World Health Organization

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Rapid Assessment of Drinking Water Quality

A handbook for implementation

Contents

1.0 Introduction

The provision of water was one of the eight components of primary health care identified by the World Health Assembly in Alma Ata in 1978. The Alma Ata Declaration on Primary Health Care expanded the concept of health care to include broader concepts of affordability, accessibility, self-reliance, inter-sectoral collaboration, community participation, sustainability and social justice.

The importance of water supply continues to be emphasised as critical to reducing poverty and improving the health and well-being of the World's children and adults. The global community has committed itself to halving the proportion of the world's population who are unable to reach or to afford safe drinking water by 2015. Although great strides have been made in meeting this challenge in terms of provision of services, the safety of many water supplies remains unknown and uncertain. The recent Global Water Supply and Sanitation Assessment 2000 Report provided statistics regarding access to technologies that were either 'improved' or 'unimproved'. This was done on the assumption that some technologies were likely to be better for health, although it was recognised that would not always be the case. However, there was no information provided on water quality within the assessment.

The inclusion of information regarding water quality in future assessments of the degree of access to water supplies is desirable. This handbook is designed to help in the implementation of rapid assessments of water quality to improve the knowledge and understanding of the level of safety of water supplies. There is significant value in reporting of independently verifiable water quality data to support national Governments and the international community in measuring progress in achieving the international development targets. Such data provides useful information regarding current conditions, deriving the likely public health burden related to inadequate water supply and to gain an understanding of the extent of major water quality problems in developing countries. These data would, therefore, provide an indication of future investment priorities and needs on a country, regional and global basis.

1.2 Rapid assessments

Rapid assessments of water quality provide useful baseline information regarding water safety. By using a variety of different techniques and by undertaking appropriate data analysis it is also possible to predict likely future water quality trends and challenges. An important aspect is therefore to ensure that the results obtained are statistically representative of the water supplies in the country.

This handbook describes how such rapid assessments can be performed and data analysed. It provides details on how surveys can be designed and reviews the parameters of interest, describes how these may be analysed and how water supplies can be inspected. It also provides information regarding the analysis and reporting of data. In Annex 1 of this handbook are a set of forms that can be used for data collection and recording. In addition to this handbook, field staff implementing the rapid assessment will have a copy of a 'Practical guide to water quality surveillance' to help them when undertaking the fieldwork (see bibliography).

The resources and capacity in different countries to undertake such rapid assessments varies enormously. This handbook provides a set of core parameters that should be included in all assessments, but in recognising that some countries may wish to undertake more extensive assessments, three levels of assessment of increasing sophistication are outlined to allow flexibility in the approach. This are summarised in Table 1.1 below. In terms of the support from WHO and UNICEF, however, it should be stressed that support will only be available for level 1 assessments.

The rapid assessment team should be headed by a senior member of staff from the Ministry of Health, Ministry of Water or Ministry of Environment. This person will take overall responsibility for the management and co-ordination of the programme and for submitting the final report on the assessment. The co-ordinator should, preferably, report to an inter-sectoral group of stakeholders from within the country.

1.3 Parameter selection

The selection of parameters included in a programme of water quality analysis is likely to be country (and possibly region) specific and may also be specific to certain types of water. Furthermore, the range of analysis and frequency of testing will be constrained by the resources available for water quality analysis and, whilst it may be desirable that a great number of parameters are analysed frequently, budget limitations may constrain how much testing and which parameters are analysed. However, there are some basic rules that should guide the development of water quality analysis programmes.

The first step in deciding whether a particular parameter should be included in the assessment programme is to make a judgement on the following four critical questions.

1. Is the parameter known to be present in the waters of the country?
2. If present, at what levels does it exist and do these approach or reach levels which are of concern?
3. What is the extent of the presence of the parameters?
4. Are there any activities in catchment areas that may cause the parameter to be present in water or for levels to increase?

In terms of priority the parameters to be included in water quality assessment and monitoring programmes can be summarised as follows:

1. Microbiological quality and those parameters that control microbiological quality (disinfectant residuals, pH and turbidity);
2. Parameters which cause rejection of water by consumers (these include turbidity, taste, colour and odour of water);
3. Chemicals of known health risk.

There is a tendency in some countries to place undue emphasis on parameters that are of limited or unproven risk to health and for which analysis is expensive and complicated. This may lead to reduced effectiveness of monitoring of key parameters, notably those relating to microbiological quality, and can be counter-productive in terms of reducing the risk to health. Very often such approaches are primarily driven by the demands of the rich to the detriment of the poor. The selection of parameters for inclusion in these assessments is based on the prioritising those that will have greatest impact on the health of all the population and to which the poor may be particularly vulnerable.

1.4 Link to monitoring programmes

Although the rapid assessments will provide good indications of water quality, there remains a need to develop and implement effective ongoing routine monitoring programmes. The value of such data in assessing water safety and in planning and prioritising interventions is profound. The survey methodology outlined in this text will also be appropriate to some such programmes, although other approaches also exist. It is strongly recommended that Co-ordinators of the assessment consult the 2nd edition of the WHO 'Guidelines for Drinking Water Quality Volume 3' and 'Urban Water Supply Surveillance: A reference manual' for more details (see bibliography).

Level of assessment	**Microbiological and related**	**Inspections and risk assessments**	**Physical and chemical**
Level 1	Thermotolerant coliforms Faecal streptococci Turbidity pH Chlorine residuals	Sanitary inspection Pollution risk assessments Brief interviews at treatment works	Colour (appearance) Conductivity Nitrate Iron Arsenic Fluoride Copper or Chromium or Manganese
Level 2	Thermotolerant coliforms Faecal streptococci Turbidity pH Chlorine residuals Bacteriophages	Sanitary inspection Pollution risk assessments Audit of treatment work records Catchment assessment Basic hydrogeological assessment	Colour (appearance) Conductivity Nitrate Iron Arsenic Fluoride Cyanide Metals (aluminium, cadmium, chromium, copper, lead, manganese, mercury) Ammonia Selenium
Level 3:	Thermotolerant coliforms Faecal streptococci Turbidity pH Chlorine residuals Bacteriophages Clostridia perfringens Pathogen assessments Cyanobacteria	Sanitary inspection Pollution risk assessments Audit of treatment work records Catchment assessment/EIA Full hydrogeological assessment Hazard analysis Microbial risk assessment	Colour (appearance) Odour Conductivity Nitrate Iron Arsenic Fluoride Cyanide Metals (aluminium, cadmium, chromium, copper, lead, manganese, mercury) Ammonia Selenium Other inorganics Organics (including pesticides and disinfectant by-products) Alkalinity Corrosivity

Table 1.1: Levels of Assessment

The process to be followed in undertaking a rapid assessment of water quality is summarised in figure 1.1 below. A national co-ordinator should be appointed to lead the overall process and the team should include one or more statisticians to aid in the survey design and data analysis.

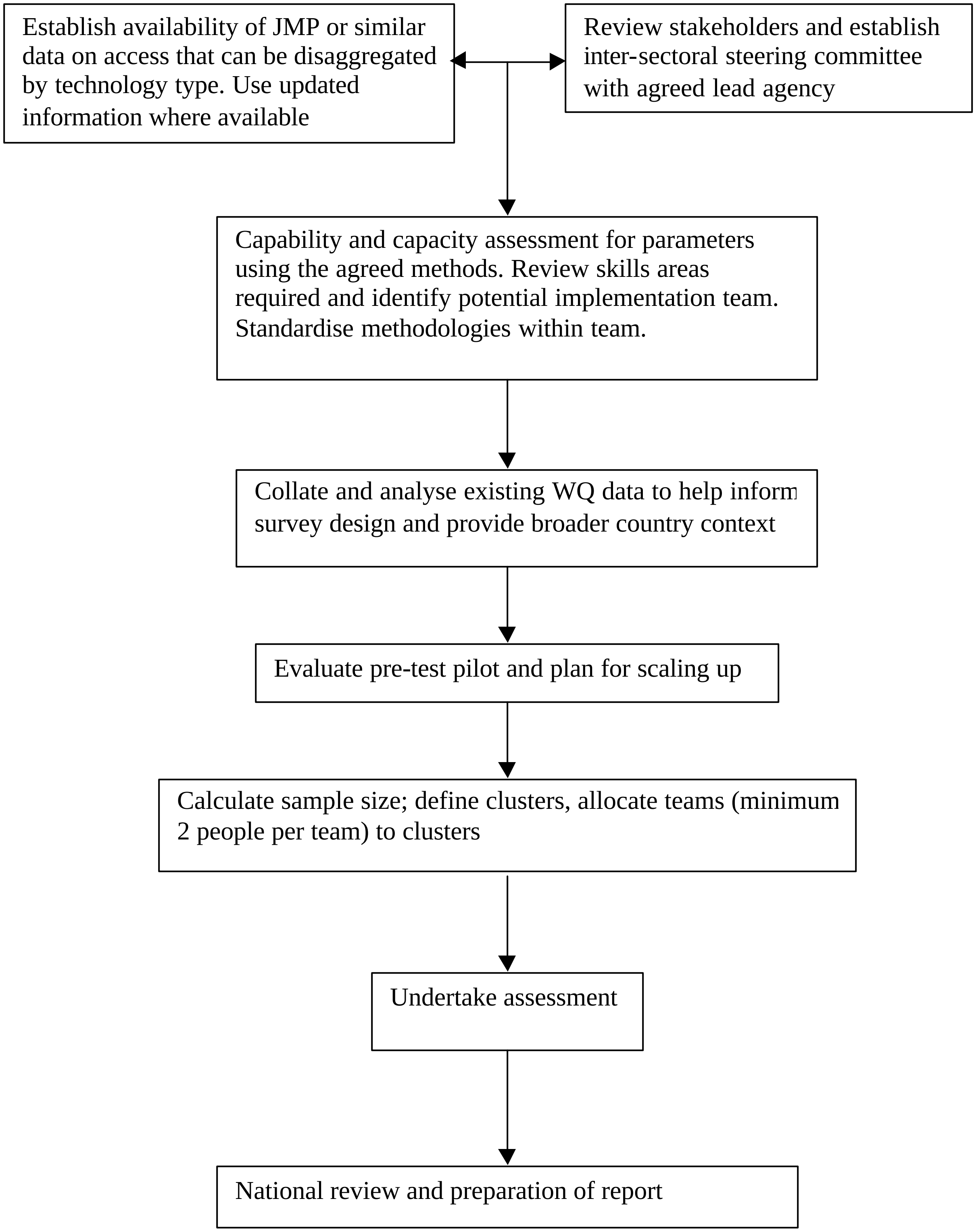

Figure 1.1: Steps in rapid assessments of water quality

2.0 Water and health

Water has a profound effect on human health both as a means to reduce disease and as a media through which disease-causing agents may be transmitted. The impact of water on health derives principally from the consumption of water containing pathogenic organisms or toxic chemicals and the use of inadequate volumes of water that lead to poor personal and domestic hygiene.

The risk of acquiring a waterborne infection increases with the level of contamination by pathogenic micro-organisms. However, the relationship is not simple and depends on factors such as infectious dose and host susceptibility. Drinking-water is only one way for the transmission of such pathogens, some agents may be transmitted from person to person, or through the contamination of food. In many cases, poor personal hygiene may lead to the transmission of pathogenic organisms through contamination of water stored within the home or by preparation of food. Poor hygiene practices often result from the use of inadequate volumes of water and therefore water quantity is also important in controlling infectious diarrhoeal diseases. In general terms, it is better to provide larger volumes of reasonable quality water than to provide very limited quantities of excellent quality. Excreta disposal is also critical as a first barrier to disease transmission.

Therefore, the reduction of morbidity and mortality from infectious diarrhoeal diseases requires improvements in the quality and availability of water, excreta disposal and general personal and environmental hygiene. Different aspects of environmental health improvement may be critical in different circumstances and will be determined by the current health burden, economic development and availability of services, as well nutritional and immune-status.

Water quality control is critical in reducing the potential for explosive epidemics, as contaminated drinking water supply is one of the most effective methods for mass transmission of pathogens to a large population. However, water quality may not be more important than other aspects in controlling endemic disease. Equally important to improvement in health is to recognise that different interventions may yield the greatest impact in different communities and at different times within the same community but that water quality will always be important.

Links between chemical quality and health are also well-known. Naturally-occurring chemicals in water are seldom acutely dangerous to health, although nitrates in water may present a serious health risk to young infants (aged under 6 months). Other naturally-occurring chemicals such as fluorides and arsenic cause chronic health problems, when ingested over a long period. Certain chemicals, such as iron or manganese, which may be present in water, are likely to affect the acceptability of water for drinking, but have limited health significance. Such chemicals may affect the taste of water, and can cause staining of food (during cooking) and clothing (when washed), factors which may lead to consumers rejecting the water for one that does not have these properties but may actually be more hazardous to health.

It is important for human health generally that all water destined for potable use should be of good quality from the point of supply up to the point of consumption. Quality is normally assessed against both microbiological and chemical parameters, although the microbiological quality has been identified as the most important aspect from a public health perspective. Water from some sources is of very good quality and needs little treatment, other water (primarily surface water) may be unsuitable for domestic use unless it first receives treatment to improve its quality. Water treatment is often impractical in rural areas, as it usually requires skilled supervision, and can be very expensive. It is therefore common to select sources that can be protected against contamination. Some water sources; springs, wells, boreholes and rainwater, should be free from microbiological pollution, providing that adequate precautions are taken to prevent the water from coming into contact with any potentially polluting material.

The majority of the world's population does not have access to continuously flowing water piped into their homes and must carry, transport and store water within their homes. In these situations, recontamination of drinking-water is often significant and is increasingly recognised as an important public health issue. Assessing the quality of water is therefore important within households as well as in sources and piped supplies.

Some water sources may be considered unsuitable by individuals or communities on the basis of personal or local preferences. The taste, odour and appearance of water must normally all be considered good for water to be acceptable for local consumption. Perceptions about water quality, based on visual examination, taste and odour, are often unreliable. Waters that look or smell unpleasant may be safe to drink, and clear odourless waters may contain chemicals or bacteria that are harmful to human health. Objective techniques for assessment of water quality are therefore necessary. These may be performed using widely available analytical techniques and supported by a range of risk assessment tools. These are described further below.

3.0 Assessment survey design

This section deals with the survey design procedures to be followed when implementing the rapid assessments of water quality. This handbook does not discuss in detail the purposes of sampling and the range of possible approaches to survey design. The bibliography in Annex 4 includes references to appropriate texts on sampling and statistics, including the UNICEF Practical Handbook for Multiple-Indicator Cluster Surveys.

The survey design for the rapid water quality assessments uses a cluster sampling approach for the selection of the water supplies to be included in the assessment. Cluster sampling means that the water supplies selected for inclusion in the assessment are located geographically close to one another (in ‘clusters’). The purpose of cluster sampling is to ensure that representative sample of all water supply technology types is obtained but, rather than selecting individual water supplies, groups of water supplies are selected. Cluster sampling is used because this is the approach used in other major international data collection exercises on water, sanitation and health, such as the Multiple Indicator Cluster Surveys (MICs), which contribute to the UNICEF/WHO Joint Monitoring Programme for Water and Sanitation. Cluster sampling improves the efficiency of the assessment by making access to the water supplies easier and by reducing costs.

In cluster survey techniques, the study population is stratified into a number of small mutually exclusive groups (i.e. members of one group cannot be simultaneously a member of another group). Each group is referred to as a cluster (or stratum). When sampling, a selection of clusters are selected rather than supplies from every cluster being selected (as would be the case in stratified sampling).

The key element of the survey design is to ensure that the selection of the water supplies to be included reflects their importance. The basic sampling unit is the water supply rather than the households that use them. The rapid assessments are primarily designed to assess the quality and sanitary condition of the water supplies. Some limited testing of the quality of water stored in households and matched to water sources included within the assessment will also be undertaken,.

In order to simplify the assessment procedure, the minimum population served by a water supply should be defined at the outset. Only water supplies with this minimum size of population or greater should be included in the assessment. The testing of very small water supplies (household or serving only a very few households) is expensive and their inclusion may not deliver a sufficient improvement in the quality of the data generated to justify the increased cost of the assessment.

The selection of a minimum community size depends in part on the distribution of settlement sizes in the country. A suggested range of minimum sizes is 200 to 1,000 people depending on the overall population size of the country. The figure of 200 reflects common design criteria for populations to be served by a point water source and 1000 may be appropriate for countries with very large populations, where community-management of water supplies extends to piped water supplies in larger villages and small towns. When establishing a minimum population, the figure selected and the reasons for this must be documented and the estimated proportion of settlements that will be excluded should be calculated. The

proportion of the population excluded from the assessment should kept as low as possible and should not exceed 5% of the national population.
The following sections outline the stages that will be followed in designing the survey and these are summarised in figure 3.1 below.

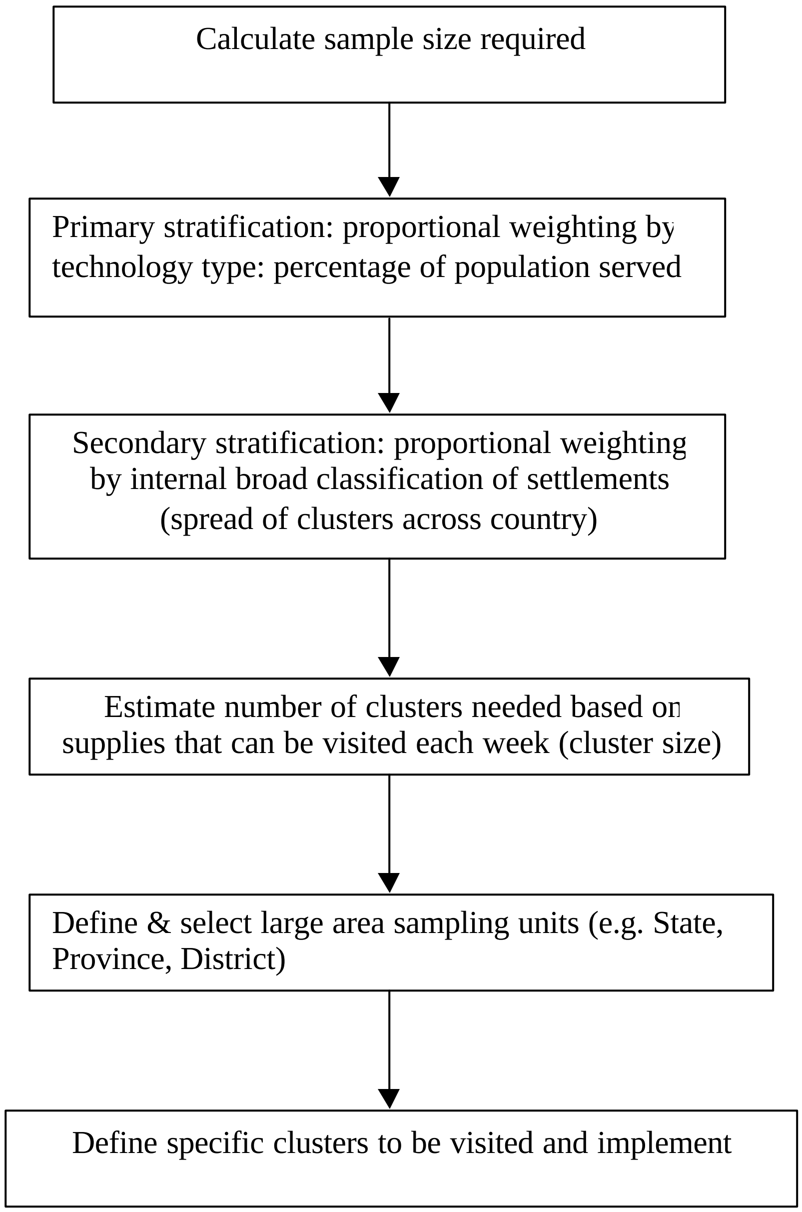

Figure 3.1: Overview of the survey design process

3.1 Defining a water supply

It is important at this stage to be clear what is meant by a water supply within the context of this assessment.

A water supply is a system of delivery of domestic water. A water supply may be a single borehole (tubewell) with handpump, protected spring or a piped water system. Water supplies of a similar nature (e.g. piped water supply) may be sub-divided in terms of their management. In these assessments, two major categories of piped water supply related to management are used as follows:

- Utility water supplies. These are piped water supplies that are managed by an organisation that is distinct from the broader community which it serves. Examples include Government Water Departments, Corporations or Utilities; Local Government (e.g. City, Municipality, Town or District Council); and, Private operators (of all sizes). This includes all small town supplies served by local Government, even where the population is relatively low.
- Community managed water supplies. These are supplies that are managed by the community which they serve. These include supplies with a Water User Association or Group managing the supply, but only where all members are drawn from the community served. If the Association has members drawn from outside the community, it represents a form of utility supply.

To avoid the danger of very large water supplies constituting a single water supply, which may be unrepresentative of its overall importance in the water supply sector, these are sub-divided into zones. For the rapid assessment, each zone is equivalent to a single water supply.

Zones are primarily defined on the basis of the sources of water, treatment work and service reservoirs (tanks) that supply different parts of the distribution system. Zoning the water supply ensures that at any point within the distribution system the analyst knows which source or treatment works the water came from and what major infrastructure it has passed through, all of which may have influenced quality. This information is essential when interpreting the results of water quality testing.

In common with many approaches to zoning, within the assessment the maximum population for an individual zone should be defined in order to prevent certain types of water supply (for instance large urban systems with ring mains) having very few zones and to ensure that sufficient urban piped ‘water supplies’ are included within the assessment. If a zone served by a service reservoir or water source contains more than the maximum number of people, it must be divided with each resulting zone treated as a water supply. The zone should be divided into two zones of equal population, not one zone equivalent to the maximum and then a very small zone.

It is recommended that the maximum population used in the zones should be set at 50,000 in line with practice in a number of countries. However, when designing the survey, it is important to review the maximum population in light of the number of utility supplies required. In some countries, a lower maximum population (for instance 20,000) may be more appropriate. If the maximum zone population size is changed from 50,000 then this should be documented and the rationale explained within the final report. This approach to zoning of piped water systems is summarised in table 3.1 below.

Supply characteristics	Zones based on system characteristics	Population criteria
Single source, single/no service reservoir (tank)	One zone	Max zone size 50,000 population
Single source, multiple (more than one) service reservoirs (tanks)	Area served by each service reservoir is one zone	Max zone size 50,000 population
More than one source with several service reservoirs (tanks)	Area served by each source and each service reservoir is one zone	Max zone size 50,000 population

Table 3.1: Distribution system zones as water supplies

3.2 Estimating a proportion for use in calculating the sample size

The first stage in calculating the sample size is to estimate the proportion (P) of the whole population under study (in this case water supplies) that will meet some pre-set criteria. This creates an obvious difficulty because the proportion is the attribute we are trying to find out in the survey.

In general (at least with larger data sets) the estimator of a proportion follows a normal distribution. If the normal distribution is considered, when the estimator is set at 0.5, this will maximise the likelihood of obtaining a sample that is representative of the central tendency of the data distribution. Therefore, if there is very limited data available on the proportion to be estimated, it is always safest to err towards 0.5. This also provides a conservative estimation of the required sample size (i.e. larger that required).

In many cluster surveys (e.g. MICS) the sample size is calculated for each variable under consideration and often the largest sample size calculated is used for the survey. In estimating the proportion it is important to define the criteria which the survey is attempting to measure. In the case of water quality assessments this will be certain levels of contamination in water supply. For microbiology, it is recommended that unless data show greater or lower levels of contamination that a target of presence of indicator bacteria in a 100ml sample be selected for utility supplies and indicator bacteria with more than 10 indicator bacteria in a 100ml sample be selected for community managed supplies. For chemical parameters, the criteria should be exceeding the WHO Guideline Value for the parameter.

For the rapid water quality assessment, the sample size needed for the microbiological quality is almost certainly likely to be the greatest as the likelihood is that most water supplies will (at least at some time) show contamination. Therefore, the sample size can be calculated solely for the microbiological quality, with some minor adjustments made for chemical contaminants.

In order to estimate the likely proportion of supplies showing contamination, two approaches can be adopted: an estimate based on expert judgement, or review of existing data as discussed in sections 3.2.2 and 3.2.3..

3.2.1 Bias and precision

A key aspect of survey design is to ensure that a representative sample from the population under study is taken. When estimating a proportion, therefore, it is important that the estimator is unbiased. Bias means that the estimator selected is skewed to one side or another of the distribution of the data (either higher or lower than the central tendency).

The precision of the estimator is a measure of its accuracy and is usually assessed by considering the variance of the estimator based on the normal distribution. The smaller the variance, the more precise or accurate the estimator.

In devising survey designs there is a trade-off between bias and precision. In general terms, controlling bias (or preventing biased surveys) is considered more important than precision and therefore bias is rarely compromised for precision. There is little value in being precisely wrong, but much value in being imprecisely correct!

3.2.2 Using expert judgement

In this approach, an informed guess must be made of the level of contamination. This may be done based on a discussions with local sector exerts. If this approach is used then it is important to discuss with both field based and managerial staff. Such approaches may be relatively reliable, particularly in situations where testing has been done but records have not been kept.

In trying to use this approach, initial reaction from water experts may be that ‘many’, ‘most’ or ‘very few’ supplies are contaminated. This is obviously creates difficulty as ‘many’ could be anywhere between say 30% and 97% of water supplies! It is important to try and estimate an actual proportion that may be contaminated, although this may only be at relatively large intervals (e.g. in 10% increases).

When using expert judgement, it will be probably be most effective to ‘pool’ information on all water supplies about likelihood of contamination. Thus, if experts believe that perhaps 60% of point sources are contaminated by only 20% of piped systems, a compromise figure can be calculated based on the proportion of people served by the different technologies. For instance, if 80% of the population rely on point sources and 20% on piped sources, then a weighted estimate would be:

$$P = (0.8*0.6) + (0.2*0.2) = 0.5$$

If the proportion is based solely on expert opinion, it is best to you should err towards 50% in order to maximise the sample size.

3.2.3 Review of existing water quality

This approach may provide a more reliable estimate of the proportion of supplies will exceed the water quality target. The process is simple, as it is a case of dividing the number of samples that exceed the target by the total number of samples taken. This should then be transformed into a proportion, for example if 450 out of 1000 samples showed contamination the equivalent proportion is 0.45.

When using existing data there are two key considerations to bear in mind. Firstly, it is important to evaluate the degree to which the available data are representative and/or of adequate quality. If the results have all be taken at particular times or year (which may therefore be concentrated in particular seasons) then these may not be representative of the time of year in which the rapid assessment will be undertaken. For instance, the quality of many supplies (particularly shallow groundwater sources that are not treated) will be likely to show significant seasonal variation. Furthermore, if there are no records of quality control or assurance procedures then the data may be more questionable. In these cases, it is important to interpret the existing data in light of expert judgement, for instance if the existing comes from wet seasons and the rapid assessment will be performed in a dry season, then the proportion of supplies expected to exceed the target may be reduced.

Secondly, it is important to consider whether there are any significant or gross imbalances in the amount of data from different water supplies, which may introduce bias into the survey design. For instance, if 90% of all data comes from utility run piped supplies that showed very few samples with the presence of indicator bacteria, this may be highly unrepresentative of community-managed water supplies in rural areas.

When relying on existing data, there are two approaches that could therefore be taken to calculating the sample size. The first is to pool all available microbiological data and use this to calculate the proportion of the water supplies that are likely to show contamination. This could be based on either the proportion of total number of samples taken that showed the presence of microbial indicators or the number of supplies that have at some point shown the presence of microbial indicators, regardless of the number of samples. This would produce a simple equation such as the one shown at the end of section 3.2.1. The proportion in both cases may then require adjustment for season or potential bias from type of supply using expert judgement.

The second approach is to divide the supplies into discrete study populations (for instance: utility and community-managed supplies and calculate the number of supplies to be included within the assessment for each category. This has the advantage of reducing some of the more gross bias in the survey design. It may, however, then become difficult to calculate a reasonable sample size for community-managed supplies, and there will be many potential biases that may be introduced and will make the overall survey design more complicated. Further complication may be introduced as the target level of water quality may be different between utility and community-managed water supplies. This reflects in part whether it is reasonable to expect community-managed water supplies sources to meet the same quality criteria as treated systems. In many countries, the available data may prevent differentiating between different technologies and management arrangements.

Unless there is a substantial data set covering different technologies and management arrangements, it is recommended that microbiological data from all water supplies is assessed together without differentiation between different types of water supply. As noted above, however, this may need to be tempered with some expert judgement regarding the overall likely proportion of supplies that will show contamination.

3.3 Design effect

This is commonly used in cluster sampling techniques as the process of clustering increases the risk of homogeneity within the clusters (i.e. there is a loss of sensitivity in detecting the true proportion of water supplies that are contaminated). The design effect allows the sample size to be increased beyond the size that would be likely in a random sampling survey in order to mitigate this risk.

In the Minimum Indicators Cluster Surveys (MICS), a range of design effects are recommended, with most variables being given a design effect weighting of 2 (i.e. doubling the sample size for random sample survey), but give a weighting of 10 for water and sanitation variables. This is because the MIC surveys ask households questions about where they collected their water, whether they have a latrine etc. Therefore significant homogeneity will be expected, as such facilities are often communal or the same type of facility is made available to many people.

When undertaking water quality assessment, the risk of homogeneity is somewhat lower as the vulnerability of water supplies to contamination is more likely to be subject to local variability due to sanitary condition or local hydrogeology. Indeed the water quality of adjacent sources would, in many cases, be more likely to be different than to be the same. Furthermore, for many water supplies, the proximity of adjacent sources is much greater than between adjacent households. The obvious exception to this is within piped systems, but this can be dealt with by ensuring that within-cluster sampling is spread throughout the entire supply.

In the design of rapid assessments of water quality the design effect weighting needs also to take into account that there may be other factors that control quality of water from a sample taken from a water supply. This includes the impact of climates (seasonality) which may affect both chemical and microbial quality, and the discrete nature of microbes within water samples. As a consequence, it is recommended that a design effect of 4 is used.

3.4 Calculating the sample size

The number of samples of water to be taken can be calculated using the equation below:

Equation 3.1:

$$n = \frac{4P(1-P)D}{e^2}$$

n = required number of samples
P = assumed proportion of water supplies with a water quality exceeding the target established
D = Design effect
e^2 = acceptable precision expressed as a proportion.

This provides the number of water supplies that should be included in the assessment to estimate the proportion of the supplies showing contamination (at a specified level) to within ± 0.05 with a confidence level of 95%. It should be noted, however, that this will not provide assurance that the sample size is sufficient in relation to other statistical objectives (for instance mean or median contamination).

For example, if the proportion is assumed to be 0.5, with a precision of ±0.05, the number of water supplies to be included within the assessment is 1600 as shown in equation 3.2.

Equation 3.2:

$$n = \frac{4 * 0.5(1-0.5) * 4}{0.05^2} = 1600$$

Once the required number of supplies to be included within the assessment has been calculated, it is important to review whether it will be feasible to visit this number of supplies and undertake water quality analysis and sanitary inspection. If it is considered that the number of supplies to be visited is too high, then the number of supplies to be included will need to be revised. When looking at equation 3.1, it is obvious that this may be achieved by either changing the proportion (P) or the precision (e^2). For instance, if the proportion of supplies estimated to show contamination is fixed at 0.5, the number of supplies included within the study for a precision of ±0.05 is 1600, but for a precision ±0.1 is 400. By contrast, large changes are needed in P is bring about significant changes in number of supplies to be included. For instance, if P is set at 0.5 with a precision of ±0.05, 1600 supplies must be included. If P is set at 0.7, the number of supplies required is 1344.

It is preferable to change the precision than the proportion, as changing the latter may introduce bias within the sample. Results from unbiased, less precise samples are preferred to more precise but biased results.

3.5 Defining the clusters and stratification

The following steps are designed to clearly define the cluster and to stratify the country in the survey design. The purpose of these stages is to ensure that the survey of water supplies reflects their importance and to ensure geographical spread. This allows the number of water supplies of each technology type and each region to be weighted proportional to their overall importance.

3.5.1 Proportional weighting to water technology types - primary stratification

The first stage will be calculate the total number of water supplies in each technology category, bearing in mind that for utility piped water supplies each zone is defined as a water supply as described in section 3.1.

The proportion of the water supplies should be calculated for in each of the technology categories shown in table 3.2 below.

Water supply technology category	**Percent population served**	**No. supplies included in assessment**
Utility water supplies (one zone = one water supply)	15	240
Community-managed piped supplies	20	320
Protected springs	30	480
Boreholes with handpumps	20	320
Dug well with handpumps	15	240
Total	100	1600

Table 3.2: Water supplies by category to be included in the assessment

There may be several sources of data to allow this calculation to be made. This will include detailed data at the national level used to complete the JMP reporting form in the Global Water Supply and Sanitation Assessment report 2000. Other sources of data may include recent Demographic Health Surveys, poverty assessments or water sector analyses.

The water supplies are the 'primary sampling unit' for the study. This means that this provides an initial basis for cluster selection. The number of supplies from each category to be included within the assessment should be based on the proportion of the population that is served by each technology type category. For example, as shown in table 3.2 for a sample size of 1600 water supplies, the number of individuals water supplies by category can be calculated.

Before the actual water supplies to be included within the survey are determined, it is important to define how many clusters will be required in order to select sub-national sampling units and clusters. The determination on the number of clusters required is based on the number of water sources that can be visited within one day. The total number of samples to be taken can then be divided by this figure to give the number of samples required. Table 3.3 below provides some guidance on how to this.

Urban/rural	**Technology type**	**Minimum**	**Maximum**
Rural	Community managed piped supply	1 per day	2 per day
Rural	Borehole/tubewell with handpump	3 per day	5 per day
Rural	Protected spring	3 per day	5 per day
Rural	Dug well	3 per day	5 per day
Urban	Utility supply	0.5 per day	1 per day
Urban	Community managed piped supply	1 per day	2 per day
Urban	Community point supplies	3 per day	5 per day

Table 3.3: Numbers of water supplies that can be visited in one day

For simplicity it is probably easiest to assume that the number of supplies to be visited within one day for each technology type will be uniform to simplify the following steps in the survey design. It may be preferable for sampling to be further concentrated and thus we can design a cluster size requirement that is equivalent to one week of sampling (i.e. 4 days). This is logical because if large distances were required for day to day movement, it may not be possible to complete the samples. The cluster sizes are then as shown below in table 3.4.

Urban/rural	**Technology type**	**Minimum cluster size**	**Maximum cluster size**
Rural	Community managed piped supply	4	8
Rural	Borehole/tubewell with handpump	12	20
Rural	Protected spring	12	20
Rural	Dug well	12	20
Urban	Utility supply	2	4

Urban	Community managed piped supply	4	8
Urban	Community point supplies	12	20

Table 3.4: Numbers of water supplies that can be visited in one week

3.5.2 Proportional weighting by area - secondary stratification

The country should be sub-divided on the basis of administrative boundaries or other characteristics to ensure that there is a reasonable spread of water supplies included within the final assessment.

The first stage is to consider whether there are any very broad level categories that define key differences within the country. These could be geographical, hydrological, administrative or socio-cultural. These should be based on current national approaches or understanding and not ones created solely for this assessment.

An example of this broad differentiation is Nepal, where although there are 75 Districts, there is an accepted division of the country into three key geographical regions: Mountains, Hills and Terai. The rapid assessment procedure would want to take these differences into account as they may affect the quality of supply. They also make a useful stratification, as it reduces the risk of bias in the selection process towards regions with lower populations (for instance in Mountain regions). If such very broad divisions do not exist, this stage may be omitted.

In a situation where are three major geographical areas in a country (like for instance Nepal), the areas would be included with the 8 water supply technology categories to give a total of 24 groups (i.e. 8 x 3), some of which may be empty (i.e. no water supplies of a particular technology type category found in a particular area). The number of water supplies of each technology type category from each area included in the assess would be proportional to the number of supplies of that type within a particular area. An example is shown in table 3.5 below.

Technology type	Area 1	Area 2	Area 3	Assessment total
Community managed piped supply	100	80	140	320
Borehole/tubewell with handpump	160	80	80	320
Protected spring	120	240	120	480
Dug well	80	120	40	240
Utility supply zone	200	40	0	240

Table 3.5: Water supplies included within the assessment by area

3.5.3 Defining and selecting 'large area' sampling units

The next stage is to make a selection of areas based on sub-national division from which we select the specific clusters. The sub-national divisions that is most appropriate to use the principal administrative divisions within the country for this stratification. This could be State in Federal systems (e.g. Nigeria and Mexico), Province in large countries (e.g. China) or District in smaller countries (e.g. Nepal). These are referred to as ‘large area’ sampling units.

To do this, the large area sampling units where each technology is present are listed. If a large area sampling unit does not have a particular technology, then it is excluded from the list for that technology. For example, table 3.5 shows a listing of large sampling areas (in this case District) that contain boreholes fitted with handpumps.

Large area sampling units are included in the survey are selected using proportional weighted sampling. To do this, a table with three columns is prepared as shown below in table 3.5 with the large areas sampling unit, number of supplies and a cumulative number of supplies. Then calculate a sampling interval to be used in selecting the large areas units to be sampled. The sampling interval is calculated by:

$$SI = \frac{Tc}{N}$$

SI = Sampling interval
Tc = cumulated total supplies
N = number of clusters

A random number is then selected that is less than or equal to the sampling interval (i.e. between 1 and the sample interval number). From the table, the secondary sampling unit is selected from the list that just exceeds this number. If more than one large area sampling unit is required, add the sampling interval to the random number and select the unit that just exceeds this number. In most cases you will need to select several large area sampling units and to do this add the sampling interval to the previous number calculated and select the areas whose cumulative population exceeds the new number.

For instance, if we calculated a sampling interval of 250 and a random number of 15, the selection of large sampling areas would be as follows:

1st large area sampling unit: first area whose cumulative population exceeds 15.
2nd large area sampling unit: first area whose cumulative population exceeds 265 (15+250).
3rd large area sampling unit: first area whose cumulative population exceeds 515 (265+250).
4th large area sampling unit: first area whose cumulative population exceeds 765 (515+250).

This process is repeated until the required number of large areas is selected.

Worked example
If the sample size for the assessment is calculated to be 1600 water supplies and 10% of the supplies are boreholes, we need to include 160 boreholes. If visiting 20 boreholes in a week is deemed feasible, we therefore need 8 clusters.

Large sampling area with boreholes	No. boreholes in sampling area	Cumulative number of boreholes
1	140	140
2	20	160
3	250	410
4	360	770
5	800	1570
6	120	1690
7	16	1706
8	87	1793
9	450	2243
10	230	2473
11	121	2594
12	56	2650
13	84	2734
14	85	2819
15	43	2862
16	44	2906
17	96	3002
18	600	3602
19	423	4025
20	238	4263
21	750	5013
22	666	5679
23	111	5790
24	358	6148
25	120	6268
26	100	6368
27	25	6393
28	90	6483
29	20	6503
30	24	6527

Table 3.5 Example of proportional weighting table

To select the large areas sampling units from which we will select specific clusters, we first calculate the sampling interval and then use the table above to select the Districts.

In this case, the sampling interval is 6527/8 = 815.9. A random number of 352 is selected (i.e. between 1 and 815.9). The first unit selected is number 3, which is the first area whose cumulative number of boreholes exceeds 352 (the random number). The second unit is number 5, the first area whose cumulative number of boreholes exceeds 1167.9 (the total of the random number plus the sampling interval). The other units selected are:

Area 9 - first to exceed 1983.8 (1167.9+815.9)
Area 14 – first to exceed 2799.7 (1983.8+815.9)
Area 19 – first to exceed 3615.6 (2799.7+815.9)
Area 21 - first to exceed 4431.5 (3615.6+815.9)
Area 22 - first to exceed 5247.4 (4431.5+815.9)
Area 24 - first to exceed 6063.3 (5247.4+815.9).

These will be the Districts from which the clusters are selected.

3.5.4 Defining the clusters

Within the large area sampling units, the final step is to define the clusters. This is to identify the exact supplies to be visited. This is done by listing all the supplies for each technology type and allocating them to clusters. The cluster should be defined as a number of water supplies that are sufficiently close together to ensure that they can be all be visited within one day or one week as discussed above. If there are water supplies that are not sufficiently close to another supply, these should be excluded from the analysis, as this will raise unacceptable logistic difficulties. Each cluster should then be given assigned a number and the required number of clusters selected using a random numbers table.

At the end of this stage, you should compile a table that indicates all the clusters identified and then allocate specific areas to specific survey teams.

3.6 Summary of survey design

To undertake the survey design, you will need to complete the following tasks:

- Establish a minimum community population for inclusion within the survey design. Only water supplies serving this number of people will be included in the population to be surveyed.

- Identify the water supplies to be included within the survey (the population) and their location within the country.

- Set the proportion (P) and precision (e^2) for the survey, differentiating between community-managed and utility supplies. Unless you have good evidence to suggest otherwise, use a P of 0.5.

- Calculate the sample size required using equation 3.1.

- On the basis of the proportion of the national population using each technology type, allocate the appropriate proportion of samples to each technology. Calculate the number of clusters required for each technology.

- Undertake secondary stratification of the country into large ‘zones’ where appropriate. This does not include the large area sampling units.

- Define the large area sampling units (e.g. District, Province, State).

- For each technology prepare a list of large area sampling units that contain the technology. Using the number of clusters required calculate the sampling interval and the select a random number. Select the large area sampling units as described in section 3.5.3.

- Define the clusters and select these from within the large area sampling units.

3.7 Sampling of water supplies

Once the clusters have been defined, the sampling within the clusters must also be defined. This is simple for communities using point water supplies. One sample should be taken from the source of water and then samples taken from 3-5 households randomly selected within the community, but not too close to the source. Make sure to confirm that the water in the household is collected from the source you have just tested. In piped systems, the number of samples to be taken as shown in Table 3.6, based on a maximum zone size of 50,000 people.

Population	No. samples	Comments
=4999	2	Sample source and end of distribution
5,000-50,000	2 samples plus 1 per additional 5,000 population (max = 22)	At least one sample from inlet and one from outlet of zone. At least one sample should be taken source must be taken during assessment of the utility supply, irrespective of number of zones.

Table 3.6: Samples to be taken from piped distribution systems

Household water should also be tested in each community using a piped water supply. For community-managed water supplies, the number of households tested should be roughly the same as the sampling of the piped system. In utility supplies, it is recommended that on each day's sampling, one-third of the samples taken are taken from households and two-thirds from the piped water system.

3.8 Implementation in the field

Once the design of the survey is completed and the clusters of water supplies identified, the field activities in the survey can be planned. A team of field staff should be identified and trained in the use of the equipment and the inspection techniques discussed further below.

The fieldwork should be undertaken by staff with some previous training in water quality analysis and who are familiar with basic water quality sampling procedures. It is recommended that a number of sampling teams of two individuals are formed and given responsibility for particular clusters within the country. Each team should then be given the appropriate equipment and forms to be able to undertake the assessment. There should be a programme defined and an agreed frequency of submitting results to the Co-ordinator. The national Co-ordinator should also make regular supervision visits to the field and aim to make at least one visit to each survey team during the assessment. A member of staff may be employed to put the data onto the database and to undertake analysis under the direction of the co-ordinator.

3.8.1 Recording the results

The results of each day's sampling should be carefully recorded in the forms provided in Annex 1. It is very important that the cluster name (or number) is clearly marked on all forms and that the date, name of analyst, community visited and sample sites are also clearly recorded.

The results of the water quality tests should be recorded on daily report sheets 1 and 2. The completed sanitary inspection forms for each day's activity should be fixed to the back of the daily report sheets and the forms kept in a folder. At the of each week's sampling, the data should be put sent to the Co-ordinator to be put into the database and the forms filed.

3.9 Analysis of the data

The data collected should be analysed as part of the report. Further more detailed guidance on analysing the data is given in chapter 7 of this handbook. Within data analysis, the most important aspect is to ensure that data are analysed and results presented on the number of supplies that failed to meet the targets established for both microbiological and chemical quality. It will be useful to also report this by technology type. Other analysis should include reporting on sanitary risk score and in particular the average sanitary risk score when water quality targets are exceeded.

It may also be of use to analyse whether there was a difference in the proportion of supplies failing to meet water quality targets based on the source water for the supply, age of the supply, the agency that constructed the supply, the agency operating the supply, whether rehabilitation work has been undertaken or specific designs/construction techniques.

3.10 The final assessment report

The final report should include the principal components outlined below.

3.10.1 Introduction

This should provide give a brief description of the country and the current levels of access to improved water supply and sanitation. The urban and rural proportions of the population should be given. The estimated numbers of people served by different technology types at a national level should be provided if possible.

3.10.2 Study sites

This section should identify the study sites selected, preferably identifying these on a map, and give a more detailed description of access to water and sanitation in these areas and any health statistics of relevance. The proportion of rural and urban population should be given.

This section should provide a brief description of the estimated numbers of people served by different technology types within the clusters and identify how many samples of each technology type were visited.

3.10.3 Water quality parameters

This section should outline which parameters were analysed for in the assessment. Any omissions from the core parameters and any additional parameters should be noted and justified. Any variations in parameters analysed for in different clusters should be noted and justified.

This section should also give a brief summary of the numbers of samples analysed for the different parameters and the sanitary inspections performed for each technology (preferably in the form of tables as far as possible).

3.10.4 Results

This section should provide a **summary** of the results obtained, giving information such as median/mean, standard deviations and range for each of the parameters and sanitary risk scores in each area and for each technology type.

The results of statistical analysis of data should be provided. This may include summaries of compliance rates, relationships between water quality and sanitary risk scores, assessments of the relationships between particular factors and contamination and assessment of sanitary integrity. When presenting the results of statistical analysis, confidence levels should be quoted and precision where possible. A brief description of major findings can be given in the text.

3.10.5 Discussion

The result should discussed in relation to the levels of exposure to water contaminants and the implications that this may have for public health. Differences between different areas and technology types should be discussed, as should differences in the quality of water sources and household water. Differences that are statistically significant should be clearly indicated and there should be limited discussion of differences that are not significant.

Implications of sanitary risk scores should be discussed in relation to future trends in water quality. Lessons learnt with regard to remedial and preventative actions should also be discussed in this section.

3.10.6 Conclusions and recommendations

This should firstly summarise the major conclusions that can be drawn from the results and discussions. It should then formulate a set of key recommendations in relation to resolving problems noted or promoting best practice.

3.10.7 Annexes

These should contain a list of team members, itineraries followed (with dates_ and provide more detailed information on the results of the water quality analyses and statistical analysis of data.

4.0 Microbiological quality monitoring

There are a wide variety of micro-organisms that may be found in water. These include those that are pathogenic and those that are not pathogenic. Some of the non-pathogenic micro-organisms may lead to other problems in water supplies such as taste and odour, which may be of particular importance to users of the supply as an indicator of safety and may influence their selection of water for consumption. However, the principal concern for microbiological quality is the potential contamination by pathogens.

Pathogens tend to be classified according to their group or family and include bacteria, helminths, protozoa and viruses. WHO have provided an indication of the range of different pathogens that may be found in drinking water, see table 4.1 below.

Although it is known that pathogens cause disease, the routine monitoring of pathogens is generally not undertaken for several reasons. For many pathogens there is a lack of analytical tools available and where these do exist they are often expensive and difficult to perform. Individual pathogens cannot be guaranteed to be present in all untreated or unprotected waters as this depends on whether the faeces (or other materials e.g. medical wastes) from an infected person are present in the water. Therefore failure to observe a particular pathogen cannot be taken to imply an absence of other pathogens. Furthermore, it is desirable to have a means of detecting contamination before there is a significant public health risk in order to ensure actions can be taken to prevent a major outbreak of disease. However, in countries where resources permit, assessments of pathogen presence in source and drinking water are a useful tool in determining the public health risk from drinking-water and in developing health-based water quality targets. The majority of human pathogens present in water are of faecal origin. Pathogen assessments should be considered under level 4 rapid assessments.

Pathogen	Health significance	Persistence in water supply	Resistance to chlorine	Relative infective dose	Important animal reservoir
Bacteria					
Camplyobacter jejuni	High	Moderate	Low	Moderate	Yes
Pathogenic *E.coli*	High	Moderate	Low	High	Yes
Salmonella typhi	High	Moderate	Low	High	No
Shigella spp.	High	Short	Low	Moderate	No
Vibrio cholerae	High	Short	Low	Moderate	No
Yersina enterocolitica	High	Long	Low	High (?)	No
Pseudomonas aeruginosa	Moderate	May multiply	Moderate	High (?)	No
Aeromonas spp.	Moderate	May multiply	Low	High (?)	No
Viruses					
Adenoviruses	High	Unknown	Moderate	Low	No
Entroviruses	High	Long	Moderate	Low	No
Hepatitis A	High	Unknown	Moderate	Low	No
Enterically transmitted non-A, non-B hepatitis viruses, hepatitis E	High	Unknown	Unknown	Low	No
Norwalk virus	High	Unknown	Unknown	Low	No
Rotavirus	High	Unknown	Unknown	Moderate	No (?)
Small round viruses	Moderate	Unknown	Unknown	Low (?)	No
Protozoa					
Entamoeba histolytica	High	Moderate	High	Low	No
Giardia intestinalis	High	Moderate	High	Low	Yes
Cryptosporidium parvum	High	Long	High	Low	Yes
Helminths					
Dracunculus medinensis	High	Moderate	Moderate	Low	Yes

Table 4.1: Examples of pathogens found in drinking-water. Source: WHO Guidelines for Drinking-Water Quality, Volume 2.

4.1 Indicator bacteria

As a result of the issues raised above and because most water-borne pathogens are derive from faeces, it is usual practice to use indicator organisms, usually bacteria, for the analysis of microbiological quality of drinking water. There are a number of indicator micro-organisms that may be used in drinking water quality monitoring programmes. The most commonly used is *Escherichia coli* (*E.coli*) or as a surrogate thermotolerant coliforms.

E.coli derives almost exclusively from human and animal faeces and contains some strains that are pathogenic (e.g. *E.coli* O157:H7). There is some evidence that *E.coli* is able to multiply in nutrient-rich tropical soils, although it is generally recognised that this is limited and in most case the indigenous bacteria would out-compete the *E.coli*. The identification of *E.coli* is simple, but time consuming as it typically requires a two-stage process of presumptive and confirmatory testing. As a result, many programmes use thermotolerant coliforms as a surrogate, because results can be obtained quickly and cheaply, although strictly speaking these only provide presumptive results.

The thermotolerant coliforms are a group of coliform bacteria that grow at 44^{o}C and which contain *E.coli* as well as other species that may have an environmental source. In temperate climates it is usually estimated that approximately 95% of thermotolerant coliforms are *E.coli*, but in tropical climates it is suggested that this proportion may be significant lower. This implies that some caution must be applied when interpreting the results of analysis and highlights the need for other data collection methods as discussed further below. Thermotolerant coliform analysis can be performed using a variety of different techniques and results can be obtained within 14-18 hours using relatively inexpensive methods.

The broader group of coliforms - often referred to as total coliforms - are also sometimes included in monitoring programmes. The total coliform group contains many different species of coliform bacteria, the majority of whom are environmental in nature and are therefore of no sanitary or public health significance. Total coliform analysis has often been used in chlorinated supplies, as they would usually be expected to be absent because they are sensitive to chlorine. Their presence, therefore, is often taken to imply that contamination of the water has occurred. However, the significance of total coliform presence in such waters is likely to be limited as the majority will almost certainly derive from biofilm within the distribution system. The health significant of re-growth remains uncertain, but believed to be insignificant. Total coliform use is not recommended in any unchlorinated water supply as they would be expected to be present and have no sanitary significance.

Faecal streptoccoci may also be used as indicators of microbiological quality. Previous studies have suggested that these bacteria have a stronger relationship to diarrhoeal disease than *E.coli* and in other studies have been shown to have a closer relationship to bacterial indicators of known human faecal origin. They are generally more environmentally resistant than *E.coli* or the thermotolerant coliforms and their use has therefore be recommended for groundwater receiving contaminated recharge water and in chlorinated distribution systems. A variety of techniques can be used for analysis and although some are simple, they are time-consuming as a result cannot be obtained for 48 hours. This may limit their usefulness in routine monitoring, but would have limited impact on their value in assessments.

4.1.1 Other indicators and bacterial problems

Other indicator bacteria can be used such as sulphite-reducing clostridia, *Clostridia perfringens, Pseudomonas aeruginosa* and sorbitol-fermenting bifido-bacteria. These indicators all have specific characteristics that make their use valuable for certain applications (for instance in measuring treatment efficiency or as a surrogate for cyst presence). Indicators for virus presence are also available, for instance there are a number of bacteriophages (a type of virus that infect bacteria) can be used. All these micro-organisms can be included in assessments where the resources permit. However, it is recommended that they only be considered in level 2 and 3 assessments.

In addition to the pathogens and indicators described above, a further water quality problem deriving from bacteria relates to toxic cyanobacteria. However, the actual health concern derives from toxins produced when these bacteria die. These bacteria commonly appear in blooms in eutrophic source waters and an evaluation of their significance is recommended under level 3 assessments.

4.2 Critique of the indicator-based approach

The principal current indicators used do have serious limitations. The relationship between pathogens and indicator bacteria is not simple, the range of pathogenic organisms is large, and their nature is broad and many do not bear many similarities with the indicator organisms. The weaknesses of current indicators in predicting health risks has been noted as there is evidence of infection by waterborne pathogens when indicators are not present in water. It has been suggested that whilst the current suite of indicators of microbiological quality have provided a useful tool in prevention of epidemics, they provide far less information about endemic disease, particularly where the disease agents are viruses. The data from these studies suggests that the current indicator bacteria are not adequate alone to predict pathogen presence.

The presence of pathogens in the absence of indicators is partly due to the different nature of the pathogen and the indicator – for instance cyst or viral pathogens and bacterial indicators. However, it may also be because the volumes used for pathogen and indicator analyses differ by anything between 3 to 1000 times larger. Therefore the lack of indicator presence may simply relate to the analysis of too small a volume.

4.1.2 Support for continued use of the indicators

However, there are strong arguments that can be made for continued use of indicator bacteria as the principal method for monitoring the microbiological quality and thus, indirectly, the likelihood of pathogen presence in drinking water supplies. A recent review of microbial indicators concluded that the use of the standard indicators has done much to improve health and their abandonment due recognised weaknesses is unjustified and likely to be counter-productive to health.

The limitations in the use of the current indicators indicates weakness in the application and interpretation of the results of analysis rather than the imperfections of the system itself. The original development of standards for water quality based on indicator bacteria in the early 20th Century were designed to verify treatment system performance. This was a logical extension of the process of public health based water quality control linked to the development of treatment processes (in particular slow sand filtration and disinfection) which had proven to be effective in pathogen removal. The bacterial indicators were only one mechanism of verification of water quality and were supported by sanitary surveys of water supplies and monitoring of treatment plant operation. However, over time, the basis of legally enforceable measures of water quality has increasingly focused of numerical limit values for faecal indicator bacteria.

The interpretation of the results of indicator bacteria analysis in the context of standards illustrates profound misconceptions of the meaning of the absence, presence and numbers of faecal indicator bacteria. Many people in water and health sectors equate an absence of faecal indicator bacteria with an absence of pathogens. As noted above this may not be true given the evidence of water-borne infections resulting from drinking water meeting current standards and nor was this the original intention of such indicators. Furthermore, many professionals also seem to equate the presence of faecal indicator bacteria with confirmation of the presence of pathogens. However, in reality it merely implies that the risk of pathogen presence has increased, as there is evidence of recent faecal contamination.

The principal flaw in the use of indicator bacteria has been in the interpretation of the findings, which has tended to translate the findings of monitoring that describe a risk (which is an inherently probabilistic approach) into a certainty. Such an approach inherently contains some degree of potential for false positive and false negative results in relation to pathogen presence. This is of relevance in that the current application of the faecal indicator bacteria means that action is usually only required when indicator bacteria are isolated.

In terms of direct public health consequences, the false negative result is of greatest concern and this has tended to be arena where most work has focused. However, this research has primarily been done in wealthy countries where other aspects of water supply – access, reliability and acceptable costs – are largely resolved. By contrast, in developing countries, the false positive result may be of equal concern in that it would imply that some form of action (and therefore investment) is required to mitigate a public health risk that does not actually exist. This may lead to a focus on improving water quality in situations where greater attention to other aspects of water supply improvement, hygiene behaviour or sanitation would yield greater health gains. Furthermore, the meaning of true positives should also be carefully considered in the context of multiple routes of infectious disease transmission. In most cases a degree of contamination of drinking water can be tolerated with limited increased health burdens if this means that resources can be allocated to other improvements in water and sanitation.

In this context, the relative numbers of faecal indicators in a water supply are more important than simple presence, as increasing numbers of indicator bacteria implies that the risk of pathogen presence increases. Whilst this would be most effective for pathogens of similar type (i.e. bacteria) it may still provide some indication of the likelihood of other pathogens being present simply as it indicates evidence of recent faecal contamination.

In conclusion, use of indicator bacteria remains an important element in protecting public health, particularly in lower-income countries. Indicator bacteria retain an intrinsic value in predicting contamination and indirectly the public health risk posed by water supply. The monitoring of indicator bacteria remains an effective tool evaluation of risks of major outbreaks derived from drinking water. However, it is clear that sole reliance on faecal indicator bacteria is unwise. Therefore there is a need to use a suite of indicators that can be used to describe overall risks of pathogen presence.

4.2 Other parameters of significance to microbiological quality

Turbidity, pH and chlorine residuals, where supplies are chlorinated, are widely accepted as other critical water quality parameters describing microbiological quality of drinking water. These parameters are recommended as they either directly influence microbiological quality (in the case of chlorine) or may influence disinfection efficiency and microbial survival (in the case of pH and turbidity).

Very low chlorine residuals or high turbidity, even in the absence of faecal indicator bacteria, may give cause for concern as they imply reduced protection against contamination and in the case of turbidity may indicate that sanitary integrity has been compromised. This set of parameters constitute, with indicator bacteria testing, the 'critical parameters' that should form the basis of a minimum approach to water quality monitoring.

In addition to these parameters, a sanitary inspection should always be undertaken. Sanitary inspections are visual assessments of the infrastructure and environment surrounding a water supply taking into account the condition, devices, and practices in the water supply system that pose an actual or potential danger to the health and well-being of the consumers. The most effective way to undertake sanitary inspections is to use a semi-quantitative standardised approach using logical questions and a simple scoring system as described further below in section 5. Sanitary inspections are complementary to water quality analysis and there is an increase in the power of subsequent analysis when both types of data are available. Sanitary inspection has an additional value as it provides a longer-term perspective on risks of future microbiological contamination.

4.3 Recommendations for rapid assessments

The section above provides a review of current knowledge and thinking with regard to possible indicators of microbiological quality of drinking water. It outlines the strengths and weaknesses of the overall approach and has concluded that the use of indicator bacteria is still justified provided it is integrated with other measures that help determine microbiological quality.

In relation to the rapid assessments, the following parameters are therefore recommended for use in level 1 assessments:

1. **Thermotolerant coliforms:** The use and rapidity of the tests for thermotolerant coliforms makes their use justified. However, where possible it is recommended that some confirmatory tests performed for *E.coli* are undertaken for each type of water source.
2. **Faecal streptococci:** 30% of all samples from water sources and piped supplies and 30% of household samples should also be tested for faecal streptococci. This is designed to provide a small-scale within-study investigation to evaluate the usefulness of these bacteria.
3. **Turbidity:** This should be tested on all samples.
4. **Sanitary inspections:** These should be performed for all water sources and household water sampled using the formats provided.
5. **Chlorine residuals:** These should only be tested where the water is chlorinated. All samples taken from chlorinated supplies should be tested for free chlorine and

approximately 20% tested for total chlorine.

6. **pH:** This should be tested on all samples taken from chlorinated supplies.

In level 2 assessments, bacteriophages can be included to provide an indication of the risks of viral pathogen presence. In level 3 assessments, the microbiological range should be expanded to include pathogen assessments, bacteriophages, C*lostridia perfringens* and assessment of toxic cyanobacteria.

4.4 Analytical methods

The choice of analytical methods is an important aspect of establishing the assessment protocols, standard operating procedures and quality control. Analysis of thermotolerant coliforms can involve presence/absence testing or enumeration. A number of kits are available for presence/absence and some of these are very low-cost. However, for the rapid assessment presence/absence tests are not recommended because of the limited information the results of such tests provide.

Presence/absence tests are generally only appropriate in circumstances where thermotolerant coliforms are rarely found and when contamination occurs only low levels are found. As it is often more useful to know about the degree of contamination when setting priorities, the use presence/absence tests will inhibit the development of a full understanding of the scale and range of microbiological quality of water. In particular such tests reduce the ability of the assessment to compare the quality of different sources of water and between sources of water and water stored in the home. The value of quantifying the level of contamination is that it will allow countries to make better-informed policy and management decisions regarding future water and sanitation investment. Furthermore, some kits (notably those using hydrogen sulphide reduction) have significant problems with false positives and negatives produced by non-faecal sulphide reducing bacteria and therefore the results should be treated with a great degree of caution.

Two approaches to thermotolerant coliform testing are available where enumeration is required: the multiple tube method and membrane filtration. In the former, the analysis of several tubes containing different amounts of sample allows a statistical estimate of the numbers of bacteria in the water and is sometimes referred to as the most probable number (MPN) approach. This technique is more cumbersome, requires greater training in the interpretation of results and often leads to delays in obtaining results. However, it is effective when samples are turbid and where the organisms are injured.

Membrane filtration (MF) is a more recent technique, but one which has been an accepted standard method for many years. The advantage of the MF technique is that direct counts of bacteria may be made from colonies grown on filter papers incubated on nutrient media for 14-24 hours. However, although direct counts are made, it should still be borne in mind that microbe densities will vary within the sample and therefore the value obtained is still subject to statistical confidence limits. The MF technique is not appropriate where samples are turbid as the filter may block and the suspended sediment may interfere with bacterial growth. However, the MF technique is simpler and quicker to perform than MPN and the results are often easier to interpret, consequently this technique is recommended for the assessment.

4.5 Field and laboratory-based approaches

The analysis of water samples can be carried out in laboratories or through the use of field equipment. Laboratory approaches have some advantages in terms of the numbers of samples that may be processed in one day and some advantages in securing an analytical environment. However, laboratory based approaches have many drawbacks, particularly when sampling is done of remote rural supplies. These particularly relate to sample deterioration, which is often significant, and increased transportation costs.

A number of proven simple, low-cost field techniques field testing kits are available for microbiological analysis using the MF technique. There appears to be no significant difference in the reliability of results obtained from such kits in comparison to laboratory testing providing the staff using them are properly trained and maintain an aseptic technique. However, as discussed further below, analytical quality control in water quality analysis is important and should be properly addressed during assessments.

Field tests kits have an advantage over the use of laboratories because problems with sample deterioration during transport can be reduced. Field equipment also increases the potential for community involvement in the process of surveillance and the portability of field equipment means that it can be readily deployed as a health education tool in its own right.

The principal perceived disadvantages of field equipment relate to numbers of samples that can be processed. The limitations of number of samples that can be processed in one day may lead to greater numbers of staff or more frequent visits to the field in order to collect and analyse the numbers of samples required. However, in rural areas given the distances involved in sampling water supplies in many areas, this rarely inhibits data collection significantly. In urban areas it may be an advantage as more frequent analysis of a smaller number of supplies provides better information than large numbers of samples taken in shorter time periods. It is therefore recommended that in the assessment, field testing kits be used for microbiological analysis.

4.5.1 Available kits

There are a suitable number of kits available for microbiological analysis. Of these the Oxfam-DelAgua supplied by the Robens Centre for Public and Environmental Health, the ELE Paqualab and the Wagtech Potakit could all be considered as being suitable for the rapid assessment. All these kits use membrane filtration and have built in incubators. Each kit can come with either a single or double incubator pot, although the temperatures are pre-set on the Oxfam-DelAgua kit, but can be changed on the other kits. This represents a limited advantage for the assessments, as the testing will only be for thermotolerant coliforms and faecal streptococci (both of which require incubation at 44^{o}C). It should be noted that when incubator temperature is changed, a period of time is usually required to allow the temperature to stabilise

All the kits are able to run from mains electricity and all have built-in batteries, although the life of these varies significantly. All can use solar panels for charging of the battery. All kits come with a range of additional equipment to test for turbidity, pH and chlorine residuals and other parameters. The kits usually come with a limited set of consumables as standard (often in the range of 200 tests). Additional consumables must then be purchased. All the kits use methanol for sterilisation, but this cannot be transported by air freight and will need to be purchased in-country. The filters used must also now be sent as hazardous cargo, although at the time of writing they can still be sent by air-freight.

4.6 Analytical quality control

Analytical quality control is important in microbiological testing, although it is more difficult as micro-organisms, unlike chemicals, are discrete particles. This is different from chemicals where variation occurs at a molecular level, which is typically below the limit of detection in routine analytical methods.

In unmixed samples micro-organisms are likely to be found in ‘clumps’ and it is important that immediately before analysis, the samples are thoroughly mixed. The organisms in a well-mixed sample will be distributed as discrete particles through the water, with some under-dispersion where clumping remains. Therefore sub-samples will inevitably contain different numbers of organisms. If replicate counts using these sub-samples give different results there is no way on knowing whether this is correct and due to random variation or incorrect due to analytical errors.

The most important way to ensure the quality of results is to ensure that an aseptic technique is used. This can be easily evaluated using a simple form provided in Annex 3. Aseptic technique evaluation should be performed on a regular basis throughout the assessment by the sampling team. This should be supplemented by an evaluation by a supervisor during their visit(s) to each survey team during the assessment. Equally important are regular checks on the incubator temperature which can be easily performed on most water testing kits. Some have a real-time digital display and in others temperature must be checked in a separate process.

One approach to quality control for microbiological analyses uses a duplicate split-sample approach. For any single result, a range of acceptable results from a second analysis can be defined based on a Poisson distribution of bacteria within the water. In this approach, a 200 ml sample is mixed thoroughly and then divided into two 100ml sub-samples. The count from the first sample is recorded and the 95% confidence limit for the second (paired) count is recorded from the table in Annex 3. The count from the second sample is then recorded alongside and if this falls outside the confidence intervals this is highlighted. This approach does work reasonably well, but it should be stressed that a pair of results where the second is outside the 95% confidence limits do not indicate contamination of the sample and the results should **not** be rejected.

Experience with the use of this approach suggests it is most effective when large numbers of control samples are taken over a period of time. In the rapid assessment of water quality it is recommended that on each day’s testing, a duplicate split sample is taken for quality control but that the results are only analysed for the full data set and not for individual days of testing.

Other approaches to quality control include the use of reference material to determine whether analysts and equipment can detect known positives and also have non-detects of bacteria in sterile samples. If appropriate reference material is available in-country such approaches can be considered. International schemes do exist to support quality control for microbiological analysis, but these are not necessarily recommended for rapid assessments.

5.0 Sanitary inspections

Although perceptions of water quality may be unreliable, yet observation is a very useful tool for identifying possible hygiene risks that could affect the quality of water supplies. Two useful observational techniques are sanitary inspection (or sanitary surveys) and qualitative visual inspection. Both techniques require inspectors to identify potential risks to the quality of the water and provide therefore an assessment of likely causes of (faecal) contamination when found and may give insights into the risk of future contamination.

5.1 Sanitary inspection

Sanitary inspection or sanitary survey is a key approach that has been promoted consistently by WHO through the Guidelines for Drinking Water Quality and by other water quality regulatory bodies such as the USEPA. Sanitary survey techniques are used to evaluate the likelihood of faecal contamination of water in both rural and urban areas. Observation is used to identify, assess and record the likely hazards, risks and possible pollution problems that may threaten drinking water quality at the source, point of abstraction, treatment works or distribution system.

Most sanitary surveys activities consider a variety of risks, which can grouped into three broad categories:

1. Hazard factors – these are potential sources of faecal materials that may represent a risk to the water supply (for example, a pit latrine close to a hand-dug well).
2. Pathway factors – these are potential routes by which contamination may enter into the water supply (for example, a broken access cover for a spring-box, or leaks in water supply pipes).
3. Indirect factors – these are factors which would facilitate the development of pathways (for example, inadequate fencing around a protected spring, which may allow animals to have access to the areas behind the spring box where they will erode the cover and may produce faeces).

In many cases the presence of risks from all 3 categories may be required in order for contamination to result.

Sanitary inspection techniques are generally used in three closely linked ways:

- identification of specific causes of known contamination;
- identification and evaluation of factors likely to affect the long-term risk of contamination; and
- assisting with monitoring and evaluation of operation and maintenance activities for water supplies.

Sanitary inspections should be undertaken at the following locations:

- at the source and intake (to assess whether the quality of the raw water is at risk, and whether the abstraction method is satisfactory);
- at the treatment works (to assess whether suitable treatment processes are being used, and

whether correct procedures are being followed);

- in the distribution system (to assess whether the quality of the water is at risk during distribution);
- at all point sources (i.e. boreholes/tubewells, protected springs, dug wells);
- household water containers.

Sanitary inspection usually makes use of a report form containing a check-list of questions, which can be answered using a mixture of visual observation and user interview. Each question is usually phrased in such a way that a 'Yes' answer indicates a potential risk that could threaten the quality of water. Use of questions provides a simple, rapid, and accurate means of assessing the risks threatening a particular water source or installation. An overall sanitary risk score (the number of questions answered ‘Yes’) can provide an indication of the likely bacterial quality of the water. Report forms can be prepared or adapted for specific water sources and situations, although standard lists of questions should be used to ensure comparability and to minimise the possible subjective nature of data collected. A set of recommended sanitary inspections forms for a number of water supply types and household water is included in Annex 2.

For simplicity, all risks are assigned equal weight, although the importance of different risks will be likely to be site specific, and contamination may not be directly proportional to the number of risks identified. Each fault increases the likelihood that contamination has occurred or could occur, and the total number of risks represents the likely overall risk of contamination. Remedial actions to eliminate one or more of the identified risks may therefore lead to some reduction in contamination. More detailed subsequent analysis may be required to investigate the potential impact of specific risk factors on water quality.

Sanitary surveys usually concentrate on the immediate area around a water source, and more distant risks affecting water quality may not be identifiable. The use of sanitary inspection forms is appropriate for water sources, but sanitary survey of more extensive facilities, such as piped water distribution systems or water treatment works, may be more difficult. In these situations, use of interviews is appropriate to supplement a list of sanitary survey questions. Interview questions that concentrate on issues which will be known to operators or users can provide a good broad indication of both likely risks to quality and of operation and maintenance performance.

In piped water supplies where inspection of the entire network may not be possible or realistic, causes of contamination may occur far from the point of sampling. Localised problems are, nevertheless, often the cause of contamination in piped networks. For piped water supplies, broader issues (such as whether supplies are intermittent, or whether there are obvious leaks) can be included within a user interview component. Furthermore, the use of standardised formats can provide a good indication of the domain of contamination - that is whether it relates to major supply faults or is due primarily to problems very close to the sampling point. This therefore provides the inspector with a good initial indication of where further investigation is needed. Such approaches may also be supported by other techniques such as mapping chlorine residuals and looking for broad trends.

In water treatment plants, it would be preferred for a detailed audit to be undertaken of the plant covering individual process performance and this may be done in level 2 and 3 assessments. However, for level 1 assessments, brief interviews and completion of the form in Annex 2 will be sufficient.

In some aquifer types (particularly fracture aquifers) sources of pollution causing contamination of groundwater source may be present beyond the immediate area of the sanitary inspection. Without a full hydrogeological risk assessment it may be difficult to identify this risks. However, by using the sanitary inspection forms, a good indication of whether this is the case can be obtained because if groundwater is found to be contaminated, but inspection shows no identifiable risks, it may be assumed that contamination is occurring remote from the source.

5.2 Pollution risk appraisal

Sanitary inspection techniques have primarily been developed to address problems of microbiological contamination and may not be as effective for chemical contaminants. However, risk assessments can also provide useful insights in relation to chemical risks in water supply and can help in directing further investigations and interventions to improve water quality.

A simple format for assessing environmental risks is given in Annex 2. This form should be used at water sources supplying piped water systems and water treatment works. It can be filled out by interviewing the operator of the works and provides qualitative data on major source water problems. This form is adequate for level 1 assessments, but should be expanded upon in level 2 and 3 assessments, leading to full environmental impact assessments and detailed hydrogeological risk assessment.

5.3 Visual inspection

Visual inspection is a technique that may be used to assess the risks affecting the quality of water within the home. Visual inspection is similar to sanitary inspection, but is less structured. It provides qualitative data that is collected by observation, and then reported in spoken or written form. The technique requires those who undertake inspections to have a basic knowledge and understanding of public health principles; and to be thorough and professional in character.

Visual inspection entails observing how water is stored, handled and used within individual homes, so that unhygienic practices can be identified. Standard reporting forms may be produced to meet the needs of local monitoring programmes, and the use of standard forms encourages objective assessment, so that data obtained by different inspectors or in different areas can be compared directly. Inspectors observe domestic hygiene practices associated with water to identify potential risks to supplies of potable water.

5.4 Advantages, limitations and applications of techniques

Both sanitary inspection and visual inspection rely on observation, so need no special equipment, and both are quick and cheap. They do not require highly-trained staff, and findings can be discussed at the time of inspection with users and community members. Inspection techniques and analytical approaches are complementary activities and neither fully replaces the other. Analytical techniques can provide data about the quality of water samples, but cannot provide reasons for the values obtained.

Observational techniques can identify possible risks or pollution problems, but cannot provide evidence of whether pollution is occurring. It is therefore important that observational and analytical techniques are used in conjunction with each other. Possible roles for water quality analyses, sanitary surveys and visual inspections are summarised in Table 5.1 below.

Water quality analysis	Sanitary survey	Visual inspection
Water quality analysis is expensive, requires equipment and competent staff, and therefore is not always easy to perform regularly or routinely.	Sanitary survey is cheap, requires no equipment or highly-skilled staff, and may easily be performed regularly or routinely.	Visual inspection is cheap, requires no equipment or highly-skilled staff, and may easily be performed regularly or routinely.
Water quality analysis gives only a snapshot - a record of the water quality at the time of sampling.	Sanitary survey can reveal conditions or practices that may cause isolated pollution incidents or longer-term pollution.	Visual inspection can reveal unhygienic domestic practices and conditions that may cause pollution of water within the home.
Water quality analysis will indicate whether a water is contaminated; but will not, usually, identify the source of contamination.	Sanitary survey reveals the most obvious possible sources of contamination, but may not reveal all sources of contamination (e.g. remote contamination of groundwater).	Visual inspection reveals only risks observed during the inspection visit, but may not reveal all unhygienic practices associated with water storage and use within a home.
Water quality analysis can provide data about the physical, chemical and bacterial quality of water samples.	Sanitary survey usually identifies risks that may affect the bacterial and physical quality of water. Risks to the chemical quality of water are not usually identified.	Visual inspection usually identifies risks that may affect the bacterial quality of water. Risks to the chemical and physical quality of water are not usually identified.

Table 5.1.A comparison of analytical and observation techniques for assessing water quality

Observational techniques (sanitary survey and visual inspection) are location specific and the forms and approaches used should be developed to take into account local conditions. Although an element of judgement is needed by the person undertaking the inspection, if standardised formats are used, there is usually a very significant concordance between different inspectors when independently inspecting specific facilities.

Sanitary survey has been shown to be an effective tool for water quality surveillance programmes, and should contribute to a reduction in the overall cost of the assessment, which is of vital importance in many low and middle-income countries. Sanitary surveys identify possible pollution problems that may threaten drinking water quality, and these potential problems are often associated with specific practices and the physical condition of facilities.

Questions answered with a ‘yes’ on the reporting form identify specific risks, and remedial action can often be identified and implemented to minimise the risks. In some cases action may be necessary to repair facilities; in others, hygiene education may be necessary to change the hygiene practices of individuals or communities. In certain cases, circumstances outside their control may make it impossible for a community or support agency to minimise risks.

5.5 Recommendation for the rapid assessments

Within the rapid assessments, it is recommended that sanitary inspections be performed at all sources of water, piped water supplies and household water. In addition, inspector should be able to provide detail from unstructured visual inspections of domestic water hygiene. For all sources of water supplying piped water systems, a pollution appraisal form should be completed in level 1 assessments, with more complete environmental appraisal performed for level 2 and 3 assessments.

6.0 Chemical and Physical quality

There are numerous chemical substances that can be found in water, which maybe of concern for public health, acceptability of water (aesthetics) and operational performance. A total of 128 chemicals were considered in the preparation of the 2nd edition of the WHO Guidelines for Drinking Water Quality and Guidelines Values set for 96 substances. It is expensive, difficult and largely unnecessary to test for all these parameters even within an assessment exercise and therefore priorities have to be set on the selection of parameters. In addition to chemical substances, there are a set of physical characteristics of water that should also be included in assessments of water quality as they are useful indicators of change in quality and are often cited by consumers as reasons for rejecting a source.

Physical and chemical parameters may have natural and anthropogenic sources and show both temporal and spatial variation in their occurrence and concentration, with temporal variation being greater in surface waters and shallow groundwater than deep groundwater. The microbiological quality of shallow groundwater and surface waters is often poor and is the principal issue of concern. The chemical quality of shallow groundwater and surface water tends to be primarily related to human activity and whist chemical quality may be poor, prevention measures are usually possible and contamination may be relatively short-lived given rapid through-flow.

In deeper groundwaters, microbiological quality is often very good and therefore chemical quality is often a higher priority. Furthermore, chemical contaminants are more likely to be natural and therefore removal rather than prevention may be required. Slow throughflow may lead to long-term contamination problems. However, the quality of such groundwater is generally stable, so the required frequency of monitoring is lower than that for shallow groundwater and surface water sources, which are both prone to both natural (e.g. erosion, run-off) and anthropogenic pollution/contamination.

Within this handbook, it is important to note that although pH, turbidity and chlorine residuals are all physical or chemical parameters they are described and discussed in the section on microbiological quality. This is because, although all may have an impact on the acceptability of water or public health risk, their primary effect is in relation to microbiological quality and in particular in relation to disinfection processes.

Table 6.1 details the parameters selected for the rapid assessment project (level 1) and the most probable parameters for levels 2 and 3, together with selected methods of analysis. The list of parameters for levels 2 and 3 (outside the scope of the rapid assessment project) is not fully comprehensive but aims to illustrate the increasing complexity and location-specificity of water quality analysis. Section 6.1 provides details on particular parameters included in the rapid assessment with some brief indication of why they are considered important. Each substance/parameter selected is also assigned to particular assessment categories to help in the prioritisation and planning for implementation of the rapid assessment. By preference, the chemicals included in more detailed assessment, i.e. levels 2 and 3 should be determined in-country based on a systematic review of known and likely problems. This may be done using existing data, national decision-making tools or the WHO Protocol for the selection of chemicals for inclusion in monitoring programmes. In level 1 field-based methods will be adequate for all the parameters. For stages 2 and 3 a mixture of field and laboratory based methods will be required.

Parameter	WHO GLV (WHO 1993)	Reason for designation	Methods for assessment **The methods in bold are recommended for this framework**
Colour	10 TCU	Aesthetic	Qualitative or **light box**
Conductivity	-	Aesthetic	**Pocket meter (0-199 mS/cm)** Meter (0-2000 µS/cm with temperature compensation)
Nitrate	50 mg/l (as NO_3)	Health	**Photometer** (0-20 mg/l as N) Comparator (0 –15 mg/l as N) Merckoquant strips (0 – 10 – 30 – 60 – 100 – 250 – 500 as NO_3) Ion-selective electrode
Ammonia	1.5 mg/l	Aesthetic	**Photometer** (0-1.0 mg/l) Spectrophotometer (0-45 mg/l)
Iron	0.3 mg/l	Aesthetic and Health	**Photometer** (0-10 mg/l) Comparator (0.1-10 mg/l)
Fluoride	1.5 mg/l	Health	**Photometer** (0 - 5 mg/l) Comparator (0 –3.5 mg/l) Ion-selective electrode
Arsenic	0.01 mg/l	Health	**Merckoquant strips** (qualitative analysis) (0 – 0.1- 0.5 – 1.0 – 1.7 – 3.0 mg/l) Field PDV (for quantitative analysis) Arsenator (for quantitative analysis) Atomic absorption spectrophotometry/ICP (laboratory-based, requires hydride reduction)
Aluminium	0.2 mg/l	Aesthetic and Health	**Photometer** (0 – 0.5 mg/l) Comparator (0 –0.5 mg/l) Atomic absorption spectrophotometry
Chromium	0.05 mg/l	Health and Aesthetic	**Photometer** Atomic absorption spectrophotometry
Copper	2.0 mg/l (1.0 mg/l)	Health and aesthetic	**Photometer** (0 – 5 mg/l) Atomic absorption spectrophotometry/ICP
Lead	0.01 mg/l	Health	Atomic absorption spectrophotometry
Manganese	0.5 mg/l (0.1 mg/l)	Health and Aesthetic	**Photometer (0 -0.03 mg/l)** Comparator (0 –0.03 mg/l) Atomic absorption spectrophotometry
Mercury	0.001 mg/l	Health	Atomic absorption spectrophotometry/ICP Spectrophotometry
Selenium	0.01 mg/l	Health	Spectrophotometry (>10µg/l) Atomic absorption spectrophotometry/ICP
Cyanide	0.07 mg/l	Health	Spectrophotometry (~0.2 – 6 2µg/l) or Titration (>2µg/l) after distillation Ion-selective electrode

Organics			Laboratory based e.g. GLC. Generally outside this framework.

Table 6.1 Water quality assessment parameters and selected methods of analysis

6.1 Impact of chemical contamination

Many chemicals contribute to the palatability (e.g. pH, salinity, and hardness) of water sources. However, some chemicals constitute a health hazard because of their toxicity (e.g. nitrate and arsenic) and others may lead to indirect adverse health impact because they render the water objectionable and may result in consumers rejecting the water in favour of an alternative, possibly more microbiologically contaminated, source of water. Naturally-occurring chemicals in water are commonly chronically rather than acutely dangerous to health, with exposure to (low) concentrations over a several years being required for long-term impacts on health.

Chronic health impacts have been recently recognised internationally through the concerns over the health effects from bio-accumulation of arsenic and fluoride. Arsenic contamination is being increasingly found in groundwater and surface water in Asia and Latin America. Consuming water with excess fluoride can lead to dental and skeletal fluorosis, a situation that occurs in many countries world-wide. Overall numbers of people affected by high fluoride is probably higher than those affected by arsenic. Acute health impacts due to naturally-occurring chemicals also occur, such as diarrhoea induced by high sulphate levels (for those not accustomed to these levels), but such effects tend to be rare.

Chemicals derived from human activity are also of concern for health. Of these, the serious health risk posed to infants (particularly under six months of age) by high nitrate concentrations is the most important. Poor recognition (because of usual concurrent diarrhoea) and/or documentation of nitrate-induced methaemaglobinaemia in developing countries is almost certainly leading to under representation of the disease burden it causes. Other anthropogenic pollutants may also cause health problems although, like the naturally-occurring chemicals, these tend to have chronic impacts unless a specific poisoning event occurs.

In addition to the health and aesthetic impact of physical and chemical quality of water, it may also affect the selection and efficiency of treatment processes. There can be marked cost impacts of changes in parameters such as pH, colour or iron, for instance through increased coagulant and/or chlorine demand. In communities unable to meet these additional (possibly seasonal) demands there may be a sudden decrease in the quality of distribution water, with a potential for serious effects on health.

6.1.1 Source water

When a water source is being developed, a pollution risk assessment should be undertaken with a full suite of chemical analyses being performed for parameters identified. This data should be used to evaluate whether the source could used and whether additional treatment is required. The role of regular and systematic pollution risk assessments in the catchments of water sources that are used for drinking is important in determining whether additional chemical parameters need to be included in assessment and monitoring programmes. Changes in land-use, new industrial developments and urban growth within the catchment should be carefully evaluated in the light of potential pollutants that may be produced.

6.1.2 Treated (distribution) water

The chemical parameters of concern in distribution water relate to chemicals present in the source water and to those used in the treatment process (e.g. aluminium). The aim of the assessment may be both to assess the potability of the treated water, the efficiency of the treatment process, the integrity of the distribution system and/or household management of water.

In general most other chemicals need not be monitored in distribution systems, although colour and conductivity should be tested in distribution as should nitrate (because of the risks of ingress of contaminated water), iron (because of corrosion of galvanised iron pipes) and lead (where lead pipes are used in plumbing).

6.2 Selection of parameters

The selection of chemical parameters for monitoring and assessment programmes should reflect their occurrence in the country/area and water source types; the potential health impact; the analytical capacity; and, the ability to remove the parameter through treatment or source protection measures. The cost of analysis for some parameters is relatively high, notably those present at low levels but known to bio-accumulate (such as organics and heavy metals). Priority should be given to those chemicals that will lead to rejection of water supplies or that have known toxic effects and which are persistent in water.

To assist in evaluation of physical and chemical parameters for their inclusion in the monitoring programme, brief details of the major parameters of concern are provided below. Further information on these and additional parameters can be found in a number of other documents, including the 2nd edition of the WHO Guidelines for Drinking water Quality Volumes 1 and 2 (and appropriate addenda), the WHO Protocol for the selection of chemicals for inclusion in monitoring programmes and in the manuals on water surveillance available at the watermark website: www.lboro.ac.uk/watermark

6.2.1 Physical parameters

The physical parameters considered are detailed in table 6.2. Note that pH and turbidity, although they are physical parameters, are described and discussed in the section on microbiological quality.

Parameter	WHO Guideline value	Reason for inclusion	Recommendation
Colour	15 TCU	aesthetic, indirect health	Level 1-3
Conductivity	-	aesthetic, indirect health	Level 1-3
Odour (and taste)	Should be acceptable	aesthetic, indirect health, treatment	Not included (to subjective)
pH	<8.0 in chlorinated water supplies	treatment	Level 1 (with microbiological assessment)
Turbidity	5 NTU	aesthetic, health, treatment	Level 1-3 (with microbiological assessment)

Table 6.2 Physical parameters

6.2.1.1 Colour

This parameter is of concern because it affects acceptability of the water to the consumer and can indicate the presence of other pollutants such as metals (e.g. iron), organic acids (e.g. from decaying vegetation), suspended solids or industrial wastes (e.g. from tannery or textile processing). Some colour, especially organic, can be difficult to remove without tertiary treatment such as activated carbon.

Natural colour in water tends to be yellow/brown and may be associated with increased turbidity. For boreholes, changes in colour over a period of time may indicate corrosion of the rising main (if metallic) as natural colour of (deep) groundwater is not prone to significant change with time. For shallow groundwater and surface water, changes in the short-term are generally indicative of contamination either due to rainfall or anthropogenic pollution sources and indicate a need for remedial action. Changes in colour with time should be investigated through more detailed analysis: if a survey indicates industrial pollution is the cause then a laboratory capable of detailed chemical analysis will need to be identified.

Monitoring colour may be through observation only (simple and virtually cost-free) or by colour measurement using a light box or a spectrophotometer and standards e.g. Hazen units or platinum colour units. In the first case, a qualitative assessment of the *appearance* of water would be made (clear, cloudy, murky etc), whilst in the second case a quantitative assessment is made.

Recommendation

Although this parameter does not provide information about specific chemicals in water, it can act as a good indicator of water quality problems, particularly when it changes with time. It is recommended as a parameter in all levels of assessment because of this and because of the ease and cost of assessment. In level 1assessments, a qualitative assessment of appearance is adequate, but quantitative assessment should be made at higher level assessment. Colour should be tested on all water samples taken.

6.2.1.2 Odour (and taste)

Both of these parameters lead to customer dissatisfaction and complaints and can also require additional treatment process for their removal from raw waters. It is inadvisable to taste water of unknown chemical and/or microbiological quality. If consumers complain about either of these parameters further assessment of water quality is recommended.

Recommendation

Although odour does not provide information about specific chemicals in water, it may be considered as an indicator of water quality problems, particularly if it changes with time. However, despite being virtually cost-free, assessment of odour (and taste) is very subjective so its inclusion in assessments is not recommended.

6.2.1.3 Conductivity

Conductivity, the ability of water to carry an electric charge, can be considered a proxy indicator of dissolved solids (conductivity of 1400 µS/cm being equivalent to a total dissolved solids value of ~1000 mg/l) and is, therefore, an indicator of the taste/salinity of the water. Whilst there is little direct health risk associated with this parameter, high values are associated with poor taste and hence customer dissatisfaction and complaints. Changes in conductivity with time and also high conductivity values can indicate contamination of the water (e.g. saline intrusion, faecal pollution or nitrate pollution) and can cause corrosion in rising mains and pipes. In this situation, further analysis of the water is recommended.

Recommendation
Although this parameter does not provide information about specific chemicals in water, it can act as a good indicator of water quality problems, particularly when it changes with time. It is recommended as a parameter in all levels of assessment because of this because of the ease and cost of assessment. A variety of inexpensive field and lab-based equipment is available for this. Conductivity measurements should be made on all water samples taken for analysis.

6.2.1.4 Other physical parameters
Hardness is often considered a major problem. For instance, in some countries water sources may be rejected for aesthetic reasons when the water is hard. However, there is no evidence of any health-related problems derived from hardness although there is some evidence that hard waters may lead to a lower risk of cardio-vascular disease. Hardness is primarily related to acceptability of the water and operational efficiency; very hard water may interfere with filtration and cause deposits to build up pipes reducing their internal diameter. In Zimbabwe, one water supply that took its water from an abandoned gold mine shaft had water that was so hard it formed calcretes (a carbonate rock) in the sand filter beds.

Corrosivity is also important for water suppliers to monitor as this may cause deterioration in the distribution network and lead to greater leakage problems.

Total dissolved solids (TDS) may also be a concern, principally for aesthetic and treatment reasons. Conductivity (see above) can be used as a proxy indicator for TDS in the field where its determination is simple.

Recommendation
These parameters are principally of technical concern and are not recommended for inclusion in assessments for most levels. They should be included in level 3 assessments to provide a complete assessment of water quality.

6.2.2 Chemical parameters

Parameter	WHO Guideline value mg/l	Reason for inclusion	Recommendation
Nitrate	50 (as NO_3)	health	Level 1
Ammonia	1.5	aesthetic, treatment,	Level 1 (if local problem) Level 2
Iron		aesthetic, treatment	Level 1
Manganese	0.5 (P)	aesthetic, treatment	Level 1 (option) Level 2
Arsenic	0.01 (P)	health	Level 1 – qualitative Level 2 - quantitative
Fluoride	1.5	health	Level 1
Lead	0.01	health	Level 2
Chromium	0.05 (P)	health	Level 1 (option) Level 2
Copper	2 (P)	health	Level 1 (option) Level 2
Aluminium	0.2	aesthetic	Level 2
Mercury	0.001 (total)	health	Level 2
Selenium	0.01	health	Level 2
Cyanide	0.07	health	Level 2
Organics	Varies with compound	health	Level 2 if problem known Level 3

Table 6.3 Chemical parameters
NB: P = Provisional Guideline Value

6.2.2.1 Nitrate

Nitrate is one of the most ubiquitous chemical contaminants of water bodies world-wide as it is derived from human activities and in particular from the disposal of human wastes and the use of inorganic fertilisers in agriculture. Nitrate is of concern because of its link to methaemoglobinaemia or 'blue-baby' syndrome. Although the actual health burden from nitrate is often considered relatively insignificant (because of breast-feeding practices etc), it is likely that the health burden is significantly under-reported.

Nitrate is also of particular concern because of its conservative nature in water that is oxidising. Once nitrate has entered a water body that is oxidising, only the processes of dilution and hydrodynamic dispersion are likely to cause significant reductions in concentrations until the input load is reduced. Thus if nitrate is allowed to increase in source waters, then long-term resource problems may result leading to costly investments later. As nitrate is extremely expensive and difficult to remove during treatment, blending nitrate-rich waters with low nitrate waters may be the only viable option.

It should be noted that in reducing or non-oxidising waters, nitrate may not be formed as organic nitrogen would be converted to ammonia and any nitrate present may be reduced to nitrite and then to ammonia or released as nitrogen gas from the action of de-nitrifying bacteria. When sampling such water nitrate should either be determined on-site or be fixed for transport to the laboratory for analysis. As there are a number of field methods available for determination of nitrate, e.g. the chemical strip test; colour comparator method, photometeric and spectrophotometric methods, field determination is recommended. Use of nitrate-specific electrodes is not recommended because of the relative complexity of the method and its variable sensitivity.

Recommendation
Nitrate should be included at all levels of assessment as a core parameter. Tests should be performed on all samples taken from water sources. Analysis within distribution systems and household waters should be done on roughly one-quarter of all samples taken for microbiological analysis.

6.2.2.2 Ammonia

Ammonia (non-ionised NH_3 and ionised NH_4^+) is found in both groundwater and surface water sources. If it is from natural sources the concentrations are low (usually <0/2 mg/l) whereas higher concentrations indicate anthropogenic origins (human wastes, livestock agriculture and industrial activities). Under anaerobic conditions organic nitrogenous waste is converted to ammonia with levels reaching ~3mg/l in groundwater. In oxygenated surface water ammonia will be converted to nitrate (via nitrite) but pollution loading can result in concentrations much higher than 3 mg/l. The presence of ammonia in surface water can serve as an indicator of pollution by sewage/animal waste and, potentially, pathogens: such pollution should be considered of concentrations are >0.1 mg/l.

Ammonia, in drinking water, whilst not of immediate health importance, does have aesthetic impacts (odour threshold concentration of 1.5 mg/l at alkaline pH and taste threshold of 35 mg/l) which may lead to consumers rejecting the water in favour of an alternative, less safe source. NB: Ammonia is very toxic to aquatic organisms at concentrations as low as 0.06 mg/l.

There are a number of field methods available for determination of ammonia, e.g. the chemical strip test; colour comparator method, photometeric and spectrophotometric methods. Field determination is recommended for level 1 assessments (if ammonia is included as an additional parameter). Higher level assessments may use laboratory-based methods for determination of all nitrogen species (organic nitrogen, ammonia, nitrite and nitrate).

Recommendation
Ammonia in drinking water does not have a health-based GLV so is not included in the Level 1 assessments. However, it does act as an indicator of possible faecal pollution and, in countries where such pollution is a particular problem, its assessment as Level 1 may be justified.

6.2.2.3 Iron (and Manganese)

Both iron and manganese may cause rejection of water by consumers because of the colour that develops when iron oxidises into the ferric state. Iron and manganese cause colouring of clothes and sanitary ware. Iron contamination is a particular problem with groundwater supplies and is usually due to the oxidation of ferrous iron in the water itself, but may also be caused by corrosion of galvanised iron riser pipes and, in some cases, the action of iron bacteria. Some surface waters also have iron problems, particularly related to colloidal iron.

Manganese is most commonly associated with surface water sources where water is pumped from lower levels and the bottom sediment is disturbed.

The analysis of iron and manganese is carried out at the wellhead/source and the treatment works. Testing of distributed waters is likely only to be done in response to complaints or where there are old galvanised iron mains pipes. As there are a number of field methods available for determination of iron and manganese, e.g. the chemical strip test; colour comparator and spectrophotometric methods, and because iron may precipitate out of solution with time, field determination is recommended.

Recommendation
Iron and manganese are mainly of aesthetic importance. Iron and manganese from natural sources normally occur together, therefore monitoring for one could be used as an indicator of possible problems with both parameters. It is recommended that iron be a core/primary parameter for the assessment because of the impact on aesthetic quality and also because of its presence (and potential problems) in some rising mains and pipes. Water treatment processes for the removal of iron also remove manganese; however, if manganese is known to be of particular regional/local concern then it may also be added to the level 1 monitoring programme, otherwise it should be included from level 2.. Tests should be performed on all samples taken from sources of water and from 10% of samples taken from distribution systems and households.

6.2.2.4 Arsenic
Arsenic is an element that is known to bio-accumulate in humans (as well as being subject to bio-amplification up the food chain) and be associated with skin disease and cancers. Drinking water with low concentrations (of 50 µg/l or lower) over a number of years can result in toxic concentrations in humans and carcinogenic effects may develop in some individuals.

Whilst most arsenic in water is naturally occurring, being derived from dissolution of arsenic-bearing minerals associated with volcanic activity, it may also be anthropogenic, being associated with mining and other industries. It became one of the principal water quality issues in the late 1990s because of its (increasing) presence in groundwater in Bangladesh and neighbouring countries. Prior to the development of this situation in Asia, data on the presence of arsenic in water were limited, mainly because of the need for laboratory based, sophisticated equipment for arsenic determination at these low concentrations. Recently new laboratory and field methods have been developed and these are helping to clarify the extent of arsenic presence in water world-wide, which appears to be extensive in Asia and Latin America.

There are field methods for qualitative determination of arsenic at concentrations above and below the current and prior WHO recommended guideline values of 10µg/l and at 50µg/l, respectively: these methods would typically be used for level 1 assessments. The cost of the more accurate quantitative equipment prohibits its adoption in all countries, but would be worthwhile on a small number of samples for level 1 assessment where resources permit and for larger numbers of samples in level 2 and 3 assessments.

Recommendation

Arsenic in drinking water, even at low concentrations, is toxic in the long-term and is associated with skin disease and cancers. It is, therefore, recommended that qualitative analysis for arsenic be included in the level 1 assessment in all pilot countries and not just in countries or districts where it is known or strongly suspected to exist. If level 2 or 3 assessments are undertaken, quantitative analysis for arsenic should be included unless there is good evidence to suggest it will not be present. Tests should be performed on all samples taken from water source types at risks in areas suspected to have arsenic contaminated water.

6.2.2.5 Fluoride

Excess fluoride is associated with dental and skeletal fluorosis that may cause severe deformation and disability in susceptible individuals. If no data on the presence of fluoride in water is available it should always be suspected if people have mottled teeth or skeletal deformities. However, a lack of fluoride is also associated with dental caries and therefore in some countries fluoride is added to drinking water to improve dental health. This remains a controversial issue and may not be the most effective mechanism to reduce the incidence of dental caries. Although fluoride may be released by industrial pollution, the majority of fluoride found in drinking-water supplies at levels of health concern is derived from natural sources. Fluoride should always be analysed during source development, in particular for groundwater sources.

Fluoride can be determined in the field using a spectrophotometer or colour comparator; it can be determined by these methods in the laboratory or by use of ion-specific electrodes.

Recommendation

There are significant health effects of long-term exposure to fluoride in water. It is, therefore, recommended that fluoride is included in the assessment in countries and districts where it is known or strongly suspected to exist. It therefore would qualify as a level 1 assessment parameter, as it would not be undertaken in all countries or even in all parts of a particular country. If level 2 or 3 assessments are undertaken, fluoride should be included unless there is good evidence to suggest it will not be present. Tests should be performed on all samples taken from water source types at risk in areas suspected to have fluoride contaminated water.

6.2.2.6 Lead

The most significant health effect from lead is the association of lead exposure with reduced cognitive development and intellectual performance in children. Although other environmental transmission routes such as air and food are important, drinking-water can be a significant reservoir of lead. This is usually derived from lead pipes used in household plumbing systems, lead solders and, in some cases, where lead has contaminated treatment chemicals. There are also natural sources of lead in groundwater and some industrial discharges may also contain lead.

There is no simple field method for quantitative determination of lead at concentrations normally occurring in water supplies: atomic absorption spectrophotometry (or method of equivalent high sensitivity) is required.

Recommendation

There are significant health effects of long-term exposure to lead in water. However, the laboratory-based assessment method required recommend that it is included in level 2 rather than level 1. In countries and districts where it is known or strongly suspected to exist and there is the internal capacity for quantitative analysis, countries may wish to add lead to their level 1 programme. If level 2 or 3 assessments are undertaken, lead should be included unless there is good evidence to suggest it will not be present. Tests should be performed on all samples taken from water source types and distribution systems in areas suspected to have lead-contaminated water.

6.2.2.7 Aluminium

Aluminium in drinking water is usually derived from poor operation of coagulation-flocculation-settling steps in water treatment leading to carry-over of micro-floc into final waters. Testing of aluminium in drinking water is primarily justified in terms of treatment efficiency monitoring. Aluminium in water affects consumer acceptability (taste and appearance).

Aluminium can be determined in the field using either a (spectro)photometer or colour comparator or in the laboratory by atomic absorption spectophotometry.

Recommendation

It is recommended that aluminium be included in level 2 assessments unless there is significantly high concern about its presence from natural sources or from breakthrough from inadequate treatment facilities when it should be designated as a secondary parameter. Testing should be done using field based methods for level 2 assessments with corroboration with laboratory methods in level 3 assessments of water from treatment plants.

6.2.2.8 Other (heavy) Metals

Metals such as chromium, copper, mercury and cadmium have chronic health impacts as well as affecting consumer acceptability of water (taste). They may be of natural or anthropogenic origin, with the later being of increasing importance in industrialising and urban areas. Testing is justified if there is either a known and on-going industrial pollution concern (e.g. chromium in tannery wastes) or a planned change in land-use leading to release of metals or evidence of past industrial pollution where sediments contain metals that can be released into the water source.

There are a range of field methods available for most metals, including Merckoquant strips and photometric methods. Laboratory-based analysis is also an option for these parameters as, being elements, they do not deteriorate with time.

Recommendation

It is recommended that metals such as chromium, copper, mercury and cadmium be included in level 2 and 3 assessments of water sources but that one heavy metal (in addition to iron) be included in level 1 This metal should be chromium, copper or manganese (for which photometric methods are available), with selection being dependent on natural and anthropogenic sources within each country.

6.2.2.9 Cyanide

Cyanide occurs in water principally as a result of industrial pollution. It also occurs in some foodstuffs, particularly in countries where cassava is a major component of the diet. Cyanides are toxic, causing chronic effects on thyroid and nervous system function and also exacerbating vitamin B_{12} deficiency. Ingestion is normally higher through food than through water sources.

Cyanide should be measured (or fixed) on site because it is unstable in water. Although it can be determined in water by both titrimetric and photometric techniques (>2µg/l), photometry is the preferred method in the field.

Recommendation
In most locations there is a low risk of cyanides being present in water so it is recommended that this parameter should only be included in level 2 and 3 assessments of water sources.

6.2.2.10 Selenium
Selenium, which is an essential mineral, is usually of natural origin when it occurs in water, with concentrations tending to be higher in groundwater than in surface water. Ingestion in food is, however, the principal source of selenium in humans. Long-term exposure to selenium can cause a number of symptoms, principally degenerative changes in hair, nails, skin and liver. Data in China showed that clinical and biochemical signs were manifested when the intake was >0.8 mg/d (WHO, 1993 and 1996). Selenium in water is most commonly measured by atomic absorption spectrophotometry with hydride reduction (detection limit of 0.5µg/l in a 10ml sample).

Recommendation
It is recommended that selenium be included in level 2 and 3 assessments of water sources and that a watching brief be placed on developments relating to the toxicity of this element.

6.2.2.11 Organics (including pesticides)
A great deal of attention is focused in many parts of the world on the monitoring of organic chemicals and pesticides in water bodies. Much of this concern has been driven by concerns in Europe and North America, but is also increasingly being considered in many low and middle-income countries. Whilst many of these products are of concern to health, the true nature and severity of their impacts often remains uncertain.

Analysis of organics and pesticides is expensive and requires large capital investment in analytical equipment and training if it is to be effective. Before embarking on assessment of these substances, it is essential that proper consideration is given to a number of key factors:

- What is the extent of the problem likely to be – is there is strong evidence of the likely presence of organics and pesticides in water sources at present or in the near future?
- What contribution will be expected to be derived from drinking water and how much from, for instance, food products?
- How severe a health problem is likely to result – are infant mortality rates and diarrhoeal disease high and life expectancy low?

Unless there is good evidence that organic substances are currently found or will be found in the near future at levels that may compromise the health of a large proportion of the population, the inclusion of such substances in *drinking* water quality assessment programmes is not justified. It may therefore be sufficient for results from environmental water assessments to be used as an indication of the scale and nature of the problem.

Recommendation
Organic chemicals should only be included in level 3 assessments. The potential for increase in contamination should be assessed through an ongoing programme of pollution risk assessment of source catchments. Once this is perceived as being sufficiently raised, then a programme of assessment could be initiated if/when resources permit.

6.3 Equipment recommendations

For level 1 assessments, the available field equipment should be adequate to undertake all the necessary physical and chemical analysis required. Photometers or colour comparators are generally preferred to spectrophotometers as they are cheaper and more portable. Where appropriate, hand-held meters may also be used for certain physical parameters. The methods recommended for the rapid assessments are outlined in Table 6.1 (the recommended method for level 1 is shown in bold typeface) and summarised in table 6.4.

6.4 Quality control

Quality control requires careful consideration of a number of aspects of the analytical process. There are a number of key terms that are commonly used, such as precision, reliability and accuracy. In terms of these assessments, the principle focus will be on precision - that is the degree to which two tests performed on the same sample agree with each other. Measures of accuracy and reliability will be more difficult to perform for level 1 assessments, where it would be expected that data was more limited, but may become more feasible in level 2 and 3 assessments.

Analytical quality control is most easily achieved for the chemical parameters by using a split sample approach. A reasonable level of precision for these assessments is 90% - that is the result of the both tests should be within 10% above or below the average value. This is calculated for by finding the difference between result 1 and the average and dividing this by the average and then multiplying by 100. For example:

Example A	**Example B**
Result 1A = 2.4 mg/l	Result 1B = 3.3
Result 2A = 2.8 mg/l	Result 2B = 2.5
Average A= 2.6	Average B = 2.9
Precision	
Result A = [(2.4 -2.6)/2.6] x 100 = -7.7%	Result B = [(3.3 – 2.9)/2.9] x 100 = 13.8%

The above example indicates that the result A is acceptable but result B is not. If the result is outside of the 90% compliance, this data should be marked as being suspect. If very few data fall outside the 90% compliance then all suspect data should be discarded for analysis. If very many data are suspect, then all the data should be analysed, but the report must highlight the quality control problems and therefore the potential limitations in any conclusions drawn.

Generally, where data are suspect, the first result should be used in the analysis as parameter values change with time so the first result should be closest to the actual value.

6.5 Recommendation for the rapid assessments

The main physical and chemical parameters for water quality assessment have been discussed, based on which, recommendations for their inclusion in rapid assessments have been made. Table 6.4 summarises recommendations for level 1 rapid assessment parameters (physical, chemical and microbiological) and other assessment methods.

Parameter category	Recommended parameters	Recommended methods
Microbiological and related	Thermotolerant coliforms Faecal streptococci Turbidity pH Chlorine residuals	Field Kit containing: Membrane filtration equipment Turbidity tube Comparator/Photometer
Inspections and risk assessments	Sanitary inspection Pollution risk assessments	Sanitary survey forms Environmental risk appraisal forms Brief interviews at treatment works
Physical and chemical	Colour (appearance) Conductivity Nitrate Iron Fluoride Copper or Chromium or Manganese Arsenic	Comparator/Photometer Pocket meter Photometer Photometer Photometer Photometer Qualitative colour strips

Table 6.4 Level 1 parameters and other assessments

7.0 Analysing data

The data in level 1 assessments should be stored in the Sanman database provided, which has a manual for its use. This database provides a structured and easy to use approach and provides a range of simple and clear reports. For level 2 and 3 assessments, software available in the organisations undertaking the assessment should be used.

In every country, one person should be responsible for data management and handling. This person should also take overall responsibility for data analysis. By preference, this person should be a statistician involved in the design of the study. Either the person with overall responsibility for data management or another member of staff within the data management team should be responsible for quality control in the input of data. This will involve checking that data input has been accurate.

The analysis of data is the principal mechanism by which raw data can be transferred into usable information for managers, communities and other decision-makers. Raw data is of relatively little use – most people will not understand what it means unless that have been directly involved in its collection and few will have sufficient time or interest to analyse data. What is required is simple, direct and comprehensible information that can be used without further manipulation and is meaningful to the target audience. The analysis of the data is therefore very important for the report, the format for which is given later in this document.

The database used is a numerical relational database. One crucial point to remember when analysing this data is that the microbiological data is unlikely to follow a normal distribution and will have a considerable number of ‘outliers’ (very high or low values). This may include tests that give a result that is too numerous to count (TNC/TNTC), which should be assigned a default value which is higher than the maximum countable result. Because of these reasons, the median rather than the mean should be used as the measure of central tendency. The median is not affected by extreme values and is a powerful statistic commonly used in water resources and water quality data analysis. Most other statistical analysis should also use non-parametric tests, such as ?^{2}, Kruskal-Wallis and Mann-Whitney U-tests. These are commonly used and show no loss of power in comparison to parametric tests.

For data on chemical parameters, it may be possible to use parametric tests, including the mean, standard deviation, students t-test and ANOVAs if there are no extreme outlier values. However, in many cases, there may either be a significant number of samples with results below the level of detection or very high values. Therefore, non-parametric tests such as those noted above may also be useful.

7.1 Basic data analysis

The basic analyses required will to be describe

- Number and proportion of sources for each source type failing to meet WHO Guidelines for each parameter
- Number and proportion of sources for each source type failing to meet national standards/guidelines for each parameter
- Median, inter-quartile range (25-75 percentile range) and distribution of microbiological

quality results (quote the 10 percentile and 90 percentiles to exclude outliers)

- Median (or mean), inter-quartile range (or standard devaiation) and distribution of physico-chemical quality results (quote the 10 percentile and 90 percentiles to exclude outliers)
- Median, inter-quartile range (25-75 percentile range) and distribution of sanitary inspection results (quote the 10 percentile and 90 percentiles to exclude outliers)

7.2 Understanding sanitary inspection data: a measure of O&M

One key element will be to analyse and comment on the maintenance of sanitary integrity (part of operation and maintenance) of the sources and to comment on what implications this may have for overall sustainability of water supply and hygiene interventions. This is a simple analysis looking at the sanitary risk score for water sources. Water supplies with a high risk score have compromised sanitary integrity and indicate weak operation and maintenance. Once an overall risk score exceeds 60%, the supply can be categorised as poorly managed and likely to be contaminated. Therefore, this simple assessment of sanitary integrity can be analysed and commented upon in relation to different water source types.

For point water sources, all the risks included in the sanitary inspection reflect on the operation and maintenance of the water supply. For piped water, measurement of operation and maintenance can focus on certain factors whose presence indicate fundamental weaknesses in O&M performance. The sanitary inspection forms for treatment works provides an effective way of assessing operation and maintenance performance during the water production phase. For distribution systems, the supply risks incorporated within a sanitary inspection cover the basic aspects of good sanitary risk management that it would be expected that a water supplier would control. These include aspects such as signs of leakage, reported pipe bursts, discontinuity within supply and the state of service reservoirs.

A further means of assessing operation and maintenance and in particular adherence to cleaning and flushing schedules, is to plot chlorine residual levels within the system and in particular to relate these to zones based on service reservoir. Mapping of chlorine residual loss provides information regarding whether the loss is due to volatilisation or due to chlorine consumption. Free chlorine loss during distribution that is not associated with total chlorine loss would be associated with chlorine consumption and would indicate that operation and maintenance has been poor and that cleaning and flushing are required. Total chlorine loss indicates volatilisation is part of the cause and whilst cleaning of reservoirs and flushing of lines may provide some temporary improvement, it may not deal with the fundamental problem of chlorine loss. In the latter case, it would be more realistic to recommend that booster chlorination be practised.

The sanitary inspection forms for piped water supply will also typically include local risks that are within the remit of the household or community to control. This covers aspects such as exposure of the household main, water collecting around the base of taps and leaks within the household main. The presence of these risks will indicate whether local operation and maintenance around the facility has been compromised and therefore remedial action and strengthening of local maintenance is required.

The next three section provide more detail on how more complex statistical analyses may be performed on the water quality and sanitary inspection data. They are written for readers with a good understanding of the statistics and access to software for statistical analysis. The analyses discussed are not essential but it is recommended that countries consider this analysis as it will enhance the value of the data collected in decision-making.

7.3 Identifying the causes of microbial contamination in point sources

The water quality and sanitary inspection data can be analysed together to evaluate which are likely to be the main controlling factors on microbiological contamination. For point sources analysis can be relatively simple or highly complex. However, it should be emphasised that the complexity of analysis will not necessarily mean that the power of the conclusions are any stronger. In some cases simple analysis will provide results in which a high degree of confidence can be placed. In other cases, more complex analysis may be required in order to provide a more accurate reflection of the factors in water quality deterioration. In some cases, only simple analysis is required as there is little variation in water quality – i.e. the same source either remains significantly contaminated or free of contamination. This may be the case where hazards are the primary cause of failure and when deeper point sources are used.

In very shallow groundwater, such as gravity springs, individual sites may show very significant variation in quality over time and it may be less easy to determine which factors are causing the failure. This then requires more complex analysis of data and development of models.

The process of risk factor evaluation can follow a simple procedure. Critical to this is to decide what exactly is being assessed and in particular an evaluation is being made regarding the incidence of contamination above a specified level or severity of contamination found in an open-ended format. These are fundamental different measures and different risk factors may be important in different aspects of contamination.

The simplest way to evaluate the impact of particular sanitary risk factors on contamination is to assess the relationship between the presence of each factor and exceeding a water quality target. The most appropriate water quality targets to use are those based on health concerns, such as those in the WHO Guidelines for Drinking-Water Quality or national standards. Although there is an increasing move to define health-based water quality targets for pathogen groups, this will usually be converted into performance targets for water supply maintenance and in relation to microbial indicator organisms.

When analysing water quality and sanitary inspection data from the rapid assessments, the purpose is not to make direct comments on the public health risks but to investigate the association between the presence of particular factors and exceeding a water quality target. For utility systems with chlorination, the most appropriate target will be an absence of thermotolerant coliforms and faecal streptococci. For untreated community-managed supplies, it may be more appropriate to use a higher target, such as less than 10 cfu/100ml.

A very simplistic way of analysing this data is to compare the frequency of risk factor reporting when a water quality target is met and when it is exceeded. If the risk factor is more commonly reported as being present when the water quality target is exceeded, this suggests that there is an association between the risk factor and contamination. An examples is shown in table 7.1 below.

Risk factor	Frequency <10 FC/100ml	Frequency =10FC/100	Difference
Surface water uphill of spring	45	95	+50
Other pollution uphill	43	84	+41
Eroded backfill	35	58	+23
Diversion ditch absent or faulty	76	95	+19
Masonry faulty	12	26	+14
Flooding of collection area	76	89	+13
Fence absent or faulty	82	95	+13
Animal access within 10m	76	84	+8
Latrine uphill within 30m	4	0	-4

Table 7.1 Combined sanitary inspection and water quality data analysis for protected springs, Kabale, Uganda

This very simple analysis provides relatively weak evidence for associations, as positive relationships may not be statically significant. To obtain results that have statistical significance, the data should be analysed using contingency tables or logistic regression models. Such analyses are effective tools for data analysis and interpretation and relatively easy to perform, especially if statistics software is available. The first type of analysis is very useful when testing the statistical significance of associations between the presence of sanitary risk factors and exceeding a water quality target. The second is useful when trying to model the influence of multiple factors on an outcome. It is recommended that this analysis is done only if there is access to software such as SPSS and this section is written for professionals who have access to and know how to use such software. It is possible to do this analysis without computer software, but this approach is not described here.

In order to undertake the analysis of this data, the water quality data should be transformed into binomial data. This means it is converted into data that can only be either yes or no – for instance, if a water quality target is exceeded then the data will be converted into a ‘yes’ and if the water quality target is met the answer is no. This is the same type of data as the data on individual sanitary risk factors. As the analysis that follows requires numerical data, the binomial data must be dummy-coded, that is a numerical value is assigned. For the analysis with sanitary inspection data, it is most convenient to code the yes answers as 1 and the no answers as 0. This is because the presence of a risk factor should, in principle, be related to the exceeding of a water quality target.

In contingency tables, the statistic most used are odds ratios, which for binomial data is the ratio of the probability of obtaining a score of 1 divided by the probability of obtaining a score of 0. An odds ratio (OR) exceeding 1 indicates that a positive relationship exists between the factor and the outcome whereas a score of less than one indicates that a negative relationship exists. An example of a contingency table is shown in table 7.2 below. In this table, p is the significance of the odds ratio calculated and the 95% CI column refers to the range of values lying with the upper and lower bound estimates of the 95% confidence level.

Risk factors	Exceeding water quality target of <10 cfu/100ml		
	Odds ratio	**p**	**95% CI**
Faulty masonry	1.29	0.278	0.81-2.06
Backfill area eroded	2.51	<0.001	1.56-4.06
Collection area floods	0.97	0.905	0.59-1.60
Fence absent or faulty	2.96	0.039	1.05-8.29
Animal access <10m	1.96	0.184	0.73-5.31
Latrine <30m uphill of spring	1.45	0.583	0.38-5.52
Surface water uphill	1.88	0.030	1.06-3.33
Diversion ditch faulty	2.14	0.003	1.30-3.53
Other pollution uphill	1.51	0.078	0.96-2.37

Table 7.2: Contingency table analysis

Logistic regression is a statistical test that allows regression analysis of discrete data. It is a powerful tool for analysing the influence of multiple factors on an outcome variable in the same way as linear (multiple) regression analysis for continuous data. Some key components of logistic regression are the model log estimate (*-2LL*) which is a goodness of fit measure of the model and determines the degree to which the observed values deviate from the predicted values. For each variable in the model, a regression co-efficient is defined, as well as the standard error associated with the predicted value of the dependent variable. The Wald statistic is also provided for each variable, which tests the hypothesis that the regression co-efficient for the explanatory variable is zero (has no effect on the dependent variable). An example of a logistic regression model in shown in table 7.3 below. Within this table, SE refers to the standard error (the standard deviation of the sampling distribution) and p refers to the significance of the variable co-efficient..

Model log estimate	Variables in model	Variable coefficient	p	SE	Wald
392.57	• Constant	0.63	0.003	0.21	8.84
	• Backfill area eroded	-0.88	<0.001	0.25	12.55
	• Diversion ditch missing/faulty	0.72	0.006	0.26	7.49

Table 7.3: Logistic regression model

There are several different ways of undertaking logistic regression. One useful method is the backward stepwise model. In this approach, a number of factors are included at the start of the analysis. The analysis then goes through a number of iterations with factors of no significance are removed until a final model that best fits the data is arrived at. Thus, the final logistic regression may have only a few terms. The factors included at the start can either be all those in a sanitary inspection or only those where contingency table analysis showed a significant association.

7.4 Identifying the causes of microbial contamination in piped water supplies

When using the sanitary inspection data to determine whether water quality failure relates to either local or supply risks, it is important not simply to look at microbiological data but also chlorine residual levels. The effective of chlorine and other disinfectants on micro-organisms in water is a function not only of the concentration of the free chlorine that causes inactivation but also of the time for which a micro-organism is exposed to the chlorine – the Ct value.

When water undergoes terminal disinfection, dosing is usually based on the chlorine demand - i.e. how much chlorine is required to achieve full disinfection. It is usual for a chlorine residual to be maintained during distribution to ensure that protection is provided against subsequent ingress of contaminated surface or groundwaters. For chlorine this is usually a minimum of 0.2mg/l, although in some countries lower levels (such 0.1mg/l) are accepted. Given that disinfectants rely on both concentration and time, microbiological failures may occur if the source of pollution is close to the sampling point and there is a direct entry for the pollutant into the pipe. This typically relates to stagnant water around the riser pipes or the presence of wastes either directly in contact with or very close to pipes. The free disinfectant residual in such cases is unlikely to be able to inactivate all bacteria and other microbes unless it is at a very high level (e.g. exceeding 1mg/l for chlorine).

Similar statistical analyses as those described for point sources can used to evaluate the influence of specific sanitary risk factors and chlorine residuals on exceeding a water quality target. It is recommended that both free and total chlorine residuals are included within the analysis, as this may provide an indication of whether low free chlorine residuals when microbial indicators are present are caused through consumption by ingress of contaminated water or whether the level of chlorine in the water was inadequate to start with. Examples of a contingency table and logistic regression for chlorinated piped water supplies is shown in table 7.4 and 7.5 below.

Risk factor	**Statistics**		
	Odds Ratio	**p**	**95%CI**
Tapstands lack support	1.87	<0.001	1.17
Surface water around tap	2.98	<0.001	1.83
Area uphill of tap eroded	0.48	<0.001	0.36
Piped exposed close to tap	1.18	0.324	0.77
Human excreta <10m of tap	1.01	0.938	0.74
Sewer <30m of tap	1.00	0.998	0.83
Discontinuity <7 days	1.12	0.585	0.90
Signs of leaks in Parish	0.86	0.359	0.26
Community report pipe break <10days	1.98	0.008	2.08
Main pipe exposed in Parish	2.20	<0.001	1.62
Adequate free chlorine	0.28	<0.001	0.73
Adequate total chlorine	0.21	<0.001	0.62

Table 7.4: Contingency table for sanitary risks in piped water supply

Model log estimate	Variables	Variable coefficient	p	SE	Wald
736.76	• Constant	1.05	0.013	0.43	6.13
	• Surface water around tap	-0.73	<0.001	0.20	13.79
	• Main exposed in Parish	-0.69	0.004	0.24	8.15
	• Discontinuity in last 7 days	-0.45	0.072	0.25	3.25
	• Supply management	-3.33	<0.001	0.22	210.32
	• Adequate free chlorine	0.98	<0.001	0.25	15.98
	• Adequate total chlorine	0.82	<0.001	0.20	16.87

Table 7.5: Logistic regression model for piped water supply

The advantage of this type of analysis is that other factors (for instance the nature of the organisation operating the supply) can also be incorporated into the analysis as a dummy-coded variable. This may be of value in situations where it is believed that some organisations are more effective water supply managers than others. This should be included within the data analysis and reporting where possible.

7.5 Using data to categorise systems

By using the water quality analysis and sanitary inspection data, the systems covered by the assessment can be categorised on the basis of contamination found and most likely cause. This not only allows a focus of attention to the areas of greatest importance in individual supplies or supplies within an urban area but also allows evaluation of the national situation regarding whether problems exist in design, construction or operation and maintenance. This then allows the development of a regional and/or national improvement strategy. An example from an assessment Ghana is summarised in table 7.4 below.

Category	Description	Assessed systems
Category 1	No contamination	Barakese direct; Owabi direct; Berekum; Kpandu
Category 2	Contamination derived from local problems	Accra MPZ/HPZ; Bolgatanga; Cape Coast; Ho; Takoradi; Tamale; Tema
Category 3	Contamination from both supply failure & local problems	Accra LPZ; Kpong direct; Keta; Kumasi High level; Obuasi; Sekondi; Sunyani; Weijja direct
Category 4	Contamination derived from major supply failure	Kibi; Koforidua; Navrongo; Nkawkaw; Shama/Elmina

Table 7.4 Categorisation of systems from an assessment in Ghana, 1999

7.6 Household water

When analysing household water quality a number of simple analyses may be performed and care should be taken to decide what the analysis is designed to show and what is being evaluated. The most obvious analysis is to assess whether the water being consumed shows evidence of being contaminated. Causes of failure can be analysed by the same approaches as for point sources.

By assessing the quality of water stored and used in the home compared to those of the source where the water was obtained, the importance of re-contamination can be evaluated. This can be evaluated further by analysing samples taken from a source, collection vessel and household water storage, which may identify where contamination occurs during the water chain and whether household treatment limits contamination at the point of consumption. The analysis of household water quality will also indicate where the major focus of an intervention strategy is required. For instance, where point sources are of good quality, but household quality is poor, the most appropriate response is clearly aimed at the household level rather than source improvement.

7.7 More detailed analysis of chemical quality data

In addition to the basic analyses described in section 7.1, more detailed statistical analysis of the data on chemical parameters will also increase the value of the results. The greater range of data collected in level 2 and 3 assessments lends itself to further detailed analysis, particularly in combination with the data from catchment and hydrogeological assessments, treatment audits and hazard analyses. In these higher level assessments, collection of data on chloride may also be useful. The analysis of the nitrate: chloride ratio is a useful tool in determining whether the nitrate is derived from faecal matter. Possible analyses are discussed briefly in this section but, for more detailed statistical analysis, users of this handbook are encouraged to consult the text by Helsel and Hirsch given in the bibliography in Annex 4.

The analysis of chemical data from level 1 assessment can use parametric or non-parametric analyses. Parametric analyses may be used when there are no significant extreme values, either very high or very low, such as below the limit of detection. Useful analyses may include analysing whether the concentration of nitrate is greater in boreholes in urban areas or those in rural areas. This may be done using a one-way analysis of variance (ANOVA) using standard statistical software. Where there are extreme values, tests that are equivalent to parametric analyses can be used, for instance the Kruskal-Wallis test is the non-parametric equivalent to an ANOVA test.

There are a number of useful analyses that can be carried out on the chemical data collected as part of level 1 assessments. The selection of correct tests is partly dependent on the nature of the data, but most analyses are likely to be comparisons between mean or median concentrations of different groups and thus ANOVA and Kruskal-Wallis will be useful tests. Some parameters may be closely related, for instance arsenic and iron and possibly arsenic and fluoride or other metals. In these cases, it is likely that a Pearson’s correlation will be suitable, but if the data do not follow a normal distribution, a Spearman’s rank correlation can be used. Only nitrate will be suitable to compare to the microbial data and will probably require a Spearman’s rank correlation as it is likely the microbial data will have a non-normal distribution and also have outliers. Statistical analysis of the chemical and sanitary inspection data is unlikely to be useful as the sanitary inspections are designed to identified primarily risks that would lead to microbial contamination and would not cover all environmental aspects of relevance for chemical contamination. These main types of analysis for the chemical parameters are summarised below in table 7.5.

Comparison	Parameters (level 1 assessments)				
	Arsenic	Fluoride	Iron	Nitrate	Copper/ Chromium/ Manganese
Between technologies	Yes	Yes	Yes	Yes	Yes
Between regions	Yes	Yes	Yes	Yes	Yes
Between urban and rural	Yes	Yes	Yes	Yes	Yes
Depth of intake	Yes	Yes	Yes	Yes	Yes
Shallow versus deep groundwater	Yes	Yes	Yes	Yes	Yes
Surface versus groundwater	Yes	Yes	Yes	Yes	Yes
Aquifer type	Yes	Yes	Yes	Yes	Yes
Correlation between parameters	Yes With iron and possibly fluoride and other metals	Possibly with arsenic	Yes with arsenic and other metals	No	Yes with iron, possibly with arsenic
Correlation with microbial data	No	No	No	Yes	No

Table 7.5: Types of analysis for chemical quality data

8.0 Remedial actions

In this section, a very brief review will be given about the ways in which the assessment data can be used as a planning tool for remedial and preventative actions. Actions may be undertaken addressing environmental concerns (for instance control of land-use around sources, reducing pollution discharges), engineering aspect (design and construction), educational interventions (hygiene and maintenance) and policy. All these may be informed by the assessment data and in particular when both water quality and sanitary inspection data are collected and analysed together.

Details on possible remedial and preventative actions are included in the *Practical guide to water quality surveillance* (see Bibliography). This document provides brief descriptions of practical measures that can be implemented at water sources and within hygiene education programmes. If more detail is desired then there are a number of documents that provide information, these include the WHO Guidelines for Drinking Water Quality Volume 3 and the manuals available on urban water supply surveillance published by WEDC and available in electronic form at the watermark website.

8.1 Environmental interventions

These will focus primarily on the protection of sources and control of polluting activities within close proximity to the source. The assessment data should provide a good indication of whether current source protection practices are adequate to maintain good quality water. For instance, if the analysis of microbiological and sanitary inspection data shows a strong association between latrines or solid waste and contamination then the current guidance on separation distances should be reviewed. Many environmental interventions will be closely linked to educational interventions within communities.

The chemical data will also provide useful indications regarding environmental interventions that are required. For instance, the nitrate levels in source waters may point to increasing contamination from human activity and this should help direct resources to provide greater control on the application of fertilisers and disposal of organic wastes. The use of the pollution risk appraisal forms can also help significantly within this process as these will identify, at least qualitatively, which types of activity are having the greatest impact on water sources.

The water quality assessment data should also be used to help determine whether there are any current problems with naturally occurring chemicals and whether there needs to be a change in resource and source use to reduce these problems. Good examples will include arsenic and fluoride where evidence of elevated levels in particular areas or from particular aquifers will help inform future development of water resources.

8.2 Engineering interventions

There are very many engineering interventions that be developed on the basis of the assessment results. Many of these will be closely linked to educational interventions to improve management and environmental interventions at water sources. Engineering interventions referred to briefly here focus on the design, construction and basic operation and maintenance of water sources, water storage containers and household water treatment.

One key use of the assessment data is to review construction and design quality of water supplies. In some cases, it may be clear that these are not of adequate quality or need revision to improve performance. For example, springs are often protected using very coarse backfill media that provides very little potential for filtration and attenuation. If the data from the assessment indicates that springs are heavily contaminated and that this cannot be solely attributed to failures in maintenance, it suggests that the design may need to be revised. This may be particularly important where springs are used in urban areas, which have much greater faecal loading. Improvements in design are often easy to achieve at relatively little additional cost.

Assessment of construction quality is also important. If recently constructed water supplies have significant sanitary risks associated with infrastructure (for instance the masonry or concrete works are failing) this suggests that construction quality is not adequate. This will help in developing new guidelines for construction quality for all organisations and contractors constructing water supplies. The sanitary inspection data will also help in identifying priorities for rehabilitation, in terms of both community and source types.

Where contamination is found and it appears that it is sanitary completion measures that are the principal cause, then rehabilitation may be justified. Where sources of faecal matter leaching into the sources appear to be most important, then rehabilitation may be less advisable and other technologies selected. Furthermore, if particular types of source always show heavy contamination and viable alternatives exist, then rehabilitation may not be appropriate and alternatives should be investigated. By looking at both nitrate and microbiological data it may be possible to determine whether groundwater is being affected by on-site sanitation or some other form of organic material, which may suggest rehabilitation is not advisable.

The sanitary inspection data from piped water systems can also help in directing remedial actions. The identification of major supply risks should lead to investment to address these problems. This may be from the sanitary inspection data or from the mapping of chlorine residuals. Where the sanitary inspection data suggest that problems largely result from poor local operation and maintenance, this should lead to action to improve management by households and communities.

The assessment data should also inform operation and maintenance needs. Through assessing the water quality and sanitary inspection data, critical maintenance tasks can be identified to maintain good water quality. This can then be used to develop better community training for sustainable management of water supplies.

The assessment data can also be used to evaluate the current performance of water storage containers and water treatment technologies. This should allow identification of the designs that provide greatest protection to water and which provide the treatment of water. This may be done by looking at those specific factors that are most associated with contamination and designing new container to reduce these risks.

8.3 Educational interventions

Educational interventions may be needed for improving both source maintenance and hygiene promotion. In both cases, the use of water testing equipment and sanitary inspections as direct learning tools should be emphasised. By directly involving communities in these activities, for instance by reading the results of water quality tests with the community, there is greater potential for sustainable improvements to be developed.

Where the sanitary risk score at sources is high, this provides a good indication that maintenance is poor and that there needs to be strengthening of local capacity to improve management. The sanitary inspection data should provide a good indication of the specific components of maintenance that are failing, but further discussions with communities are likely to be required to understand the underlying reasons for maintenance failure.

One area that the assessment can help to inform is whether household water treatment or hygiene education will be most useful in addressing problems of poor water quality in the home. If hygiene education interventions will be able to provide a safe water chain from the source to the household then there may be no need for household water treatment.

Where the water quality at the source is relatively good (for instance less than 10 cfu/100ml thermotolerant coliforms and/or faecal streptococci) but the water stored within households is poor (>50-100cfu/100ml) this suggests that hygiene education alone may be able to resolve water contamination. Where these situations are found then the sanitary inspection data should be analysed to assess what particular factors seem to be most associated with re-contamination, for instance design or type of container or means of taking water from the container. By identifying the critical sanitary risk factors, the hygiene education programme can develop specific messages aimed at improving water handling hygiene.

Where the water source itself is heavily contaminated and there is little possibility of improving the source, it may be necessary to promote low-cost household water treatment. If this is followed then it is important to consider carefully what type of technology may be most appropriate and how this will be promoted most effectively. Generally, promoting boiling of water is rarely sustainable for long periods of time, as it is expensive, produces water with a poor taste and which must be cooled, and may lead to deforestation and air pollution. It is better not to regularly promote messages regarding boiling of water, but to leave these until times of greatly increased risk (for instance during an epidemic or mass contamination of water). Alternative technologies such as SODIS and the CDC Safe Water System may be more appropriate.

If household water treatment systems are promoted, it is important to be sure that households can purchase these easily and cheaply and that any consumables can be easily purchased close to or preferably within their community. Selecting appropriate promotional methods is important and social marketing is often an important component of this. Water quality and sanitary inspection data can be useful as they can provide the evidence of the performance of the treatment system and be used to promote the use of the treatment technology.

8.4 Policy interventions

One key aspect of the assessment data should be to promote the need for routine water quality monitoring. The data from the assessment can be an effective tool to illustrate to policy-makers the value of water quality monitoring, particularly when assessing the overall impact on health form investments in water and sanitation.

The assessment data should also form the basis of developing a number of policy-orientated intervention. These include the need to establish guidelines, standards and other water quality targets and to ensure that these are both adopted and enforced. Through evaluation of current performance priorities can be set for future support to water supply managers (particularly communities) in improving water supply maintenance. This may involve both planning for improvements in delivery of training for communities when new water supplies are being constructed and in developing programmes for support to existing supplies.

The data from the assessment should also provide support for policy interventions in relation to the types of water sources that should be promoted. For instance, although point sources of water are often not preferred in urban areas, their use may be promoted for low-income families if either the quality of existing sources is good or if sanitary inspection data indicates that problems result from poor maintenance rather than large-scale contamination of the resource. This may be an important policy shift if it allows poor families to gain access to better water supplies that they can afford. The data can also be used to develop policies regarding household water treatment and its promotion. A policy acceptance of such approaches may provide substantial health gains and be a constructive outcome of the assessment.

Annex 1
Report forms

Daily Report Sheet: Microbiological data

Cluster No: **Cluster name:**

Date **Analyst**

Sample No.	Sample source	Source code No.	SI score	Time	Colour	Turbidity TU	Chlorine mg/l		pH	TTC cfu/100ml	FS cfu/100ml
							Free	Total			

Comments

Signature of analyst

Daily Report Sheet: Chemical data

Cluster No: **Cluster name:**

Date **Analyst**

Sample No.	Sample source	Source code No.	Time	Nitrate mg/l	Iron mg/l	Conductivity μS/cm	Arsenic mg/l	Fluoride mg/l	Cu/Cr/Mn mg/l	

Comments

Signature of analyst

Final report of survey

Suggested contents list

Introduction

General description of country
Breakdown of water source availability by technology type and region
Description of survey design

Sites surveyed

Descriptions of large areas used in survey design
Descriptions of clusters identified (including technologies found)
Map of country showing large areas and clusters

Water quality parameters included and means analysis

Level of assessment undertaken (1, 2 or 3)
Parameter included within study
Description of methods used for analysis
Quality control and assurance procedures followed
Sanitary inspection forms used

Results

For each technology type:
- Microbiological and related parameters
- Sanitary inspection
- Physical and chemical analysis
- Geographical variations

Discussion and implications o findings

Overall picture of water quality
- Microbiological
- Sanitary status of water supplies
- Physical and chemical

Differences in water quality between technology types
Differences in water quality between different regions
Operation and maintenance of sanitary protection measures by technology and/or region
Other likely causative factors influencing quality (e.g. aquifers, climate, management approach etc)
Need for development of routine monitoring

Conclusions and recommendations

Safety of drinking water
Key interventions required to improve/maintain safety
Future development of monitoring capacity

Annexes

Annex 2
Sanitary inspection and pollution risk assessment forms

I. Type of Facility PIPED WATER

1. General Information : Cluster No:

   : Cluster Name:

2. Community name

3. Date of Visit:

4. Water samples taken? …….. Sample Nos. ………

II Specific Diagnostic Information for Assessment

(please indicate at which sample sites the risk was identified)

	Risk	Sample No
1. Do any tapstands leak	Y/N	………….
2. Does surface water collect around any tapstand?	Y/N	………….
3. Is the area uphill of any tapstand eroded?	Y/N	………….
4. Are pipes exposed close to any tapstand?	Y/N	………….
5. Is human excreta on the ground within 10m of any tapstand?	Y/N	………….
6. Is there a sewer within 30m of any tapstand?	Y/N	………….
7. Has there been discontinuity in the last 10 days at any tapstand?	Y/N	………….
8. Are there signs of leaks in the mains pipes in the Parish?	Y/N	………….
9. Do the community report any pipe breaks in the last week?	Y/N	………….
10. Is the main pipe exposed anywhere in the Parish?	Y/N	………….
Total Score of Risks	…./10	

Risk score: 9-10 = Very high; 6-8 = High; 3-5 = Medium; 0-3 = Low

III Results and Recommendations:

The following important points of risk were noted: (list nos. 1-10)

Signature of Inspector:

Comments:

I. **Type of Facility** **PIPED WATER WITH SERVICE RESERVOIR**

1. General Information : Cluster No:

: Cluster Name:

2. Community name:

3. Date of Visit

4. Water samples taken? …….. Sample Nos. ………

II **Specific Diagnostic Information for Assessment**

(please indicate at which sample sites the risk was identified)	**Risk**	**Sample No**
1. Do any standpipes leak at sample sites?	Y/N	………….
2. Does water collect around any sample site?	Y/N	………….
3. Is area uphill eroded at any sample site?	Y/N	………….
4.Are pipes exposed close to any sample site?	Y/N	………….
5. Is human excreta on ground within 10m of standpipe?	Y/N	………….
6. Sewer or latrine within 30m of sample site?	Y/N	………….
7. Has there been discontinuity within last 10 days at sample site?	Y/N	………….
8. Are there signs of leaks in sampling area?	Y/N	………….
9. Do users report pipe breaks in last week?	Y/N	………….
10. Is the supply main exposed in sampling area?	Y/N	………….
11. Is the service reservoir cracked or leaking?	Y/N	………….
12. Are the air vents or inspection cover insanitary?	Y/N	………….
Total Score of Risks	…./12	

Risk score: 10-12 = Very high; 8-10 = High; 5-7 = Medium; 2-4 = Low; 0-1 = Very Low

III **Results and Recommendations:**

The following important points of risk were noted: (list nos. 1-12)

Signature of Inspector:

Comments:

I. **Type of Facility** **GRAVITY-FED PIPED WATER**

1. General Information : Cluster No:
   : Cluster Name:
2. Community name:
3. Date of Visit
4. Water samples taken? …….. Sample Nos. ………

II **Specific Diagnostic Information for Assessment**

(please indicate at which sample sites the risk was identified)

	Risk	**Sample No**
1. Does the pipe leak between the source and storage tank?	Y/N	
2. Is the storage tank cracked, damaged or leak?	Y/N	
3. Are the vents and covers on the tank damaged or open?	Y/N	
4. Do any tapstands leak?	Y/N	………….
5. Does surface water collect around any tapstand?	Y/N	………….
6. Is the area uphill of any tapstand eroded?	Y/N	………….
7. Are pipes exposed close to any tapstand?	Y/N	…………
8. Is human excreta on the ground within 10m of any tapstand?	Y/N	………….
9. Has there been discontinuity n the last 10 days at any tapstand?	Y/N	………….
10. Are there signs of leaks in the main supply pipe in the system?	Y/N	………….
11. Do the community report any pipe breaks in the last week?	Y/N	………….
12. Is the main supply pipe exposed anywhere in the system?	Y/N	………….
Total Score of Risks	…./12	

Risk score: 10-12 = Very high; 8-10 = High; 5-7 = Medium; 2-4 = Low; 0-1 = Very Low

III **Results and Recommendations:**

The following important points of risk were noted: (list nos. 1-12)

Signature of Health Inspector/Assistant:

Comments:

I. **Type of Facility** **DEEP BOREHOLE WITH MECAHNISED PUMPING**

1. General Information : Cluster No:

   : Cluster Name:

2. Community name:

3. Date of Visit

4. Water sample taken? …….. Sample No. ……… FC/100ml ………..

II **Specific Diagnostic Information for Assessment**

	Risk
1. Is there a latrine or sewer within 100m of pumphouse	Y/N
2. Is the nearest latrine unsewered	Y/N
3. Is there any source of other pollution within 50m	Y/N
4. Is there an uncapped well within 100m	Y/N
5. Is the drainage around pumphouse faulty	Y/N
6. Is the fencing damaged allowing animal entry	Y/N
7. Is the floor of the pumphouse permeable to water	Y/N
8. Does water forms pools in the pumphouse	Y/N
9. Is the well seal insanitary	Y/N
Total Score of Risks	…./9

Risk score: 7-9 = High; 3-6 = Medium; 0-2 = Low

III **Results and Recommendations:**
The following important points of risk were noted: (list nos. 1-9)

Signature of Health Inspector/Assistant:

Comments:

I. Type of Facility BOREHOLE WITH HANDPUMP

1. General Information : Cluster No:

: Cluster Name:

2. Community name:

3. Date of Visit

4. Water sample taken? …….. Sample No. ……… FC/100ml ………..

II Specific Diagnostic Information for Assessment

	Risk
1. Is there a latrine within 10m of the borehole?	Y/N
2. Is there a latrine uphill of the borehole?	Y/N
3. Are there any other sources of pollution within 10m of borehole? (e.g. animal breeding, cultivation, roads, industry etc)	Y/N
4. Is the drainage faulty allowing ponding within 2m of the borehole?	Y/N
5. Is the drainage channel cracked, broken or need cleaning?	Y/N
6. Is the fence missing or faulty?	Y/N
7. Is the apron less than 1m in radius?	Y/N
8. Does spilt water collect in the apron area?	Y/N
9. Is the apron cracked or damaged?	Y/N
10. Is the handpump loose at the point of attachment to apron?	Y/N
Total Score of Risks	…./10

Risk score: 9-10 = Very high; 6-8 = High; 3-5 = Medium; 0-3 = Low

III Results and Recommendations:

The following important points of risk were noted: (list nos. 1-10)

Signature of Health Inspector/Assistant:

Comments:

I. Type of Facility PROTECTED SPRING

1. General Information : Cluster No:

   : Cluster Name:

2. Community name:

3. Date of Visit:

4. Water sample taken? …….. Sample No. ……… FC/100ml ………..

II Specific Diagnostic Information for Assessment

	Risk
1. Is the spring unprotected?	Y/N
2. Is the masonary protecting the spring faulty?	Y/N
3. Is the backfill area behind the retaining wall eroded?	Y/N
4. Does spilt water flood the collection area?	Y/N
5. Is the fence absent or faulty?	Y/N
6. Can animals have access within 10m of the spring?	Y/N
7. Is there a latrine uphill and/or within 30m of the spring?	Y/N
8. Does surface water collect uphill of the spring?	Y/N
9. Is the diversion ditch above the spring absent or non-functional?	Y/N
10. Are there any other sources of pollution uphill of the spring? (e.g. solid waste)	Y/N
Total Score of Risks	…./10

Risk score: 9-10 = Very high; 6-8 = High; 3-5 = Medium; 0-3 = Low

III Results and Recommendations:

The following important points of risk were noted: (list nos. 1-10)

Signature of Health Inspector/Assistant:

Comments:

I. **Type of Facility** **DUG WELL WITH HANDPUMP/WINDLASS**

1. General Information : Cluster No:

: Cluster Name:

2. Community name:

3. Date of Visit

4. Water sample taken? …….. Sample No. ……… FC/100ml ………..

II **Specific Diagnostic Information for Assessment**

	Risk
1. Is there a latrine within 10m of the well?	Y/N
2. Is the nearest latrine uphill of the well?	Y/N
3. Is there any other source of pollution within 10m of well? (e.g. animal breeding, cultivation, roads, industry etc)	Y/N
4. Is the drainage faulty allowing ponding within 2m of the well?	Y/N
5. Is the drainage channel cracked, broken or need cleaning?	Y/N
6. Is the fence missing or faulty?	Y/N
7. Is the cement less than 1m in radius around the top of the well?	Y/N
8. Does spilt water collect in the apron area?	Y/N
9. Are there cracks in the cement floor?	Y/N
10. Is the handpump loose at the point of attachment to well head?	Y/N
11. Is the well-cover insanity?	Y/N
Total Score of Risks	…./11

Risk score: 9-11 = Very high; 6-8 = High; 3-5 = Medium; 0-3 = Low

III **Results and Recommendations:**

The following important points of risk were noted: (list nos. 1-11)

Signature of Health Inspector/Assistant:

Comments:

I. Type of Facility WATER TREATMENT PLANT

General Information : Cluster No:

: Cluster Name:

Date of survey: ________________

Inspector: ________________________

Name of plant: ________________________

Age of plant: _________

Design capacity (m^3): __________ Current production (m^3/day): _________

Fence around plant? Y/N Fencing in good condition? Y/N Security guard? Y/N/ day/night

II. Source (circle one): Reservoir Stream River Well Other

(Note: If more than one source used, then circle all those used)

III Intake:

Condition of intake works: Good Average Poor

Is the intake works damaged (e.g. concrete cracked)? Y/N

Is there erosion around intake? Y/N

Is the screen or grit chamber blocked with excessive debris? Y/N

IV Treatment processes (list all those used):

Process 1: Process 4:

Process 2: Process 5:

Process 3: Process 6:

Sedimentation:

No. of sedimentation tanks: __________ Frequency of desludging: _____________

Appearance of final water (e.g. clear, cloudy/turbid, visible particles etc): _______________

Filtration

No. of filters: ________________ Filtration rate: __________________

Filter run (time): _________________ Depth of gravel: __________________

Depth of sand: ________________ Air scour Y/N Rate_______
Duration: _____________

Disinfection

Dosage of disinfectant: ______ Dosing method: _________________________

Clear water tanks

No. of tanks: ___________ Capacity of each tank: _____________

Are any tanks leaking? Y/N Are tanks properly covered and locked? Y/N

Is the inside of the tank clean? Y/N

Are air vents and overflow pipes protected by screens? Y/N

Records of process control tests

1. Jar test	Yes	No	Frequency: ___________
2. pH	Yes	No	Frequency: ___________
3. Free chlorine:	Yes	No	Frequency: ___________
4. Colour:	Yes	No	Frequency: ___________
5. Turbidity:	Yes	No	Frequency: ___________
6. Thermotolerant coliforms:	Yes	No	Frequency: ___________

Record keeping

1. Chemical consumption	Good	Poor	Updated: __________
2. Process control tests	Good	Poor	Updated: __________
3. Bacteriological quality:	Good	Poor	Updated: __________
4. Residual chlorine:	Good	Poor	Updated: __________

XIII Personnel

1. No. of present staff: Permanent__________ Casual___________

2. Educational level of principal operator: ______________

3. Number of years operator at this plant: _________

4. Total number of years experience of operator in water treatment: ____________

XIV Problems recorded with:

1. Treatment processes: ____
(please list processes and describe problems)

2. Customer complaints: ____
(please indicate how many complaints, nature of complaints and frequency)

Signature of Inspector:

Comments:

Household water quality inspection

Cluster No: Cluster Name: Community name: Water Source

1. Is drinking water kept in a separate container (ask to be shown this)?

❑ Yes ❑ No

2. Is drinking water container kept above floor level and away from contamination?

❑ Yes ❑ No

3. Do water containers have a narrow mouth/opening?

❑ Yes ❑ No

4. Do containers have a lid/cover?

❑ Yes ❑ No

5. Is this is in place at time of visit

❑ Yes ❑ No

6. How is water taken from the container?

❑ Poured ❑ Cup ❑ Other utensil

7. Is the utensil used to draw water from the container clean?

❑ Yes ❑ No

8. Is the utensil used to draw water the container kept away from surfaces and stored in a hygienic manner?

❑ Yes ❑ No

9. How often is the container cleaned?

❑ Every day ❑ Every month ❑ Never

❑ Every week ❑ Rarely

10. How is the container cleaned?

……………………………………………………………………………..

11. Is the inside of the drinking water container clean?

❑ Yes ❑ No

12. Is the outside of the drinking container clean?

❑ Yes ❑ No

Rapid Environmental Risk Appraisal Form

Cluster No: Cluster Name:

Name of Community /scheme

Please use blank sheets to add any additional information in answering the questions.
Where possible, indicate the location of the pollution source on a photocopy of an existing map or on a sketch map (an example is attached)
Please fill in the boxes below or tick where appropriate.

1. Does the water source have any known pollution problems?			**Yes**	**No**
2. Does the water source have any of the following water quality problems?				
Colour Y/N	**Turbidity Y/N**	**Coliforms Y/N**	**Iron Y/N**	**Algae Y/N**
3. Please list any other pollution problems with the water source.				

4. If there are any problems, when do the occur?												
Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	
Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	colour
am pm	am pm	am pm	am pm	am pm	am pm	am pm	am pm	am pm	am pm	am pm	am pm	
Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	
Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	turbidity
am pm	am pm	am pm	am pm	am pm	am pm	am pm	am pm	am pm	am pm	am pm	am pm	
Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	
Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	coliforms
am pm	am pm	am pm	am pm	am pm	am pm	am pm	am pm	am pm	am pm	am pm	am pm	
Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	
Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	iron
am pm	am pm	am pm	am pm	am pm	am pm	am pm	am pm	am pm	am pm	am pm	am pm	
Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	
Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	algae
am pm	am pm	am pm	am pm	am pm	am pm	am pm	am pm	am pm	am pm	am pm	am pm	

5. For each of the following POTENTIAL sources of pollution indicate whether it is present (Yes/No) and how far it is from the water source.

Potential source of pollution (see overleaf for guidance on classification)	**S**	**L**	**Distance from source**			
			<50m	<500m	<1km	<5km
Residential						
• settlement (town/village/encroachment)						
• construction						
Agricultural activity						
• livestock						
• crops						
• chemical storage						
• aquaculture						
Industrial activity						
• food processing						
• textile						

• tannery						
• brewery						
• oil/petroleum(including garages)						
• abattoir (slaughter house)						
• mining						
• **chemical**						
Miscellaneous						
• deforestation						
• erosion						
• other (specify)						

Annex 3
Quality control forms microbiological data

Aseptic technique evaluation form

Quality control factors	Assessment	Comments
1) Was the kit and apparatus clean (including incubator)	Yes No	
2) Is the media stored in a dark and preferably cool place	Yes No	
3) Was the media fresh and uncontaminated	Yes No	
4) Was the pad placed in the petri-dish correctly	Plates: Fail:	
5) If pad not successfully placed in dish, did staff member use sterilised forceps to replace pad	Plates: Fail:	
6) Was filtration apparatus and sample cup sterilised before each analysis and was this done correctly	Tests: Fail:	
7) Was filtration & sample cup left for 5 minutes after sterilisation	Tests: Fail:	
8) Were forceps sterilised before each use, including if touched	Tests: Fail:	
9) Are forceps kept away from contamination when in use	Tests: Fail:	
10) Were filters sealed before use	Tests: Fail:	
11) Was the filter touched by staff member	Tests: Fail:	
12) Was the filter laid on the pad correctly	Tests: Fail:	
13) Was the sample cup rinsed before sample taken	Tests: Fail:	
14) Did staff member only read the yellow colonies on filter	Plates: Fail:	
15) Did staff member correctly state the number of coliforms per 100ml	Plates: Fail:	

Quality control table for microbiological tests (95% confidence interval counts 0-100)

Count 1	Count 2	Count 1	Count 2	Count 1	Count 2
0	0-5	34	19-53	68	47-93
1	0-7	35	20-54	69	47-95
2	0-9	36	21-55	70	48-96
3	0-11	37	22-56	71	49-97
4	0-12	38	22-58	72	50-98
5	0-14	39	23-59	73	51-99
6	1-16	40	24-60	74	52-100
7	1-17	41	25-61	75	52-102
8	2-19	42	26-63	76	53-103
9	2-20	43	26-64	77	54-104
10	3-22	44	27-65	78	55-105
11	3-23	45	28-66	79	56-106
12	4-24	46	29-67	80	57-107
13	5-26	47	29-69	81	58-108
14	5-27	48	30-70	82	58-110
15	6-28	49	31-71	83	59-111
16	6-30	50	32-72	84	60-112
17	7-31	51	33-73	85	61-113
18	8-32	52	33-75	86	62-114
19	8-34	53	34-76	87	63-115
20	9-35	54	35-77	88	63-117
21	10-36	55	36-78	89	64-118
22	10-38	56	37-79	90	65-119
23	11-39	57	38-80	91	66-120
24	12-40	58	38-82	92	67-121
25	13-41	59	39-83	93	68-122
26	13-43	60	40-84	94	69-123
27	14-44	61	41-85	95	69-125
28	15-45	62	42-86	96	70-126
29	16-47	63	42-88	97	71-127
30	16-48	64	43-89	98	72-128
31	17-49	65	44-90	99	73-129
32	18-50	66	45-91	100	74-130
33	19-52	67	46-92		

Annex 4
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