RAPID ASSESSMENT OF DRINKING-WATER QUALITY IN THE FEDERAL DEMOCRATIC REPUBLIC OF ETHIOPIA

COUNTRY REPORT

World Health Organization

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RAPID ASSESSMENT OF DRINKING-WATER QUALITY IN THE FEDERAL DEMOCRATIC REPUBLIC OF ETHIOPIA

COUNTRY REPORT OF THE PILOT PROJECT IMPLEMENTATION IN 2004-2005

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Foreword

One of the targets of the Millennium Development Goals, promulgated by the United Nations in 2000, is to halve by the year 2015 the proportion of people without sustainable access to a safe water supply and basic sanitation, therefore reducing the burden of associated disease. Unfortunately, recent statistics on water and sanitation do not provide specific evidence about the quality of water being provided to communities, households and institutions, and the safety of the drinking-water supply can only be inferred. There is, therefore, an urgent need to obtain independently verifiable water-quality data, to support national governments in their efforts to provide safe water to households. Such data would provide useful information about current conditions and the likely public-health burden related to an inadequate and unsafe water supply. The data would also reveal the extent of major water quality problems and inform future investment priorities.

A priority for obtaining data on water supplies is a rapid, low-cost, field-based technique for assessing water quality. As a result, at a World Health Organization/United Nations Children's Fund (WHO/UNICEF) consultative meeting in Bangkok in 2002, six countries (China, Ethiopia, Jordan, Nicaragua, Nigeria and Tajikistan) were selected to implement pilot projects on the Rapid Assessment of Drinking-Water Quality (RADWQ). Project implementation in Ethiopia started in July 2004 with the formation of a steering committee to oversee and plan the project. The committee was composed of representatives from the Federal Ministry of Health (FMOH), the Federal Ministry of Water Resources (FMOWR), the Ethiopian Health and Nutrition Research Institute (EHNRI), the Quality and Standards Authority of Ethiopia, the Ethiopian Environment Protection Authority, UNICEF and WHO (Annex 1). The committee identified the FMOH as the lead institution for implementing and overseeing the RADWQ project, with Mr Worku Gebreselassie, Head of the Department of Hygiene and Environmental Health, FMOH, as the person responsible. The steering committee further established a core technical working group (its composition is presented in Annex 1) to develop the survey design, and to plan and implement the RADWQ project. Mr Dagnew Tadesse was the responsible project coordinator.

Training for the core technical working group and field staff was provided by international consultants in December 2004. It covered the survey design methodology, field implementation, use of field testing equipment and sanitary inspection methods. Field implementation began in December 2004 and lasted until April 2005, during which time 1815 water sampling points were visited in the regional states of Ethiopia. A final review meeting with the core technical working group took place during a second consultancy visit, in September 2005.

Acknowledgements

The core technical working group (from left to right): Assefa Desta, Solomon Fisseha, Woldemariam Girma, Aberra Geyid, Dagnew Tadesse and Shimelese Tizazu, December 2004, Addis Ababa.

It would not have been possible to successfully implement the project without the hard work and dedication of the project coordinator, the core technical working group, international consultants, field teams and drivers, and the support of many other individuals. Special thanks are due to: individuals of the Regional Health Bureaus, Regional Water Bureaus, Woreda Health Offices, Woreda Water Desks and water treatment authorities, as well as to the operators of the water supplies visited during the survey, for their collaboration and valuable support to the field teams; to field team members for their dedicated work under challenging field conditions; to the FMOH administration for generously providing vehicles for fieldwork throughout the project, as well as providing administrative and technical support. Particular thanks are due to Dr Tsehaynesh Messele, Director of the EHNRI, for kindly providing a vehicle for fieldwork and for allowing her staff (Dr Aberra Geyid, Mr Assefa Desta, Mr Woldemariam Girma) to work on the project and provide substantial input to the core technical working group; to Mr Emiru Makonnen, Head of the Legedadi water treatment plant, Addis Ababa Water Supply and Sewerage Authority, for his support during the training of field staff at his waterworks facilities; to UNICEF Ethiopia and Mr Hans Spruijt, Ms Therese Dooley and Mr Tekka Gebru, for providing the additional budget required to successfully complete the project; Mr Olisegun Babaniyi, WHO Representative in Ethiopia, for his support to the project; to Mr Mekdes Aklilu, Managing Director of Wagtech Ethiopia Plc., for his technical support; and to Mr Neil Wrigglesworth of Wagtech International Ltd., for his excellent training efforts. Finally, the financial support received from the Department for International Development/UKAID of the United Kingdom is gratefully acknowledged.

Acronyms

EHNRI	Ethiopian Health and Nutrition Research Institute
FMOH	Federal Ministry of Health
FMOWR	Federal Ministry of Water Resources
JMP	Joint Monitoring Programme
RADWQ	Rapid Assessment of Drinking-water Quality
RHB	Regional Health Bureau
SNNPR	Southern Nations, Nationalities and Peoples Region
UNICEF	United Nations Children's Fund
WHO	World Health Organization

Executive summary

During 2004–2005, the Federal Republic of Ethiopia, together with five other countries, participated in a World Health Organization/United Nations Children's Fund (WHO/UNICEF) pilot project to test the methodology for a Rapid Assessment of Drinking-Water Quality (RADWQ). The purpose was to test a tool to help the WHO/UNICEF Joint Monitoring Programme (JMP) monitor access to safe drinking-water globally. The RADWQ methodology is based on the UNICEF Multiple Indicators Cluster Surveys. It uses a cluster sampling approach to select, across an entire country, individual drinking-water sources to be tested for selected parameters. The number and type of parameters to be measured depend on the extent of the survey and on local potential health hazards. The output of a RADWQ survey is a snapshot of the drinking-water quality at each improved source tested.

Using the RADWQ methodology, 1815 sample sites in 64 clusters were visited by four field teams over a period of five months (December 2004 to April 2005). The total sample size was split over four broad areas and over four improved supply technologies (i.e. utility piped supplies, boreholes, protected dug wells and protected springs), each serving more than 5% of the total Ethiopian population. The surveys took place in the regional states or cities of Addis Ababa, Amhara, Dire Dawa, Oromiya, Southern Nations, Nationalities and Peoples Region, Somali and Tigray. Using portable field kits, water was analysed for the following parameters: thermotolerant coliforms, faecal streptococci, pH, turbidity, chlorine residual, appearance, conductivity, arsenic, nitrate, fluoride, and iron. In addition, 10% of the total number of household samples was analysed for the deterioration of water quality during distribution and storage. Sanitary inspections were also carried out at each of the 1815 sample sites, using standardized questionnaires.

The results of the RADWQ project provide an excellent, statistically representative snapshot of the status of the microbiological and chemical quality of drinking-water sources in Ethiopia. For thermotolerant coliforms, 72% of drinking-water supplies tested were in compliance with both the WHO guideline value and the Ethiopian drinking-water standard ES 261:2001. Compliance ranged from 43% for protected springs to 88% for utility piped supplies. Overall compliance was 68% for thermotolerant coliforms and toxic chemicals such as arsenic, fluoride and nitrate combined, and ranged from 43% for protected springs to 80% for utility piped supplies.

For fluoride, compliance with the WHO guideline value and the national standard of 1.5 mg/l was approximately 94%. Although this figure appears good, it disguises the fact that the fluoride content of drinking-water poses a major public health problem, particularly in the Rift Valley of Ethiopia, a fact confirmed by the RADWQ project findings. The main areas affected by excessive fluoride concentrations in drinking-water were the East Shewa Zone (maximum fluoride concentrations of 10.5 mg/l) and some areas in the Somali Region. For nitrate, nearly 100% of the water supplies investigated during the RADWQ study complied with the WHO guideline value and the national standard of 50 mg/l, and it was concluded that nitrate does not cause widespread water-quality problems in Ethiopia. However, compliance in some areas was only 80%, with nitrate concentrations as high as 123 mg/l (e.g. Dire Dawa). For arsenic, compliance was 100% with the WHO guideline value and the national standard for all technologies and in all broad areas investigated. In general, the RADWQ survey confirmed the results of earlier findings, in particular the results of routine monitoring that are kept in an electronic database at the Ethiopian Health and Nutrition Research Institute.

1 Introduction

1.1 The WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation

In 1990, at the end of the International Drinking Water Supply and Sanitation Decade, WHO and UNICEF decided to combine their experience and resources in a Joint Monitoring Programme for Water Supply and Sanitation (JMP). At its inception, the overall aim of the JMP was to improve planning and management of the water supply and sanitation within countries by assisting countries in the monitoring of their drinking-water supply and sanitation sector. This concept, and the associated objectives, evolved over time. The Millennium Declaration in 2000 and the subsequent formulation of targets under the Millennium Development Goals (MDGs) marked a fundamental change. As the official monitoring instrument for progress towards achieving MDG 7 target C, the JMP prepares biennial global updates of this progress. Prior to 2000, JMP assessments had been undertaken in 1991, 1993, 1996 and 2000. The results for the year 2000 survey are presented in *Global water supply and sanitation assessment 2000 report* (WHO/UNICEF, 2000), which contains data for six global regions: Africa, Asia, Europe, Latin America and the Caribbean, Northern America, and Oceania. This report introduced a monitoring approach based on household surveys and censuses which has subsequently been refined. The methods and procedures lead to an estimate of numbers of people with access to improved water sources and improved sanitation. Since the 2000 report, five more JMP reports have been published. The latest, published in March 2010, shows that by the end of 2008 an estimated 884 million people in the world lacked access to improved sources of drinking-water and 2.6 billion people lack access to improved sanitation facilities. If the current trend continues, the MDG drinking-water target will be exceeded by 2015, but the sanitation target will be missed by about 1 billion people (over and above the 1.7 billion who would not have access even if the target were achieved).

In the past, the JMP drew guidance from a technical advisory group of leading experts in water supply, sanitation and hygiene, and from institutions involved in data collection and sector monitoring. With the formulation and adoption of the JMP Strategy for 2010-2015, this technical support structure will be further strengthened. The JMP strategy further states the vision and mission of the JMP as, respectively: *To accelerate progress towards universal, sustainable, access to safe water and basic sanitation by 2025*[1]*, including the achievement of the MDG targets by 2015 as a key milestone* and *to be the trusted source of global, regional and national data on sustainable access to safe drinking-water and basic sanitation, for use by governments, donors, international organizations and civil society.*

To fulfil its mission, the JMP has three strategic objectives:

- to compile, analyse and disseminate high quality, up-to-date, consistent and statistically sound global, regional and country estimates of progress towards internationally established drinking-water and sanitation targets in support of informed policy and decision making by national governments, development partners and civil society;
- to serve as a platform for the development of indicators, procedures and methods aimed at strengthening monitoring mechanisms to measure sustainable access to safe drinking-water and basic sanitation at global, regional and national levels;
- to promote, in collaboration with other agencies, the building of capacity within government and international organizations to monitor access to safe drinking-water and basic sanitation.

These priorities translate into four strategic priorities for the JMP over the next five years:

- maintaining the integrity of the JMP data base and ensuring accurate global estimates:
- dissemination of data to sector stakeholders;
- fulfilling JMP's normative role in developing and validating target indicators;
- interaction between countries and the JMP

The JMP defines access to drinking-water and sanitation in terms of the types of technology and levels of service afforded. The JMP definitions used at the time of this study are shown in Table 1.1, while current definitions can be found on www.wssinfo.org .

Table 1.1 **JMP definitions of water supply and sanitation (2004)**

Category	Water supply	Sanitation
Improved	Household connection Public standpipe Borehole Protected dug well Protected spring Rainwater collection	Connection to a public sewer Connection to septic system Pour-flush latrine Simple pit latrine Ventilated improved pit latrine
Unimproved	Unprotected well Unprotected spring Vendor-provided water Bottled water [a] Tanker truck-provided water [b]	Service or bucket latrines (where excreta are manually removed) Public latrines Latrines with an open pit

[a] Normally considered to be "unimproved" because of concerns about the quantity of supplied water.
[b] Considered to be "unimproved" because of concerns about access to adequate amounts of water, about inadequate treatment, or about transportation of the water in inappropriate containers.

The JMP database is the source for WHO and UNICEF estimates on access to and use of drinking-water and sanitation facilities. At the time of the RADWQ pilot studies the database drew upon some 350 nationally representative household surveys, but the database has rapidly expanded and by the beginning of 2010 contained over 1200 such datasets. The data come from household surveys and censuses, including the Demographic Health Survey, the UNICEF Multiple Indicators Cluster Surveys, the World Bank Living Standard Measurement Survey and the World Health Survey (by WHO). These are national cluster sample surveys, covering several thousand households in each country. The samples are stratified to ensure that they are representative of urban and rural areas of each country.

Prior to 2000, coverage data were based on information from service providers, such as utilities, ministries and water authorities, rather than on household surveys. The quality of the information thus obtained varied considerably. Provider-based data, for example, often did not include facilities built by householders themselves, such as private wells or pit latrines, or even systems installed by local communities. For this reason, in 2000, JMP adopted the use of household surveys, which provide a more accurate picture by monitoring the types of services and facilities that people actually use.

Information collected by the JMP is analysed and presented for dissemination in the form of maps and graphs, which can be found, together with other information, on the JMP web site www.wssinfo.org.

Although the use of household surveys and the presentation of data by drinking-water and sanitation ladders and wealth quintiles have significantly increased the quality and comparability of information on improved drinking-water sources and sanitation, there continues to be room for further improvements in the JMP database so it will be even more useful to policy-makers by:

- *Harmonizing indicators and survey questions*. Surveys use different indicators and methodologies, making it difficult to compare information. A guide that harmonizes questions and response categories for drinking-water supply and sanitation, *Core questions on drinking-water, sanitation and hygiene for household surveys* (WHO/UNICEF, 2007), has been prepared and is regularly updated. On-going discussions aim to incorporate updated and new questions into major household survey programmes and population censuses. Currently, the Demographic

Health Survey, the Multiple Indicators Cluster Surveys, and the World Health Survey have all adopted the harmonized set of questions for their surveys.

- *Measuring gender disparities*. Data on water and sanitation are collected at the household level and therefore gender-specific data cannot be calculated. However, questions can be designed to determine who bears the main responsibility for collecting water and how much time is spent collecting it. Questions along these lines are being incorporated into the design of new surveys.
- *Measuring water quality*. Existing surveys do not provide reliable information on the quality of water, either at the source or at the household level.

In response to the third challenge, WHO and UNICEF, with the support of the Department for International Development of the Government of the United Kingdom, developed a method for the rapid assessment of drinking-water quality. Pilot studies using the method, referred to as RADWQ (rapid assessment of drinking-water quality), have been carried out in China, Ethiopia, Jordan, Nicaragua, Nigeria and Tajikistan. The six pilot countries represent different regions of the world with a range of environmental and socio-economic conditions, presenting different water quality issues and at various stages of development.

At the conception of the RADWQ pilot studies it was foreseen that the methodology, if proved feasible and successful, could be of value to many countries as a vehicle for building capacity in water quality monitoring at policy, institutional and technical levels. The direct involvement of water authorities and national experts in the studies was also expected to enhance a sense of ownership. Countries could benefit from RADWQ surveys by using the data to create a baseline for future monitoring programmes (e.g. post-2015); for external evaluations; to assess the drinking-water quality in specific geographical areas; or to assess a specific drinking-water supply technology. The RADWQ approach would also provide the international community with the tools to measure improvements in access to safe drinking-water worldwide.

1.2 Background information on Ethiopia

Geography and climate

Ethiopia is situated in the Horn of Africa and shares its borders with Djibouti, Eritrea, Kenya, Somalia and Sudan. The country's territory covers an area of approximately 1.1 million km^2 and presents a diverse topography, ranging from 110 m below sea level to 4550 m above sea level. Ethiopia is broadly divided into three climatic zones: the hot lowland zone (below approximately 1500 m), known as the "Kolla"; the "Weyna Dega" zone (altitudes between 1500 and 2400 m); and, the cool zone (highlands above 2400 m, referred to as the "Dega"). In general, the highlands of Ethiopia receive more rain than the lowlands.

Demography (2004 data)

With a population of approximately 71 million people in 2004 (national data), Ethiopia is the third most populous country of Africa. The average household size is 4.8 people and about 85% of the total population is rural, making the country one of the least urbanized in the world. Only nine urban centres have populations greater than 100 000 people, and Addis Ababa, the capital city, is the only urban centre with a population greater than one million people (Table 1.2).

Administration

Ethiopia is a federation of nine regional states: Afar; Amhara; Benshangul; Gambella; Harari; Oromiya; Southern Nations, Nationalities and Peoples Region (SNNPR); Somali; and Tigray, and two city administrations, Addis Ababa and Dire Dawa. The regional states are further divided into zones (Figure 2.3), which at the time of the study were being dissolved as the country underwent decentralization. The zones are further divided into 611 woredas, and the woredas into kebeles, which represent urban dwellers associations in towns and peasant associations in rural areas.

1.3 Historical water-quality data, the current water-quality surveillance/monitoring system and national standards

Coverage data for water supply technology

A summary of the water supply coverage at the time of the pilot studies is shown in Table 1.2. The information was largely collected from regional health bureaux (RHBs), but was complemented by statistical data from the Federal Ministry of Water Resources (FMOWR). According to the data, only approximately 37% of the Ethiopian population was supplied by technology considered to be improved (by the JMP definition, Table 1.1), and only one fifth was served by utility piped supplies. Most of the population (approximately 63%) relied on sources that are unimproved, such as ponds, lakes, rivers and open dug wells.

At the time of the study, coverage by improved technology varied significantly between regions, from ca. 8% in Afar, to 100% in Addis Ababa (Table 1.2). Other than utility piped supplies, improved sources that served more than 5% of the population include protected dug wells, springs and boreholes; trucked water plays an important role only in the region of Harari. Consistent with earlier FMOWR estimates, 72% of the urban population and 24% of the rural population have access to safe water sources (Mudgal, 2001). However, the actual coverage by improved technology in the rural areas is likely to be lower than reported, as the FMOWR estimates that 30–60% of existing systems are out of order at any time.

The accuracy of the database is uncertain and the data may need to be checked. For example, the RADWQ core technical working group considered that the coverage figure of 80% for improved water-supply technology in Tigray was too high, but it could not be checked for lack of reliable information.

Water-quality surveillance and monitoring

The Federal Ministry of Health (FMOH) is responsible for water quality monitoring and surveillance, according to Public Health Proclamation No. 200/2000. The Department of Hygiene and Environmental Health is in charge of developing policy guidelines on water quality surveillance. The FMOH does not run its own water quality laboratory, but relies on facilities at the Ethiopian Health and Nutrition Research Institute (EHNRI). This is a semi-autonomous national research institute with its own Board of Directors, chaired by the Federal Minister of Health. The FMOH mandates the RHBs, which are mainly responsible for providing health-related services to the population, to carry out water quality surveillance in the regions.

Although all RHBs run their own laboratory facilities, at the time of the pilot study none was capable of conducting physicochemical water quality analyses, and only some were able to conduct microbiological analyses. According to information from the FMOH Department of Hygiene and Environmental Health, the following regional health laboratories were able test the microbiological quality of water:

- Tigray Health Research Centre at Makelle (Tigray Regional State)
- Public health laboratory of Dessie town (Amhara Regional State)
- Amhara Health Research Laboratory at Bahir Dar (Amhara Regional State)
- Public health regional laboratory of Awassa (SNNPR)
- Public health laboratory of Arba Minch town (SNNPR)
- Public health laboratory of Mizan Teferi town (SNNPR)
- Public health laboratory of Jinka town (SNNPR)
- Public health laboratory of Jimma town (Oromiya Regional State)
- Public health laboratory of Adama town (Oromiya Regional State)
- Public health laboratory of Nekemte town (Oromiya Regional State)

- Public health laboratory of Harari (Harari Regional State)

Also, many water samples collected by the FMOH or the RHBs are analysed at EHNRI laboratories. The results of the analyses are usually examined by the Department of Hygiene and Environmental Health before sending them back to the health institution and responsible RHB. If they show that drinking-water quality has been compromised, the results are sent back with recommendations for follow-up actions (i.e. sanitary surveys, disinfection of the water supply).

The other main government institution in Ethiopia involved in providing drinking-water is the FMOWR. The FMOWR has a mandate to coordinate the water-supply sector at the national level, and set policy on tariffs and protecting water sources. At the regional level, the regional bureaux of water resources are responsible for providing safe water, which involves planning, developing, constructing and managing the water supplies. Most of the regional bureaux are equipped with laboratories that can carry out physical, chemical and microbiological analyses of water quality, and it has been estimated that they check approximately 5–10% of point sources annually (Mudgal 2001). Also, all water-treatment plants have their own water-quality laboratories (Mudgal, 2001). Although the FMOWR or the regional bureaux frequently test the quality of water from newly constructed water points, it is not mandatory to test new community water schemes before they are handed over to the community.

In practice, the monitoring of drinking-water quality is poorly enforced. For many reasons, neither the FMOH nor the FMOWR follow a structured or even coordinated approach. In part, this is because there are no financial resources, but also partly because of poor logistics, too few human resources, inadequate laboratory equipment, and limited availability of reagents at the regional level. Although the role of each ministry in water-quality monitoring and surveillance is formally defined, interaction and exchange of information between the RHBs and the regional bureaux of water resources is poor. In Ethiopia, water-quality monitoring and surveillance are ad hoc. This is particularly evident when new water supplies are being developed or commissioned; when there is a disease outbreak; when dealing with customer complaints; and when significant changes in water-quality are reported during inspection.

Historical water-quality data

EHNRI probably maintains the most comprehensive database on drinking-water quality. It has been developed since the 1960s and includes all test results from routine analysis of drinking-water samples that were carried out at EHNRI laboratories. For the RADWQ project, the past 10 years of data from the EHNRI database were compiled for relevant water-quality parameters (Table 1.3, Table 1.4). However, the data quality was affected by the following:

- sampling was not always carried out by professionals;
- the spatial distribution of the sampling points was random;
- the water sources were not sampled at the same times of the year;
- storage and transportation of samples to the laboratory was often inadequate.

A summary of the compliance levels for *Escherichia coli* between 1995 and 2004 is shown in Table 1.3 for the different water-supply technologies. For regional states not listed in Table 1.3 there were no test results in the database. Over this period, approximately 74% of samples nationally complied with the current national standard or with the WHO guideline value (i.e. *E. coli* were absent). For improved supply technologies, compliance was significantly higher for chlorinated supplies, ranging from 91% for piped supplies to 74% for wells. For unchlorinated supplies, compliance ranged from 75% for piped systems, to 30% for springs.

Aggregated data for fluoride, nitrate, iron and conductivity, subdivided by supply type and regional state, is shown for the period from 1995 to 2004 (Table 1.4). Of 769 samples analysed for fluoride, overall compliance was approximately 83%, with maximum concentrations up to 26.5 mg/l in Oromiya. Lowest levels of compliance were in Afar (52%), Oromiya (71%) and Somali (73%). Although overall compliance for nitrate was high in Ethiopia (ca. 97%), in Dire Dawa the figure was only 67%, with nitrate concentrations of up to 208 mg/l recorded, the highest in the last 10 years.

Table 1.2. **Water-supply coverage for Ethiopia in 2004, by technology type and region**[a]

Region	Total population (projected)	Piped water (%)	Bore-holes (%)	Dug wells (%)	Springs (%)	Vehicle trucking (%)	Roof catchment (%)	Total improved technologies (%)	Total unimproved technologies (%)
Addis Ababa	2 805 000	82.1	12.5	4.8	0.6	0.0	0.0	100.0	0.0
Afar	1 340 000	4.5	0.5	2.6	0.2	0.0	0.0	7.8	92.2
Amhara	18 143 000	10.2	2.0	9.0	7.4	0.9	0.0	29.6	70.4
Benshangul	594 000	5.1	6.7	14.0	3.1	0.0	0.0	28.9	71.1
Dire Dawa	370 000	29.4	0.5	5.1	3.5	0.0	0.0	38.5	61.5
Gambella	234 000	20.0	1.0	2.1	6.0	0.0	0.0	29.1	70.9
Harari	185 000	15.0	2.4	6.6	1.5	60.0	0.0	85.5	14.5
Oromiya	25 098 000	26.1	3.4	1.8	4.7	0.0	0.1	36.0	64.0
SNNPR	14 085 000	10.4	3.1	3.1	14.1	0.0	0.0	30.7	69.3
Somali	4 109 000	9.9	4.5	9.5	0.4	0.0	0.0	24.2	75.8
Tigray	4 113 000	29.4	33.9	8.9	8.6	0.0	0.0	80.8	19.2
National	71 076 000	19.8	5.1	5.0	7.0	0.4	0.0	37.3	62.7

[a] Sources: Federal Ministry of Health; Federal Ministry of Water Resources; regional health bureaux.

In preparation for new Ethiopian drinking-water standards (see below), the FMOWR conducted a study that included 2798 water-quality tests throughout the country (FMOWR, 2000; 2001). Given the lack of data on national surveillance and water quality monitoring, the FMOWR results were the most comprehensive sources of information about the realistic status of water-quality coverage in the country, and were combined with data from the EHNRI database (e.g. see the discussions in Section 3 of this report).

National drinking-water standards

A national standard for drinking-water, *ES 261:2001 Drinking-water – specifications* (see Annex 2), was established in 2001 by the Quality and Standards Authority of Ethiopia, the organization responsible for setting standards in Ethiopia. The 2001 standard supersedes the first edition of 1990 (*ES 261:1990*), which was limited to piped drinking-water supplies and supplies that served more than 10 000 people (Warner et al., 2000). *ES 261:2001* was developed by a national technical committee of members from FMOH, FMOWR, EHNRI and the Ethiopian Environmental Protection Agency, as well as from other governmental and nongovernmental organizations. The national standards were largely based on the second edition of the WHO *Guidelines for drinking-water quality* (the latest guidelines at the time), but drinking-water standards for Kenya and India were also used.

The *ES 261:2001* standard specified maximum permissible levels, as well as methods for testing, for 18 physicochemical parameters that affect the palatability of drinking-water; 24 toxic chemicals (including 11 pesticides); total viable organisms; faecal streptococci; coliform organisms; and *E. coli* type 1 strain (thermotolerant). The maximum permissible levels for the parameters used in the RADWQ project were consistent with the WHO guideline value. The *ES 261:2001* standard also specified sampling frequencies for bacteriological and physicochemical parameters (presented in Annex 2).

Table 1.3 **Compliance of water samples in Ethiopia with national standards for *E. coli* between 1995 and 2004, by technology type** [a]

Source type	Addis Ababa		Afar		Amhara		Benshangul		Dire Dawa		Harari		Oromiya		SNNPR		ETH	
	No. samples	Compliance (%)	No. samples	Compliance (%)	No. samples	Compliance (%)	No. samples	Compliance (%)	No. samples	Compliance (%)	No. samples	Compliance (%)	No. samples	Compliance (%)	No. samples	Compliance (%)	No. samples	Compliance (%)
Piped chlorinated	312	95	3	100	46	85			25	96	3	33	70	90	11	45	470	
Piped unchlorinated	100	71	9	56	97	70							179	82	9	44	394	
Piped well chlorinated	23	65			3	33							42	86			68	
Piped well unchlorinated	60	73	4	100	17	59							87	76	6	17	174	
Well chlorinated	29	79			6	50			2	100			30	73	2	50	69	
Well unchlorinated	95	64	3	100	42	45	4	50	17	82	4	75	150	79	3	0	318	
River chlorinated	2	0			1	100							1	100			4	
River unchlorinated	11	18			1	100							14	7			26	
Spring chlorinated	2	100			4	75					2	50	2	100	3	67	13	
Spring unchlorinated	17	35			51	43					2	50	45	13	2	0	117	
Totals	651	80	19	79	268	62	4	50	44	91	11	55	620	75	36	36	1 653	

[a] Source: EHNRI database. ETH = Ethiopia. SNNPR = Southern Nations, Nationalities and Peoples Region.

Table 1.4 **Physicochemical analyses of water quality in Ethiopia, 1995–2004** [a]

Region	Source type	No. of samples	Fluoride			Nitrate			Iron			Conductivity		
			Compl. (%)	Min (mg/l)	Max	Compl. (%)	Min (mg/l)	Max	Compl. (%)	Min (mg/l)	Max	Compl. (%)	Min (µS/cm)	Max
Addis Ababa	**Total**	**115**	**96.5**	**0.04 -**	**4.10**	**96.5**	**0.15 -**	**71.00**	**91.3**	**< 0.01 -**	**4.93**	**99.1**	**0.06 -**	**1.88**
	Piped	38	100.0	< 0.05 -	1.30	100.0	< 0.5 -	29.40	94.7	< 0.01 -	4.93	100.0	0.06 -	0.72
	Reservoir	1	100.0	0.10 -	0.10	100.0	1.10 -	1.10	100.0	0.04 -	0.04	100.0	0.15 -	0.15
	River	1	100.0	0.85 -	0.85	100.0	3.10 -	3.10	0.0	0.33 -	0.33	100.0	0.66 -	0.66
	Spring	4	100.0	< 0.05 -	0.40	100.0	2.92 -	9.00	75.0	0.03 -	0.66	100.0	0.12 -	0.49
	Well	71	94.4	< 0.05 -	4.10	94.4	0.15 -	71.00	91.5	< 0.01 -	2.90	98.6	0.07 -	1.88
Afar	**Total**	**64**	**51.6**	**0.02 -**	**6.20**	**93.8**	**0.25 -**	**130.30**	**93.8**	**< 0.01 -**	**0.70**	**56.3**	**0.23 -**	**32.11**
	Piped	6	100.0	0.10 -	1.50	100.0	< 0.5 -	14.07	100.0	< 0.01 -	0.09	50.0	0.23 -	19.99
	Pond	1	0.0	2.80 -	2.80	100.0	2.00 -	2.00	100.0	0.01 -	0.01	100.0	0.42 -	0.42
	Spring	4	25.0	0.93 -	3.00	100.0	< 0.5 -	2.66	100.0	0.02 -	0.07	100.0	0.50 -	1.22
	Well	53	49.1	0.02 -	6.20	92.5	0.25 -	130.30	92.5	< 0.01 -	0.70	52.8	0.44 -	32.11
Amhara	**Total**	**103**	**100.0**	**0.04 -**	**1.23**	**95.1**	**< 0.5 -**	**84.08**	**89.3**	**< 0.01 -**	**0.96**	**96.1**	**0.09 -**	**1.92**
	Piped	2	100.0	< 0.05 -	< 0.05	100.0	< 0.5 -	0.90	100.0	0.04 -	0.22	100.0	0.23 -	0.43
	Reservoir	2	100.0	< 0.05 -	< 0.05	100.0	0.52 -	0.72	50.0	0.27 -	0.50	100.0	0.23 -	0.23
	River	2	100.0	< 0.05 -	0.13	100.0	0.60 -	10.00	100.0	0.05 -	0.13	100.0	0.22 -	0.30
	Spring	37	100.0	0.04 -	0.78	97.3	< 0.5 -	51.60	89.2	< 0.01 -	0.96	97.3	0.09 -	1.41
	Well	60	100.0	< 0.05 -	1.23	93.3	< 0.5 -	84.08	90.0	< 0.01 -	0.96	95.0	0.12 -	1.92
Benshangul	**Total**	**37**	**100.0**	**0.03 -**	**0.60**	**97.3**	**0.06 -**	**93.60**	**97.3**	**< 0.01 -**	**0.32**	**100.0**	**0.03 -**	**0.66**
	Spring	2	100.0	0.08 -	0.08	100.0	0.36 -	0.36	50.0	0.03 -	0.32	100.0	0.03 -	0.09
	Well	35	100.0	0.03 -	0.60	97.1	0.06 -	93.60	100.0	< 0.01 -	0.26	100.0	0.06 -	0.66
Dire Dawa	**Total**	**9**	**100.0**	**0.32 -**	**0.60**	**66.7**	**20.90 -**	**208.00**	**100.0**	**< 0.01 -**	**0.08**	**100.0**	**0.71 -**	**1.33**
	Spring	2	100.0	0.32 -	0.40	100.0	32.90 -	38.00	100.0	< 0.01 -	0.01	100.0	0.73 -	1.04
	Well	7	100.0	0.32 -	0.60	57.1	20.90 -	208.00	100.0	< 0.01 -	0.08	100.0	0.71 -	1.33
Gambella	**Total**	**9**	**100.0**	**0.22 -**	**0.42**	**100.0**	**40.00 -**	**40.00**	**100.0**	**0.03 -**	**0.29**	**100.0**	**0.16 -**	**0.92**
	Well	9	100.0	0.22 -	0.42	100.0	40.00 -	40.00	100.0	0.03 -	0.29	100.0	0.16 -	0.92
Harari	**Total**	**10**	**100.0**	**0.04 -**	**0.60**	**90.0**	**3.20 -**	**79.14**	**100.0**	**< 0.01 -**	**0.18**	**90.0**	**0.25 -**	**1.59**
	Spring	6	100.0	0.04 -	0.60	100.0	3.20 -	18.12	100.0	0.03 -	0.18	100.0	0.25 -	0.65
	Well	4	100.0	0.20 -	0.45	75.0	4.40 -	79.14	100.0	< 0.01 -	0.10	75.0	0.80 -	1.59
Oromiya	**Total**	**311**	**71.1**	**0.02 -**	**26.50**	**99.0**	**0.09 -**	**207.40**	**92.0**	**< 0.01 -**	**2.90**	**89.1**	**0.02 -**	**26.24**
	Dam	3	100.0	0.20 -	1.40	100.0	7.53 -	33.70	66.7	0.05 -	0.65	100.0	0.14 -	0.59
	Piped	17	76.5	0.07 -	4.10	100.0	< 0.5 -	18.98	88.2	< 0.01 -	0.36	94.1	0.06 -	2.47
	Pond	3	100.0	< 0.05 -	1.07	100.0	< 0.5 -	0.55	100.0	0.07 -	0.29	100.0	0.08 -	0.21
	Reservoir	2	50.0	< 0.05 -	2.25	100.0	1.68 -	2.39	100.0	0.02 -	0.25	100.0	0.07 -	0.85
	River	17	70.6	< 0.05 -	11.20	94.1	0.47 -	207.40	82.4	0.01 -	0.89	100.0	0.08 -	1.08
	Spring	38	89.5	0.03 -	8.85	100.0	0.14 -	45.04	89.5	< 0.01 -	0.92	76.3	0.06 -	19.59
	Well	231	67.1	0.02 -	26.50	99.1	0.09 -	90.80	93.5	< 0.01 -	2.90	89.6	0.02 -	26.24
SNNPR	**Total**	**54**	**90.7**	**< 0.05 -**	**11.25**	**98.1**	**< 0.5 -**	**61.00**	**96.3**	**< 0.01 -**	**0.37**	**100.0**	**0.03 -**	**1.09**
	Piped	2	100.0	0.18 -	0.33	100.0	0.66 -	1.90	100.0	< 0.01 -	0.04	100.0	0.17 -	0.29
	River	2	100.0	0.26 -	0.56	100.0	1.30 -	2.20	50.0	0.24 -	0.34	100.0	0.15 -	0.24
	Spring	18	94.4	< 0.05 -	8.80	94.4	< 0.5 -	61.00	100.0	< 0.01 -	0.29	100.0	0.03 -	0.94
	Well	32	87.5	< 0.05 -	11.25	100.0	0.17 -	12.92	96.9	< 0.01 -	0.37	100.0	0.08 -	1.09
Somali	**Total**	**11**	**72.7**	**0.23 -**	**3.35**	**90.9**	**< 0.5 -**	**101.20**	**81.8**	**< 0.01 -**	**0.39**	**36.4**	**0.47 -**	**37.59**
	River	2	100.0	0.30 -	0.87	100.0	0.91 -	1.94	100.0	0.03 -	0.04	100.0	0.47 -	0.47
	Well	9	66.7	0.23 -	3.35	88.9	< 0.5 -	101.20	77.8	< 0.01 -	0.39	22.2	0.53 -	37.59
Tigray	**Total**	**46**	**100.0**	**< 0.05 -**	**0.80**	**95.7**	**< 0.5 -**	**53.00**	**87.0**	**< 0.01 -**	**1.20**	**93.5**	**0.09 -**	**2.79**
	Piped	2	100.0	0.06 -	0.10	100.0	0.79 -	2.20	100.0	< 0.01 -	0.07	100.0	0.09 -	0.11
	Spring	12	100.0	0.05 -	0.30	100.0	< 0.5 -	37.20	100.0	< 0.01 -	0.16	100.0	0.09 -	0.39
	Well	32	100.0	< 0.05 -	0.80	93.8	< 0.5 -	53.00	81.3	< 0.01 -	1.20	90.6	0.15 -	2.79
Ethiopia	**Total**	**769**	**82.7**	**0.02 -**	**26.50**	**96.7**	**0.06 -**	**208.00**	**92.1**	**< 0.01 -**	**4.93**	**89.9**	**0.02 -**	**37.59**
	Dam	3	100.0	0.20 -	1.40	100.0	7.53 -	33.70	66.7	0.05 -	0.65	100.0	0.14 -	0.59
	Piped	67	94.0	< 0.05 -	4.10	100.0	< 0.5 -	29.40	94.0	< 0.01 -	4.93	94.0	0.06 -	19.99
	Pond	4	75.0	< 0.05 -	2.80	100.0	< 0.5 -	2.00	100.0	0.01 -	0.29	100.0	0.08 -	0.42
	Reservoir	5	80.0	< 0.05 -	2.25	100.0	0.52 -	2.39	80.0	0.02 -	0.50	100.0	0.07 -	0.85
	River	24	79.2	< 0.05 -	11.20	95.8	0.47 -	207.40	79.2	0.01 -	0.89	100.0	0.08 -	1.08
	Spring	123	93.5	0.03 -	8.85	98.4	0.14 -	61.00	91.9	< 0.01 -	0.96	91.9	0.03 -	19.59
	Well	543	79.0	0.02 -	26.50	95.9	0.06 -	208.00	92.6	< 0.01 -	2.90	88.2	0.02 -	37.59

[a] Source: EHNRI database. Compl. = compliance with water-quality standard. Max. = maximum. Min. = minimum.

2 Methods

2.1 Survey design methodology

A detailed description of the RADWQ methodology is given in *Rapid assessment of drinking-water quality: a handbook for implementation (draft)* (Howard, Ince & Smith, 2003). Briefly, the RADWQ project used a cluster sampling approach to identify the number, type and location of water supplies to be included in the assessment. Cluster sampling meant that the water supplies included in the assessment were geographically close to one another (in "clusters"), but they were representative of all types of water supplies in the country. The RADWQ used this approach because it is used in major international surveys of water, sanitation and health (e.g. Multiple Indicator Cluster Surveys) that contribute to the WHO/UNICEF JMP. Cluster sampling also improved the efficiency of the assessment by making it easier to access the water supplies and by reducing costs.

To try to ensure that the water supplies included in the RADWQ project reflected the actual situation in Ethiopia, only improved technologies supplying more than 5% of the population were included. The basic sampling unit was the water supply itself, rather than the households that used it. The rapid assessments were primarily designed to assess the quality and sanitary condition of the water supplies, and hence the risk to water safety. The RADWQ also compared the quality of water stored in households with that of the matched water source, for a limited number of water supplies.

The number of water samples to be taken was calculated using Equation 2.1:

$$n = \frac{4P(1-P)D}{e^2} = \frac{4 * 0.5(1-0.5) * 4}{0.05^2} = 1600 \qquad \text{(Equation 2.1)}$$

n = required number of samples;
P = assumed proportion of water supplies with water quality exceeding the water-quality target(s);
D = design effect;
e = acceptable precision expressed as a proportion.

For the RADWQ pilot project, it was assumed that P = 0.5, e = ±0.05, and D = 4, giving the number of water supplies to be included within each country assessment as 1600 (Equation 2.1). The steps of the assessment are summarized in Figure 2.1 and Figure 2.2, and the range of parameters tested and the inspections undertaken is shown in Table 2.1.

Table 2.1 **RADWQ water-quality parameters and inspections**

Microbiological and related	Physical and chemical	Inspections
Thermotolerant coliforms	Appearance	Sanitary inspection
Faecal streptococci	Conductivity	
Turbidity	Nitrate	
pH	Iron	
Chlorine residuals	Arsenic	
	Fluoride	
	Copper	

Figure 2.1 **Steps in RADWQ surveys**

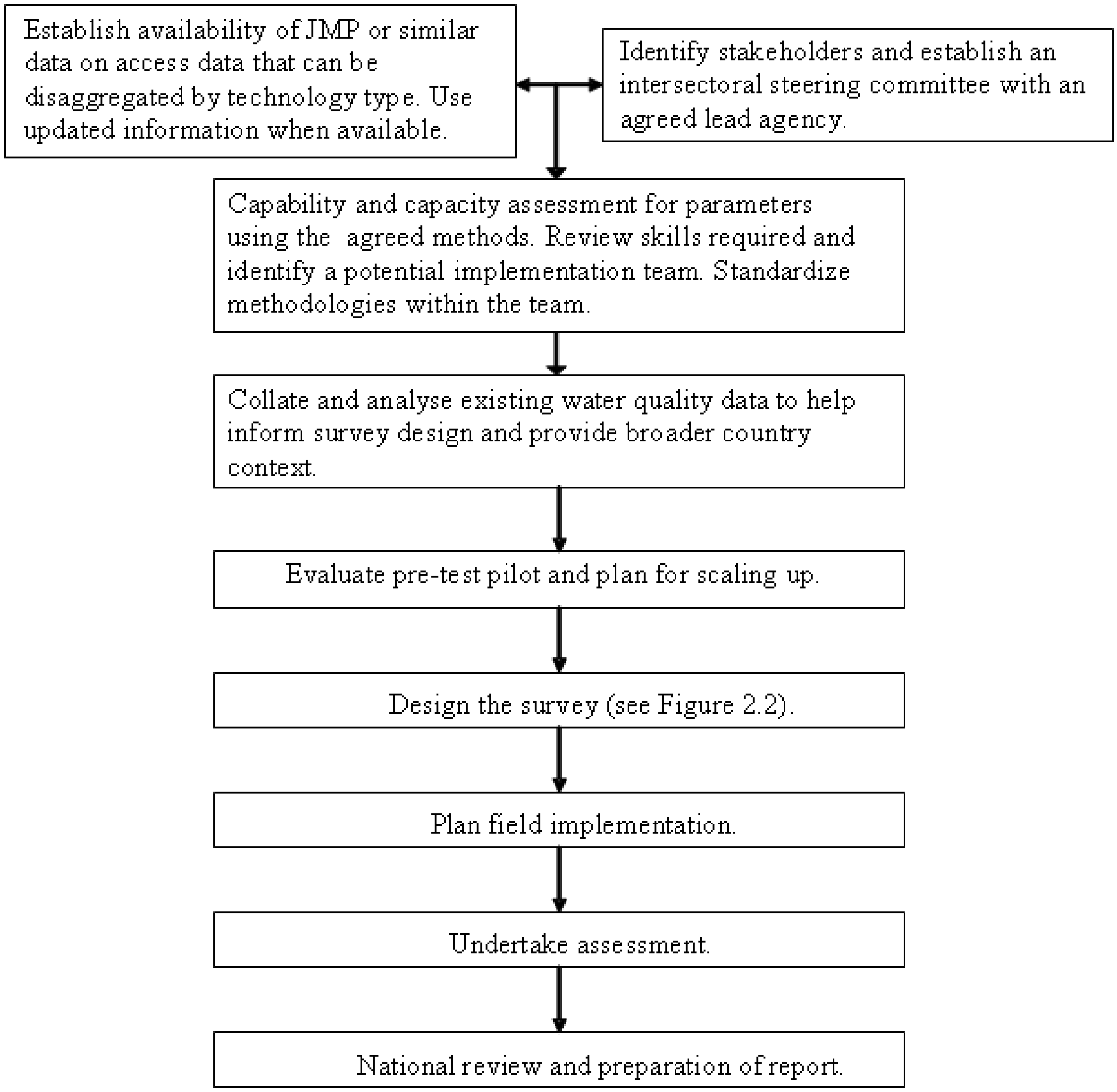
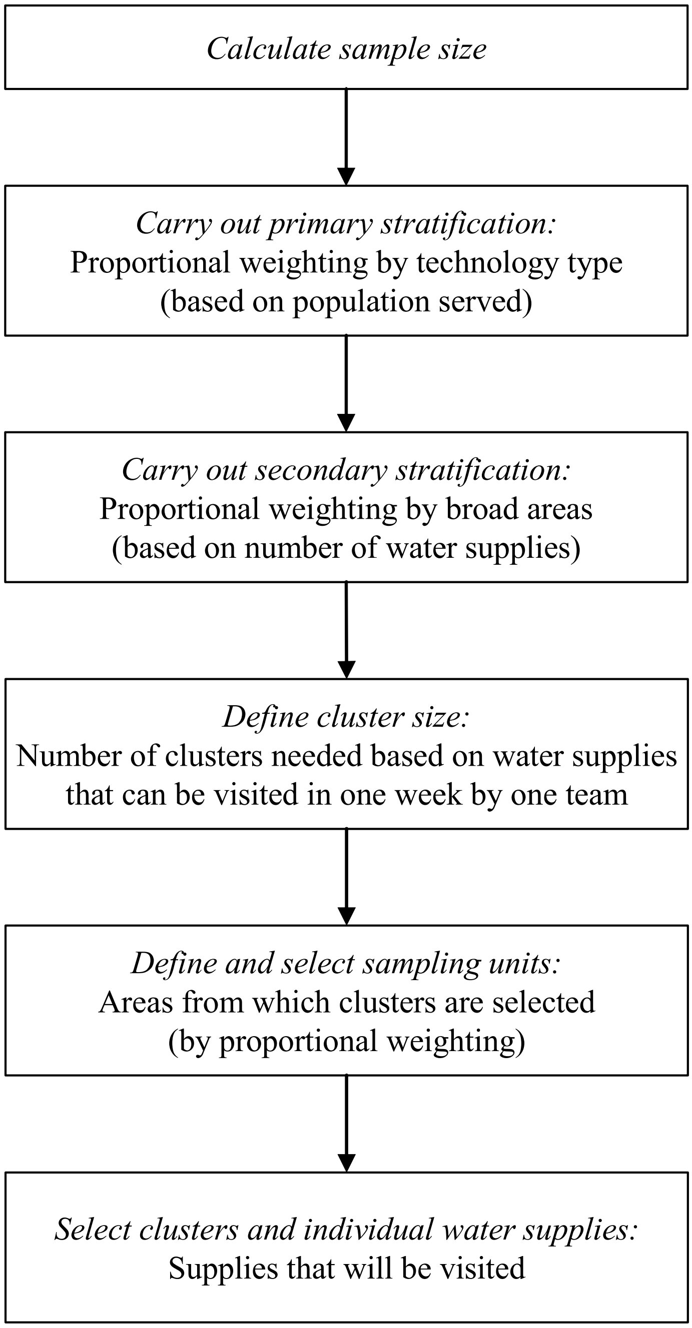


Figure 2.2 **Design of the RADWQ survey for Ethiopia**



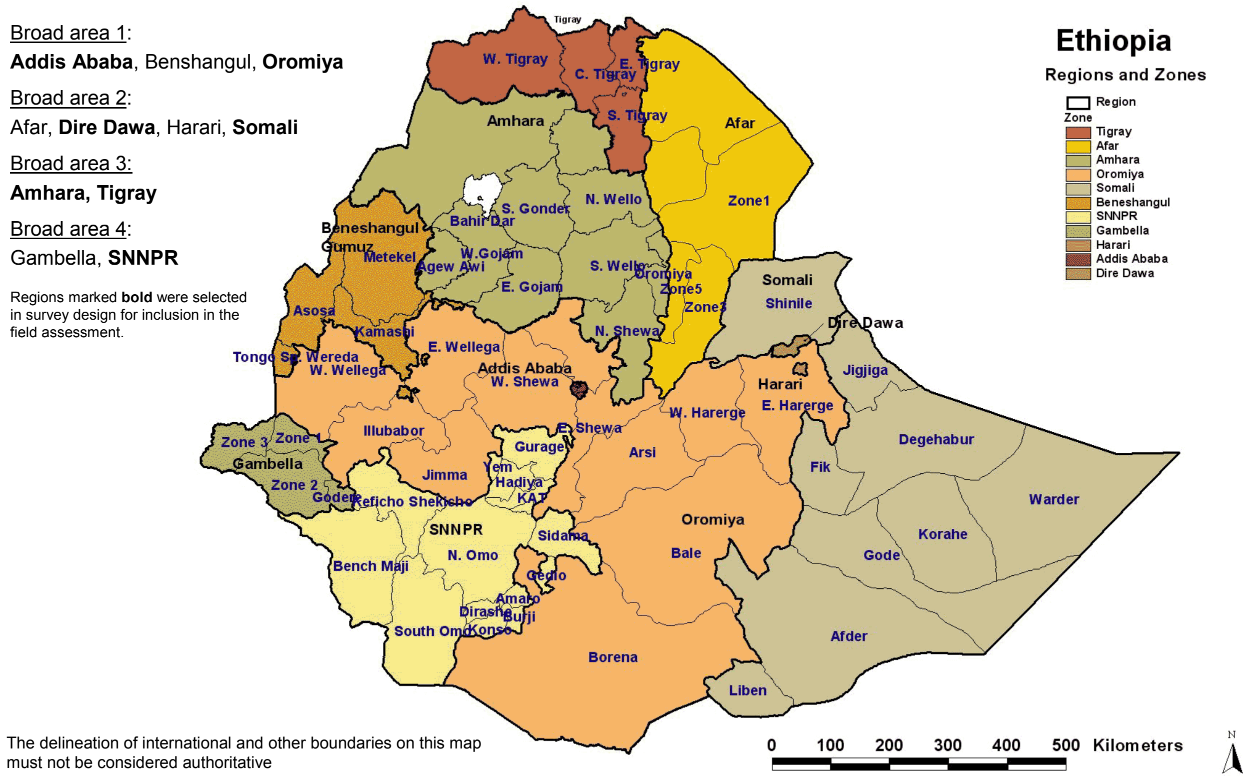
2.2 RADWQ survey design for Ethiopia

A training workshop on the RADWQ methodology was held between 6 and 10 December 2004 and this was followed up by meetings of the core technical working group, whose members discussed which data to include in the RADWQ study for Ethiopia, as well as other country-specific aspects of the survey design.

A summary of the survey design for Ethiopia is shown in Table 2.2; the individual survey steps are presented in Annex 3. The survey design for Ethiopia is described in more detail in the following bullet points:

- *Database*: Coverage data for water supply technologies, and data on the number of water supplies in the country were available for only one administrative level (i.e. the nine regional states and two city administrations). As a result, it was not possible to disaggregate the data for lower administrative units, such as zones or woredas. The data were largely collected from the RHBs and used to derive an aggregate figure for the whole of Ethiopia (Table 1.2). Gaps in the data were filled with informed assumptions by the core technical working group and additional statistical information from the FMOWR. It was unclear how accurate the database figures were (Section 1.3), but a particular concern was that the survey design may have been geographically skewed towards Tigray.
- *Primary stratification*: Nationally, utility piped supplies, springs, dug wells and boreholes each served more than 5% of the population, while other improved technologies (JMP definition) served less than 5% of the population. (Table 1.2). The figures for springs and dug wells in the database did not differentiate between protected and non-protected sources, and the primary stratification for the RADWQ survey had to rely on these overall figures. In the actual fieldwork carried out during the RADWQ survey, by contrast, the teams tested only springs and dug wells considered to be protected. It was estimated that 62.7% of the Ethiopian population relied on water from sources that were unimproved according to national sector data (Section 1.3).
- *Secondary stratification*: The nine regions and two city administrations of the country were grouped into four broad areas, mainly on the basis of their geographical proximity (Table 2.2, Figure 2.3). The nature of the data available for the RADWQ survey did not allow a stratification by other characteristics (e.g. climate zones, catchments or geophysical characteristics).
- *Sampling units*: The zone was the principal administrative unit used to sample regions within the four broad areas (Figure 2.3). Although the RADWQ handbook recommended using proportional weighting to select which zones to include in the RADWQ study, this was not possible because there were no zone-sharp data for water supply coverage in the country. Instead, zones were selected from within the broad areas, using the expert judgement of members of the core technical working group, who considered factors such as the geological conditions of a region, the spatial distribution of zones and assumptions about whether there were enough individual supply technologies in a zone to build a cluster. To maintain a “random element” in the survey design, proportional weighting was carried out at the level of the region. This selected one or two regions per broad area for inclusion in the field assessments (Figure 2.3; Annex 3).
- *Cluster size*: When determining the cluster sizes the accessibility of water points, the time required to perform the field tests and the skills of the field teams were taken into consideration. The cluster sizes ranged from 20 for point sources to 35 for utility piped supplies. This was based on the assumption that the latter would be mainly found in urban centres and thus travel times between samples would be less than those between point sources in rural areas.
- *Selection of clusters and individual water supplies*: Individual clusters or water supplies to be visited by the field teams were selected during the week in the field, after seeking advice from regional and/or local authorities, or from the local population. For utility piped supplies, when there were no official inspection taps at a sampling point, a nearby public or yard tap directly connected to the distribution system was chosen as a surrogate sampling point. Household water samples were taken only from containers, based on the assumption by the core technical working group that the population stored water for consumption mostly in containers.

Figure 2.3 **Broad areas for the RADWQ survey in Ethiopia** [a]



[a] Source: RADWQ Team, Ethiopia. The designations do not imply any opinion whatsoever on the part of the World Health Organization or the United Nations concerning the legal status of any country, territory, city or area; or of their authorities; or concerning the delimitation of their frontiers or boundaries. SNNPR = Southern Nations, Nationalities and Peoples Region.

Table 2.2 **Country-specific survey design for Ethiopia**[a]

Step	Method described in the RADWQ project handbook	RADWQ survey design in Ethiopia	Justification for any variation from the method described in the handbook
1	**Calculate sample size** (= 1600).	A total of 1815 sampling points were included in the survey: 1655 from source waters (=sample size) plus 160 from households.	Rounding at steps 3 and 4 increased the sample size to 1655.
2	**Primary stratification**: Proportional weighting by technology type, based on percentage of population served. (NB: only technologies serving >5% of population).	The study area covered the whole of Ethiopia. Four technologies served more than 5% of the population and were selected for primary stratification: • utility piped supplies (857 sample points); • boreholes (222 sample points); • protected dug wells (217 sample points); • protected springs (303 sample points).	
3	**Secondary stratification**: Proportional weighting by broad areas (based on the number of water supplies across the country).	Four broad areas were identified by grouping the regional states (see also Figure 2.3): • BA 1: Addis Ababa, Oromiya, Benshangul • BA 2: Afar, Dire Dawa, Harari, Somali • BA 3: Amhara, Tigray • BA 4: Gambella, SNNPR	Proportional weighting tables were used to select regions to be included in the study (Annex 3). Of the 11 regions in Ethiopia, 8 were selected for inclusion in the RADWQ survey (see underlined regions in the left-hand cell).
4	**Define clusters (size and number)**: This was based on water supplies could be visited in one week by one team (cluster size).	Cluster sizes were defined as 35 for UPS and 20 for BH, DW and PS. In total, 64 clusters were identified, resulting in 1655 sampling points. Their distribution by broad area and water-supply technology is as follows: • BA 1: 25 (15 UPS; 5 BH; 1 DW; 4 PS); • BA 2: 3 (2 UPS; 1 DW); • BA 3: 26 (5 UPS; 5 BH; 8 DW; 8 PS); • BA 4: 10 (3 UPS; 2 BH; 1 DW; 4 PS).	The proportional weighting used the results of primary stratification and cluster sizes given to the left, to calculate the total number of clusters required per technology and the respective sampling intervals.
5	**Define and select sampling units**: These are the areas from which clusters are selected by proportional weighting.	Zones were defined as the sampling unit.	Zone selection could not be based on proportional weighting, because there were no coverage data. Instead, zone selection relied on expert judgement. The zones selected and the individual water-supply technologies are presented in Annex 3.
6	**Select clusters and individual water supplies**: There are the water supplies to be assessed for water quality.	Sampling plans were prepared for field teams (example presented in Annex 4) that provided details about the zones from which clusters or supplies were to be selected, and on the WSS numbers to be assigned. Selection of individual supplies/sample points was undertaken by the field teams, after seeking advice from regional/local authorities or from the local population.	

[a] BA = broad area; BH = borehole; DW = drilled well; PD = protected dug well; PS = protected spring; UPS = utility piped supply; WSS = water supply scheme.

2.3 Field implementation and data recording

Preparation and implementation of fieldwork

Fieldwork started immediately after finalizing the survey design and lasted approximately 3.5 months, from 27 December 2004 until 16 April 2005. Field implementation was carried out by four teams assembled by staff of the RHBs, EHNRI and FMOH (see Annex 5 for a list of field team members). Each field team consisted of four people: one health environmentalist or sanitary engineer who acted as team leader and who had responsibility for conducting sanitary inspections; two experienced laboratory technicians who conducted microbial and chemical water quality analyses; and a driver. The composition of field teams did not change during the study, except for field team C, in which one team member was replaced.

All team members received training during the first consultancy visit in December 2004. Training covered all aspects of field implementation, including: the use of the Wagtech field testing equipment; the purpose and use of sanitary inspections; how to select sampling sites; quality assurance procedures; and practical aspects of planning and organizing fieldwork. The training comprised laboratory based and field exercises, including a review of lessons learned during the day in the field. During the training some questions on the standard sanitary inspection forms were slightly modified for clarity's sake and to better reflect the situation in Ethiopia. The final set of questions is presented in Table3.14.

To prepare for the fieldwork, an inventory of equipment and reagents supplied through the RADWQ project was prepared and reviewed by the core technical working group (see Annex 6 for the inventory). Items needed to successfully implement the fieldwork were also procured (e.g. methanol, distilled water, tissue paper, beakers, reagents for nitrate testing; for the full list see Annex 7). Photocopies had to be made, to provide the field teams with the necessary forms and information (e.g. the daily record sheets, sanitary inspection forms, quality assurance record sheets, sampling plans, aseptic technique evaluation forms, quality control tables for microbiological testing, resuscitation time[1] memo sheets, and copies of all Wagtech manuals). Copies of fieldwork checklists were also made (Annex 8).

A work plan for field implementation was prepared on the basis of the survey design, which specified the duration of individual field trips and assigned specific clusters to each of the four field teams (Annex 9). In total, four field trips were undertaken with all four teams working in the same broad area. After finishing a field trip, field teams returned to Addis Ababa for a meeting with the core technical working group to jointly review lessons learned during the fieldwork and to plan the next trip. Each trip lasted approximately 30 days, except for field trip 1 to Addis Ababa, which lasted only six days (Annex 9). The 30-day period was sufficient to finish the clusters as planned in the work plan because teams worked weekends and public holidays. A period of 30 days for the field trips was adopted primarily for practical considerations – the FMOH could only pay the per diem for 30 days in advance.

During the first field trip to Addis Ababa, field teams carried out all analyses at the sampling site, but the field teams and core technical working group decided to organize fieldwork differently for trips 2, 3 and 4, mainly because of the time constraints expected in the regions. On those trips, the team leader (a health environmentalist) carried out the inspection, collected the water samples and transported them to laboratory facilities at a RHB, zonal health department, zonal water desk or district health office. The analysis of the water was then carried out by the other two team members. Standard procedures were used to preserve the samples during storage and transportation, and field teams were supplied with enough sodium thiosulfate (through EHNRI), vaccine boxes and ice packs (through RHB) for this purpose.

Each field team was given detailed sampling plans (Annex 4 provides an example). The plans provided information on the zones from which the clusters or individual supplies were to be selected; on the water-supply scheme number to be used for water sources and household samples; and, on the water quality parameters to be tested at individual sampling points, for each of the broad areas. Individual water supplies to be visited were selected during a week in the field, after seeking advice from the regional and local authorities, particularly from the regional, zonal and woreda health or water departments. The

[1] A period of 2-4 hours is needed to "resuscitate" bacteria before incubation, because they get injured by the membrane filtration process.

FMOH provided field teams with supporting letters that outlined the purpose of the study, asked regional and local authorities for their collaboration and support, and to facilitate access to treatment works, storage reservoirs and households.

After each trip, team leaders prepared a brief summary report of the trip activities (see Annex 10 for an example report). At the end of the RADWQ project the team leaders were also asked to provide a report that summarized the major sanitary risks encountered. The biggest difficulties encountered by the teams during fieldwork included:

- There was not enough cash/pocket money to cover miscellaneous expenditures, such as labour costs for transporting test kits and other luggage to remote water points, and allowances for the staff of the local zonal or woreda health or water offices who helped the field teams locate the water supplies in rural areas.
- Additional equipment was needed, such as clipboards and document bags for record keeping.
- There was a shortage of sampling bottles and vaccine boxes for bacteriological testing.
- There was a shortage of reagents for nitrate testing.
- The daily government allowance rate was insufficient, particularly in light of the hardship of fieldwork, with work days of more than 12 hours and increased personal expenditures.

After the second field trip, extra cash, equipment and reagents were provided to the field teams, but daily allowances were never increased during the project.

Supervisory visits to the field by the core technical working group were only carried out during field trip 1 in Addis Ababa, but not in the other regions. This decision was based on the agreement that field team leaders would supervise water quality analyses and provide direct feedback to team colleagues. The field teams also met with the core technical group between field trips and any problems or queries were addressed at those meetings. The core technical group reported to the consultant by e-mail about every four weeks via Dr Solomon Fisseha of the WHO Representative's Office in Ethiopia.

The total budget for project implementation in Ethiopia was approximately US$32 000. The budget mainly covered expenses for fuel, per diem and the purchase of additional equipment (Annex 11). It did not cover the costs of the 3500 photocopies of forms and materials for the field teams, and expenses for photocopying were kindly covered by WHO Ethiopia. Vehicles were provided for free by EHNRI and FMOH, otherwise the transport would not have been covered by the budget either. If it had been necessary to hire suitable cars on the local market, costs for field implementation would have been two or three times higher.

Data recording

Each day, the results of sampling and sanitary inspections were recorded in daily report sheets (Annex 12). Completed sanitary inspection forms were attached to the daily report sheets. All field records were delivered to the project coordinator after each of the field trips, and were later forwarded to the data manager who entered the information into SanMan. The data manager was trained in using SanMan software during the first consultancy visit in December 2004.

Each sample site was identified in SanMan by a unique 8-digit water supply scheme number. In the case of Ethiopia, the following coding was used:

- Digits 1–3: country code (= ETH);
- Digit 4: broad area code;
- Digits 5–6: cluster code (consecutive numbering within one broad area);
- Digits 7–8: sample code (consecutive numbering within one cluster).

2.4 Data analysis

Data analysis is one of the most important aspects of the report, because it is the principal mechanism by which raw data are transferred into usable information for project managers, communities and other decision-makers. Raw data itself is of little use – most people will not understand what it means and few will have sufficient time or interest to analyse the data. What is required is simple, direct and comprehensible information that can be used without further manipulation and is meaningful to the target audience.

All water quality and sanitary inspection results were entered and stored using the SanMan software, and later exported to Microsoft Excel for data analysis. Before entry, the data were edited for consistency (i.e. dates given according to the Ethiopian calendar had to be transferred into the Gregorian system). After entry, the data were checked for plausibility or for unrecognized characters by the international consultant and the data manager. If necessary, the entered data were also compared with the original records and the SanMan database corrected as needed.

The "clean" data set was exported to Excel and from there to SPSS for analysis. Data analysis was performed with SPSS, rather than Excel, mainly because the project data manager was more experienced with SPSS. There was no difference in the results when the data were analysed in Microsoft Excel (by the international consultant). Data entry and analysis took approximately three months in total.

Data were analyzed following the guidelines provided by the international consultant. This included an analysis by broad area and supply technology to see if microbiological, physical and chemical parameters were in compliance with WHO guideline values (which are equivalent to the Ethiopian Standards; see Section 1.3). Household samples were also analysed for microbiological and chemical parameters, and particularly for the deterioration of drinking-water quality between the distribution system and the household taps.

In line with the 2004 *WHO guidelines for drinking-water quality*, all samples were assessed for sanitary risks by inspections that used a standard set of questionnaires developed for the RADWQ pilot project. Individual water supplies were assigned to risk categories using a "risk-to-health matrix", which cross-checks a sanitary risk score with the count for thermotolerant coliforms, to give a measure of the potential health risk.

An analysis of proxy parameters (i.e. turbidity for bacteria, conductivity for chemicals) was also done. The output of the analysis was Pearson's *r*, a linear correlation coefficient that can easily be calculated within Excel. A drawback is that the derivation of Pearson's *r* assumes that the input data are distributed normally, and the analysis uses means and standard deviations, so that outlier values[2] can disproportionately influence the results. More rigorous analyses exist, but cannot be carried out within Excel. For example, Spearman's *rho* does not assume the data are normally distributed, and uses a rank transformation method that makes it resistant to outliers.

[2] A value far from most others in a set of data.

3 Results

3.1 Microbiological parameters

A variety of microorganisms are found in water, including pathogenic and non-pathogenic species. Non-pathogenic microorganisms may cause taste and odour problems with water supplies, which can influence whether people use the water for consumption, but the principle concern for microbiological quality is contamination by pathogenic species. Pathogens found in drinking-water include species of bacteria, viruses, protozoa and helminths (Table 3.1).

Table 3.1 **Waterborne pathogens and their significance in water supplies**[a]

Pathogen	Health significance	Persistence in water supply	Resistance to chlorine	Relative infectivity	Important animal source
Bacteria					
Burkholderia pseudomallei	Low	May multiply	Low	Low	No
Campylobacter jejuni	High	Moderate	Low	Moderate	Yes
Escherichia coli - pathogenic	High	Moderate	Low	Low	Yes
E. coli – enterohaemorrhagic	High	Moderate	Low	High	Yes
Legionella spp.	High	Multiply	Low	Moderate	No
Non-tuberculous mycobacteria	Low	Multiply	High	Low	No
Pseudomonas aeruginosa	Moderate	May multiply	Moderate	Low	No
Salmonella typhi	High	Moderate	Low	Low	No
Other salmonellae	High	May multiply	Low	Low	Yes
Shigella spp.	High	Short	Low	Moderate	No
Vibrio cholerae	High	Short	Low	Low	No
Yersinia entercolitica	High	Long	Low	Low	Yes
Viruses					
Adenoviruses	High	Long	Moderate	High	No
Enteroviruses	High	Long	Moderate	High	No
Hepatitis A	High	Long	Moderate	High	No
Hepatitis B	High	Long	Moderate	High	Potentially
Noroviruses and Sapoviruses	High	Long	Moderate	High	Potentially
Rotavirus	High	Long	Moderate	High	No
Protozoa					
Acanthamoeba spp.	High	Long	High	High	No
Cryptosporidium parvum	High	Long	High	High	Yes
Cyclospora cayetanensis	High	Long	High	High	No
Entamoeba histolytica	High	Moderate	High	High	No
Gardia intestinalis	High	Moderate	High	High	Yes
Naegleria fowleri	High	May multiply	High	High	No
Toxoplasma gondii	High	Long	High	High	Yes
Helminths					
Dracunculus medinensis	High	Moderate	Moderate	High	No
Schistosoma spp.	High	Short	Moderate	High	Yes

[a] Source: WHO (2004).

Even though it is useful for determining the public-health risk from drinking-water and for developing health-based water quality targets, the routine monitoring of pathogens is generally not carried out, because the analytical tools either do not exist, or the tests are expensive and difficult to perform. Instead, most drinking-water programmes monitor indicator organisms (usually bacteria) to analyse the microbiological quality of the drinking-water.

The most commonly used indicator microorganisms include *E. coli* (type 1) and thermotolerant coliforms (as surrogates), which derive almost exclusively from human and animal faeces, in common with most waterborne pathogens. Thermotolerant coliforms can grow at 44–45°C, and the group includes *E. coli* type 1 and other bacterial species that have an environmental source (e.g. *Citrobacter* spp. or *Klebsiella* spp.). The identification of *E. coli* strains from contaminated water is simple, but time consuming, as it requires a two-stage process of presumptive and confirmatory testing. Many programmes that monitor drinking-water quality therefore use thermotolerant coliforms as proxy indicators, because the results are obtained quickly and cheaply, even though they are only presumptive.

The broader group of coliforms, known as total coliforms, are also used to monitor water quality. These total coliforms are of no sanitary or public-health significance, but they are very sensitive to chlorine and their presence in chlorinated water implies the chlorination was ineffective and that the water may be unsafe to drink. Monitoring of total coliforms is not recommended, however, because they can be present in any unchlorinated water in the distribution system and have no sanitary significance.

Faecal streptococci are also used as indicators of the microbiological quality of drinking-water. These bacteria have a stronger relationship to diarrhoeal disease than *E. coli* and show a closer relationship to bacterial indicators of known human faecal origin. Since faecal streptococci are more resistant than *E. coli* or thermotolerant coliforms (i.e. they survive longer in a water environment and are more resistant to drying and chlorination), they are recommended for monitoring groundwater subject to receiving contaminated recharge water and for monitoring water quality in chlorinated distribution systems. A variety of techniques are available for analysing faecal streptococci, but the main limitation is that they are time-consuming (the results take 48 hours to obtain), which limits the usefulness of faecal streptococci for routine monitoring.

Other water quality parameters include pH, turbidity and residual chlorine (where supplies are chlorinated). They are recommended in water quality monitoring programmes, as they either directly influence microbiological quality (in the case of chlorine) or influence disinfection efficiency and microbial survival (in the cases of pH and turbidity).

Microbiological parameters used in the RADWQ project in Ethiopia

The following microbiological and related parameters were used in the RADWQ study in Ethiopia:

- thermotolerant coliforms were tested for in 100% of source and household water samples;
- faecal streptococci were tested for in 10% of the source water samples;
- pH and turbidity were measured in 100% of source and household water samples;
- if supplies were chlorinated, residual free chlorine was measured in 100% of source and household water samples, and residual total chlorine in approximately 15% of source water samples (results not discussed in this report).

Results for thermotolerant coliforms

Of the 1602 samples tested for thermotolerant coliforms in Ethiopia, 72.0% met both the national standard and the WHO guideline value of <1 cfu/100 ml (Table 3.2, Table 3.3). Among the four technology categories investigated, compliance was significantly higher for utility piped supplies: 87.6% of 838 water samples collected from utility piped supplies (i.e. from treatment plants and the distribution system) met both the WHO guideline value and national standards, but only 67.9%, 43.3% and 54.8% of boreholes, protected springs and protected dug wells, respectively, were in compliance. Regionally, compliance levels ranged from 82.6% in Oromiya and Addis Ababa to 58.6% in SNNPR (Table 3.2). Overall, 14.3% of the 1602 samples tested for thermotolerant coliforms had a count of 11−100 cfu/100 ml, but almost one third (29.2%) of protected springs showed this count level (Table 3.3). Very high counts (higher than 100 cfu/100 ml) were found in only 6.8% (or 109) of all samples.

The higher compliance levels found with utility piped supplies were not unexpected, because they were generally better protected than springs, dug wells and boreholes. Utility piped supplies were also often chlorinated, in contrast to point sources, and thus provided better protection against microbial contamination. The low level of compliance for protected springs, particularly in SNNPR (21.3%, Table 3.2), may be explained by the poor sanitary conditions. Indeed, many of the protected springs visited could not be classified as such (Section 3.5; Table 3.14). In general, the RADWQ results were consistent with those in the EHNRI database (Section 1.3).

Table 3.2 Compliance with the national standard and WHO guideline value for thermotolerant coliforms[a]

Broad area	Utility piped supplies		Boreholes		Protected springs		Protected dug wells		Total	
	No. of samples	Compl. (%)	No. of samples	Compl. (%)	No. of samples	Compl. (%)	No. of samples	Compl. (%)	No. of samples	Compl. (%)
Oromiya & Addis Ababa	517	89.9	109	71.6	80	51.3	8	75.0	714	82.6
Dire Dawa & Somali	70	80.0	19	42.1	0	-	0	-	89	71.9
Tigray & Amhara	171	84.2	120	72.5	159	50.3	127	46.5	577	64.1
SNNPR	80	86.3	42	57.1	80	21.3	20	100.0	222	58.6
National	838	87.6	290	67.9	319	43.3	155	54.8	1 602	72.0

[a] Compl. = compliance. SNNPR = Southern Nations, Nationalities and Peoples Region. "-" = data unavailable.

Table 3.3 Count categories and cumulative frequencies for thermotolerant coliforms in Ethiopian water supplies [a]

Count category (cfu/100 ml)	Utility piped supplies		Boreholes		Protected springs		Protected dug wells		Total	
	Prop. (%)	Freq. (%)	Prop. (%)	Freq. (%)	Prop. (%)	Freq. (%)	Prop. (%)	Freq. (%)	Prop. (%)	Freq. (%)
<1	87.6	87.6	67.9	67.9	43.3	43.3	54.8	54.8	72.0	72.0
1-10	4.2	91.8	9.0	76.9	10.0	53.3	11.0	65.8	6.9	78.9
11-100	6.4	98.2	16.9	93.8	29.2	82.4	21.3	87.1	14.3	93.2
>100	1.8	100.0	6.2	100.0	17.6	100.0	12.9	100.0	6.8	100.0
Total no. of samples	838		290		319		155		1 602	

[a] cfu = colony-forming unit. Freq. = cumulative frequency. Prop. = proportion of water samples showing corresponding count category.

Results for faecal streptococci

Of the 110 samples analysed for faecal streptococci, 66.4% were in compliance with both the national standard and the WHO guideline value (Table 3.4). Water samples from protected springs showed highest compliance (76.9% with <1 cfu/ml), followed by those from utility piped supplies and boreholes (both 68.2%), and dug wells (44.4%) (Table 3.5). When comparing different broad areas, lowest overall compliance was observed in Oromiya and Addis Ababa, where only 56.1% of the 41 samples tested for faecal streptococci met both the national standard and the WHO guideline value (<1 cfu/ml).

The cumulative frequency for faecal streptococci is shown in Table 3.5. Nationally, 73 of 110 (66.4%) samples tested for faecal streptococci had counts <1 cfu/100ml and were in compliance with both the national standard and the WHO guideline value (Table 3.5). However, 14% had counts of 1–10 cfu/100 ml, and another 14% had counts of 11–100 cfu/100 ml. Overall, 5.5% of all samples had counts >100 cfu/100 ml, but this proportion was significantly higher for protected springs and protected dug wells (7.7% and 11.1%, respectively) than for the other two supply technologies.

Table 3.4 **Compliance with both the national standard and WHO guideline value for faecal streptococci**[a]

Broad area	Utility piped supplies		Boreholes		Protected springs		Protected dug wells		Total	
	No. of samples	Compl. (%)	No. of samples	Compl. (%)	No. of samples	Compl. (%)	No. of samples	Compl. (%)	No. of samples	Compl. (%)
Oromiya & Addis Ababa	27	63.0	8	37.5	6	50.0	0	-	41	56.1
Dire Dawa & Somali	3	100.0	2	100.0	0	-	0	-	5	100.0
Tigray & Amhara	12	75.0	8	75.0	14	78.6	16	50.0	50	68.0
SNNPR	2	50.0	4	100.0	6	100.0	2	0.0	14	78.6
National	44	68.2	22	68.2	26	76.9	18	44.4	110	66.4

a Compl. = compliance. SNNPR = Southern Nations, Nationalities and Peoples Region. "-" = data unavailable.

Table 3.5 **Cumulative frequencies for faecal streptococci**[a]

Count category (cfu/100 ml)	Utility piped supplies		Boreholes		Protected springs		Protected dug wells		Total	
	Prop. (%)	Freq. (%)	Prop. (%)	Freq. (%)	Prop. (%)	Freq. (%)	Prop. (%)	Freq. (%)	Prop. (%)	Freq. (%)
<1	68.2	68.2	68.2	68.2	76.9	76.9	44.4	44.4	66.4	66.4
1-10	15.9	84.1	9.1	77.3	11.5	88.5	22.2	66.7	14.5	80.9
11-100	13.6	97.7	18.2	95.5	3.8	92.3	22.2	88.9	13.6	94.5
>100	2.3	100.0	4.5	100.0	7.7	100.0	11.1	100.0	5.5	100.0
Total no. of samples	44		22		26		18		110	

a cfu = colony-forming unit. Freq. = cumulative frequency. Prop. = proportion of water samples showing corresponding count category.

3.2 Chemical parameters

Water gathers impurities from both natural and anthropogenic sources, and these cause the physical and chemical parameters of drinking-water to vary over time and by location. Natural and anthropogenic sources of water contamination include (WHO, 2004):

- naturally occurring chemicals and other substances;
- chemicals from industrial sources and human dwellings;
- chemicals from agricultural activities;
- chemicals used in water treatment or from materials in contact with drinking-water;
- pesticides used in water for public-health purposes;
- cyanobacterial toxins and other contaminants derived from biological sources.

Many chemicals found in drinking-water sources may be the cause of adverse human health effects (e.g. arsenic, fluoride), affect the acceptability of water (i.e. turbidity, iron, conductivity, taste, colour, odour; see Section 3.3) and lower the effectiveness of water treatment. Although some chemicals can cause acute health effects, their concentrations rarely reach sufficient levels in drinking-water, except as a result of the accidental contamination of a water supply. The main problems associated with chemical constituents of drinking-water arise primarily from their ability to cause adverse health effects after prolonged periods of exposure. Contaminants that have cumulative toxic properties, such as heavy metals and carcinogens, are of particular concern (WHO, 2004).

It would be expensive, difficult and largely unnecessary to test for all chemicals that might be of concern in drinking-water and so the chemical parameters to measure have to be prioritized. Priority should be given to parameters that have the greatest impact on the health of the general population, and on infants and young children. People who are debilitated, sick or elderly, or who live under unsanitary conditions may be particularly vulnerable to chemicals in drinking-water. The parameters should be country-specific (and region-specific, if possible). Judgement should be based on criteria presented on page 2 of the RADWQ handbook and on historical water-quality data (Howard et al., 2003; WHO, 2004). In the case of Ethiopia, the physicochemical parameters recommended for RADWQ level 1 assessments were relevant and were therefore adopted for this study (Table 3.6).

Table 3.6 **Physicochemical parameters included in this RADWQ study**

Parameter	Reason for inclusion	Testing frequency
Arsenic	Health	100% of source and household samples
Fluoride	Health	100% of source and household samples
Nitrate	Health, indicator of sanitary quality	100% of source and household samples
Copper (see Section 3.8)	Health and aesthetic	Only in household samples where copper is used in plumbing
Iron (see Section 3.3)	Aesthetic	100% of source and household samples
Conductivity (see Section 3.3)	Aesthetic, indirect health	100% of source and household samples
Turbidity (see Section 3.3)	Aesthetic	100% of source and household samples
Appearance[a]	Aesthetic, indirect health	

[a] These results are not presented in this study.

Nitrate

Nitrate is one of the most ubiquitous chemical constituents/contaminants of water bodies worldwide as it is derived from human activities, particularly from the disposal of human and animal wastes and the use of nitrogenous fertilizers in agriculture. The intensification of farming practices, for example, has increased nitrate levels in many groundwater resources (Howard et al., 2003; WHO, 2004). In rare cases, nitrate in groundwater resources derives from geological formations like caleche (Taye, 1999).

In the RADWQ project, a total of 1598 water samples collected from 852 utility piped supplies, 272 boreholes, 155 dug wells and 319 protected springs were analysed for nitrate (Table 3.7). Of these, 1582 samples (99.0%) complied both with the WHO guideline value and the national standard. The median concentration for the whole of Ethiopia was 2.0 mg NO_3/l, with maximum concentrations of 123.2 mg NO_3/l in Dire Dawa and Somali.

Table 3.7 **Compliance with the Ethiopian national standard and WHO guideline value for nitrate[a]**

Broad area	Utility piped supplies		Boreholes		Protected springs		Protected dug wells		Total	
	No. of samples	Compl. (%)	No. of samples	Compl. (%)	No. of samples	Compl. (%)	No. of samples	Compl. (%)	No. of samples	Compl. (%)
Oromiya & Addis Ababa	521	100.0	110	100.0	80	100.0	8	100.0	719	100.0
Dire Dawa & Somali	70	80.0	19	100.0	0	-	0	-	89	84.3
Tigray & Amhara	172	100.0	101	100.0	159	99.4	127	100.0	559	99.8
SNNPR	89	98.9	42	100.0	80	100.0	20	100.0	231	99.6
National	852	98.2	272	100.0	319	99.7	155	100.0	1 598	99.0

[a] Compl. = compliance. SNNPR = Southern Nations, Nationalities and Peoples Region. "-" = data unavailable.

The high compliance rates seen for nitrate in the RADWQ project are inconsistent with earlier studies, including the results in the EHNRI database (Table 1.4), in which high nitrate concentrations and low compliance rates were reported for groundwater resources in many regions of Ethiopia, particularly Addis Ababa, Oromiya, Afar, SNNPR, Amhara, Harari, Dire Dawa and Somali (FMOWR, 2000; Tamiru, 2000;

Reimann et al., 2003). Indeed, the veracity of the 100% compliance rate reported by the RADWQ project for nitrate in the broad area Oromiya and Addis Ababa (Table 3.7) is particularly questionable, because nitrate contamination is known to exist in the broad area (FMOWR, 2000; 2001).

The reason for the discrepancy may be attributable to the limited number of samples assayed during the RADWQ project; as a consequence supplies with nitrate problems were not detected. Other possibilities include the fact that the RADWQ project measured only improved water supplies, and that sources with nitrate values exceeding the standards may not be in use any more due to preventive measures taken by regulatory authorities.

In contrast, for the broad areas Dire Dawa and Somali, Tigray and Amhara, and SNNPR the RADWQ project findings are consistent with historical water-quality data and other reports (FMOWR, 2000; 2001). In Dire Dawa town, the high nitrate levels in groundwater resources (Taye, 1999) are likely caused by:

- a lack of proper sewers and other waste disposal facilities;
- the presence of more than 20 000 open pit latrines; and,
- geological conditions.

It is worth noting that not a single case of the well-known health problem associated with nitrate ingestion, methaemoglobinaemia (or blue-baby syndrome), has ever been reported, according to the records of the outpatient department of Dire Dawa hospital (Taye, 1999). In general, owing to the fact breast-feeding is a widespread practice in Ethiopia (for both cultural and economic reasons), the actual health burden from nitrate can be considered to be relatively insignificant.

Although in-depth studies were not available for the Somali region, the high nitrate concentrations in the supplies relying on groundwater resources could be caused by factors similar to those causing nitrate problems in Dire Dawa. Animal wastes could be a major source of nitrate contamination, because there is a lot of cattle in the region and sanitary conditions are poor.

Fluoride

Fluoride is one of the most important chemicals to affect the quality of drinking-water. In the Rift Valley region of Ethiopia, the problem of high fluoride concentrations in natural waters, especially groundwater, is severe and widespread (Haile, 1999; Tamiru, 2000; Reimann et al., 2003; Berhanu, 2004; Samson, 2004; Tesfaye, 2004). The high fluoride concentrations are primarily associated with:

- volcanic and fumarolic activity, which adds fluoride to the groundwaters;
- water interacting with fluoride-bearing volcanic and sedimentary rocks, such as pumice, ignimbrite, obsidian and rhyolite; and,
- low calcium concentrations, which restrict the precipitation of fluoride as fluorite (CaF_2).

In addition to the Rift Valley region, groundwater resources in a few isolated pockets in Oromiya were shown to contain significant fluoride concentrations (FMOWR, 2000; 2001; EHNRI database, see Section 1.3). In some areas of the Somali region (e.g. Deghabur, Kebri Dehar, Jerer Valley, Hargele and Warder), historical water-quality data indicate that fluoride concentrations in groundwater resources are well above the WHO guideline value or the national standard. The cause is believed to be of geological origin.

In the RADWQ project, 1613 water samples were collected from 852 utility piped supplies, 292 boreholes, 155 dug wells and 313 protected springs and analysed for fluoride. Overall, the results indicated that 1519 samples (94.2%) complied with the WHO guideline value and the national standard (Table 3.8). The maximum fluoride concentration detected was 10.5 mg/l.

In Oromiya, fluoride concentrations exceeded the WHO guideline value and the national standard at almost all the water supplies in the East Shewa Zone, which is located in the main Rift Valley system of Ethiopia. The RADWQ results are consistent with historical national water quality data and with numerous study findings, and all agree that fluoride levels pose a major water quality problem in the Zone (Haile 1999; Tamiru 2000; Reimann et al., 2003; Berhanu 2004).

Table 3.8 **Compliance with the Ethiopian national standard and WHO guideline value for fluoride**[a]

Broad area	**Utility piped supplies**		**Boreholes**		**Protected springs**		**Protected dug wells**		**Total**	
	No. of samples	Compl. (%)	No. of samples	Compl. (%)	No. of samples	Compl. (%)	No. of samples	Compl. (%)	No. of samples	Compl. (%)
Oromiya & Addis Ababa	520	87.1	110	99.1	74	100.0	8	100.0	712	90.4
Dire Dawa & Somali	70	71.4	19	94.7	0	-	0	-	89	77.5
Tigray & Amhara	173	100.0	121	100.0	159	100.0	127	99.2	580	99.8
SNNPR	89	98.9	42	97.6	80	100.0	20	100.0	231	99.1
National	852	89.7	292	99.3	313	100.0	155	99.4	1 612	94.4

[a] Compl. = compliance. SNNPR = Southern Nations, Nationalities and Peoples Region. "-" = data unavailable.

The RADWQ results for the broad area of SNNPR indicate that overall compliance with fluoride standards was 99.1%, and that fluoride was not a problem for the drinking-water supplies in the region. This figure probably underestimates the true extent of the fluoride problem in the area, however, because many areas in the SNNPR are within the main Rift Valley system of Ethiopia and are known to have high levels of fluoride in the water supplies. Most of these areas were not visited during the RADWQ field assessment, possibly as a consequence of the survey design.

In Dire Dawa and Somali, only water supplies from the Somali Region had fluoride concentrations above the WHO guideline value. This concurred with historical data indicating that fluoride levels caused problems for drinking-water quality in the region. Even so, the low level of overall compliance for the broad area (77.5%, Table 3.8) probably underestimates the actual level of compliance. The high fluoride concentrations in the groundwater resources of the region are believed to be of geological origin.

In Tigray and Amhara, the RADWQ results agreed almost completely with historical water-quality data and confirmed that fluoride did not cause a water-quality problem in the area. However, fluoride levels exceeding the WHO guideline value were found in one sample from a dug well in the Amhara region, West Gojam Zone. The reason for this unexpected result is unclear, but the high fluoride levels could be of geological origin, result from accidental contamination, or simply be an analytical error.

Table 3.9 **Compliance with the Ethiopian national standard and WHO guideline value for arsenic**[a]

Broad area	**Utility piped supplies**		**Boreholes**		**Protected springs**		**Protected dug wells**		**Total**	
	No. of samples	Compl. (%)	No. of samples	Compl. (%)	No. of samples	Compl. (%)	No. of samples	Compl. (%)	No. of samples	Compl. (%)
Oromiya & Addis Ababa	517	100.0	110	100.0	80	100.0	8	100.0	715	100.0
Dire Dawa & Somali	70	100.0	19	100.0	0	-	0	-	89	100.0
Tigray & Amhara	173	100.0	121	100.0	159	100.0	127	100.0	580	100.0
SNNPR	89	100.0	42	100.0	80	100.0	20	100.0	231	100.0
National	849	100.0	292	100.0	319	100.0	155	100.0	1 615	100.0

[a] Compl. = compliance. SNNPR = Southern Nations, Nationalities and Peoples Region. "-" = data unavailable.

Arsenic

A total of 1615 drinking-water supply sources, comprising 849 utility piped supplies, 292 boreholes, 155 dug wells and 319 protected springs, were screened for the presence of arsenic (Table 3.9). All the water samples complied both with the WHO guideline value and the national standard for arsenic.

What little information on arsenic in Ethiopian drinking-water supplies that exists agrees with the RADWQ project finding that arsenic is not a problem for the water supplies (USAID, 2000). The arsenic in drinking-water sources comes primarily from naturally occurring minerals and ores (mostly arsenic sulphide/arsenopyrite, metal arsenates and arsenides), which dissolve into the water resources. There are no anthropogenic sources of arsenic, such as mining, and to our knowledge no case of chronic arsenic poisoning from drinking contaminated water has ever been reported in Ethiopia.

3.3 Aesthetic parameters

Iron

Iron is one of the most abundant metals in the earth's crust. Iron contamination is a particular problem for anaerobic groundwater supplies, but iron can get into drinking-water from the use of iron coagulants or from corrosion of galvanized iron, steel and cast-iron pipes in the distribution system. Iron also promotes the growth of iron bacteria, which oxidize ferrous iron to ferric iron, and in the process corrode the piping and deposit a slimy coating on its surface (Howard et al., 2003; WHO, 2004). Some surface waters also have iron problems, particularly related to colloidal iron.

In Ethiopia, high concentrations of iron were found in the groundwater supplies of Addis Ababa, Afar, Amhara, Benshangul, Gambella, Western Oromiya and SNNPR (FMOWR, 2000; 2001), and high iron concentrations commonly cause consumers to reject groundwater-supplied drinking-water in Chelelektu and Yirgachefe towns of Gedio zone, Sidama, Bench Maji and Keffa-Sheka zones of SNNPR (FMOWR, 2000; 2001). The problem was so severe at Chelelektu and Yirgachefe towns that iron removal plants had to be installed.

For the RADWQ project, a total of 1619 water samples were collected from 853 utility piped supplies, 292 boreholes, 155 dug wells and 319 protected springs and analysed for iron (Table 3.10). Overall, 1517 samples (93.7% of the total analysed) complied with the WHO "suggested" value and the national standard. These results agree closely with the historical water-quality data and reports for Ethiopia (FMOWR, 2000; 2001).

Table 3.10 Compliance with the national standard and WHO "suggested" value for iron[a]

Broad area	Utility piped supplies		Boreholes		Protected springs		Protected dug wells		Total	
	No. of samples	Compl. (%)	No. of samples	Compl. (%)	No. of samples	Compl. (%)	No. of samples	Compl. (%)	No. of samples	Compl. (%)
Oromiya & Addis Ababa	521	97.1	110	78.2	80	92.5	8	87.5	719	93.6
Dire Dawa & Somali	70	97.1	19	94.7	0	-	0	-	89	96.6
Tigray & Amhara	173	95.4	121	95.9	159	99.4	127	96.9	580	96.9
SNNPR	89	79.8	42	73.8	80	98.8	20	75.0	231	84.8
National	853	95.0	292	86.0	319	97.5	155	93.5	1 619	93.7

[a] Compl. = compliance. SNNPR = Southern Nations, Nationalities and Peoples Region. "-" = data unavailable.

Turbidity

Turbidity in water is caused by suspended matter, such as clay, silts, finely divided organic and inorganic matter, soluble coloured organic matter, and plankton and other microscopic organisms. It can arise in drinking-water if the water is inadequately treated or if sediment is re-suspended. Turbidity can also come from biofilm or corrosion products in the distribution system. High levels of turbidity can protect microorganisms from the effects of disinfection and can stimulate bacterial growth. Low turbidity minimizes both the amount of chlorine required for disinfection of water and the potential for transmitting infectious diseases.

In the RADWQ project, a total of 1618 water samples were collected from 853 utility piped supplies, 291 boreholes, 155 dug wells and 319 protected springs and analysed for turbidity (Table 3.11). Overall, 1406 samples (86.9% of the total) complied with the WHO "suggested" value and the national standard.

The RADWQ findings agree closely with historical water-quality data and reports for Ethiopia. In Ethiopia, colour and turbidity problems with drinking-water have been common in almost all regions (FMOWR, 2000; 2001). Boreholes, dug wells and protected springs had the lowest compliance levels of all the water-supply technologies, at 80.4%, 80.0% and 78.4%, respectively (Table 3.11). As expected, utility piped supplies had the highest level of compliance (93.6%).

Given the high concentrations of iron found in many water supplies and the poor sanitary conditions of water supplies in almost all broad areas, it is plausible that turbidity is a major water-quality problem for a significant proportion of the water supplies in the country. The causes of turbidity are primarily natural, with some contribution from anthropogenic sources (from corrosion products and products formed by nuisance organisms in piped distribution systems).

Conductivity

Conductivity is a proxy indicator of total dissolved solids, and therefore an indicator of the taste or salinity of the water. Although this parameter does not provide information about specific chemicals in water, it acts as a good indicator of water-quality problems, particularly when it changes with time. There is little direct health risk associated with this parameter, but high values are associated with poor taste, customer dissatisfaction and complaints (Howard et al., 2003; WHO, 2004). High conductivity water, for example, can cause excessive scaling in water pipes, heaters, boilers and household appliances. The conductivity of water varies considerably by geological region, owing to differences in the mineral and chemical properties of the water body. However, changes in conductivity over time, and high conductivity values, indicate the water is contaminated, which can cause corrosion in rising mains and pipes.

Table 3.11 **Compliance with the national standard and WHO "suggested" value for turbidity**[a]

Broad area	Utility piped supplies		Boreholes		Protected springs		Protected dug wells		Total	
	No. of samples	Compl. (%)	No. of samples	Compl. (%)	No. of samples	Compl. (%)	No. of samples	Compl. (%)	No. of samples	Compl. (%)
Oromiya & Addis Ababa	521	93.5	109	74.3	80	73.8	8	62.5	718	88.0
Dire Dawa & Somali	70	87.1	19	68.4	0	-	0	-	89	83.1
Tigray & Amhara	173	96.5	121	89.3	159	88.1	127	86.6	580	90.5
SNNPR	89	93.3	42	76.2	80	63.8	20	45.0	231	75.8
National	853	93.6	291	80.4	319	78.4	155	80.0	1 618	86.9

[a] Compl. = compliance. SNNPR = Southern Nations, Nationalities and Peoples Region. "-" = data unavailable.

A total of 1619 water samples were collected in the RADWQ project from 853 utility piped supplies, 292 boreholes, 155 dug wells and 319 protected springs, and analysed for conductivity (Table 3.12). Overall, 1540 (95.1%) of the samples complied with the WHO "suggested" value and the national standard. The RADWQ findings closely agree with historical water-quality data, and national reports for Ethiopia (FMOWR, 2000; 2001).

Table 3.12 Compliance with the national standard and WHO "suggested" value for conductivity[a]

Broad area	Utility piped supplies		Boreholes		Protected springs		Protected dug wells		Total	
	No. of samples	Compl. (%)	No. of samples	Compl. (%)	No. of samples	Compl. (%)	No. of samples	Compl. (%)	No. of samples	Compl. (%)
Oromiya & Addis Ababa	521	97.3	110	95.5	80	97.5	8	62.5	719	96.7
Dire Dawa & Somali	70	50.0	19	68.4	0	-	0	-	89	53.9
Tigray & Amhara	173	97.7	121	95.9	159	99.4	127	97.6	580	97.8
SNNPR	89	100.0	42	97.6	80	100.0	20	100.0	231	99.6
National	853	93.8	292	94.2	319	99.1	155	96.1	1 619	95.1

[a] Compl. = compliance. SNNPR = Southern Nations, Nationalities and Peoples Region. "-" = data unavailable.

For the broad area Oromiya and Addis Ababa, only water supplies from the East Shewa zone of the Oromiya region had conductivity levels that exceeded the WHO "suggested" value. This zone is located in the main Rift Valley of Ethiopia where high conductivity values for natural waters are common (Haile, 1999; Tamiru, 2000; Berhanu, 2004; Tesfaye, 2004).

The lowest overall compliance (53.9%) was seen in the Dire Dawa and Somali area (Table 3.12), but all the samples with conductivity values that exceeded the WHO "suggested" value or the national standard came exclusively from the Somali region. In Dire Dawa, although the conductivity values of the water supplies complied with the standards, the values for most of the supplies were close to or above 1 µS/cm.

For Tigray and Amhara, most water supplies with conductivity values exceeding the WHO "suggested" value were from Tigray. This was expected, because even though many water supplies in Tigray had conductivity values below the WHO "suggested" value or the national standard, the levels were still high and scaling in water pipes, heaters, boilers and household appliances were common problems in this region.

For broad area SNNPR, almost all the water supplies had low conductivity values, which is characteristic of the supplies in the area.

3.4 Overall compliance

In the RADWQ project, overall compliance was defined as the proportion of water samples meeting the WHO guideline value and national standards for thermotolerant coliforms and for chemicals with health effects (i.e. arsenic, fluoride and nitrate). Overall, compliance was 68.0%, ranging from 57.2% in SNNPR to 75.8% in Oromiya and Addis Ababa (Table 3.13). Utility piped supplies showed significantly higher compliance levels (80.4%) than boreholes, protected dug wells and springs (65.6%, 54.8% and 43.5%, respectively).

Table 3.13 **Overall compliance with national standards and WHO guideline values for TTC, fluoride, arsenic and nitrate**[a]

Broad area	Utility piped supplies		Boreholes		Protected springs		Protected dug wells		Total	
	No. of samples	Compl. (%)	No. of samples	Compl. (%)	No. of samples	Compl. (%)	No. of samples	Compl. (%)	No. of samples	Compl. (%)
Oromiya & Addis Ababa	512	80.3	109	70.6	74	52.7	8	75.0	703	75.8
Dire Dawa & Somali	70	68.6	19	42.1	0	-	0	-	89	62.9
Tigray & Amhara	170	84.1	100	69.0	159	50.3	127	46.5	556	63.1
SNNPR	80	83.8	42	54.8	80	21.3	20	100.0	222	57.2
National	832	80.4	270	65.6	313	43.5	155	54.8	1 570	68.0

[a] Compl. = compliance. SNNPR = Southern Nations, Nationalities and Peoples Region. TTC = thermotolerant coliforms. "-" = data unavailable.

Compliance rates with the WHO guideline values and the national standards for nitrate, fluoride and arsenic were high (99%, 94.4%, 100.0%, respectively; Table 3.7, Table 3.8, Table 3.9), but only 72.0% of the water supplies were in compliance for thermotolerant coliform counts (Table 3.2). These figures indicate that microbial contamination is the primary cause of drinking-water contamination throughout the country, which is consistent with the unsanitary conditions seen at water supplies throughout Ethiopia during the RADWQ project (Section 3.5). Fluoride and nitrate do not contribute significantly to the relatively low overall compliance level of 68%.

Although the contribution of fluoride contamination to the overall rate of non-compliance was small, the problem was predominantly confined to the relatively densely populated Rift Valley area, where a significant number of people have adverse health effects from fluoride (i.e. dental and skeletal fluorosis). In public health terms, fluoride is the second most important contaminant of drinking-water supplies in Ethiopia, after microbial contamination.

3.5 Sanitary risk factors

In addition to the analysis of microbial, chemical and aesthetic parameters, sanitary inspections were carried out at all supply points visited during the RADWQ study. 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 drinking-water quality and thus to the health and well-being of the consumer. The most effective way to undertake sanitary inspections is to use a semiquantitative standardized approach using logical questions and a simple scoring system. Sanitary inspections are complementary to a water quality analysis and there is an increase in the power of analysis when both types of data are available. Sanitary inspections have additional value as they provide a longer-term perspective on the risks of future microbiological contamination, and thus complements a snapshot analysis of water quality.

Eight questionnaires, each with ten questions, were developed to determine the sanitary risk by technology type, and they were used in sanitary inspections of all water supply points visited. The ten questions were formulated with "yes" or "no" answers, which simplified the work of the enumerator (Table 3.14).

The major sanitary risk factors identified in the RADWQ study were cracks or breaks in the infrastructure; leaks; unsanitary conditions around the source; a latrine, sewer or other potential source of pollution nearer to the water supply than prescribed by technology standards; animal access to the water source; and, a poor drainage system.

The causes of the sanitary risks were classified into three categories:

- *Poor workmanship or lack of maintenance.* This resulted in cracks in the infrastructure at various levels of the system. In treatment plants, cracks were evident in the pre-filters and 11% of the mixing tanks leaked. Leaks were seen in 25% of the piped-water distribution system and in 16% of household pipes, which increased the potential for contamination by microbes or chemicals. In more than one-fifth of the cases the main water supply pipeline was exposed and the concrete was cracked in 20% of the water inspection taps. Some 35% of the boreholes with mechanized pumps either lacked a drainage system or the system was inappropriate and more than one-third of springs had faulty or missing collection or spring boxes and masonry that protected the springs. In 35% of the springs the back-fill area behind the retaining wall was faulty or eroded.
- *Poor site selection and failure to minimize sanitary risks.* A latrine or source of pollution was closer than allowed by the standard in 49% of the piped water distribution systems, 53% of the boreholes with mechanized pumps, 40% of the boreholes with hand pumps and 45% of the protected springs.
- *Poor sanitary conditions.* In treatment works, 11% and 21% of the mixing and sedimentation tanks, respectively, were unsanitary. The problem was even worse for the piped distribution systems, where 53% of the inspection taps and 56% of the household pipes were unsanitary. At many boreholes animals had free access, which also compromised sanitary conditions.

The RADWQ sanitary data can be used for an in-depth analysis of the most significant risk factors at the regional level, or at the level of individual water supplies, to identify priorities for future rehabilitation, maintenance or education programmes aimed at improving the safety of sources.

3.6 Risk-to-health analysis

A combined analysis of the sanitary inspection and water-quality data was used to assign a relative measure of the health risk for the water-supply technologies (Table 3.15, Table 3.16). Estimates of the longer-term risks of microbiological contamination (from the sanitary inspections), were combined with current data on thermotolerant coliform levels in the drinking-water, to derive a risk-to-health matrix (Table 3.15). Ranking the water supplies in this way helps to set priorities for individual interventions and supports rational decision making.

Table 3.14 **Results of sanitary inspections**

	Questions for the sanitary risk inspection	Risk frequency (%)
PIPED WATER: TREATMENT PROCESS: 19 sites inspected		
1	Are there evident cracks in the pre-filters?	21.1
2	Are there leaks in the mixing tank?	10.5
3	Is the mixing tank in an unsanitary condition?	15.8
4	Are there evident hydraulic surges at the intake?	10.5
5	Is any sedimentation tank in an unsanitary condition?	21.1
6	Is the air and water supply distribution in any sand bed uneven?	5.3
7	Are there mud balls or cracks in any of the filters?	15.8
8	Are there evident cross-connections between backwashed and treated water?	0.0
9	Is there evidence of insufficient coagulant dosing (e.g. alum)?	10.5
10	Are free residual chlorine concentrations (minimum 0.2 mg/l) not being achieved?	10.5
PIPED WATER: DISTRIBUTION SYSTEM: 428 sites inspected		
1	Do any taps or pipes leak at the sample site?	25.0
2	Does water collect around the sample site?	30.8
3	Is the area around the tap unsanitary?	52.6
4	Is there a sewer or latrine within 30 m of any tap?	49.3
5	Has there been discontinuity in supply over the last ten days?	24.3
6	Is the supply main pipeline exposed in the sampling area?	22.9
7	Do users report any pipe breaks within the last week?	8.9
8	Is the supply tank cracked or leaking?	7.5
9	Are the vents and covers on the tank damaged or open?	8.6
10	Is the inspection cover or concrete around the cover damaged or corroded?	20.6
BOREHOLE WITH MECHANISED PUMPING: 104 sites inspected		
1	Is there a latrine or sewer within 100 m of the pumping mechanism?	52.9
2	Is there a latrine within 10 m of the borehole?	9.6
3	Is there any source of other pollution within 50 m of the borehole (e.g. animal breeding, cultivation, roads, industry, etc)?	34.6
4	Is there an uncapped well within 100 m?	11.5
5	Is the drainage channel absent or cracked, broken or in need of cleaning?	34.6
6	Can animals come within 50 m of the borehole?	62.5
7	Is the base of the pumping mechanism permeable to water?	6.7
8	Is there any stagnant water within 2 m of the pumping mechanism?	10.6
9	Is the well seal unsanitary?	15.4
10	Is the borehole cap cracked?	4.8
BOREHOLE WITH HAND PUMP: 188 sites inspected		
1	Is there a latrine within 10 m of the borehole?	2.1
2	Is there a latrine uphill of the borehole?	31.4
3	Is there any source of other pollution within 10 m of the borehole (e.g. animal breeding, cultivation, roads, industry, etc)?	39.9
4	Is the drainage absent or faulty allowing ponding within 2 m of the borehole?	58.5
5	Is the drainage channel absent or cracked, broken or in need of cleaning?	77.1
6	Can animals come within 10 m of the borehole?	68.1
7	Is the apron less than 2 m in diameter?	14.4
8	Does spilt water collect in the apron area?	40.4
9	Is the apron or pump cover cracked or damaged?	11.2
10	Is the hand pump loose at the point of attachment or, for rope-washer pump: is the pump cover missing?	13.8

	Questions for the sanitary risk inspection	Risk frequency (%)
PROTECTED SPRING: 316 sites inspected		
1	Is the collection/spring box absent or faulty?	38.3
2	Is the masonry protecting the spring absent or faulty?	33.9
3	Is the backfill area behind the retaining wall absent or eroded?	34.8
4	Does spilled water flood the collection area?	47.2
5	Is the fence absent or faulty?	76.6
6	Can animals have access within 10 m of the spring?	94.6
7	Is there a latrine uphill and/or within 30 m of the spring?	9.5
8	Does surface water collect uphill of the spring?	18.0
9	Is the diversion ditch above the spring absent or non-functional?	87.0
10	Are there any other sources of pollution uphill of the spring (e.g. solid waste)?	26.9
DUG WELL WITH HAND PUMP: 155 sites inspected		
1	Is there a latrine within 10 m of the well?	5.2
2	Is the nearest latrine uphill of the well?	35.5
3	Is there any source of other pollution within 10 m of the well (e.g. animal breeding, cultivation, roads, industry, etc)?	44.5
4	Is the drainage absent or faulty, allowing ponding within 3 m of the well?	53.5
5	Is the drainage channel absent or cracked, broken or in need of cleaning?	66.5
6	Is the cement/slab less than 2 m in diameter around the top of the well?	8.4
7	Does spilt water collect in the apron area?	50.3
8	Are there cracks in the cement floor/slab?	27.7
9	Is the hand pump loose at the point of attachment, or for rope-washer pump: is the pump cover missing?	7.7
10	Is the well-cover absent or unsanitary?	20.6
HOUSEHOLD CONTAINER: 159 sites inspected		
1	Is the water storage container used for storing any other liquid/material?	15.1
2	Is the water storage container kept at ground level?	87.4
3	Is the water storage container lid/cover absent or not in place?	44.7
4	Is the storage container cracked or leaking or unsanitary?	49.1
5	Is the area around the storage container unsanitary?	76.1
6	Do any animals have access to the area around the storage container?	66.0
7	Is the tap/utensil used to draw water from the container unsanitary?	66.0
8	Is the water from the container also used for washing/bathing?	69.8
9	Has there been discontinuity in water supply over the last 10 days?	13.8
10	Is the water obtained from more than one source?	7.5
HOUSEHOLD PIPED WATER: 407 sites inspected		
1	Is the tap sited outside the house (e.g. in the yard)?	78.9
2	Is the water stored in a container inside the house?	73.0
3	Are any taps leaking or damaged?	16.0
4	Are any taps shared with other households?	36.1
5	Is the area around the tap unsanitary?	56.0
6	Are there any leaks in the household pipes?	19.7
7	Do animals have access to the area around the pipe?	69.8
8	Have users reported pipe breaks in the last week?	3.4
9	Has there been discontinuity in water supply in the last 10 days?	27.0
10	Is the water obtained from more than one source?	6.6

Table 3.15 **Risk-to-health matrix for water supplies**[a]

SI score	Utility piped supplies				Boreholes				Protected springs				Protected dug wells				Total			
	TTC count (cfu/100 ml)				TTC count (cfu/100 ml)				TTC count (cfu/100 ml)				TTC count (cfu/100 ml)				TTC count (cfu/100 ml)			
	<1	1-10	11-100	>100	<1	1-10	11-100	>100	<1	1-10	11-100	>100	<1	1-10	11-100	>100	<1	1-10	11-100	>100
0-2	288	7	20	5	76	6	8	4	16	8	13	4	46	5	4	4	426	26	45	17
3-5	375	20	22	7	111	16	28	13	91	13	50	28	32	9	22	9	609	58	122	57
6-8	69	6	11	3	10	3	12	0	28	10	25	21	7	3	7	7	114	22	55	31
9-10	0	2	0	0	0	0	0	1	3	1	5	3	0	0	0	0	3	3	5	4

[a] cfu = colony forming unit. SI = sanitary inspection. TTC = thermotolerant coliform.

VERY LOW	LOW	MEDIUM	HIGH

Most of the water supplies in the RADWQ study were classified as "very low" or "low" risk (66.5%, Table 3.16). One fifth of all supplies in Ethiopia were at "high" risk, but the proportion varied from 6.7% for utility piped supplies to 47.0% for protected springs. These numbers essentially mirror the results for thermotolerant coliform counts (Table 3.2) and sanitary risk factors (Section 3.5).

Table 3.16 **Overall risk-to-health classification for water supplies**

Risk category	Utility piped supplies		Boreholes		Protected springs		Protected dug wells		Total	
	No. of supplies	Prop. (%)	No. of supplies	Prop. (%)	No. of supplies	Prop. (%)	No. of supplies	Prop. (%)	No. of supplies	Prop. (%)
Very low	288	34.5	76	26.4	16	5.0	46	29.7	426	26.7
Low	382	45.7	117	40.6	99	31.0	37	23.9	635	39.8
Medium	109	13.1	34	11.8	54	16.9	20	12.9	217	13.6
High	56	6.7	61	21.2	150	47.0	52	33.5	319	20.0

3.7 Analysis of proxy parameters

Selected water-quality parameters were examined to determine if one parameter could be used as a proxy indicator for the other. The following parameters were analysed for correlation:

- faecal contamination (thermotolerant coliforms) and turbidity;
- thermotolerant coliforms and faecal streptococci; and
- conductivity and nitrate, fluoride and arsenic.

Pearson's r was used to measure the strength of association. This correlation coefficient measures the linear association between two variables. If the data lie exactly along a straight line with positive slope, then $r = 1$; if they lie exactly along a straight line with negative slope, then $r = -1$; if there is no correlation, then $r = 0$. The main limitations of Pearson's r are: the method measures only a linear association between two variables; it assumes the data are distributed normally; and the value of r is disproportionately affected by outlier[3] data points. The justifications for using the method are that r can be easily calculated in Microsoft Excel and that the snapshot nature of RADWQ does not justify using a more complicated analysis.

There overall correlation coefficients between thermotolerant coliforms and faecal streptococci (0.26), as well as between thermotolerant coliforms and turbidity (0.12; Table 3.17). The overall correlation coefficients were greater for conductivity and nitrate (0.40) and for conductivity and fluoride (0.36). The similarity of the correlation coefficients for conductivity and the two anions reflected the fact that both

[3] An outlier is a value far from most others in a set of data.

nitrate and fluoride were almost always present in Ethiopian natural waters. Their concentrations varied depending on factors such as the hydrogeology and prevailing environmental conditions. The strongest correlation coefficients were for conductivity and nitrate level in utility piped supplies (0.55), and for conductivity and fluoride in protected dug wells (0.48). It was not possible to establish any correlation between conductivity and arsenic, because all water samples had concentrations <10 µg/l.

Table 3.17 **Analysis of proxy parameters**[a]

Technology	**Pearson's *r***				
	TTC *vs.*		Conductivity *vs.*		
	Turbidity	FS	NO_3	F	As
Utility piped supplies	-0.03	-0.08	0.55	0.44	-
Boreholes	-0.03	0.18	0.19	0.17	-
Protected springs	0.22	0.26	0.06	0.23	-
Protected dug wells	0.11	0.42	-0.01	0.48	-
Totals	0.12	0.26	0.40	0.36	-

[a] FS = faecal streptococci; TTC = thermotolerant coliform; "-" = not available.

3.8 Household water quality

The quality of household water was also tested in the RADWQ study to examine the extent to which drinking-water became contaminated between the source and the household. Some 160 households were to be included in the assessment (10% of the total sample size of 1600), which were to be proportionally divided both by broad area and by water supply technology. Because the household water was matched to the source, this examination could only be carried out in communities with a water supply. The plan was to test in-house or in-yard taps, in case the household was connected to a utility piped supply, or, if taps were not available, to test the water in the storage containers. In practice, all samples were taken from containers (156 in total), because it could be assumed that the majority of the population stored water in containers before consumption (Section 2.2). An additional 398 household piped water sites were also selected as a proxy for inspection taps (e.g. public taps or taps in the yard directly connected to the distribution system), because there were not enough inspection taps in the distribution systems of utility piped supplies included in the study.

Thermotolerant coliforms

Of the 554 household samples analysed in this study, 73.6% complied with the WHO guideline value and the national standard for thermotolerant coliforms (Table 3.18). Compliance was significantly higher for household piped water (85.4%) than for water from household containers (43.6%). For the majority of sites inspected, there was no change in the thermotolerant coliform counts between source and household, but for more than one fifth of the sites the microbiological quality of the water deteriorated after collection from the source (Table 3.19). The results show that household water quality must be given serious attention, especially for water stored in household containers, more than half of which showed post-source contamination.

Risk-to-health matrixes

Most household water supplies tested were classified as having very low or low risk (64.2%;Table 3.20, Table 3.21). Water supplies in more than one fifth of all households were, however, classified as having high risk-to-health, as were more than half of all the household containers (Table 3.21). These figures emphasize the need to pay particular attention to drinking-water quality issues at the household level.

Table 3.18 Compliance of household water quality with the national standard and WHO guideline value for thermotolerant coliforms

Technology	No. of samples	Compliance (%)
Household piped water	398	85.4
Household container	156	43.6
Total	554	73.6

Table 3.19 Comparison of thermotolerant coliform counts for source and household water

Thermotolerant coliform count in household water compared to the source	Household piped water		Household container		Total	
	No. of samples	Proportion (%)	No. of samples	Proportion (%)	No. of samples	Proportion (%)
Lower	13	3.5	10	6.8	23	4.5
Equal	308	83.5	62	42.2	370	71.7
Higher	48	13.0	75	51.0	123	23.8

Table 3.20 Risk-to-health matrix for household water quality[a]

SI score	Utility piped supplies				Boreholes				Protected springs				Protected dug wells				Total			
	TTC count (cfu/100 ml)				TTC count (cfu/100 ml)				TTC count (cfu/100 ml)				TTC count (cfu/100 ml)				TTC count (cfu/100 ml)			
	<1	1-10	11-100	>100	<1	1-10	11-100	>100	<1	1-10	11-100	>100	<1	1-10	11-100	>100	<1	1-10	11-100	>100
0-2	78	1	8	2	12	0	0	1	90	1	8	3	78	1	8	2	12	0	0	1
3-5	220	9	14	5	42	8	22	12	262	17	36	17	220	9	14	5	42	8	22	12
6-8	40	5	11	1	14	8	18	17	54	13	29	18	40	5	11	1	14	8	18	17
9-10	0	1	0	0	0	0	0	1	0	1	0	1	0	1	0	0	0	0	0	1

[a] cfu = colony forming unit; SI = sanitary inspection; TTC = thermotolerant coliform.

VERY LOW	LOW	MEDIUM	HIGH

Table 3.21 Overall risk-to-health classification for household water quality

Risk category	Household piped water		Household container		Total	
	No. of samples	Proportion (%)	No. of samples	Proportion (%)	No. of samples	Proportion (%)
Very low	78	19.7	12	7.7	90	16.4
Low	221	55.9	42	27.1	263	47.8
Medium	57	14.4	22	14.2	79	14.4
High	39	9.9	79	51.0	118	21.5

Nitrate

Nitrate concentrations in the water supplies of many households were higher than at the source, particularly for piped water supplies (Table 3.22). Some variation in nitrate level between source and household waters was expected, because nitrate is part of the nitrogen-cycle and the kinetics of the nitrification/denitrification reactions are influenced by the physiochemical and microbiological properties of the waters. It is also possible, however, that the increases resulted from contamination of the household water, but the source of contamination could not be established based on the RADWQ data.

Table 3.22 Nitrate concentrations in corresponding source and household water supplies

Nitrate concentration in household water compared with the source		Household piped water		Household container		Total	
		No. of samples	Proportion (%)	No. of samples	Proportion (%)	No. of samples	Proportion (%)
Increased by	>10%	184	48.7	38	25.3	222	42.0
	≤10%	35	9.3	7	4.7	42	8.0
Equalled		26	6.9	9	6.0	35	6.6
Decreased by	≤10%	32	8.5	10	6.7	42	8.0
	>10%	101	26.7	86	57.3	187	35.4

Residual free chlorine

The residual free chlorine decreased by more than 10% between source and household water supply in 54.7% of all samples examined in the RADWQ project (Table 3.23). The proportion of piped water supplies showing a >10% decrease in residual free chlorine (56.4%) was similar to that for household container supplies (47.0%).

The free chlorine concentration increased by more than 10% in 16.7% of all household water supplies, when compared with the corresponding water sources (Table 3.23). Given that chlorine is unstable in aqueous solution, the only explanation for such anomalous results is human error.

Table 3.23 Free chlorine concentrations in corresponding source and household water supplies

Chlorine concentration in household water compared with the source		Household piped water		Household container		Total	
		No. of samples	Proportion (%)	No. of samples	Proportion (%)	No. of samples	Proportion (%)
Increased by	>10%	60	16.3%	15	18.1%	75	16.7%
	≤10%	4	1.1%	1	1.2%	5	1.1%
Equalled		86	23.4%	27	32.5%	113	25.1%
Decreased by	≤10%	10	2.7%	1	1.2%	11	2.4%
	>10%	207	56.4%	39	47.0%	246	54.7%

Copper

Copper is both an essential nutrient and a drinking-water contaminant. Although it is ingested via food, drinking-water can also be a significant reservoir of copper. Copper concentrations in drinking-water vary widely, with the primary source most often being the corrosion of interior copper plumbing and copper-containing solders. Both short-term and long-term exposures to copper in piped drinking-water systems can have significant health effects, especially when the water is acidic and/or aggressive (Howard et al., 2003; WHO, 2004).

In the RADWQ project, a total of 53 water samples collected from household containers were analyzed for their copper content. Overall, 98.1% of the samples complied with the WHO guideline value and the national standard (Table 3.24), which was not surprising given that copper piping is not used in piped-water distribution systems in Ethiopia. This result is inconsistent with a study that found appreciable copper values in all regions of Ethiopia, except Gambella and Benishangul (FMOWR, 2001). In light of this, and the fact that the RADWQ result was based only on 60 samples, a more extensive assessment is recommended that better accounts for industrial areas where copper pollution might be expected.

Table 3.24 **Compliance of household water supplies with the national standard and WHO guideline value for copper** [a]

Broad area	Household container	
	No. of samples	Compliance (%)
Oromiya & Addis Ababa	30	100.0
Dire Dawa & Somali	8	87.5
Tigray & Amhara	8	100.0
SNNPR	7	100.0
National	53	98.1

[a] SNNPR = Southern Nations, Nationalities and Peoples Region.

In Dire Dawa and Somali, a single sample out of eight tested for copper registered a value above the WHO guideline value. An examination of the database indicated that the likely cause was a water container, which was probably made of copper or its alloys (brass or bronze) and may have been corroded.

3.9 Quality control procedures

Analytical quality control is particularly important when testing for microbial contamination, because microorganisms are discrete particles that can vary individually, in contrast to the situation with chemicals, where variation occurs at the molecular level, which is typically below the limit of detection in routine analytical methods. Aseptic technique is the most important way to ensure the quality of the test results. Evaluating whether aseptic technique has been followed is easily accomplished using a simple form (provided in the RADWQ handbook). Field teams assessed aseptic technique weekly throughout the RADWQ project and these evaluations were supplemented with monitoring field visits by members of the core technical group. Quality assurance procedures were also discussed at regular review meetings of all field team members (see also Section 2.3).

A duplicate split-sample approach was used in quality control tests of microbiological analyses. For any single result, a range of acceptable results from a second analysis can be defined assuming a Poisson distribution for the bacteria in the water. In this approach, a 200 ml sample is mixed thoroughly and then divided into two 100 ml sub-samples. The count from the first sample is recorded and the 95% confidence limit for the second (paired) count is recorded from the quality control table for microbiological tests (presented in the RADWQ handbook). The count from the second sample is then recorded alongside the first and if the second reading falls outside the confidence intervals it is highlighted.

Daily quality control tests were planned for the microbiological analyses, but this procedure was not followed mainly due to time constraints during fieldwork. In practice, quality control was assessed at only one third of the targeted water sites (Table 3.25). Of the 108 analyses performed, approximately 94% fell within the suggested 95% confidence interval. Quality control analysis for faecal streptococci was not performed for lack of reagents.

Table 3.25 **Quality control for thermotolerant coliforms, chemicals assays**

Parameter	No. of quality control analyses targeted	No. of quality control analyses performed	Proportion performed (%)	Proportion of samples within suggested confidence interval (%)
Thermotolerant coliforms	320	108	34	94
Chemicals:				
Arsenic	64	26	41	100
Fluoride	64	26	41	85
Nitrate	64	27	42	93
Iron	64	26	41	96
Turbidity	64	28	44	96
Conductivity	64	28	44	96
pH	64	30	47	100
Residual free chlorine	64	7	11	86

A split sample approach was also used in quality control tests of the chemical analyses. A reasonable level of precision for these assessments was 90% (i.e. the results of both tests should be within 10% of the average value). This was calculated by finding the difference between the first result and the average, and then dividing this by the average and multiplying by 100. If the result was outside of the 90% compliance, the data were marked as suspect.

Weekly quality control assessments were planned for the chemical analyses, but only 41–47% of the planned analyses were carried out for arsenic, fluoride, nitrate, iron, turbidity, conductivity and pH, and only 11% for residual free chlorine (Table 3.25). The acceptable level of precision (90%) was achieved in 85–100% of the analyses, depending on the chemical parameter.

In the field, all quality control results were recorded on weekly record sheets (Annex 13). The results were not entered into the SanMan database, but recorded on a separate Excel worksheet.

4 Conclusions and recommendations

4.1 Drinking-water quality in Ethiopia

Overall compliance with WHO guideline values and national standards was 68% for the 1570 water supply samples tested for thermotolerant coliforms, fluoride, arsenic and nitrate (Table 4.1). Overall compliance for fluoride, arsenic and nitrate was generally high (94−100%), but was significantly lower for thermotolerant coliforms and faecal streptococci (72% and 66%, respectively). Of the four water-supply technologies assessed (Table 4.1), utility piped supplies had the highest overall level of compliance (80%) and protected springs the lowest (44%).

Table 4.1 **Summary of overall compliance with WHO guideline values and Ethiopian national standards**[a]

Parameter	Overall for Ethiopia (%)	Utility piped supplies (%)	Boreholes (%)	Protected springs (%)	Protected dug wells (%)
TTC	72	88	68	43	55
Faecal streptococci	66	68	68	77	44
Arsenic	100	100	100	100	100
Fluoride	94	90	99	100	99
Nitrate	99	98	100	100	100
Overall compliance for TTC, As, F and NO_3	68	80	66	44	55
Iron	94	95	86	98	94
Turbidity	87	94	80	78	80
Conductivity	95	94	94	99	96

[a] TTC = thermotolerant coliforms.

Comments on water-quality parameters

Thermotolerant coliforms. Overall compliance for thermotolerant coliforms was 72%, although compliance levels differed significantly between technologies, with utility piped supplies having the highest (88%) and protected springs the lowest (43%) (Table 4.1). There were also clear differences between broad areas or regions (Table 3.2). The RADWQ results are consistent with the historical water-quality data for *E. coli*, particularly those from the EHNRI database (Section 1.3). For the period 1995−2004, for example, the average EHNRI compliance figure for *E. coli* was 74% (Table 1.3), while the RADWQ figure for thermotolerant coliforms was 72% (Table 4.1). Despite this agreement, it can be assumed that overall compliance for all drinking-water sources in Ethiopia is significantly lower than those found in the RADWQ study, because the study covered only improved sources (according to the JMP definition, Table 1.1), whereas 62.7% of the population of Ethiopia relies on unimproved water sources according to national sector data (Table 1.2).

RADWQ results represent a snapshot of the quality of drinking-water in Ethiopia. Hazardous events, such as faecal pollution of source waters after heavy rainfalls, spills orf failure of treatment works can lead to contaminated drinking-water, but the RADWQ findings will only reflect such events if they happened to coincide with the surveys. Instead, the results provide statistically representative baseline information on water quality that, in conjunction with the findings from sanitary inspections, can be used to develop long-term regional or national intervention strategies to improve water safety.

Arsenic. All technologies and regions investigated during the RADWQ project were in compliance both with the WHO guideline value and the national standard for arsenic (Table 3.9). These findings are consistent with most prior data on groundwater resources in Ethiopia, which suggest that arsenic does not pose a water quality problem in the country. However, one study of 138 drinking-water sources in the Rift Valley did find arsenic concentrations of up to 96 µg/l, particularly in hot springs (Reimann et al., 2003).

Fluoride. Overall compliance with the WHO guideline value and the national standard of 1.5 mg/l was approximately 94% (Table 4.1). While the overall figure appears good, it disguises the fact that fluoride in drinking-water poses a major public health problem, particularly in the Rift Valley of Ethiopia, which extends over 1000 km in a north-northeast direction and covers about 12% of the country (Berhanu, 2004). The inhabitants of the region have been found to suffer from dental and skeletal fluorosis, owing to the excessive fluoride concentrations in the drinking-water (Samson, 2004), and this was confirmed by the RADWQ project. The areas most affected by excessive fluoride concentrations in the drinking-water were the East Shewa Zone (in Oromiya, broad area 1), with maximum concentrations of up to 10.5 mg/l, and some pocket areas in the Somali Region. The results in the EHNRI database confirmed these findings (Table 1.4).

Nitrate. Nearly 100% of the water supplies investigated during the RADWQ study complied with the WHO guideline value and the national standard of 50 mg/l for nitrate (Table 4.1). Only in Dire Dawa (broad area 2) was compliance poor (80%) with nitrate concentrations of up to 123 mg/l (Table 3.7). The RADWQ findings are consistent with those in the EHNRI database, which show high overall compliance for Ethiopia (96.7%), but low compliance (66.7%) and high nitrate concentrations (up to 208.0 mg/ml) in Dire Dawa (Table 1.4). On the basis of these results, it can be concluded that nitrate is not a widespread water quality problem in Ethiopia.

Comments on sanitary risk factors

The three most common risk factors encountered during site visits are summarized in Table 4.2. It should be noted that the level of protection for dug wells and springs was generally low and that many of the water supplies could not be categorized as "protected" (by JMP standards, Table 1.1). When the RADWQ survey was being designed, there was neither a clear definition of "protected" technology in Ethiopia, nor information on the protection of individual springs or dug wells.

4.2 The RADWQ project in Ethiopia

Project management and implementation

- Before the start of the RADWQ project, the question whether FMOWR or FMOH had a mandate for the project had to be answered, because the responsibilities in drinking-water monitoring were unclear. Although the FMOWR had been involved with the project from the very beginning (i.e. at the Bangkok meeting), the FMOH finally took the lead for project implementation, but it had to run the project as an "emergency project", as it was not included in the original work plan for 2004/2005.
- The core technical working group provided strong managerial and technical support to the project coordinator at FMOH, which substantially facilitated project implementation.
- The initial budget for RADWQ implementation in Ethiopia was too low, which would have constrained field implementation, but thanks to additional funding from the UNICEF country office the project was successfully implemented without substantial delay. The budget outlined in Annex 11 would have been considerably higher if the FMOH and EHNRI had not provided vehicles for the project. In future RADWQ programmes, the budgets need to be planned more carefully.
- In addition to the budget constraints, the administrative system at the FMOH did not have the flexibility to implement projects such as the RADWQ study, which involve many staff and field exercises of several months. However, the FMOH administration tried its best to facilitate project implementation, and the efforts of the administrative staff were greatly appreciated.
- The international consultants provided satisfactory training, but in future more time and attention should be given to using the testing equipment, and to practising sanitary inspections under real field conditions, before the start of the project. At least three days of field-based training are suggested.

Table 4.2 **Most common sanitary risk factors**

Sanitary risk questions [a]		Risk frequency (%)
PIPED WATER: TREATMENT PROCESS: 19 sites inspected		
1	Are cracks evident in the pre filters?	21.1
5	Is any sedimentation tank unsanitary?	21.1
3	Is the mixing tank unsanitary?	15.8
7	Are there mud balls or cracks in any of the filters?	15.8
PIPED WATER: DISTRIBUTION SYSTEM: 428 sites inspected		
3	Is the area around the tap unsanitary?	52.6
4	Is there a sewer or latrine within 30 m of any tap?	49.3
2	Does water collect around the sample site?	30.8
BOREHOLE WITH MECHANISED PUMPING: 104 sites inspected		
6	Can animals come within 50 m of the borehole?	62.5
1	Is there a latrine or sewer within 100 m of the pumping mechanism?	52.9
3	Is there any source of pollution within 50 m of the borehole (e.g. animal breeding, cultivation, roads, industry, etc)?	34.6
5	Is the drainage channel absent or cracked, broken or in need of cleaning?	34.6
BOREHOLE WITH HAND PUMP: 188 sites inspected		
5	Is the drainage channel absent or cracked, broken or in need of cleaning?	77.1
6	Can animals come within 10 m of the borehole?	68.1
4	Is the drainage absent or faulty, allowing ponding within 2 m of the borehole?	58.5
PROTECTED SPRING: 316 sites inspected		
6	Can animals have access within 10 m of the spring?	94.6
9	Is the diversion ditch above the spring absent or non-functional?	87.0
5	Is the fence missing or faulty?	76.6
DUG WELL WITH HAND PUMP: 155 sites inspected		
5	Is the drainage channel missing, cracked, broken or in need of cleaning?	66.5
4	Is the drainage missing or faulty, allowing ponding within 3 m of the well?	53.5
7	Does spilt water collect in the apron area?	50.3
HOUSEHOLD CONTAINER: 159 sites inspected		
2	Is the water-storage container kept at ground level?	87.4
5	Is the area around the storage container unsanitary?	76.1
8	Is the water from the container also used for washing/bathing?	69.8
HOUSEHOLD PIPED WATER: 407 sites inspected		
1	Is the tap outside the house (e.g. in the yard)?	78.9
2	Is the water stored in a container inside the house?	73.0
7	Do animals have access to the area around the pipe?	69.8

[a] The question number in the left-hand column refers to the questions in Table 3.14.

- Experiences and comments reported by the field teams included:
  - Regular review meetings between fieldwork were extremely useful and they helped the field teams maintain quality control and consistency in their work.
  - It was feasible to implement the RADWQ study with the cluster sizes chosen during survey design, but the field teams worked 6–7 days a week to meet the targets within the 30-day duration of individual field trips.
  - Owing to a lack of information in the field, in some cases dug wells could not be found in specific zones and boreholes were tested instead. This underpins the need for zone-sharp data on the number of drinking-water supplies and the population served.
  - Quality control procedures were adequate and could be carried out under field conditions. However, the quality control protocols could have been improved if there had been a supply of standard solutions for testing the chemical parameters. This would also have helped to determine whether the analytical instruments were functioning correctly.
  - The checklist for field implementation (Annex 8) should cover additional items, such as a tent, sleeping bags, mosquito nets and medication/first aid kits. It would be a good idea to include a checklist for fieldwork in the RADWQ handbook.
  - There needs to be a mechanism for providing extra cash/pocket money to field team members to cover miscellaneous expenditures. In the case of this project such expenditures included labour costs for transporting test kits and other luggage to remote water points, and payments to local staff of the zone or woreda health or water offices, who helped the field teams locate rural water supplies.
  - The daily government allowance was inadequate, particularly given the hardship of the fieldwork, with 12-hour work days and personal expenditures.

Data storage software

All data were entered into SanMan and from there exported to Microsoft Excel and SPSS for analysis. Questions were raised as to whether the SanMan software was better than standard database software, such as Microsoft Access. Standard software would be more common, easy to use and have all the facilities for checking the quality of entered data.

Specific comments by the data manager and project statistician were:

- Data entry into SanMan was time consuming if there was no computer network, as data had to be entered by one person.
- The database software should have a "rule" function that defines whether entered values or ranges of values are legitimate, as this would reduce data-entry errors.
- It is recommended that the SanMan database accept only numerical data (with decimal places). Currently, the database does not differentiate between numbers and characters, which causes formatting problems during data export.
- An additional check box should be added to the sanitary inspection questionnaire to indicate whether a sanitary inspection was carried out. Currently, it is not possible to distinguish "zero risk" and "sanitary inspection not carried out".
- In the sanitary inspection questionnaire, the analyst's name should be predefined (in a dropdown menu) to avoid spelling errors.

Field kits and consumables

- The field kits used to test water supplies were suitable and robust enough for Ethiopian conditions, where lack of transportation and power frequently hampered monitoring. It would be desirable to use the kits for routine monitoring purposes at the RHB laboratories, but it was questioned whether the kits could be maintained after the RADWQ study because there were limited funds to buy reagents and consumables.
- Some consumables provided with the Wagtech test-kits (e.g. pH buffers and conductivity standard solutions) leaked during transportation and damaged many of the membrane filters by soaking them.

Fortunately, Wagtech Ethiopia replaced both the spilled solutions and the membrane filters within two weeks after the training.

- The project ran short of two reagents (i.e. nitrate and membrane lauryl sulphate broth) during the last field trip and extra supplies had to be purchased. Possibly this occurred because the field teams were unable to measure the correct amount of reagent using the spoon provided with the reagent pack.
- Turbidity standards had an extremely short shelf life, and ran out during field implementation. Also, conductivity standards were spilled, or were not the correct standard (i.e. 12.88 µS/cm). Luckily, the chemical laboratory at EHNRI provided field teams with additional conductivity calibration solutions.
- Some consumables were supplied for parameters not included in a RADWQ level 1 study (e.g. ammonia). These were sent to the RHB laboratories together with the field kits.
- The RADWQ manual should include more information on the comparability of field-kit methods with standard laboratory methods, including information about the accuracy, precision, reproducibility and detection limits of the RADWQ methods.
- There should have been extra field kits for the RADWQ project in case equipment malfunctioned, which would have affected the project schedule and entailed extra expenses.

Added value of the project and potential future uses

- The RADWQ project created stronger partnerships between stakeholders in the Ethiopian drinking-water sector at both the federal and regional levels. Stakeholders included FMOH, EHNRI, FMOWR, UNICEF, WHO and regional institutions (i.e. the RHBs and regional water bureaux). The project therefore reinforced awareness of water quality issues and triggered discussions about viable approaches to monitoring in the future, and the important role of government bodies in that task.
- At the time of this study, a memorandum of understanding on an integrated water supply, sanitation and hygiene education programme was due to be signed between FMOH, FMOWR and the Federal Ministry of Education. The memorandum aimed to define roles and responsibilities in the drinking-water and sanitation sector, including those for water quality testing and surveillance. It also aimed to facilitate cooperation in joint planning, implementation and monitoring for all water and sanitation in Ethiopia. According to Mr Worku, Head of the Department of Hygiene and Environmental Health, the RADWQ activities significantly helped in arriving at agreement about the memorandum.
- The RADWQ project represented a systematic approach to monitoring drinking-water quality and provided the first statistically representative data for drinking-water quality and sanitary conditions throughout Ethiopia.
- The Department of Hygiene and Environmental Health at the FMOH intended to use the RADWQ experience as a "springboard" for developing an effective approach to routine monitoring and surveillance of drinking-water quality in Ethiopia. The approach should include a mechanism to monitor progress in the area of drinking-water quality and establish an information basis for result-oriented interventions. Such a programme would complement "hardware issues" (i.e. increasing access to improved water supplies through their construction and rehabilitation) and "software issues" (i.e. water-related hygiene education programmes). The programme to be developed should:
  - outline a well-planned and cost-effective monitoring system at the central and regional level;
  - strengthen the national monitoring capacity by increasing the capacities of laboratories and field teams;
  - establish a national reference laboratory for water-quality analysis;
  - include comprehensive training on sanitary surveillance, quality control procedures, data analysis, prioritization and remedial action planning.
- The RADWQ pilot survey presents a snapshot of water quality from improved sources from all over the country. It is recommended that these results be complemented by additional targeted studies evaluating the quality of "unimproved" drinking-water sources, which are used by more than 60% of the Ethiopian population. This will allow a better comparison of water quality and sanitary conditions for improved and unimproved sources. Drinking-water supplies in areas of known chemical pollution, such as areas of the Rift Valley affected by high levels of fluoride from geological formations, should also be evaluated. This would give a more detailed delineation of which water supplies are affected by fluoride in the Rift Valley area. Other areas known to be polluted include Benshangul (arsenic from gold mining) and Dire Dawa and Somali (nitrate).

- The RADWQ project identified major information gaps in water supply coverage and usage data for the zonal and woreda level. The FMOH intends to establish a more reliable system for providing detailed information, by improving the reporting system between institutions at different administrative levels.
- The field-team members responded very positively to the training by international experts. They are now better qualified in water quality analysis, particularly in the use of field testing equipment, and they acquired practical experience in implementing water quality monitoring surveys. The RADWQ project therefore contributed to building capacity for planning and implementing water quality assessments at the regional level.
- Actions should be taken to address the major findings of this survey, with special emphasis given to:
  - the sanitation problems, both at household level and at the site of the water points;
  - improving the workmanship, maintenance and site selection when constructing water points;
  - building capacity in water-quality monitoring, particularly in the regions; and
  - improving networking and integration of the stakeholders working in the field.
- All members of the core technical working group were interested in publishing the results of the RADWQ study in the scientific literature.

4.3 Suggestions for improving the RADWQ methodology

- The RADWQ handbook is a comprehensive summary of important water quality issues, but the core technical working group felt that the section on the survey methodology needed revision to increase clarity, because the field-team members often only fully understood the methodology after the training by the consultant. The presentation materials used during the training were clear and could serve as a basis for the handbook revision.
- The survey design for Ethiopia had to be modified from the handbook recommendations, due to the absence of statistical data on the number of supply schemes per technology and on the prevailing population served, for three administrative levels (i.e. national, regional and zonal; see Section 2.2). The first modification was to use expert judgement to select the large area sampling units (i.e. the zones from which clusters/individual supplies were to be chosen by the field teams), rather than proportional weighting tables. The other modification was that proportional weighting tables were employed at the secondary step (i.e. to select regions to be included in the study), to maintain a random element in the survey design.
- When revising the survey methodology, the following recommendations should be considered:
  - the RADWQ methodology should provide clear guidance on alternative design options for countries where data availability on water supply coverage is limited to two administrative levels only; the example of Ethiopia could be used to develop that guidance;
  - the handbook should be clearer and provide more detail on the selection criteria for sampling points in big utility piped supplies, particularly on where to take samples from the distribution network in systems that have too few inspection taps; and,
  - in light of the situation in Ethiopia, where almost two thirds of the population consumes water from sources that are unimproved, it would be useful not to restrict the methodology to improved sources only; while this was a legitimate approach in the pilot study, future rapid assessments should allow the inclusion of all drinking-water sources that serve more than 5% of the population.
- A resource package providing case study examples and training materials could be provided with the RADWQ handbook.
- Although the sanitary risk inspection questionnaires were generally applicable to Ethiopia, the RADWQ handbook should emphasize that the standard set of sanitary risk inspection forms may need to be adapted to prevailing conditions and adopting the terminology used in the country.
- The pilot project took more than five months to implement and as many as 16 professionals had to remain in the field throughout. Most field team members considered this cumbersome and were of the opinion that the onerous nature of the process discouraged a repeat of the survey. Other approaches are therefore needed to ensure a sustainable high-quality monitoring system.

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Annex 1. Members of the steering committee and core technical working group

Steering committee

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Mr Teka Geberu	UNICEF	Officer
Dr Solomon Fisseha	WHO, Emergency Response Officer	Project secretary

Annex 2. Ethiopian Standard ES 261:2001 "Drinking-water – Specifications"

Foreword

This Ethiopian Standard has been prepared under the direction of Environment and Health Protection. Safety and Hygienic practices Technical Committee and published by the Quality and Standards Authority of Ethiopia (QSAE).

This second edition cancels and replaces the first edition, ES 261:1990 (Old designation ES B.W1.001:1990), "*Drinking water – Specification* ", which has been technically revised.

The revision changes made relate to addition of requirements and test methods, structure and format.

In preparing this standard, reference has been made to the following:

- Guidelines for drinking-water quality, second edition, 1993, Volume 1, Recommendations, published by the World Health Organization (WHO), Geneva.
- KS 05-459:1985, *Specification for drinking water, Part 1: The requirements for drinking water,* published by the Kenyan Bureau of Standards.
- IS 10500:1991, *Drinking water – Specification.*, published by the Bureau Indian Standards.
- Dr. Frank J. Welcher, 1963, *Standard methods of chemical analysis*, 6th edition volume II, part B, D. VAN Nostrand company, Inc. USA;

Acknowledgement is made for the use of information from the above publications

STANDARD

ES 261:2001

Second edition
2001-06-27

Drinking water — Specifications

Descriptors: physical, chemical and bacteriological requirements, test methods.

Price based on 7 pages.

Reference number
ES 261:2001

ES ISO 6703-1:2001, *Water quality – Determination of cyanide – Part 1: Determination of total cyanide.*

ES ISO 6777:2001, *Water quality – Determination of nitrite – molecular absorption spectrometric method.*

ES ISO 7027:2001, *Water quality – Determination of turbidity.*

ES ISO 7150-2:2001 *Water quality – Determination of ammonium – Part 2: Automated spectrometric method.*

ES ISO 7393:2001, *Water quality – Determination of free chlorine and total chlorine.*

ES ISO 7875-1:2001, *Water quality – Determination of surfactant – Part 1:Determination of anionic surfactants by measurement of the methylene blue index (MBAS).*

ES ISO 7887:2001, *Water quality – Examination and determination of colour.*

ES ISO 7890-3:2001, *Water quality – Determination of nitrate - Part 3:Spectrometric method using sulfosalicylic acid.*

ES ISO 7899-1:2001, *Water quality – Detection and enumeration of intestinial enterococci in surface and waste water – Part 1:* Miniaturized method (Most Probable Number) by in occultation in liquid medium.

ES ISO 7899-2:2001, *Water quality – Detection and enumeration of fecal streptococci – Part 2: Method by membrane filtration*

ES ISO 7980:2001, *Water quality – Determination of calcium and magnesium – Atomic absorption spectrometric method.*

ES ISO 8165-1:2001, *Water quality – Determination of selected monovalent phenols – Part 1:Gas chromatographic method after enrichment by extraction.*

ES ISO 8288:2001, *Water quality – Determination of cobalt, nickel, copper, zinc, cadmium and lead – Flame atomic absorption spectrometric method.*

ES ISO 9280:2001, *Water quality – Determination of sulfate – Gravimetric method.*

ES ISO 9297:2001, *Water quality – Determination of chloride – Silver nitrate titration with chromate indicator (mohr's method).*

ES ISO 9308-1:2001, *Water quality – Determination and enumeration of coliform organisms, thermotolerant coliform organisms and presumptive escherichia coli – Part 1:Membrance filtration method.*

ES ISO 9308-2:2001, *Water quality – Determination and enumeration of coliform organisms, thermotolerant coliform organisms and presumptive escherichia coli – Part 2:Multiple tube (most probable number) method.*

ES ISO 9390:2001, *Water quality – Determination of borate – Spectrometric method using azomethine –H.*

ES ISO 9696:2001, *Water quality – Measurement of gross alpha activity in non-saline water – Thick source method.*

ES ISO 9697:2001, *Water quality – Measurement of gross beta activity in non-saline water.*

ES ISO 9963-1:2001, *Water quality – Determination of alkalinity Part 1:Determination of total and composite alkalinity.*

ES ISO 9964-1:2001, *Water quality – Determination of sodium and potassium – Part 1: Determination of sodium by atomic absorption spectroscopy.*

ES ISO 9964-2:2001, *Water quality – Determination of sodium and potassium – Part 2: Determination of potassium by atomic absorption spectroscopy.*

Drinking water — Specifications

1 Scope

This Ethiopian Standard specifies the physical, chemical and bacteriological requirements of water for drinking and domestic purpose.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this Ethiopian Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this Ethiopian Standard are encouraged to investigate the possibility of applying the most recent editions of the Ethiopian Standards indicated below. Registers of currently valid standards are maintained in the Quality and Standards Authority of Ethiopia.

ES 605:2001, *Water quality - Determination of odour and taste.*

ES ISO 606:2001, *Water quality – Determination of barium by atomic absorption spectrometry.*

ES ISO 607:2001, *Water quality – Determination of total hardness.*

ES ISO 609:2001, *Water quality – Determination of total solids and dissolved solids.*

ES ISO 4833:2001, *Microbiology – General guidance for the enumeration of micro – organisms – Colony count technique at 30°c.*

ES ISO 5666-3:2001, *Water quality – Determination of total mercury by flameless atomic absorption spectrometry – Method after digestion with bromine.*

ES ISO 5667-1:2001, *Water quality – Sampling- Part 1: Guidance on the design of sampling programs.*

ES ISO 5667-2:2001, *Water quality – Sampling – Part 2:Guidance on sampling techniques.*

ES ISO 5667-3:2001, *Water quality – Sampling –Part 3: Guidance of the preservation and handling of samples.*

ES ISO 5667-5:2001, *Water quality – Sampling – Part 5:Guidance on sampling of drinking water and water used for food and beverage processing.*

ES ISO 5961:2001, *Water quality – Determination of cadmium by atomic absorption spectrometer.*

ES ISO 6107:2001, *Water quality – Vocabulary.*

ES ISO 6332:2001, *Water quality – Determination of iron spectrometric method using 1,10-phenanthroline.*

ES ISO 6333:2001, *Water quality – Determination of manganese Formaldoxime spectrometric method.*

ES ISO 6468:2001, *Water quality – Determination of certain organochlorine insecticides, polychlorinated biphenyls and chlorobenzenes – Gas chromatographic method after liquid – liquid extraction.*

ES ISO 6595:2001, *Water quality – Determination of total arsenic – Silver diethyl dithiocarbonate spectrophotometric method.*

4.2 Chemical requirements

4.2.1 Palatability properties

Characteristics that affect the palatability of water shall conform to the levels specified in Table 2.

4.2.2 Content of toxic and/or disease causing substances

a) When tested, the characteristics that affect the safety of drinking water shall conform to the levels specified in Table 3.

b) If nitrates (expressed as N) are present in concentrations in excess of 10 mg/l, the water may be unsuitable for use by infants under one year of age, and an alterative source of supply must be found for such infants use or the water from the same source should be corrected in case of lack of other sources.

Table 2 – Characteristics that affect the palatability of drinking water

Substance or characteristic	Maximum permissible level	Test method
Total hardness (as $CaCO_3$)	300	ES 607
Total dissolved solids mg/l, Max	1000	ES 609
Total Iron (as Fe) mg/l, Max	0.3	ES ISO 6332
Manganese (as Mn) mg/l, Max	0.5	ES ISO 6333
Ammonia (NH_3+NH^+_4)* mg/l, Max	1.5	ES ISO 7150-2
Residual, free chlorine mg/l, max	0.5	ES ISO 7393
Anionic surfactants, as mass concentration of MBAS mg/l, Max	1.0	ES ISO 7875-1
Magnesium (as Mg) mg/l, Max	50	ES ISO 7980
Calcium (as Ca), mg/l, Max	75	ES ISO 7980
Copper (as Cu) mg/l, Max	2	ES ISO 8288
Zinc (as Zn) mg/l, Max	5	ES ISO 8288
Sulfate (as SO_4) mg/l, max.	250	ES ISO 9280
Chloride (as Cl), mg/l, Max	250	ES ISO 9297
Total alkalinity (as $CaCO_3$) mg/l, Max	200	ES ISO 9963-1
Sodium (as Na), mg/l, Max	200	ES ISO 9964-1
Potassium (as K), mg/l, max	1.5	ES ISO 9964-2
pH value, units	6.5 to 8.5	ES ISO 10523
Aluminium (as Al) mg/l, Max	0.2	ES ISO 12020

* The term ammonia includes the non-ionized (NH_3) and ionized (NH^+_4) species.

NOTE 1 - Several of the inorganic elements for which maximum permissible levels has been settled are recognized to be essential elements in human nutrition. No attempt has been made here to define a minimum desirable concentration of such substances in drinking water.

ES ISO 9965:2001, *Water quality – Determination of selenium – Atomic absorption spectrometric method (hydride technique).*

ES ISO 10301:2001, *Water quality – Determination of volatile halogenated hydrocarbons – Gas – chromatographic method.*

ES ISO 10359-1:2001, *Water quality – Determination of fluoride – Part 1: Electrochemical probe method for potable and lightly polluted water.*

ES ISO 10523:2001, *Water quality – Determination of pH.*

ES ISO 11083:2001, *Water quality – Determination of chromium (vi) – Spectrometric method using 1,5-diphenylcarbazide.*

ES ISO 12020:2001, *Water quality – Determination of aluminium – Atomic absorption spectrometric method.*

3 Definitions

For the purpose of this standard, the following definitions and terms defined in ES ISO 6107 shall apply.

3.1
maximum permissible level
a requirement level whose non-fulfillment would disqualify the water for drinking and domestic use because of its probable hazard to health

3.2
palatable water
water that is safe to drink, pleasant to the taste and useable for domestic purpose

3.3
quality water
water intended for drinking and domestic use that conforms with all the requirements specified in this Ethiopian Standard

3.4
safe water
water intended for drinking and domestic use whose limits for toxic substances, bacteriological and organo leptic levels conform to the requirements of this standard.

4 Requirements and test methods

4.1 Physical requirements

The physical characteristics of drinking water shall conform to the levels specified in Table 1.

Table 1 – Physical characteristics of drinking water

Characteristic	Maximum permissible level	Test method
Odour*	Unobjectionable	ES 605
Taste	Unobjectionable	
Turbidity, NTU	5	ES ISO 7027
Colour, TCU	15	ES ISO 7887

* Threshold number, Max. = 3

4.4.2 If any coliform organisms are found in a sample, a second sample shall be taken immediately after the tests on the first sample have been completed and shall be free from coliform organisms.

4.4.3 Not more than 2 percent of the total number of water samples from any one distribution system tested per year may contain coliform organisms.

4.4.4 Any treated water shall not contain faecal and coliform organisms when tested with the corresponding test methods.

4.4.5 Any treated water shall not contain any faecal streptococci when tested according to ES ISO 7899-1 or ES ISO 7899-2.

Table 4 – Bacteriological levels

Organism	Maximum permissible level	Test method
Total viable organisms, colonies per ml	must not be detectable	ES ISO 4833
Faecal streptococci per 100ml	must not be detectable	ES ISO 7899-1 ES ISO 7899-2
Coliform organisms, number per 100 ml	must not be detectable	ES ISO 9308-1
E. Coli, number per 100 ml	must not be detectable	ES ISO 9308-1 ES ISO 9308-2

5 Sampling

5.1 Sampling for bacteriological examination.

5.1.1 Frequency of sampling

Sampling should be regular (see the guide given in Table 5) and its frequency will mainly depend on the following factors:

a) quality of the water harnessed;

b) type of treatment for drinking worthiness;

c) risks of contamination;

d) background of public water supply network; and

e) number of people served.

Table 5 — Minimum sampling frequencies for drinking water in the distribution system

Population served	Samples to be taken monthly
Less than 5,000	1 sample
5,000 - 100,000	1 sample per 5,000 population
More than 100,000	1 sample per 10,000 population plus 10 additional samples

5.1.2 Collection, transportation and storage for samples shall be in accordance with ES ISO 5667-5.

5.2 Sampling for physical and chemical examination

5.2.1 Frequency of sampling

Sampling frequency for the examination of physical and chemical characteristics shall be carried out at least twice per year; one is in the rain season and the other one is in the dry season the frequency of this examination shall be increased when toxic substances are known to be present at sub-tolerance levels in the source of supply, or in certain special circumstances as, for example, when new industries that may be discharging toxic wastes are established in the area and the danger of epidemic arising.

5.2.2 Collection, transportation and storage of samples shall be in accordance with ES ISO 5667-5.

Table 3 – Content of toxic and/or disease causing substances of drinking water

Substance or characteristic	Maximum permissible level	Test method
Barium (as Ba) mg/l, Max	0.7	ES 606
Total mercury (as Hg) mg/l, Max	0.001	ES ISO 5666-3
Cadmium (as Cd) mg/l, Max	0.003	ES ISO 5961
Arsenic (as As) mg/l, Max	0.01	ES ISO 6595
Cyanide(as CN) mg/l, Max	0.07	ES ISO 6703-1
Nitrite (as NO_2), Mg/l, Max	3	ES ISO 6777
Nitrate as NO_3 Mg/l, Max	50	ES ISO 7890-3
Phenolic compound as phenols , mg/l, Max.	0.002	ES ISO 8165-1
Lead (as Pb) mg/l, Max	0.01	ES ISO 8288
Boron (as B) mg/l, Max	0.3	ES ISO 9390
Selenium (as Se) mg/l, Max	0.01	ES ISO 9965
Fluoride (as F) Max	1.5	ES ISO 10359-1
Chromium (as Cr) mg/l, Max	0.05	ES ISO 11083
~~Pesticides and~~ Organic constituents, Mg/l, Max		
a) DDT	2	
b) Heptachlor and heptachlor epoxide	0.03	
c) Hexchchlorobenzene	1	
d) Lindane (Gamma – BHC)	2	
e) Methoxychlor	20	ES ISO 6468
f) Aldrin/Dieldrine	0.03	
g) 1,2 Dichloro ethane	30	
h) 1,1,1- Trichloro ethane	2001	
i) – Trichloro ethene	70	ES ISO 10301
j) Trichlorobenzenes (total)	20	
k) Hexachlorobutadiene	0.6	

NOTE - 2 Because of the possibility of simultaneous occurrence of nitrite and in drinking water, the sum of the ratios of the concentration of each to its standard value should not exceed 1, i.e. $\frac{C_{nitrite}}{SV_{nitrite}} + \frac{C_{nitrate}}{SV_{nitrate}} \leq 1$,

Where, C is concentration and SV is standard value.

NOTE – 3 The limit value for fluoride should consider climatic conditions, volume of water consumed and intake from other sources provided the limit specified in the above table is satisfied.

4.3 Other constituents

4.3.1 Radioactivity if present shall not exceed the following levels, when determined according to ES ISO 9696 and ES ISO 9697 respectively :

a) gross alpha activity 0.1 Bq/l max.

b) gross beta activity 1Bq/l max.

NOTE – 4 If a screening value is exceeded, more detailed radionuclide analysis is necessary. Higher values do not necessarily imply that the water is unsuitable for human consumption.

4.4 Bacteriological requirements

4.4.1 When tested with the corresponding test methods, the bacteriological requirements of treated drinking water shall not exceed the levels shown in Table 4.

Annex 3. Steps of the RADWQ survey

Primary stratification

Technology category	Proportion of population served (%)	Included in RADWQ?	Reason for inclusion or exclusion	Number of water supplies in primary stratification
Utility piped supplies	19.8	YES	Improved technology: MORE than 5% of population	857
Boreholes	5.1	YES	Improved technology: MORE than 5% of population	222
Protected dug wells	5.0	YES	Improved technology: MORE than 5% of population	217
Protected springs	7.0	YES	Improved technology: MORE than 5% of population	303
Trucked water	0.4	NO	Improved technology: LESS than 5% of population	0
Community rainwater systems	0.0	NO	Improved technology: LESS than 5% of population	0
Not improved technologies	62.7	NO	Not improved technology according to JMP	0
Totals	100.0			1 599

Secondary stratification[a]

Broad area	Utility piped supplies					Boreholes				
	RADWQ number	*Prop. (%)*	*SecStrat number*	*Cluster size*	*Weeks required per cluster*	*RADWQ number*	*Prop. (%)*	*SecStrat number*	*Cluster size*	*Weeks required per cluster*
Oromiya, Addis Ababa, Benshangul	1 775	63.2	542	35	16	3 513	44.2	98	20	5
Harari, Dire Dawa, Somali, Afar	120	4.3	37	35	2	194	2.4	6	20	1
Tigray, Amhara	612	21.8	187	35	6	3 151	39.7	88	20	5
SNNPR, Gambella	301	10.7	92	35	3	1 086	13.7	30	20	2
Total	2 809	100.0	857		27	7 944	100.0	222		13

Broad area	Protected dug wells					Protected springs				
	RADWQ number	*Prop. (%)*	*SecStrat number*	*Cluster size*	*Weeks required per cluster*	*RADWQ number*	*Prop. (%)*	*SecStrat number*	*Cluster size*	*Weeks required per cluster*
Oromiya, Addis Ababa, Benshangul	1 627	14.7	32	20	2	2 431	28.1	85	20	5
Harari, Dire Dawa, Somali, Afar	589	5.3	12	20	1	55	0.6	2	20	1
Tigray, Amhara	7 736	70.1	152	20	8	4 101	47.4	144	20	8
SNNPR, Gambella	1 088	9.9	21	20	2	2 060	23.8	72	20	4
Total	11 040	100.0	217		13	8 647	100.0	303		18

[a] Prop. = Proportion of water-supplies in the secondary stratification. SecStrat number = number of water-supplies in the secondary stratification.

Selection of regions by proportional weighting[a]

	Utility piped supplies		Boreholes		Protected dug wells		Protected springs	
Supplies to be visited	857		222		217		303	
Clusters size	35		20		20		20	
Cluster required	25		12		11		16	
Total No. supplies	2 809		7 944		11 040		8 647	
Sampling interval	112		662		1 004		540	
Random number	68		134		947		36	
Region	**No.**	**Cumulative no.**	**No.**	**Cumulative no.**	**No.**	**Cumulative no.**	**No.**	**Cumulative no.**
Addis Ababa	460	460	11	11	18	18	6	6
Afar	12	472	16	27	116	134	4	10
Amhara	370	842	245	272	4 542	4 676	3 376	3 386
Benshangul	6	848	100	372	220	4 896	42	3 428
Dire Dawa	22	870	6	378	126	5 022	37	3 465
Gambella	9	879	5	383	15	5 037	25	3 490
Harari	6	885	9	392	47	5 084	9	3 499
Oromiya	1 309	2 194	3 402	3 794	1 389	6 473	2 383	5 882
SNNPR	292	2 485	1 081	4 875	1 073	7 546	2 035	7 917
Somali	81	2 566	163	5 038	300	7 846	5	7 922
Tigray	242	2 809	2 906	7 944	3 194	11 040	725	8 647

Selected region	Broad area	Utility piped supplies			Boreholes			Protected dug wells			Protected springs			Total		
		Clust.	No.	HH	Clust.	No.	HH	Clust.	No.	HH	Clust.	No.	HH	Clust.	No.	HH
Addis Ababa	1	4	140	15	0	0	0	0	0	0	0	0	0	4	140	15
Benshangul	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oromiya	1	11	385	35	5	100	10	1	20	0	4	80	10	21	585	55
Afar	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dire Dawa	2	1	35	5	0	0	0	1	20	0	0	0	0	2	55	5
Harari	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Somali	2	1	35	5	0	0	0	0	0	0	0	0	0	1	35	5
Amhara	3	3	105	10	1	20	0	4	80	10	7	140	10	15	345	30
Tigray	3	2	70	5	4	80	10	4	80	10	1	20	0	11	250	25
Gambella	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SNNPR	4	3	105	10	2	40	5	1	20	0	4	80	10	10	245	25
Totals		25	875	85	12	240	25	11	220	20	16	320	30	64	1 655	160

[a] Clust. = number of clusters in the corresponding broad area. No. = number of water supplies in the corresponding cluster. HH = number of household water supplies in the corresponding cluster. SNNPR = Southern Nations, Nationalities and Peoples Region.

Total weeks of field implantation for 4 teams = 16

Zones from where clusters were selected

Broad area	Region [a]	Tech type [b]	Cluster number	Zones (sampling units) [c]
1	Addis Ababa	UPS	1	Addis Ababa (Arada, Gulele, Ledeta)
1	Addis Ababa	UPS	2	Addis Ababa (Yeka, Bole, Cherkose)
1	Addis Ababa	UPS	3	Addis Ababa (Nefassilk Lafeto, Akaki Kaletie, Cherkose)
1	Addis Ababa	UPS	4	Addis Ababa (Addis Ketema, Kolete, Keraniyo, Ledeta)
1	Oromiya	UPS	5	East Shewa
1	Oromiya	UPS	6	East Shewa
1	Oromiya	UPS	7	East Shewa
1	Oromiya	UPS	8	West Shewa
1	Oromiya	UPS	9	West Shewa
1	Oromiya	UPS	10	Jimma
1	Oromiya	UPS	11	Illubabor
1	Oromiya	UPS	12	West Wellaga
1	Oromiya	UPS	13	East and/or West Harrarghe
1	Oromiya	UPS	14	Arsi and/or Bale
1	Oromiya	UPS	15	Borena
1	Oromiya	BH	16	East and/or West Shewa
1	Oromiya	BH	17	Jimma and/or Illubabor
1	Oromiya	BH	18	West Wellaga
1	Oromiya	BH	19	East and/or West Harrarghe
1	Oromiya	BH	20	Arsi and/or Bale
1	Oromiya	PD	21	Borena
1	Oromiya	PS	22	Bale
1	Oromiya	PS	23	Arsi
1	Oromiya	PS	24	Jimma
1	Oromiya	PS	25	Illubabor
2	Dire Dawa	UPS	1	Dire Dawa
2	Dire Dawa	PD	2	Dire Dawa
2	Somali	UPS	3	Jigjiga and/or Degehabur
3	Tigray	UPS	1	Central and/or East Tigray
3	Tigray	UPS	2	Mekele and/or South Tigray
3	Tigray	BH	3	Central and/or East Tigray
3	Tigray	BH	4	Central and/or East Tigray
3	Tigray	BH	5	South Tigray
3	Tigray	BH	6	West Tigray
3	Tigray	DW	7	Central and/or East Tigray
3	Tigray	DW	8	Central and/or East Tigray
3	Tigray	DW	9	South Tigray
3	Tigray	DW	10	West Tigray
3	Tigray	PS	11	Central Tigray
3	Amhara	UPS	12	West Gojam
3	Amhara	UPS	13	South Wello
3	Amhara	UPS	14	North and/or South Gonder
3	Amhara	BH	15	South Gonder and/or North Wello
3	Amhara	PD	16	West Gojam
3	Amhara	PD	17	South Wello

Broad area	Region [a]	Tech type [b]	Cluster number	Zones (sampling units) [c]
3	Amhara	PD	18	North and/or South Gonder
3	Amhara	PD	19	North Shoa
3	Amhara	PS	20	West Gojam
3	Amhara	PS	21	South Wello
3	Amhara	PS	22	North Gonder
3	Amhara	PS	23	South Gonder
3	Amhara	PS	24	North Shoa
3	Amhara	PS	25	East Gojam
3	Amhara	PS	26	North Wello
4	SNNPR	UPS	1	Sidama
4	SNNPR	UPS	2	North and/or South Omo
4	SNNPR	UPS	3	Guraghe and/or Hadiya and/or KAT
4	SNNPR	BH	4	North and/or South Omo and/or Amaro and/or Derashe
4	SNNPR	BH	5	Guraghe and/or Hadiya and/or KAT
4	SNNPR	PD	6	Sidama and/or Gedio
4	SNNPR	PS	7	North Omo
4	SNNPR	PS	8	South Omo
4	SNNPR	PS	9	Amaro and/or Derashe
4	SNNPR	PS	10	Guraghe and/or Hadiya and/or KAT

[a] Selected by proportional weighting. SNNPR = Southern Nations, Nationalities and Peoples Region.
[b] Technology types are: BH = borehole; DW = dug well; PD = protected dug well; PS = protected spring; UPS = utility piped supply.
[c] Selected by expert judgement.

Annex 4. Example of a sampling plan for field teams [a]

WSS number	Country code	Region	Broad area code	Zone(s) from which clusters need to be selected	Cluster code	Sample code	Sample type	Source WSS number for HH	Working day	Appearance, turbidity, pH, conductivity	TTC	FS	Cl free	Cl total	As F Fe NO_3	Cu
ETH20101	ETH	Dire Dawa	2	Dire Dawa	01	01	Piped		Mon	1	1		1	1	1	
ETH20102	ETH	Dire Dawa	2	Dire Dawa	01	02	Piped		Mon	1	1		1		1	
ETH20103	ETH	Dire Dawa	2	Dire Dawa	01	03	Piped		Mon	1	1		1		1	
ETH20104	ETH	Dire Dawa	2	Dire Dawa	01	04	Piped		Mon	1	1		1		1	
ETH20105	ETH	Dire Dawa	2	Dire Dawa	01	05	Piped		Mon	1	1		1	1	1	
ETH20106	ETH	Dire Dawa	2	Dire Dawa	01	06	Piped		Mon	1	1		1		1	
ETH20107	ETH	Dire Dawa	2	Dire Dawa	01	07	Piped		Mon	1	1		1		1	
ETH20108	ETH	Dire Dawa	2	Dire Dawa	01	08	Piped		Mon	1	1		1		1	
ETH20109	ETH	Dire Dawa	2	Dire Dawa	01	09	Piped		Tue	1	1		1	1	1	
ETH20110	ETH	Dire Dawa	2	Dire Dawa	01	10	Piped		Tue	1	1		1		1	
ETH20111	ETH	Dire Dawa	2	Dire Dawa	01	11	Piped		Tue	1	1		1		1	
ETH20112	ETH	Dire Dawa	2	Dire Dawa	01	12	Piped		Tue	1	1		1		1	
ETH20113	ETH	Dire Dawa	2	Dire Dawa	01	13	Piped		Tue	1	1		1	1	1	
ETH20114	ETH	Dire Dawa	2	Dire Dawa	01	14	Piped		Tue	1	1		1		1	
ETH20115	ETH	Dire Dawa	2	Dire Dawa	01	15	Piped		Tue	1	1		1		1	
ETH20116	ETH	Dire Dawa	2	Dire Dawa	01	16	Piped		Tue	1	1		1		1	
ETH20117	ETH	Dire Dawa	2	Dire Dawa	01	17	Piped		Wed	1	1		1		1	
ETH20118	ETH	Dire Dawa	2	Dire Dawa	01	18	Piped		Wed	1	1		1	1	1	
ETH20119	ETH	Dire Dawa	2	Dire Dawa	01	19	Piped		Wed	1	1		1		1	
ETH20120	ETH	Dire Dawa	2	Dire Dawa	01	20	Piped		Wed	1	1		1		1	
ETH20121	ETH	Dire Dawa	2	Dire Dawa	01	21	Piped		Wed	1	1		1		1	
ETH20122	ETH	Dire Dawa	2	Dire Dawa	01	22	Piped		Wed	1	1		1	1	1	
ETH20123	ETH	Dire Dawa	2	Dire Dawa	01	23	Piped		Wed	1	1		1		1	
ETH20124	ETH	Dire Dawa	2	Dire Dawa	01	24	Piped		Wed	1	1		1		1	
ETH20125	ETH	Dire Dawa	2	Dire Dawa	01	25	Piped		Thu	1	1		1		1	
ETH20126	ETH	Dire Dawa	2	Dire Dawa	01	26	Piped		Thu	1	1		1	1	1	
ETH20127	ETH	Dire Dawa	2	Dire Dawa	01	27	Piped		Thu	1	1		1		1	
ETH20128	ETH	Dire Dawa	2	Dire Dawa	01	28	Household	ETH20127	Thu	1	1		1		1	1
ETH20129	ETH	Dire Dawa	2	Dire Dawa	01	29	Household	ETH20127	Thu	1	1		1		1	1
ETH20130	ETH	Dire Dawa	2	Dire Dawa	01	30	Household	ETH20127	Thu	1	1		1		1	1
ETH20131	ETH	Dire Dawa	2	Dire Dawa	01	31	Household	ETH20127	Thu	1	1		1		1	1
ETH20132	ETH	Dire Dawa	2	Dire Dawa	01	32	Household	ETH20127	Thu	1	1		1		1	1
ETH20133	ETH	Dire Dawa	2	Dire Dawa	01	33	Piped		Fri	1	1		1		1	
ETH20134	ETH	Dire Dawa	2	Dire Dawa	01	34	Piped		Fri	1	1		1		1	
ETH20135	ETH	Dire Dawa	2	Dire Dawa	01	35	Piped		Fri	1	1		1	1	1	
ETH20136	ETH	Dire Dawa	2	Dire Dawa	01	36	Piped		Fri	1	1		1		1	
ETH20137	ETH	Dire Dawa	2	Dire Dawa	01	37	Piped		Fri	1	1		1		1	
ETH20138	ETH	Dire Dawa	2	Dire Dawa	01	38	Piped		Fri	1	1	1	1		1	
ETH20139	ETH	Dire Dawa	2	Dire Dawa	01	39	Piped		Fri	1	1	1	1	1	1	
ETH20140	ETH	Dire Dawa	2	Dire Dawa	01	40	Piped		Fri	1	1	1	1		1	
ETH20201	ETH	Dire Dawa	2	Dire Dawa	02	01	Dug well		Mon	1	1				1	
ETH20202	ETH	Dire Dawa	2	Dire Dawa	02	02	Dug well		Mon	1	1				1	
ETH20203	ETH	Dire Dawa	2	Dire Dawa	02	03	Dug well		Mon	1	1				1	
ETH20204	ETH	Dire Dawa	2	Dire Dawa	02	04	Dug well		Mon	1	1				1	
ETH20205	ETH	Dire Dawa	2	Dire Dawa	02	05	Dug well		Tue	1	1				1	
ETH20206	ETH	Dire Dawa	2	Dire Dawa	02	06	Dug well		Tue	1	1				1	
ETH20207	ETH	Dire Dawa	2	Dire Dawa	02	07	Dug well		Tue	1	1				1	
ETH20208	ETH	Dire Dawa	2	Dire Dawa	02	08	Dug well		Tue	1	1				1	
ETH20209	ETH	Dire Dawa	2	Dire Dawa	02	09	Dug well		Wed	1	1				1	
ETH20210	ETH	Dire Dawa	2	Dire Dawa	02	10	Dug well		Wed	1	1				1	
ETH20211	ETH	Dire Dawa	2	Dire Dawa	02	11	Dug well		Wed	1	1				1	
ETH20212	ETH	Dire Dawa	2	Dire Dawa	02	12	Dug well		Wed	1	1				1	
ETH20213	ETH	Dire Dawa	2	Dire Dawa	02	13	Dug well		Thu	1	1				1	
ETH20214	ETH	Dire Dawa	2	Dire Dawa	02	14	Dug well		Thu	1	1				1	
ETH20215	ETH	Dire Dawa	2	Dire Dawa	02	15	Dug well		Thu	1	1				1	
ETH20216	ETH	Dire Dawa	2	Dire Dawa	02	16	Dug well		Thu	1	1				1	

WSS number	Country code	Region	Broad area code	Zone(s) from which clusters need to be selected	Cluster code	Sample code	Sample type	Source WSS number for HH	Working day	Appearance, turbidity, pH, conductivity	TTC	FS	Cl free	Cl total	As F Fe NO_3	Cu
ETH20217	ETH	Dire Dawa	2	Dire Dawa	02	17	Dug well		Fri	1	1				1	
ETH20218	ETH	Dire Dawa	2	Dire Dawa	02	18	Dug well		Fri	1	1				1	
ETH20219	ETH	Dire Dawa	2	Dire Dawa	02	19	Dug well		Fri	1	1	1			1	
ETH20220	ETH	Dire Dawa	2	Dire Dawa	02	20	Dug well		Fri	1	1	1			1	
ETH20301	ETH	Somali	2	Jigjiga and/or Degehabur	03	01	Piped		Mon	1	1		1	1	1	
ETH20302	ETH	Somali	2	Jigjiga and/or Degehabur	03	02	Piped		Mon	1	1		1		1	
ETH20303	ETH	Somali	2	Jigjiga and/or Degehabur	03	03	Piped		Mon	1	1		1		1	
ETH20304	ETH	Somali	2	Jigjiga and/or Degehabur	03	04	Piped		Mon	1	1		1		1	
ETH20305	ETH	Somali	2	Jigjiga and/or Degehabur	03	05	Piped		Mon	1	1		1	1	1	
ETH20306	ETH	Somali	2	Jigjiga and/or Degehabur	03	06	Piped		Mon	1	1		1		1	
ETH20307	ETH	Somali	2	Jigjiga and/or Degehabur	03	07	Piped		Mon	1	1		1		1	
ETH20308	ETH	Somali	2	Jigjiga and/or Degehabur	03	08	Piped		Mon	1	1		1		1	
ETH20309	ETH	Somali	2	Jigjiga and/or Degehabur	03	09	Piped		Tue	1	1		1	1	1	
ETH20310	ETH	Somali	2	Jigjiga and/or Degehabur	03	10	Piped		Tue	1	1		1		1	
ETH20311	ETH	Somali	2	Jigjiga and/or Degehabur	03	11	Piped		Tue	1	1		1		1	
ETH20312	ETH	Somali	2	Jigjiga and/or Degehabur	03	12	Piped		Tue	1	1		1		1	
ETH20313	ETH	Somali	2	Jigjiga and/or Degehabur	03	13	Piped		Tue	1	1		1	1	1	
ETH20314	ETH	Somali	2	Jigjiga and/or Degehabur	03	14	Piped		Tue	1	1		1		1	
ETH20315	ETH	Somali	2	Jigjiga and/or Degehabur	03	15	Piped		Tue	1	1		1		1	
ETH20316	ETH	Somali	2	Jigjiga and/or Degehabur	03	16	Piped		Tue	1	1		1		1	
ETH20317	ETH	Somali	2	Jigjiga and/or Degehabur	03	17	Piped		Wed	1	1		1		1	
ETH20318	ETH	Somali	2	Jigjiga and/or Degehabur	03	18	Piped		Wed	1	1		1	1	1	
ETH20319	ETH	Somali	2	Jigjiga and/or Degehabur	03	19	Piped		Wed	1	1		1		1	
ETH20320	ETH	Somali	2	Jigjiga and/or Degehabur	03	20	Piped		Wed	1	1		1		1	
ETH20321	ETH	Somali	2	Jigjiga and/or Degehabur	03	21	Piped		Wed	1	1		1		1	
ETH20322	ETH	Somali	2	Jigjiga and/or Degehabur	03	22	Piped		Wed	1	1		1	1	1	
ETH20323	ETH	Somali	2	Jigjiga and/or Degehabur	03	23	Piped		Wed	1	1		1		1	
ETH20324	ETH	Somali	2	Jigjiga and/or Degehabur	03	24	Piped		Wed	1	1		1		1	
ETH20325	ETH	Somali	2	Jigjiga and/or Degehabur	03	25	Piped		Thu	1	1		1		1	
ETH20326	ETH	Somali	2	Jigjiga and/or Degehabur	03	26	Piped		Thu	1	1		1	1	1	
ETH20327	ETH	Somali	2	Jigjiga and/or Degehabur	03	27	Piped		Thu	1	1		1		1	
ETH20328	ETH	Somali	2	Jigjiga and/or Degehabur	03	28	Household	ETH20327	Thu	1	1		1		1	1
ETH20329	ETH	Somali	2	Jigjiga and/or Degehabur	03	29	Household	ETH20327	Thu	1	1		1		1	1
ETH20330	ETH	Somali	2	Jigjiga and/or Degehabur	03	30	Household	ETH20327	Thu	1	1		1		1	1
ETH20331	ETH	Somali	2	Jigjiga and/or Degehabur	03	31	Household	ETH20327	Thu	1	1		1		1	1
ETH20332	ETH	Somali	2	Jigjiga and/or Degehabur	03	32	Household	ETH20327	Thu	1	1		1		1	1
ETH20333	ETH	Somali	2	Jigjiga and/or Degehabur	03	33	Piped		Fri	1	1		1		1	
ETH20334	ETH	Somali	2	Jigjiga and/or Degehabur	03	34	Piped		Fri	1	1		1		1	
ETH20335	ETH	Somali	2	Jigjiga and/or Degehabur	03	35	Piped		Fri	1	1		1	1	1	
ETH20336	ETH	Somali	2	Jigjiga and/or Degehabur	03	36	Piped		Fri	1	1		1		1	
ETH20337	ETH	Somali	2	Jigjiga and/or Degehabur	03	37	Piped		Fri	1	1		1		1	
ETH20338	ETH	Somali	2	Jigjiga and/or Degehabur	03	38	Piped		Fri	1	1	1	1		1	
ETH20339	ETH	Somali	2	Jigjiga and/or Degehabur	03	39	Piped		Fri	1	1	1	1	1	1	
ETH20340	ETH	Somali	2	Jigjiga and/or Degehabur	03	40	Piped		Fri	1	1	1	1		1	

[a] HH = household. TTC = thermotolerant coliforms. WSS number = water supply scheme number.

Annex 5. Field team members

Field team	Name	Position
A	Mr Yemane Ashebir	Health environmentalist, Tigray
	Mr Ibrahim Hassen	Health environmentalist, Tigray
	Mr Belay Bezabih	Medical laboratory technologist, Amhara
	Mr Asfawossen	Medical laboratory technologist, Tigray
	Mr Mekonen Beyene	Driver, Federal Ministry of Health
B	Mr Birhanu Dabessa	Health environmentalist, Harari
	Mr Eferem Birhanu	Medical laboratory technologist, Harari
	Mr Keder Yesufe	Laboratory technician, SNNPR
	Mr Tegestu Woldemariam	Driver, Federal Ministry of Health
C	Mr Lulseged Bahiru	Health environmentalist, Oromiya
	Mr Derebew Getahun	Chemist, Ethiopian Health and Nutrition Research Institute
	Mr Andualem Mekonen	Chemist, Ethiopian Health and Nutrition Research Institute
	Mr Paulos Reji	Medical laboratory technologist, Oromiya
	Mr Jemmal Mohamed	Driver, Federal Ministry of Health
D	Mr Yared Tadesse	Assistant sanitary engineer, Federal Ministry of Health
	Dr Mekonen Gebereselassie	Biochemist, Regional Health Bureau, Addis Ababa
	Mr Tesefay Tamene	Medical laboratory technologist, Regional Health Bureau, Amhara
	Mr Gezahegn	Driver, Ethiopian Health and Nutrition Research Institute
	Mr Belay Tadesse	Driver, Federal Ministry of Health

Annex 6. Inventory of equipment and consumables

Inventory of equipment

Inventory no.	Item description	Unit	Total no.
1	12V Battery cable with crocodile clips	Each	4
2	12V Electrical cable for car socket	Each	4
3	Aluminium Petri dish	Each	72
4	Sterile plastic Petri dish	Each	40
5	Ball-point pen	Each	
6	Membrane filtration unit	Set	4
	Components:		
	6.1. Bronze membrane support disc	Each	4
	6.2. Filter assembly base	Each	4
	6.3. Filter funnel and locking collar	Each	4
	6.4. Hand bellows pump	Each	4
	6.5. Sample cup and cable	Each	4
	6.6. Upper and lower O rings	Each	4
7	7.1. JMP kit rucksack	Each	4
	7.2. Wag-sac	Each	11
8	Lockable carry case	Each	4
9	Cigarette lighter	Each	4
10	Mains adaptor/Battery charger	Each	4
11	Media measuring device	Each	240
12	Membrane filters, 0.45µm, gridded	Each	2 400
13	Membrane forceps	Each	4
14	Membrane pad dispenser	Each	12
15	Membrane pads (media pads)	Each	2 400
16	Operating instructions for:		
	16.1. Photometer 5000	Each	4
	16.2. pH/Temperature meter	Each	4
	16.3. Conductivity/TDS meter	Each	4
	16.4. Turbidity meter	Each	4
	16.5. Visual colour detection kit (VCDK)	Each	4
	16.6. Diskette comparator for free, combined and total chlorine	Each	4
	residuals	Each	4
	16.7 Bacteriological tests (WE 10480)		
17	Pasteur pipettes (dropping pipettes), plastic, 1ml capacity with markings at 0.5 ml and 1 ml	Each	101
18	Petri dishes rack	Each	4
19	Polypropylene bottle (autoclavable)	Each	16
20	Rechargeable battery	Each	4
21	Single pot incubator, switchable between 37°C and 44°C	Each	4
22	Spirit thermometer	Each	4
23	Incubator calibration lid	Each	4
24	Hand lens	Each	4
25	Screwdriver	Each	4
26	De-ion pack (de-ionized water maker)	Pack	2
27	JMP kit for bacteriological testing, WE 10480	Set	4
28	Photometer 5000, WE 30210	Each	4
29	pH/ Temperature meter, WE 30020	Each	4
30	Conductivity/TDS meter, WEDIST6	Each	4
31	Turbidity meter, WE 30140	Each	4

32	Visual colour detection kit (VCDK) for arsenic test, WE 10600.	Set	4
	Components:		
	32.1. Bottle brush	Each	4
	32.2. Tweezers/Forceps	Each	4
	32.3. Reagents A1 and A2	50/Pack	8
	32.4. Hydrogen sulphide removal filters	Each	4
	32.5. Black filter slide (detection)	Each	4
	32.6. Red filter slide (removal)	Each	4
	32.7. Filter paper (container labelled black)	Each	4
	32.8. Filter paper (container labelled red)	Each	4
	32.9. Dilution tube	Each	4
	32.10.Graduated flask, 100 ml	Each	4
	32.11.Colour chart	Each	4
	32.12.Tri-filter arsenic trap (bung)	Each	4
33	Diskette comparator pack for free, combined and total chlorine residuals test	Pack	4
	Components:	1/ Pack	4
	37.1. Diskette comparator	1/ Pack	4
	37.2. Square test tube (square cuvette)	1/ Pack	4
	37.3. Tablet crushing device	1/ Pack	4
	37.4. Operating instructions for the comparator	50/ Pack	4
	37.5. Tablets		
34	Lubrication grease	Tube	12

Inventory of reagent supplies

A. Physicochemical tests

Inventory number	Water-quality parameter	Reagent	Tests per pack	Quantity	Total number of tests
1	Nitrate	Nitratest powder	200	12	2 400
		Nitratest tablet	200	12	2 400
		Nitricol tablet	200	12	2 400
2	Iron	Iron HR tablet	250	11	2 750
3	Fluoride	Fluoride No 1 tablet	200	11	2 200
		Fluoride No 2 tablet	200	11	2 200
4	Copper	Coppercol No 1 tablet	250	3	750
5	Arsenic	A1 powder	200	12	2 400
		A2 tablet	200	12	2 400
6	Electrical conductivity	Conductivity standard, 1 413 µS/cm	Bottle	4	Depends on calibration frequency
		Conductivity standard, 12 880 µS/cm	Bottle	1	
7	Ammonia	Ammonia No 1 tablet	250	11	2 750
		Ammonia No 2 tablet	250	11	2 750
8	Aluminium	Aluminum No 1 tablet	250	11	2 750
		Aluminum No 2 tablet	250	11	2 750
9	Manganese	Manganese No 1 tablet	250	11	2 750
		Manganese No 2 tablet	250	11	2 750
10	pH, range 6.8–8.4	Phenol red tablet	250	11	2 750
11	Colour	Glass microfibre filters (GF/B) for removing turbidity in colour measurements	200/Pack	11	2 200

B. Physicochemical tests related to bacteriology

Inventory number	Water quality parameter	Reagent	Tests per pack	Quantity	Total number of tests
1	pH	Buffer solution, pH 4.0	60 ml bottle	12	Depends on calibration frequency
		Buffer solution, pH 7.0	60 ml bottle		
		Buffer solution, pH 10.0	60 ml bottle		
2	Turbidity	Turbidity standards:			
		0.02 NTU	Vial	4	Depends on calibration frequency
		20 NTU	Vial	4	
		100 NTU	Vial	4	
		800 NTU	Vial	4	
3	Residual chlorine:				
	3.1 Free chlorine	DPD No. 1 tablet	250/pack	3	750
	3.2 Free, combined and total chlorine	DPD No. 3 tablet	250/pack	3	250
	3.3 Reagents supplied with diskette comparator pack	Reagents for free, combined and total chlorine	50/pack	4	200

C. *Microbiological media*

Inventory number	Water-quality parameter	Media	Tests per pack	Quantity	Total number of tests
1	Thermotolerant coliforms	Membrane lauryl sulphate broth media, 38.1g pack	200/pack	11	2 200
2	Faecal streptococci	Nutri-disk azide	50/pack	4	200

D. *Arsenic refill pack*

Refill pack number	Item description	Unit of measurement	Quantity	Total quantity
1	Reagent A1	50/Pack (Four)	11	2 200
2	Reagent A2	50/Pack (Four)	11	2 200
3	Black filter slide (detection)	Each	2	2
4	Red filter slide (removal)	Each	2	2
5	Filter paper (container labelled black)	200/pack	11	2 200
6	Filter paper (container labelled red)	200/pack	11	2 200
7	Tweezers/forceps	Each	11	11
8	Hydrogen sulphide removal filters	5/pack	11	55
9	Gloves	Pair	1	11
10	Waste bag	Each	3?	3?

Annex 7. List of additional equipment and reagents

Description	Quantity
Beakers, borosilicate heat resistant simax glass, low form with spout, capacity 100 ml	12
Beakers, borosilicate heat resistant simax glass, low form with spout, capacity 500 ml	6
Graduated cylinder with stopper, borosilicate glass, single scale, 10 ml capacity	8
Graduated cylinder with stopper, borosilicate glass, single scale, 25 ml capacity	8
Cooking pot, 2 litres	4
Kerosene stove	4
Sampling bottle for physicochemical analysis	40
Sampling bottle for microbial analysis	40
Basin, plastic	4
Bottle brush	4
Jerry can, plastic 50 litres	
Sponge	8
Detergent powder, 3 kg	12
Napkin/paper tissue, 120 rolls	24
Scissors	4
Methanol, 2.5 litres	4
Denatured alcohol, 70%, 1 litre	8
Distilled water, 1 litre	55
Cooking pots, 2 litres, stainless steel	4
Cigarette lighters	12
Stationery (pens, pencils, briefcases, clipboards, notebooks)	50
Batteries for JMP turbidity meter (type: AAA or LRO3), 1.5V alkaline	16
Batteries for JMP conductivity meter (type: A76 or LR44), 1.5V alkaline	16
Batteries for JMP pH meter (type: A76 or LR44), 1.5V alkaline	16
Batteries for Photometer 500 (type: LR6, AAA, M3, MN 1500), 1.5V alkaline	32
Nitrates powder and tablets for 200 tests	4
Nitricol tablet for photometer for 200 tests	4
Membrane lauryl sulphate broth media 38.1 g	4

Annex 8. Fieldwork checklist

Before leaving for the field ensure you have the following *extras*, *in additional to the main equipment and reagents*:

- Photocopied sanitary inspection forms
- Photocopied daily report forms
- Log book
- Methanol and alcohol
- Cooking pot
- Cigarette lighter
- Digital timer
- Waste disposal plastic bags
- Disposal container/bottle for arsenic waste
- Two one-litre sampling bottles (sterilizable)
- Plug adapter
- Tissue paper/clean towel
- Liquid detergent and sponge
- Marker pen, normal pen, pencils
- De-ionized or distilled water
- Spare beakers
- Spare batteries for turbidity, conductivity, pH and photometer

Sufficient consumables for analysis:

- Tablets for nitrate, fluoride, copper, chlorine and iron (photometer)
- Tablets and powder for arsenic
- Calibration solutions for turbidity, pH and conductivity meter
- Faecal streptococci: prepared plastic Petri dishes, sterile de-ionized water, sterile pipettes
- Thermotolerant coliforms: pads, filters, media and the media measuring devices (MMDs)

Don't forget your personal comfort and check:

- Drinking-water
- Hat and/or umbrella (rain or sun)
- Food (biscuits)

Additional equipment required when storage and transportation of samples is necessary:

- Sodium thiosulphate
- Sampling bottles
- Cool bag
- Ice blocks

Morning checklist:

- Check completeness of main equipment, extra items and consumables (listed above)
- Calibrate conductivity and pH meters every morning
- Calibrate turbidity meter every morning
- Prepare sufficient amount of media for the day's number of samples, using the pre-sterilized MMDs
- Prepare sufficient number of Petri dishes for the day's number of samples, dispense media pads

Annex 9. Fieldwork plan

Field trip	Duration	Team A	Team B	Team C	Team D
		Preparation for fieldwork			
1	27–31 Dec 2004	Addis Ababa / BA 1 Cluster 01	Addis Ababa / BA 1 Cluster 02	Addis Ababa / BA 1 Cluster 03	Addis Ababa / BA 1 Cluster 04
		Review of the previous field trip and preparation for the next			
2	10 Jan–2 Feb 2005	Tigray / BA 3 Cluster 01	Tigray / BA 3 Cluster 02	Amhara / BA 3 Cluster 12	Amhara / BA 3 Cluster 13
		Tigray / BA 3 Cluster 03	Tigray / BA 3 Cluster 05	Amhara / BA 3 Cluster 16	Amhara / BA 3 Cluster 17
		Tigray / BA 3 Cluster 04	Tigray / BA 3 Cluster 09	Amhara / BA 3 Cluster 20	Amhara / BA 3 Cluster 21
		Tigray / BA 3 Cluster 07	Tigray / BA 3 Cluster 06	Amhara / BA 3 Cluster 25	Amhara / BA 3 Cluster 26
		Tigray / BA 3 Cluster 08	Tigray / BA 3 Cluster 10	Amhara / BA 3 Cluster 19	Amhara / BA 3 Cluster 22
		Tigray / BA 3 Cluster 11	Amhara / BA 3 Cluster 14	Amhara / BA 3 Cluster 24	Amhara / BA 3 Cluster 23
		Amhara / BA 3 Cluster 15	Amhara / BA 3 Cluster 18		
		Review of the previous field trip and preparation for the next			
3	10 Feb–2 Mar 2005	SNNPR / BA 4 Cluster 01	SNNPR / BA 4 Cluster 02	SNNPR / BA 4 Cluster 03	SNNPR / BA 4 Cluster 07
		SNNPR / BA 4 Cluster 06	SNNPR / BA 4 Cluster 04	SNNPR / BA 4 Cluster 05	SNNPR / BA 4 Cluster 08
		Oromiya / BA 1 Cluster 12	Oromiya / BA 1 Cluster 15	SNNPR / BA 4 Cluster 10	SNNPR / BA 4 Cluster 09
		Oromiya / BA 1 Cluster 18	Oromiya / BA 1 Cluster 21	Oromiya / BA 1 Cluster 05	Oromiya / BA 1 Cluster 16
				Oromiya / BA 1 Cluster 06	Oromiya / BA 1 Cluster 13
		Review of the previous field trip and preparation for the next			
4	11 Mar–16 Apr 2005	Oromiya / BA 1 Cluster 25	Oromiya / BA 1 Cluster 20	Oromiya / BA 1 Cluster 07	Oromiya / BA 1 Cluster 19
		Oromiya / BA 1 Cluster 17	Oromiya / BA 1 Cluster 14	Oromiya / BA 1 Cluster 08	Dire Dawa / BA 2 Cluster 01
		Oromiya / BA 1 Cluster 10	Oromiya / BA 1 Cluster 23	Oromiya / BA 1 Cluster 09	Dire Dawa / BA 2 Cluster 02
		Oromiya / BA 1 Cluster 11	Oromiya / BA 1 Cluster 22	Oromiya / BA 1 Cluster 24	Somali / BA 2 Cluster 03

Annex 10. Example of a field-team summary report

1-Feb-05

Reports on activities of Team B

Concerning study of RADWQ Rapid Assessment of Drinking-Water Quality.

Date 25/06/97 E.C – 25/07/97 E.C

Group B

Composition	Name	Responsibility
1. Environmental health professional	Birhanu Dabessa	Team Leader
2. Chemist	Keder Yesufe	Team member
3. Laboratory technologist	Eferem Birhanu	Team member
4. Driver	Tegestu W/mariam	Team member

Sample population: 120

Areas: South Tigray, Mekele, West Tigray, North Gonder, South Gonder.

Sample distribution	Piped utility supply	Borehole	Dug well	Totals
South Tigray or Mekele	--[a]	25	25	50
Mekele	35	--	--	35
West Tigray	--	20	20	40
North Gonder	40	--	--	40
South & North Gonder	--	--	20	20
Totals	**75**	**45**	**65**	**185**

[a] "–" indicates that no samples were to be taken.

Task

To analyse physicochemical parameters of water supplies related to bacteriological quality physicochemical; carry out sanitary inspections; and report the data for the given population.

Strategies

1. Communicate with relevant governmental and other bodies.

Regional health offices	Regional rural development and water offices.
Zonal health departments	Zonal water desks
District health offices	District water disks
Nearby health institutions	Development agencies

2. After obtaining the cooperation of the relevant government body:
   - A. Designate a place for the laboratory analysis.
   - B. Arrange mechanisms for ensuring sterility, if necessary.

C. Borrow vaccine carriers and ice packs for sample collection (health agencies have usually provided this support). Collect samples with the help of designated individuals.
D. Carry out the laboratory tests.
E. Prepare a daily report.

Achievement

The field team assigned to broad area 3 collected 100% of the planned samples.

Factors for effective progress

1. The commitment from governmental authorities and team members was excellent.
2. The integrity of the governmental bodies was high, except for the head of the desk for the North Gonder Zone.
3. The work team effectively explained the general and specific objectives of the study, and the support needed.

Problems identified

1. Team members were seriously discomforted by a shortage of money.
2. The time schedule was irrelevant, because events and conditions made it impossible to adhere to it.
3. There were not enough spare parts for instruments, especially fragile parts such as the test tube for the photometer.
4. The sample bottles did not have the proper caps, which made it difficult to sterilize the bottles properly.
5. There were no funds to pay people who helped to collect the samples and supplied information. Although this was explained to the people, it was a source of discomfort to the project team members and this issue should be examined carefully in future projects.

Field-team recommendations

1. Keep to the timetable prepared by the consultant, as far as possible.
2. Ensure the availability of spare parts (test tubes, etc.).
3. Use the proper sample bottles, with tight fitting covers and filters that fit exactly.
4. Devise a mechanism to tip staff who spend time helping the team members.
5. Set up a petty cash fund for emergencies or other contingencies.

Birhanu Dabessa	Team Leader -----------------------
Keder Yesufe	Team member ----------------------
Eferem Birhanu	Team member ----------------------
Tegestu W/mariam	Team member ----------------------

Annex 11. RADWQ project budget[a]

No.	Description of expenses	Expense
1	Training for 30 trainees (field staff)	32 105
	Field assessment in Addis Ababa (trip 1)	
	Subtotal (ETB)	***32 105***
	Subtotal (USD)	***3 698***
	Field assessment in Tigray and Amhara (trip 2)	
2	Per diem for field staff and drivers	35 040
3	Transportation (including fuel for 23 000 km and maintenance costs)	21 520
	Subtotal (ETB)	***56 560***
	Subtotal (USD)	***6 514***
	Field assessment in SNNPR and Oromiya (trip 3)	
4	Per diem for field staff and drivers	30 840
5	Transportation (including fuel for 22 000 km and maintenance costs	18 080
6	Running cost (i.e. for transporting the test kits to rural water points, translation etc.)	6 200
	Subtotal (ETB)	***55 120***
	Subtotal (USD)	***6 349***
	Field assessment in Dire Dawa, Somali and Oromiya (trip 4)	
7	Per diem for field staff and drivers	30 840
8	Transportation (including fuel for 22 000 km and maintenance costs)	18 080
9	Running cost (i.e. for transporting the test kits to rural water points, translation etc.)	6 200
	Subtotal (ETB)	***55 120***
	Subtotal (USD)	***6 349***
	Field assessment and return of field staff to home (trip 5)	
10	Per diem for field staff and drivers	34 320
11	Transportation (including fuel for 10 000 km and maintenance costs)	4 500
12	Running cost (i.e. for transporting the test kits to rural water points, translation etc.)	1 500
	Subtotal (ETB)	***40 320***
	Subtotal (USD)	***4 644***
	Data management and report writing	
13	Per diem for data entry	2 000
14	Per diem for the core technical working group (data analysis and report writing)	8 750
15	Transportation expenses for the core technical working group	367
	Subtotal (ETB)	***11 117***
	Subtotal (USD)	***1 280***
16	Procurement of additional equipment and reagents (see Annex 7)	26 105
	Subtotal (ETB)	***26 105***
	Subtotal (USD)	***3 133***
	Grand total (ETB)	**276 447**
	Grand total (USD)	**31 967**

[a] SNNPR = Southern Nations, Nationalities and Peoples Region.

Annex 12. Daily report sheet

WSS-No	ETH	**Date**	
BA/Region		**Time**	
Zone		**Analyst 1**	
Village/Town		**Analyst 2**	
Technology Category			
Local name			
Sampling point			

Parameter	**Units**	**Reading**	**Comment**
Appearance			
Thermotolerant coliforms	CFU/100 ml		
Faecal streptococci	CFU/100 ml		
pH	pH units		
Conductivity	µS/cm		
Turbidity	NTU		
Free chlorine	mg/l		
Total chlorine	mg/l		
Nitrate	mg NO_3/l		
Arsenic	mg/l		
Iron	mg/l		
Fluoride	mg/l		
Copper	mg/l		

PRINT NAME SIGNATURE

Analyst 1: ______________________________

Analyst 2: ______________________________

Annex 13. Quality control report sheet

Week (date):		Team:	

Parameter	Day	Units	WSS No. of source related to quality control measurement	Quality control reading
TTC	Mon	CFU/100 ml		
TTC	Tue	CFU/100 ml		
TTC	Wed	CFU/100 ml		
TTC	Thu	CFU/100 ml		
TTC	Fri	CFU/100 ml		
pH	Once a week	pH units		
Conductivity		µS/cm		
Turbidity		NTU		
Free chlorine		mg/l		
Nitrate		mg NO_3/l		
Arsenic		mg/l		
Iron		mg/l		
Fluoride		mg/l		
Copper		mg/l		

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