5 MANGANESE

Manganese in groundwater has mainly natural (pyrite) or agricultural (soil-texture improvers) origins. Presence in drinking water may create acceptance problems (dark-coloured water and taste). Above 0.1 mg/l, manganese causes staining problems (as does iron), and a black deposit can be formed in water pipes. Certain organisms concentrate manganese, which leads to turbidity and taste problems.

AEP standard upper limit is 0.05 mg/l Mn. In-situ analyses are recommended.

WHO guideline 2003 (health): 0.4 mg/l.

3.5.6 OTHER ELEMENTS

Other elements, like cadmium, selenium, bromine etc. may present a serious risk for human health. They are extremely time-consuming and expensive to measure and are only exceptionally tested for in most situations where ACF works.

3.6 Biological indices

Some relevant information that is not picked up by chemical analyses can be picked up by using biological indices that characterise an aquatic environment according to the organisms found.

Each living organism has some particular environmental requirement. Aquatic environments are thus colonised by animal and plant populations with structures corresponding to a certain balance.

If the environment is disrupted, a modification of the structure of those populations can be observed.

- Vertebrates (frogs and toads) prefer cleaner water and cannot survive in water depleted of oxygen.
- Massive fish death indicates severe depletion of oxygen (heavy organic load) or toxic pollution.
- A large number of plants and algae (often of a murky green colour) indicates a high nutrient level in water: pollutants such as fertilisers, sewage, industrial wastes.
- Water looking like ‘pea soup’ (light green, murky) contains blue-green algae that secrete substances that make water unfit for drinking.
- The presence of sewage fungus indicates heavy organic pollution.

4 Water analysis

Properly-conducted water analysis involves three stages: sampling, analysis and presentation of results/interpretation.

4.1 Sampling

4.1.1 METHODOLOGY

Sampling is vital, because it affects the significance of the analysis. Strict procedures should be used, that provide representative samples of what is being analysed. The protocol for sampling will depend on the type of analysis. See Section 4.1.1 and Annex 7C for more details.

4.1.2 CONTAINER MATERIALS

Polyethylene is recommended for all kinds of sampling. Although it is relatively porous to gases, and glass may be preferred for sampling and preservation of highly gaseous water, it is less fragile than glass, and gas diffusion is slow.

Polyvinyl chloride, which is used to make sterile disposable sampling bags, has the disadvantage of liberating chlorine if the bags are exposed to light for too long. Sterile bags are fragile and must be protected during transport of samples.

Glass containers are suitable for most determinations. Brown bottles should be used as they reduce photosensitive reactions.

4.1.3 MODIFICATIONS AND PRESERVATION OF THE SAMPLES

The fact of taking a water sample and removing it from its natural environment inevitably modifies it, to a greater or lesser extent, depending on the parameters of concern. Some of them can be considered stable over the timescale in which we work, but others change very quickly (e.g. oxidation processes, chemical changes): temperature, conductivity, pH, dissolved gas, nitrates, sulphates, arsenic and toxic minerals change quickly.

A variation in temperature causes a modification in the equilibrium constants of elements in solution. In order to establish new equilibria at the new temperature, several chemical reactions occur, which may cause the precipitation of salts, favour solution of gas etc. Nonetheless, a low temperature (around 4°C) slows reactions down sufficiently.

Contact with the air and decompression can also be responsible for changes in solution.

Each type of ion contributes to the total conductivity of a solution, and any modification of the chemical equilibria, and therefore of the relative proportions of the dissolved elements, causes a change in conductivity. The higher the temperature of the water, the more dissolved CO₂ tends to

Table 4.XII: Sample preservation.

Determination	Sample Container	Preservative	Filtration required?	Max. time before analysis
Acidity or alkalinity	Plastic or Glass	None	Yes	14 days
BOD	Plastic or Glass	None	No	6 hours
Chloride	Glass	None	Yes	28 days
Chlorine (residual)	Plastic or Glass	None	No	<i>In situ</i>
Conductivity, pH	Glass	None	No	28 days / <i>in situ</i>
Fluoride	Plastic	None	Yes	28 days
Hardness	Glass	HNO ₃ to pH <2	Yes	6 months
Metals, trace-elements	Plastic	HNO ₃ to pH <2	Yes	6 months
Ammonia nitrogen	Glass	H ₂ SO ₄ to pH <2	Yes	28 days
Nitrate & nitrite nitrogen	Glass	H ₂ SO ₄ to pH <2	Yes	28 days
Nitrate & nitrite nitrogen	Glass	None	Yes	48 hours
Phosphate, sulphate	Glass	None	Yes	28 days
Sulphide	Glass	None	Yes	7 days

escape. A loss of CO₂ provokes precipitation of carbonate, which modifies the pH. Nitrates and sulphates can be reduced by bacterial activity after the sampling stage.

In adverse conditions, changes can occur in just a few hours. Preservatives prevent these changes, but are sometimes not practical logistically in the field (e.g. concentrated acid). Table 4.XII lists the sample containers and preservatives to be used for the main parameters to be determined.

As a general rule, it is best to analyse the samples as soon as possible after collection. Specific recommendations for field situations are given in Section 4.1.4.

4.1.4 SPECIFIC RECOMMENDATIONS

4.1.4.1 Samples for bacteriological analysis and BOD

Samples for bacteriological analyses and BOD must always be taken and preserved in a sterile container. The use of sterile disposable bags is advisable. Biological analyses are carried out 6 hours maximum after taking the samples if they are kept cool (4°C), or within 1 hour if kept at room temperature, in the dark. Even if it is possible to conduct biological analysis on site (e.g. with a DelAgua kit), the use of a mini-laboratory is strongly recommended.

Specific recommendations for sampling for bacteriological analysis are as follows:

- Use extremely clean containers for sampling (see Section 4.1.2), wash your hands with soap.
- Rinse the container several times with the water to be analysed:
 - for a pump, work the pump for enough time to renew and rinse the inlet and outlet pipes, and the pump body;
 - for a tap, clean the tap (with alcohol or soap), let the tap run fully for about 30 seconds, flame it with a pad soaked in alcohol, let it run again for 30 seconds.
- Always fill sample containers to the brim and stopper them so that no air is left above the sample, since it could favour the emission of some gas dissolved in the water, which would modify the chemical balance in the solution.
- Mark the bottle (or sterile bag).
- Systematically take three samples for bacteriological analysis (due to high variability in the results of this analysis).
- Record in a notebook.
- Keep the sample in cool box (4°C, 6 hours maximum before analysis).

4.1.4.2 Chemical parameters

Temperature, pH, conductivity, alkalinity, free residual chlorine and dissolved oxygen must be systematically measured *in situ*.

If complex preparation is required for transport of samples for carrying out certain chemical tests in a laboratory (for instance, for As, metals, toxic minerals and trace-elements), these tests should be done *in situ*, to avoid this complication.

The analysis must be carried out as soon as possible, not more than 72 h after taking the samples. If this is not possible, the samples must be prepared for preservation (Table 4.XII); the sample is passed through a 0.45 µm filter (the bacteriological analysis filtration system may be used), and then acidified until a pH close to 2 is obtained (see Table 4.XII). The samples can be kept for 3 months at room temperature or, even better, at around 4°C.

4.2 Methods of analysis

4.2.1 METHODS

4.2.1.1 Bacteriological analysis

Bacteriological analysis mainly involves determining the presence of *faecal coliforms*, as an indication of faecal contamination (see Section 3.2.2).

The method most commonly used in the field is filtration through a membrane and development of bacteria colonies in a favourable environment. It is relatively easy to carry out in the field and consists of:

- Filtering a known volume of water through a porous membrane, designed to retain bacteria (0.45 µm).
- Putting this membrane under conditions that allow the development of thermotolerant (faecal) coliforms but not other bacteria: 16-24 h incubation at 44°C in a favourable nutritional environment for thermotolerant coliforms multiplication. Incubation at 37°C is used for total coliforms identification.
- After 16-24 h, the colonies formed by the bacteria are visible to the naked eye, with a specific colour (Figure 4.6), and can be counted. The results are expressed in number of colonies per 100 ml of water sample.

The timing and temperature for incubation, as well as the colour developed by each type of bacteria colony, is closely linked to the type of culture medium, that can be more or less selective. Refer to the instructions provided with each product used. The characteristics of the most common culture media are presented in Table 4.XIII.

Table 4.XIII: Characteristics of common culture media used to detect coliforms by incubation.

Product	Resuscitation process	Incubation process	Detection	
			<i>E. coli</i>	Faecal coliforms
Lauryl sulphate broth	Room temperature 3 to 4 hours	44 °C +/- 0.5 °C 16–18 hours	Yellow	
Millipore MFC Broth	35 °C +/- 0.5 °C 4 hours	44.5 °C +/- 0.2 °C 14–16 hours	Blue	
Coliscan – MF Broth	Room temperature 20-30 min	35 °C +/- 0.5 °C 18-24 hours	Black	Blue-grey, red-pink, cream
Coliscan Easygel	Room temperature 20-30 min	35 °C +/- 0.5 °C 24 hours	Purple-black	Light blue, blue green, white

Figure 4.6: Example of a bacteriological analysis result.

Note. – Bacteriological analyses are commonly carried out in the field, but results are often highly variable and correct analysis requires sterile conditions. Therefore, three samples per site must be analysed.

Bacteriological testing equipment

The DelAgua kit (see Annex 7D) has become widespread as incubator for bacteriological analyses. ACF uses a modified DelAgua kit (with an integrated 220 V and 12 V supply instead of an internal battery).

The culture medium used is the ready-to-use Millipore MFC (membrane faecal coliform) broth, which develops a specific colour with faecal coliforms. ACF also uses disposable plastic sachets for sterile water sampling.

Many countries (including India and Pakistan) produce precise incubators (with temperature control and electronic alarm), with high capacity (about 100 petri dishes) and competitive prices.

Refrigerator and cool boxes

Essential for the conservation of both samples and culture media.

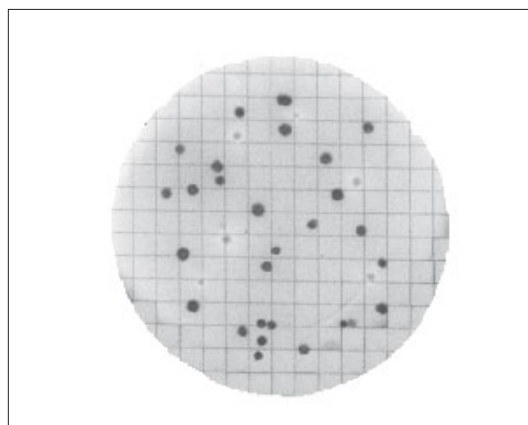
4.2.1.2 Chemical analysis

There are different analysis techniques for chemicals (see Table 4.XIV), each with its own purpose.

Colorimetric or visual interpretation techniques (e.g. pH strips) are not very accurate, but are appropriate for situations where speed and simplicity are more important than complete accuracy.

Table 4.XIV: On-site methods and materials for water analysis.

Parameter	Measurement by portable electrochemical probe	Photometry (spectrometry)	Titration or colorimetry
pH	X		
Conductivity	X		
Chlorides	X	X	X
Alkalinity			X
Phosphates	X	X	X
Sulphates		X	X
Nitrates/nitrites	nitrate		
Ammonia	X	X	X
Calcium	X	X	X
Magnesium	X	X	X
Sodium	X		
Potassium	X	X	X
Hardness		X	X
Iron		X	X
Manganese		X	X
Fluorides	X	X	
Silica		X	X
Aluminium			X
Chlorine			X
Hydrogen sulphide		X	X
Oxygen	X		
Oxidability			X



Analyses with specific electrochemical probes are simple, but the probes are fragile, have a limited life (≈ 1 year), and are expensive.

In order to obtain accurate results for major ions, it is advisable to contact a laboratory (or a university). This can also be done to verify analyses carried out with on-site equipment (validation of a specific health risk identified with a colorimeter or photometer, e.g. in the case of significant arsenic or fluoride presence).

Basic physical and chemical testing equipment

Pool tester, pocket kits: colorimetric method, where tablets are dissolved in the sample and the resulting colour read on a colour scale (major elements).

Electronic stick meters: small portable electronic equipment that gives a digital reading when the electrode is submerged. Needs regular calibration (pH, conductivity). This equipment is cheap, very easy to use and robust but its precision is generally limited.

Turbidity tube: the tube is filled, then water is poured out until the reference circle marked on the bottom of the tube appears.

Comparator with disks: tablets are dissolved in a small tube. The sample in the tube is viewed in the comparator against a graded colour on an interchangeable disk (pH).

Photometer: colorimetric method. Electronic instrument with a digital display. Tablets are dissolved in the sample and the concentration of the colour is read electronically. The instrument uses blank sample and calibration (F, As).

Note. – Field analysis equipment (pH meter, GPS) can be seen as dangerous equipment in specific contexts. Staff should adapt their behaviour and be careful in handling this material, especially in areas of conflict.

4.2.2 THE USE OF A MINI-LAB

A mini-lab can be a small room (3 m x 3 m) containing all the equipment required for chemical and bacteriological analyses. It can be attached to an existing facility in the case of long-term programmes. Its use is for all types of off-site analysis, and for safe keeping of chemical products, equipment and samples. It is especially useful for microbiological analyses, which require care and the cleanest environment practical. It contains:

- a refrigerator (for samples and culture media);
- a working surface, such as a white-topped bench or table, that is easy to disinfect with alcohol;

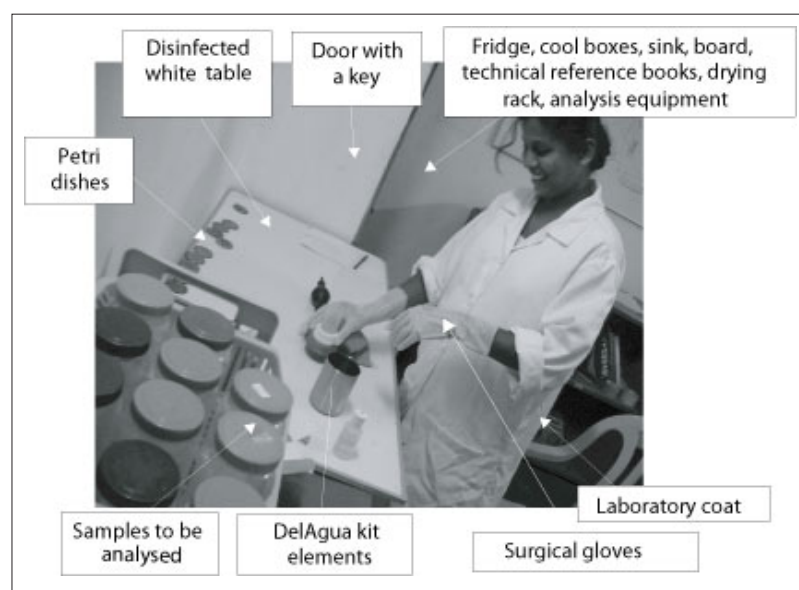


Figure 4.7: Mini lab for biological analysis (ACF, Sri Lanka, 2000).

- a sink and draining rack;
- all the necessary technical documentation;
- special medical / laboratory dishes;
- stove and saucepans for sterilisation.

The operator must always wear a laboratory coat and surgical gloves for microbiological analyses. They must remove their shoes and replace them with plastic sandals before entering the mini-lab. The mini-lab is regularly disinfected.

Note. – In some countries, it is not appropriate for a woman to work with a man in a closed room.

4.3 Presentation of results and interpretation

4.3.1 PRESENTATION OF RESULTS

It is essential to record and keep the results of the analysis (mainly if a sanitary risk is identified). Normally, one sheet per site analysed is recommended (see Annex 7E). The information to be reported includes:

- general location (plus GPS data);
- date of sampling / analysis;
- type of site (river, borehole, well, reservoir);
- the person in charge of sampling / analysis;
- the full analysis table;
- comments on the quality of the water and the site.

The full analysis table contains three columns (three samples are taken at each site, systematically for bacteriological analyses, ideally for other elements as well). Each result is given with the mean of the three samples, the maximum value and the standard deviation observed. If the three

Table 4.XV: Water analysis modalities and their interpretation.

Purpose of the analysis (programme steps)	1) Regional study of quality of the water resource (feasibility study)	2) Analysis of water quality at the water point (validation)
Location	Region / village	Water point (spring, borehole, well or distribution network)
Timing	During selection of the programme area	During work and after completion of technical work, before handing over
Parameters to be checked	Chemical parameters, toxic minerals, physicochemical characteristics (conductivity, pH etc.) Parallel study on morbidity data must be done	Chemical (toxic minerals) and physicochemical characteristics, microbiological quality
Reporting	Mapping (GPS)	Chemical profile included in contractual handover documents
Body responsible	Implementing agency	Implementing
Interpretation		
Implications for the programme	Validation of the water resource selection; if not: – Choice and design of water treatment – Selection of an alternative type of resource – Application of the precaution principle	Validation of the water point; if not: – Choice and design of water treatment – Abandoning the source & finding another area or kind of water source

samples do not give reasonably homogeneous results, the whole analysis (including sampling) has to be done again, because the variation is probably due to non-representative sampling or a mistake during analysis. A good practice is to register and keep the filtration membranes in a file (in the case of bacteriological analysis), to come back if needed to check suspicious results.

4.3.2 REPRESENTATIVENESS

The analysis is done on water sampled at a specific moment, in a specific place and according to a specific methodology. The question is “How representative is the sample of the source or the water point to be analysed?”. It is important to define clearly what the analysis means and what are the factors that can affect representativeness.

Spatial or temporal variability of chemicals, for instance, can indicate an absence of mineral toxic risks during the dry season; however, during the rainy season, leaching can cause the spread of chemicals. Poor sampling can also reduce the real representativeness of an analysis. See Box 4.5 for two examples of specific representativeness of water analysis.

4.3.3 INTERPRETATION

The interpretation of water-quality analysis can also be questioned in a larger sense; What are we analysing? Why? When and with which frequency? What is the general purpose of the analysis? What are the standards chosen to characterise the water quality? Are the water-quality standards selected for the programme realistic in comparison with the water consumed by the population as a whole? etc.

All these questions show that a water analysis is not representative in itself, but rather it must be read with a critical sense and properly used. An overview of water-analysis interpretation is suggested in Table 4.XV.

3) Monitoring of water quality at the water-delivery point	4) Monitoring of water quality between collection and household
At the point of delivery of water to the house	In recipients used for water transport, storage and consumption
On a regular basis after handing over	On a regular basis, after being sure that people use the water point/delivery system
Microbiological water quality Technical and sanitary inspection of the water point must be done in parallel	Microbiological water quality Hygiene inspection of the recipient used for water transport, storage and consumption must be done in parallel
Water analysis standard format Sanitary inspection form	Water analysis standard format Sanitary inspection form
agency, water-point committee, government institutions, local NGOs, private companies	
Comparison with relevant standards (adapted to context)	
Validation of correct functioning; if not: – Repair of water-supply equipment – Definition (or adjustment) of treatment process (temporary or permanent) – Restructuring of the water point committee – Redefinition of maintenance activities	Validation of the hygiene practices; if not: – Design of a specific hygiene-promotion programme – Hygien kits distribution

Box 4.5

Examples of specific representativeness.

Wells and boreholes

An analysis of water that has been stagnant for a long time is not representative of the aquifer, but of the well, at a specific time: the water may also have been affected by casing or pipe material constituents (metal) and exterior elements (pollution, rain etc.). To obtain an average sample of the horizon involved, it is advisable to pump for long enough to renew the water contained in the pipes or tanks. If the work covers several aquifer horizons, the sample will be a mixture of water from different levels, with proportions directly linked to the transmissivity of different levels. To obtain point samples at various depths, it is possible to use ballasted containers, provided with a closing system operated from the surface. To limit water mixing while taking the sample, it is advisable to use sample collectors with a diameter much smaller than that of the borehole, and also to operate them very slowly. Lowering sample collectors in the open position allows them to be rinsed as they go down.

Surface water

Samples are taken avoiding boundary effects (e.g. for a river, oxygenation near the surface, suspension of solid matter near the bottom, stagnant water near the banks etc.) as much as possible. It may be necessary to make up an 'average' sample by mixing several samples taken in different sections of a stream, to obtain a better understanding of the average chemistry of the water in a given section. Surface waters are often subject to extreme spatial and temporal variability.

Water-analysis interpretation (selection of parameters and standards) will depend mostly on the context. Section 1.2 explains how water quality is considered in emergency or long term projects. It will also depend on the implementation phase of the project (see Section 1.2. and Table 4.XV).

Faecal contamination indicates a risk of water contamination by pathogens (see Section 2.3.1: low risk, significant risk, high risk). But the interpretation does not concern only the sanitary risk: it can also be used to identify technical problems in a water-supply system.

- *Open wells*: faecal contamination can be linked to the use of a dirty bucket or rope. Regular disinfection and hygiene promotion can reduce the risk of contamination.

- *Boreholes or wells equipped with pumps*: faecal contamination is totally unacceptable even if the contamination is low and doesn't present a significant sanitary risk. This contamination often indicates a failure in the installation that allows the contamination of the source by infiltration (e.g. incorrect sealing of headworks), or groundwater contamination (e.g. from a nearby latrine). In such cases, rehabilitation of the installation must be done, or the source of contamination must be removed.

- *Distribution networks*: faecal contamination indicates a technical failure in the system: the pipelines (e.g. buried pipes are cracked or corroded, allowing contaminated water to enter), the treatment plant or the intake (contamination of the source). In all such cases, the system must be inspected in order to identify the source of contamination.