RAPID ASSESSMENT OF DRINKING-WATER QUALITY IN THE FEDERAL REPUBLIC OF NIGERIA

COUNTRY REPORT

RAPID ASSESSMENT OF DRINKING-WATER QUALITY IN THE FEDERAL REPUBLIC OF NIGERIA

COUNTRY REPORT OF THE PILOT PROJECT IMPLEMENTATION IN 2004-2005

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Foreword

Water is essential for human existence, and its importance for individual health and the well-being of a nation cannot be underestimated. Notwithstanding, many people in developing countries do not have access to safe and clean drinking-water or to adequate amounts of water for basic hygiene. This situation can lead to a variety of health problems. Consumption of water contaminated by disease-causing agents (pathogens) or toxic chemicals can cause health problems such as diarrhoea, cholera, typhoid, dysentery, cancer and skin diseases. Also, inadequate amounts of water for basic hygiene can contribute to poor hygiene practices, which in turn can lead to skin and eye diseases, and act as a key factor in the transmission of many diarrhoeal diseases.

From a perspective of human societies, the staggering burden of disease attributable to the consumption of contaminated water often translates into lost incomes and meals for affected families, which reinforces the deadly cycle of poverty, malnourishment and disease. The morbidity and mortality burden associated with the lack of access to safe drinking-water and poor hygiene practices in developing countries also undercuts the economic vitality and future of these nations.

To reduce the morbidity and mortality from infectious diarrhoeal diseases in developing countries, the situation with regard to drinking-water and sanitation needs to be improved, including the quality and availability of water, excreta disposal, and personal and environmental hygiene. It is also critical to have an effective quality control mechanism for water supplies to reduce the potential for explosive epidemic outbreaks: A contaminated drinking-water supply is an efficient way to quickly transmit pathogens in a large population.

Unfortunately, existing statistical data on water and sanitation provide no information about the quality of water being provided to communities, households and institutions. Also, different surveys of drinking-water quality and sanitation often use different methods, making it difficult both to measure the current scope of the problem and to compare results over time and between countries.

A rapid, low-cost, field-based technique for assessing water quality is one of the options to obtain comparable data. In response to this need, WHO and UNICEF, with the support of the UK Department for International Development, undertook pilot studies of such a method, the Rapid Assessment of Drinking-Water Quality (RADWQ), in six countries: China, Ethiopia, Jordan, Nicaragua, Nigeria, and Tajikistan.

For Nigeria, the RADWQ pilot study was carried out in 12 states distributed across eight hydrological areas of the country. This report presents the outcome of the assessment. It is hoped that the information will sensitize all the stakeholders of the water and sanitation sector in Nigeria, and help the managers of the state water agencies focus more on the need to carry out regular water quality surveillance in their areas.

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Acronyms and abbreviations

cfu	colony-forming unit
JMP	WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation
NTU	Nephelometric Turbidity Unit
RADWQ	Rapid Assessment of Drinking-Water Quality
UNICEF	United Nations Children's Fund
µS	MicroSiemen(s)
WEDC	Water, Engineering and Development Centre, Loughborough University, UK
WHO	World Health Organization
WSS No.	Water Supply Scheme Number

Executive summary

Between 2004 and 2005 six countries, including Nigeria, participated in a World Health Organization/United Nations Children's Fund (WHO/UNICEF) pilot project aimed at testing a rapid, low-cost method for assessing drinking-water quality in the field. The method, the Rapid Assessment of Drinking-Water Quality (RADWQ), was based on the UNICEF Multiple Indicators Cluster Surveys, and was developed as a tool for the WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation (JMP) to monitor global access to safe drinking-water. The method uses a cluster sampling approach to select individual drinking-water sources across an entire country, which are then tested for relevant water quality parameters. The number and types of parameters tested depend on the extent of the survey and on local conditions. For Nigeria, the RADWQ Level 1 parameters included in the assessment are described in the RADWQ handbook for implementation (Howard, Ince & Smith, 2003; an updated version of this handbook is in preparation). The parameters included appearance, thermotolerant coliform levels, faecal streptococci levels, pH, conductivity, turbidity, and levels of arsenic, fluoride, nitrate and iron (Table 1). Sanitary inspections were also carried out at the water sources visited by the field teams. The output of the RADWQ survey was the drinking-water quality for each category of improved water source tested.

Table 1 **Level 1 parameters included in the RADWQ survey for Nigeria**

Parameter	Compliance with WHO guideline or suggested value (%)
Thermotolerant coliforms	77.0
Faecal streptococci	78.0
Arsenic	100.0
Fluoride	97.1
Nitrate	89.9
Iron	91.0
Turbidity	61.0
Conductivity	98.0
pH	57.8

To implement the project in Nigeria, a 22-member steering committee was set up with the Federal Ministry of Water Resources as the lead agency for the project (Annex 1). The steering committee was made up of representatives from the Federal Ministry of Environment, Federal Ministry of Health, Federal Ministry of Water Resources, National Bureau for Statistics, National Food and Drug Administration and Control, National Water Resources Institute, Niger Delta River Basin Development Authority, Ondo State Rural Water Supply Projects, UNICEF, University of Lagos, WHO, and the Yobe State Rural Water and Sanitation Agency. The RADWQ project in Nigeria effectively began in 2004, with the planning and design of the survey, assisted by the international consultant for the project.

To facilitate the survey design, an in-country data collection exercise was carried out to gather available water quality data in selected states. This exercise showed that there were no reliable water quality data that could be used to establish a baseline for the status of drinking-water quality. Instead, data on household distribution by state and major sources of drinking-water were used to design the RADWQ survey (FOS, 2003). A technical subcommittee (Annex 1) was set up to develop the framework and initiate the field survey design, and a local consultant was engaged to fine-tune the output from the subcommittee. Toward the end of 2004, the international consultant for the project visited the country, at which time the survey design was concluded.

Nigeria is divided into eight hydrological areas, and these were taken as the broad areas for the secondary stratification of the water sources to be visited by the field teams (Table 2). States were

selected from within the hydrological areas, based on technology options, the location of the State in the hydrological area, the population served, and the potential for water-quality hazards. Hazards included industrial activities upstream or downstream of a water source, oil sector activities, intensive/extensive agricultural activities, salt water intrusion into water sources and activities associated with mining. Four field teams, each of two people, were selected from staff members of the Federal Ministry of Water Resources and the National Water Resources Institute and trained in the RADWQ methodology. These field teams visited over 1600 sample sites in 58 clusters during a five-month period between November 2004 and March 2005 and analysed water samples for the following parameters: thermotolerant coliforms, pH, turbidity, faecal streptococci, appearance, conductivity, free/total chlorine, arsenic, nitrate, fluoride, and iron. In addition, water samples were analysed from households at 10% of the sites visited, to determine whether the water quality had deteriorated between the network and the consumer tap. A total of 1841 samples (1608 water source samples, 160 household container samples, and 73 quality-control samples) were collected and analysed with Wagtech water testing kits supplied by WHO/UNICEF.

Table 2 **Broad hydrological areas used in the secondary stratification of sampling points for the RADWQ survey in Nigeria**

Broad Area	States	Technology options examined
HA1	Kebbi	Piped water, borehole, protected dug well
HA2	Kaduna	Piped water, borehole, protected dug well
HA3	Adamawa	Piped water, borehole, protected dug well
HA4	Benue and Plateau	Piped water, borehole, protected dug well
HA5	Rivers	Piped water, borehole, protected dug well
HA6	Lagos and Oyo	Piped water, borehole, protected dug well, vehicle tanker
HA7	Enugu	Piped water, borehole, protected dug well
HA8	Kano (Borno and Yobe)	Piped water, borehole, protected dug well

Nationally, overall compliance with WHO guideline or suggested values for drinking-water quality was 72.9% for all water sources (excluding household samples), but this figure varied significantly by parameter, by technology type and by broad area. Protected dug wells, for example, had the lowest compliance levels, with values ranging from 22% to 100%, and a national average of 51%. Of the water quality parameters tested, national compliance was lowest for turbidity (61%) and pH (58%) (Table 1). Although pH analysis is not required by the RADWQ methodology, the steering committee included it in the Nigeria project, prompted by the low pH values found in many areas visited during field exercises.

The results of the sanitary risk inspections showed that only 30% of all water sources visited were in a very low risk-to-health category (Table 3). The major factors affecting sanitary status were pollution of the area around the water point and poor maintenance. In addition, only 77% of all water supplies nationally were in compliance with the WHO guideline value for thermotolerant coliforms (<1 cfu/100 ml; Table 1), and only 4% of the samples tested had adequate levels of free chlorine. Together, these results raise serious concerns about the quality of water supplied by public agencies, which underscores the need to put in place national water quality standards, backed by an effective enforcement agency.

Table 3 **Risk-to-health categories for Nigerian water sources**

Risk-to-health category	Proportion (%)	Cumulative frequency (%)
Very Low	30.1	30.1
Low	38.0	68.1
Medium	21.0	89.2
High	10.9	100.0

Overall, the RADWQ methodology worked well in Nigeria, but the methodology leaves room for improvement. One improvement would be to simplify the main text of the current RADWQ handbook, by placing more of the detailed statistical methods in an annex. Another would be to visit the water sampling sites after selecting them, to physically locate the sites. Some sites visited by the field teams did not have the technology that was allocated to them in the initial design of the project. Also, communications could be improved between field-teams and local communities and government officials. Finally, implementing a RADWQ project in a country as large as Nigeria involves a huge amount of resources and significant costs, which are largely needed for travel, transportation and accommodation. To spread the cost burden of future RADWQ surveys in large countries such as Nigeria, it is recommended that partnerships be sought with external support agencies

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, not because of concerns over the water quality.
[b] Considered to be "unimproved" because of concerns about access to adequate volumes, and concerns regarding inadequate treatment or transportation 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 Country background

Nigeria is located in West Africa, between latitudes 4^o 1’ and 13^o 9’ North, and longitudes 2^o 2’ and 14^o 30’ East. It is bordered by four countries: the Republic of Niger to the North, the Republic of Chad and Cameroun, both to the East, and the Republic of Benin to the West. To the South, it is bounded by the Atlantic Ocean, with a coastline of about 800 km. The country has a total surface area of 923 770 km^2, with a land area of 910 770 km^2 and a water area of 13 000 km^2. It is richly endowed with oil and gas reserves, has substantial agricultural resources and large deposits of solid minerals, including tin, columbite, iron ore, coal, limestone, lead, zinc, precious metals, and gemstones. Environmental issues include soil degradation, rapid deforestation, overexploitation of groundwater, oil pollution, erosion, desertification and improper disposal of solid waste.

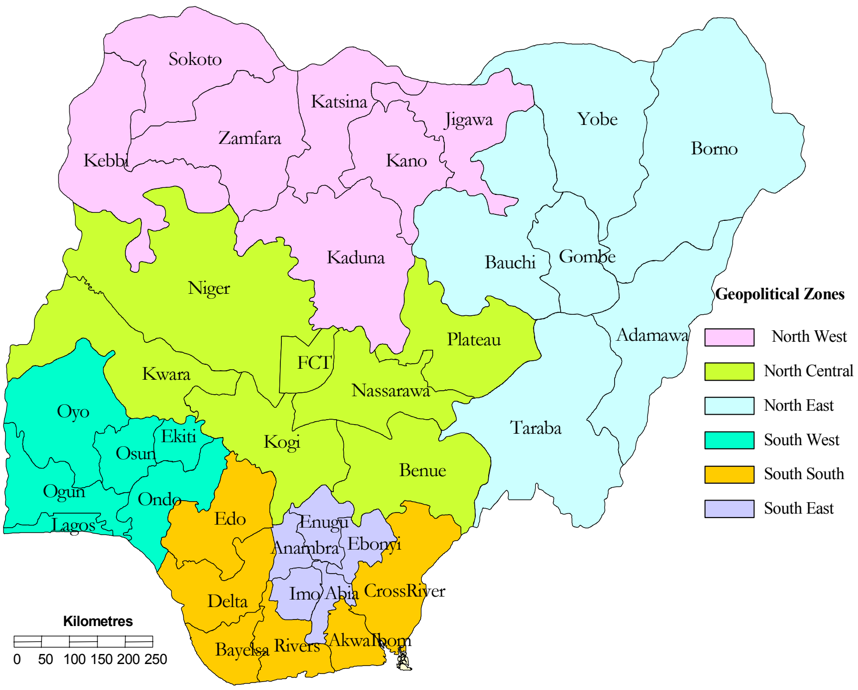
At the time of this study, the population of Nigeria was estimated to be about 143.3 million people, spread across urban, semi-urban and rural areas, and the national population growth rate is estimated to be 2.9%. The major ethnic groups are Hausa, Yoruba and Ibo, and national languages include Hausa, Yoruba and Ibo, with English as the official language. The country is divided into 36 states and the Federal Capital Territory, which are grouped into six geopolitical zones (Figure 1.1 and Annex 2), and 774 local government areas. These act as the administrative divisions of the country.

The country is endowed with about 267 billion cubic metres of surface water and about 52 billion cubic metres of groundwater, annually. In the southern part of the country, where rainfall is high, surface water and springs are often the most appropriate source of water, particularly where groundwater aquifers are deep. In the North, where rainfall is scarce and aquifers are shallow, groundwater is usually the only practical source. The geology is such that well yields are unpredictable; often the water can only be accessed using a hand pump.

Generally, the quality of groundwater in Nigeria is better than that of surface water in terms of health criteria, but much of the groundwater is corrosive, and some areas have iron, nitrate or fluoride concentrations above WHO guideline values. The corrosive nature of the groundwater necessitates the use of stainless steel and plastic materials for water supply equipment. If pH is used as an index of corrosive potential, about 20% of the groundwater is highly corrosive (pH <6.5), 40% is moderately corrosive (pH 6.5–6.8), and 40% noncorrosive (pH >6.8) (NWSSP, 2000).

Despite the generous endowment of surface and groundwater, which are capable of meeting demands, according to national sector data at the time of this study the average national water supply coverage was only about 57% (about 60% for urban areas, 50% for semi-urban areas, and 55% for rural areas). In urban areas, both surface water and groundwater are used as water sources. Urban systems require treatment plants, distribution systems, elevated tanks, piped systems, house connections, yard taps and public standpipes. In semi-urban areas, water supplies are mainly based on mechanized boreholes and overhead tanks, as well as piping with yard taps and public standpipes. Each public standpipe is generally intended to serve 250 people. Rural water supplies generally involve boreholes with hand pumps, and protected wells, although rainwater harvesting and natural springs are also used.

Figure 1.1 **Nigerian states and the Federal Capital Territory**



Source: RADWQ Team, Nigeria. 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 frontiers or boundaries.

Sanitation receives far less attention than water supply in Nigeria. Urban sanitation is in a dismal state and improving the situation requires better-formulated policies and a massive injection of investments. In semi-urban areas, according to national sector data at the time of this study 15% of the people had no way to dispose of excreta safely, 75% used pit latrines, and 60% of the people discharged wastewater directly into the environment. The situation in rural areas appeared no better: only 55% of the people were said to have access to reliable sanitation facilities. Nationally, access to sanitation was estimated to be only 42%. The poor state of the water and sanitation sector in Nigeria is reflected in the high infant mortality and morbidity rates for the country: Mortality rates for infants and children under five years old were 100 and 201 per 1000 live births, respectively (NDHS, 2003).

The three major causes were malaria, diarrhoea and acute respiratory infections, all of which are related to unclean water and inadequate sanitation. Together with typhoid, these diseases account for more than 70% of all child mortality and morbidity in Nigeria.

1.3 Historical water-quality data

Reliable data that could be used to establish a baseline for drinking-water quality in the country are hard to come by. The water supply data that do exist come mostly from state water agencies and other sources, such as the Federal Office of Statistics (MICS, 1999), the Federal Ministry of Water Resources and UNICEF. While urban water supply agencies carry out routine water quality analyses at the treatment plants on a daily or weekly basis, there is usually no record kept of the results of such analyses. Rural water supply and sanitation agencies do not carry out routine water quality tests, but usually do a water quality test on every new borehole drilled to ascertain that it is suitable for human consumption. Also, the format for data gathering is not uniform across the Nigerian states that do keep records of their water quality data and there are no specific guidelines as to which parameters are to be tested.

Prior to the RADWQ project, a rapid assessment of water quality was carried out nationwide in 2003. The goal was to examine the status of water quality management in the country and to discover any problems of water quality in the supply system. The assessment revealed that the iron content was high in virtually all groundwater-based water supplies, and that high turbidity was a common problem for supplies relying on surface water, especially in the rainy season when rivers carry a high sediment load. For some water supplies, public health was a real concern owing to the levels of chemicals that were either of natural geological origin (from rock-water interaction), or of anthropogenic origin (caused by human activities). The preliminary assessment also identified the following concerns:

- Fluoride levels were elevated in water supplies in parts of Gombe (Kaltungo, Billiri, Gombe, Pindiga and Dass) and Plateau States (Langtang area), as well as in some boreholes from Abia State.
- There were appreciable levels of cyanide in groundwater from boreholes in Gombe Township.
- Arsenic was present at one location (an abandoned mining pond used for water supply) in Bukuru, Plateau State.
- Saltwater intrusion threatened water supplies in the coastal zones, which could put large populations at risk of water shortages and associated hazards.
- The groundwater in inland basins was contaminated by saline (e.g. in the Uju, Guma and Songo areas of Benue State).

In urban and periurban settings across the country, there is a real threat that shallow groundwater and streams will become polluted from on-site sanitation systems, industrial effluent discharges and non-point pollution sources. Some of the major water supplies are drawn from rivers that are heavily polluted by chemical and biological industrial discharges, and by domestic septic tanks.

1.4 Current status of water-quality surveillance and monitoring in Nigeria

Details of the current water-quality monitoring and surveillance system are given in Table 1.2. Just prior to the RADWQ project, the Federal Ministry of Water Resources initiated the Water Quality Laboratories and Monitoring Network project, which plans to establish two reference laboratories in Lagos and Kano, and four regional laboratories in Akure, Enugu, Minna and Gombe. The laboratories are to monitor drinking-water quality for both rural and urban areas, and to carry out training for the State water agencies. Two laboratories, in Minna and Akure, had already been commissioned and were operational. The reference and regional laboratories intend to significantly improve the management and oversight of water quality throughout Nigeria.

Table 1.2 **Structure of the Nigerian surveillance and monitoring system for drinking-water quality**

Actors	Roles and responsibilities
Federal Ministry of Health	Surveillance activities
Federal Ministry of Water Resources	Monitoring and surveillance nationally and in each state
National Water Resources Institute	Research, training and monitoring
Federal Ministry of the Environment	Issuing standards on environmental regulation and surveillance
Universities and polytechnics	Research and training
International donors	Capacity development (equipment, funds, etc.)
National Bureau for Statistics	Collection , collation and issuing of data
River Basin Development Authority	Monitoring activities
State water agencies	Monitoring activities
Rural water-supply and sanitation agencies	Monitoring activities
Institute of Public Analysts of Nigeria	Monitoring and quality assurance
National Agency for Food and Drug Administration and Control	Enforcement of quality standards for packaged water
Standards Organisation of Nigeria	Issuing standards on water quality

1.5 National standards

Currently, there are two national standards for drinking-water in Nigeria, one was published by the Federal Environmental Protection Agency in 1999, and the other by the Standard Organization of Nigeria, in 2003. Neither of the standards is widely accepted, however, and instead the WHO guidelines and suggested values for drinking-water quality were used to analyse the RADWQ data for Nigeria (WHO, 2004; see also Annex 3).

2. Methods

2.1 General design of a RADWQ survey

Six countries participated in RADWQ pilot surveys - China, Ethiopia, Nicaragua, Nigeria, Jordan and Tajikistan - and the results are presented in individual country reports (of which this is one) and consolidated in synthesis report. Details of the RADWQ methodology are presented in the handbook: *Rapid assessment of drinking-water quality: a handbook for implementation* (Howard, Ince & Smith, 2003; a revised version of this handbook is under preparation). The main steps are:

- select water sources as representative sampling points, using a statistically-based survey design (cluster sampling);
- implement a field analysis of the selected water sources for a suite of parameters (Table 2.1);
- analyse the data and compare the results with historical data;
- formulate conclusions and recommendations based on the data analysis.

A RADWQ survey uses cluster sampling to identify the number, type and location of water supplies to be included in the assessment. Cluster sampling means that the water supplies included in the assessment are geographically close to one another (in "clusters"), but are representative of all water supply technology types. This can lower costs (e.g. by reducing transportation costs to/from the sampling points), without compromising the statistical validity of the sampling method. This method is used in a RADWQ survey because it is already used in major international surveys of water, sanitation and health that contribute to the WHO/UNICEF JMP database, such as the Multiple Indicators Cluster Surveys.

To try to ensure that the results of any RADWQ survey accurately reflect the situation in a country, only improved technologies supplying at least five percent of the population are included in it. The basic sampling unit is the water supply, rather than the households that use them, and thus a RADWQ survey primarily assesses the quality and sanitary condition of the water supplies, and hence the risk to water safety. For a limited number of households, a RADWQ survey also compares the quality of water stored in households with that of the matched source.

The number of water samples to be taken is 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 a water quality exceeding the target established;
D = design effect;
e = acceptable precision expressed as a proportion.

For the RADWQ pilot survey in Nigeria, it was assumed that P = 0.5, e = ±0.05 and D = 4, giving the number of water supplies to be included in the assessment, n = 1600. The steps of a generalized RADWQ survey are summarized in Figure 2.1, with the parameters tested and inspections undertaken are presented in Table 2.1. A detailed description of the parameters is given in Annex 7.

2.2 RADWQ survey design for Nigeria

The steering committee for Nigeria (for its composition: see Annex 1) commissioned an initial assessment of the RADWQ survey design, based on the method of Howard, Ince & Smith (2003). The assessment used all available data on water supplies from the states of the Federation, as well as other sources information, principally the Federal Office of Statistics (MICS, 1999), the Federal Ministry of Water Resources and UNICEF (Kehinde, 2003). In consultation with the committee, the preliminary design of the RADWQ survey was fine-tuned during the initial visit by the international consultant to ensure that site selection was random, but representative of technologies, and that water quality problems specific to Nigeria were addressed.

Table 2.1 **Water-quality parameters and inspections for a RADWQ survey**

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

The major modifications to the RADWQ design for Nigeria were:

- The number of water systems for each technology type was not available. Primary stratification of the data was therefore by the proportion of households with access to water technology type in the 36 states of the Federation and the Federal Capital Territory of Abuja (Table 2.2; FOS, 2003).
- Water supplied by vehicle or tanker truck covered <5% of the population nationally (Table 2.3), which would normally exclude this technology from a RADWQ survey (Table 1.1), but in some urban areas this technology covered >5% of the population. It was therefore decided to assess water quality for this type of supply technology in one cluster, chosen to be in Hydrological Area 6 (Table 2.4), as it had the highest population supplied by tanker truck technology.
- Fluoride is a water-quality issue in some areas of Nigeria (e.g. Plateau State) and samples within one cluster were assessed for this water-quality parameter.
- Mining is a water quality issue in some areas of Nigeria (e.g. Plateau State) and samples within one cluster were assessed to determine its impact on water quality.
- The broad hydrological areas originally suggested for secondary stratification of the water sampling points were found to be too large, because it would not have been possible for the field teams to visit the sampling points in even two states within the hydrological areas in a reasonable time period, let alone all the proposed sampling points. Instead, the most representative state within each hydrological area was selected as the secondary stratification unit. In some cases, more than one state was included to ensure that all technologies and other relevant parameters were covered (Table 2.4). For example, Hydrological Area 6 had the largest number of water points to be sampled (Table 2.5), but no single state within Hydrological Area 6 had sufficient coverage of all the necessary technologies. Consequently, both Lagos, with few protected dug wells, and Oyo, with many such wells, were included in the secondary stratification of the water-sampling points for Hydrological Area 6.

Sample size

The steering committee decided to use the standard sample size (i.e. 1600), considering it to be a conservative number and noting that it was based on the RADWQ handbook recommendations. In practice, the total number of samples analysed during the pilot project in Nigeria was 1841, because an additional 73 samples were taken for quality control, and additional 160 samples were taken (at 10% of the water-sampling points) to determine if water quality had deteriorated between the supply mains and household taps. Other samples came from one cluster to assess tanker-supplied water, and one cluster to cover the potential impact of mining and natural fluoride. Adjustments in the number of sampling points were also needed during implementation, particularly for protected wells, when the field teams tried to identify actual water points.

Primary and secondary stratification of sampling points

The primary and secondary stratifications of the water sources to be visited by the field teams were guided by the RADWQ implementation handbook (Howard, Ince & Smith, 2003) and modified as needed by the availability of data, travel times for field teams, budgetary constraints, and the preference to include all geopolitical areas of Nigeria. Primary stratification was by distribution of technology type to served populations and households (Table 2.3). Secondary stratification was by state within broad hydrological areas (Table 2.4). The distribution of the total number of water-sampling points by technology type and broad hydrological area are given in Table 2.5.

Cluster size and cluster allocation

Cluster size was defined as the number of water supplies (or sample sites) a field team could visit in one week (four working days plus one planning day). The cluster size for each technology was determined by the steering committee for Nigeria (Table 2.6), and it was agreed that these values could apply to all hydrological areas, as field teams would be able to work from different locations within each state.

The number of clusters to assign to each hydrological area was calculated by proportionally distributing the number of sample sites (i.e. 1600) according to the population of each area given in the census (FOS, 2003) and then dividing these numbers by the sample size. Clusters were then assigned by building proportional weighting tables (Howard, Ince & Smith, 2003). Two additional clusters were also assigned, one to assess the impact of fluoride and mining, and the second to assess tanker supplies in hydrological area 6. It was agreed that the total number of clusters for the RADWQ survey in Nigeria should be 58: 19 for piped water supplies, 20 for boreholes and tubewells, 18 for protected dug wells, and 1 for vehicle tankers (Table 2.7).

Before starting the field work, it was agreed that some clusters should be reallocated (from Kano to Yobe and Borno; and from Lagos to Oyo) to make the final RADWQ survey results more representative of the country as a whole (Table 2.8). The final distribution of sampling sites used in the RADWQ survey is shown on a map of Nigeria (Figure 2.3).

Selection of sampling units

Sampling units were identified at locations within the states included in the hydrological areas. For each area, the state with the highest population and, in general, the most representative spread of technologies was selected. More than one state was included in a hydrological area if it was necessary to ensure that all relevant technologies were assessed, or if specific water-quality concerns had been identified in a hydrological area.

Selecting the locations of clusters and individual water supplies

There was too little information to identify the locations of individual water supplies, and instead the numbers of each type of supply within local government areas and/or towns in the selected states were used to design the work plan for the field teams. The final location of water sampling points was determined after consultation with local experts (Figure 2.3; Annex 4).

Frequency and methodology of testing RADWQ parameters

The Level 1 water-quality parameters to be tested and the frequency of testing are described in detail in the RADWQ manual (Howard, Ince & Smith, 2003; see also Tables 2.10 and 2.11). At some locations, the water samples collected during the day were processed by membrane filtration at the overnight accommodation. This varied from the methodology suggested in the manual, but was deemed necessary either for the security of field teams (e.g. to minimize the time field teams spent in some urban locations) or to reduce overall analysis time. This had the additional advantages of protecting the samples from contamination by wind-blown dust, and the field teams from heat and rain.

Figure 2.1 **Steps in a RADWQ survey**

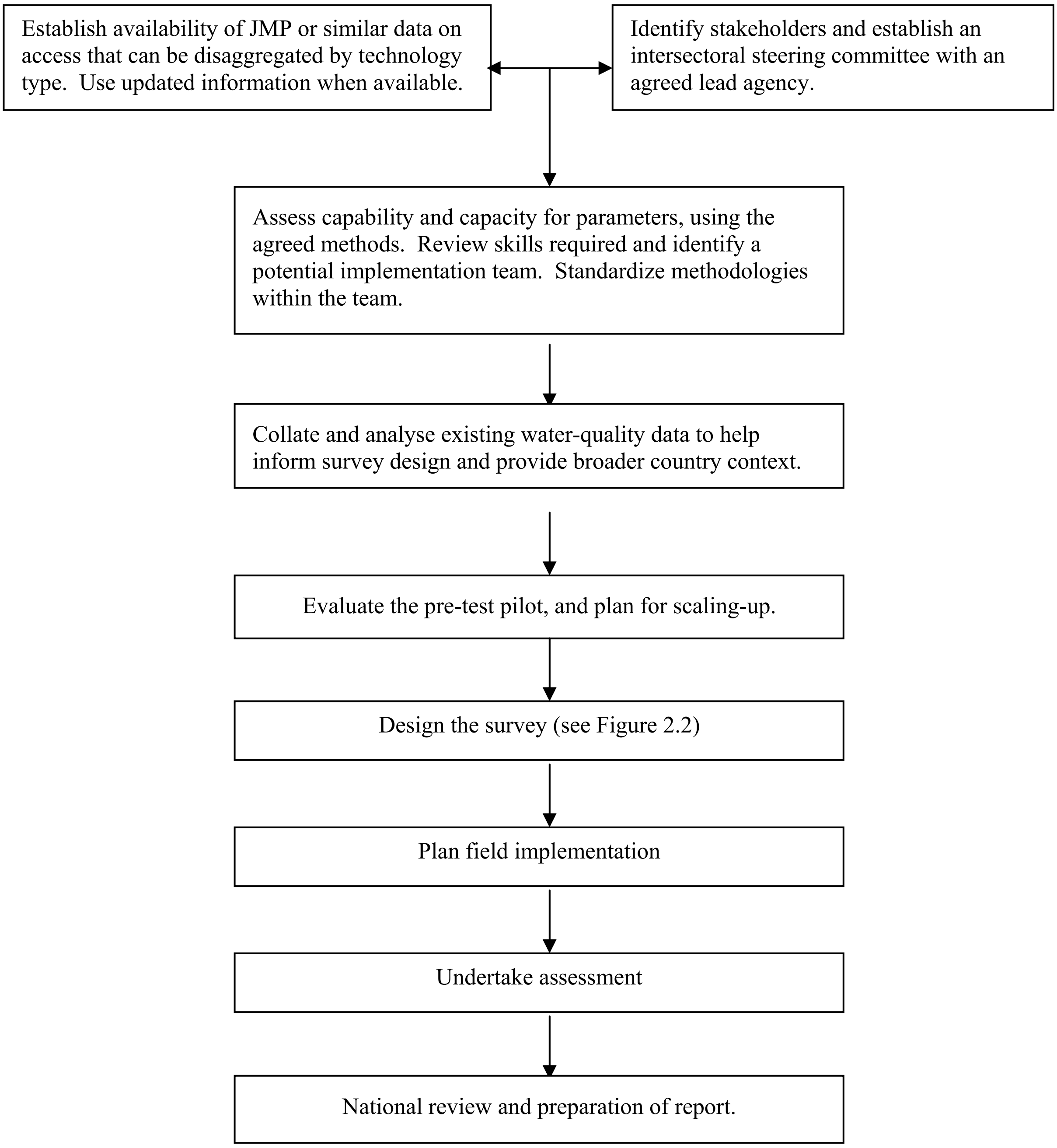


Figure 2.2 **RADWQ survey design for Nigeria**

Determine the sample size
This is the total number of water sampling points to be visited in the RADWQ survey (Equation 2.1).

↓

Primary stratification of sampling points
Proportionally weight the sampling points by technology type, based on the population served by the technology (Tables 2.2, 2.3). Only assess technologies that serve at least 5% of the population.

↓

Secondary stratification of sampling points
Proportionally assign the sampling points by broad area, based on the number of water supplies in each broad area (Tables 2.4, 2.5). In Nigeria, the broad area corresponded to eight hydrological areas.

↓

Define cluster size
This is the number of water sampling points that can be visited in one week by one team. For the RADWQ survey in Nigeria, cluster size varied from 20–35 sampling points, depending on location and technology type (Table 2.6).

↓

Designate large area sampling units
The States are divided into nonoverlapping, large area sampling units (hydrological areas). The clusters are then assigned to these areas by proportional weighting, based on the population (Tables 2.7, 2.8).

↓

Designate clusters and individual water supplies
These are the clusters and associated water sampling points that will be visited by the RADWQ survey field teams (Figure 2.3; Annex 4).

Table 2.2 **Household access to water supplies, by state and technology type**[a]

State	Total No. households	"Improved" technologies[b]					"Unimproved" technologies			Totals
		Piped water	Boreholes, tubewells	Protected dug wells	Tankers, vendors	Subtotals	Ponds, streams, rainwater	Unprotected dug well	Subtotals	
Abia	635 550	23.0	7.7	1.8	12.8	45.3	54.7	0.0	54.7	100
Adamawa	551 850	9.9	11.2	18.7	3.0	42.8	43.6	13.6	57.2	100
Akwa Ibom	610 200	8.9	16.2	0.0	0.0	25.1	75.0	0.0	75.0	100
Anambra	716 250	6.8	4.4	3.3	19.7	34.2	64.2	1.6	65.8	100
Bauchi	595 188	9.6	29.2	2.4	0.0	41.2	7.9	51.0	58.9	100
Bayelsa	339 892	24.1	4.9	0.0	0.0	29.0	60.0	11.0	71.0	100
Benue	714 560	6.9	6.1	29.7	2.6	45.3	47.6	7.2	54.8	100
Borno	670 956	31.6	12.5	13.5	11.5	69.1	3.0	27.8	30.8	100
Cross River	644 904	1.1	21.6	0.2	0.0	22.9	76.5	0.6	77.1	100
Delta	869 400	1.0	31.3	24.7	0.8	57.8	38.0	4.2	42.2	100
Ebonyi	324 058	0.9	22.0	0.9	0.3	24.1	73.4	2.6	76.0	100
Edo	716 844	20.0	17.0	3.7	7.8	48.5	49.8	1.6	51.4	100
Ekiti	647 820	5.4	3.0	26.1	0.2	34.7	63.1	2.2	65.3	100
Enugu	643 542	27.0	1.5	1.9	9.9	40.3	55.1	4.6	59.7	100
Gombe	326 700	17.6	8.7	7.3	0.2	33.8	22.2	44.0	66.2	100
Imo	805 350	13.0	7.3	1.5	16.8	38.6	59.8	1.5	61.3	100
Jigawa	533 400	13.2	25.6	4.3	0.0	43.1	3.5	53.3	56.8	100
Kaduna	856 090	32.2	4.1	8.8	0.0	45.1	6.6	48.3	54.9	100
Kano	1 293 102	25.8	21.3	11.4	18.9	77.4	6.5	16.1	22.6	100
Katsina	850 780	8.0	8.1	28.5	0.0	44.6	2.2	53.2	55.4	100
Kebbi	622 340	14.8	31.5	41.2	0.0	87.5	1.7	10.7	12.4	100
Kogi	552 240	12.9	10.2	7.3	19.3	49.7	41.7	8.6	50.3	100
Kwara	528 064	59.5	11.0	7.8	0.0	78.3	21.1	0.7	21.8	100
Lagos	1 906 700	51.1	39.3	1.2	5.6	97.2	2.8	0.0	2.8	100
Nassarawa	269 512	12.6	2.0	10.5	1.9	27.0	63.4	9.6	73.0	100
Niger	653 268	22.4	7.8	11.7	0.2	42.1	50.7	7.1	57.8	100
Ogun	1 094 450	29.0	10.8	22.9	0.0	62.7	31.9	5.4	37.3	100
Ondo	933 330	9.6	8.0	26.9	1.4	45.9	49.6	4.6	54.2	100
Osun	719 453	22.4	12.0	28.2	0.0	62.6	37.4	0.0	37.4	100
Oyo	1 186 634	24.2	9.0	32.9	0.0	66.1	29.8	4.2	34.0	100
Plateau	427 679	17.9	4.8	10.7	0.4	33.8	55.7	10.7	66.4	100
Rivers	819 808	15.2	29.9	3.7	0.0	48.8	34.0	17.1	51.1	100
Sokoto	939 600	11.7	6.0	18.3	0.0	36.0	17.7	46.3	64.0	100
Taraba	384 000	0.8	3.7	4.1	4.1	12.7	79.9	7.4	87.3	100
Yobe	367 517	27.4	15.8	5.8	0.2	49.2	5.6	45.2	50.8	100
Zamfara	535 920	12.1	7.8	1.9	0.0	21.8	21.2	57.1	78.3	100
FCT[c]	118 030	19.6	0.3	3.8	9.7	33.4	42.8	23.8	66.6	100
Total households	25 404 981									
Total households with access (%)		19.6	14.7	12.9	4.4	51.5 47.1[d]			48.5	

[a] Source: FOS (2003). Values for access to water-technology types are in percentages.
[b] See Table 1.1 for JMP definitions of "improved" and "unimproved" water-technology types.
[c] Federal Capital Territory.
[d] The subtotal percentage of all households served by "improved" water technologies, if water supplied by tanker truck or animal-drawn tankers is excluded from the analysis.

Table 2.3 Primary stratification of sampling points by technology type and households or population served

Technology type	Proportion of total population served (%)	Number of assigned water-sampling points[a]
Piped water	19.6	665
Borehole or tubewell	14.7	499
Protected dug well	12.9	437
Improved water supplies that serve ≥5% of the total population of Nigeria	47.1	1601
Vehicle or animal-drawn tanker (considered to be improved, but <5% total samples taken)	4.4	None under RADWQ methodology
Population of Nigeria served by unimproved water supplies	48.5	None under RADWQ methodology

[a] Calculated from: (% total population served by the technology type / 47.1) * 1600.

Table 2.4 State composition of broad hydrological areas

Hydrological Area	States within hydrological area[a]
HA 1	**Kebbi**, Sokoto, Zamfara, Katsina
HA 2	**Kaduna**, Kwara, Federal Capital Territory, Niger
HA 3	**Adamawa**, Gombe, Taraba, Bauchi
HA 4	**Benue, Plateau**, Nassarawa, Kogi
HA 5	**Rivers**, Anambra, Delta, Bayelsa
HA 6	**Oyo, Lagos**, Osun, Ondo, Ogun, Ekiti, Edo
HA 7	**Enugu**, Akwa Ibom, Cross River, Ebonyi, Abia, Imo
HA 8	**Kano**, **Borno, Yobe**, Jigawa

[a] All the states that are underlined in the table were initially to have been included in the RADWQ study, but budgetary and other constraints meant that the number of included states had to be reduced. Some samples were also reallocated from Kano to Borno and Yobe, so that the RADWQ survey would better represent the technology options. The states finally included in the study are shown in bold font.

Table 2.5 Secondary stratification of water sampling points by hydrological area and technology

Hydrological Area	Piped water	Borehole or tubewell	Dug well	Totals
HA 1	45	49	91	184
HA 2	101	19	26	147
HA 3	23	37	21	81
HA 4	31	17	44	91
HA 5	35	76	36	147
HA 6	268	171	176	615
HA 7	65	57	5	128
HA 8	96	74	38	208
Nigeria	664	500	437	1601

Table 2.6 Cluster size for Nigeria, by technology type

Technology type	Cluster size suggested by RADWQ guide	Cluster size for Nigeria[a]
Utility piped water	20–80	35
Borehole or tubewell	12–40	Urban: 30 Rural: 20 Average: 25
Protected dug well	12–40	Urban: 30 Rural: 20 Average: 25
Vehicle tanker	12–80	30

[a] Cluster size was determined from the number of water supplies that could be visited in one week by a field team, based on a 5-day week, and reading the results for faecal streptococci on day 6.

Table 2.7 Number of clusters for each hydrological area, by technology type

State	Hydrological Area	Geopolitical zones	Piped water supply	Boreholes or tubewells	Protected dug well
Kebbi	1	NW	1	2	4
Kaduna	2	NW	2		1
Adamawa	3	NE			2
Plateau	4	NC		1	1
Benue	4	NC	1	1	3
Rivers	5	SS	1	3	
Lagos	6	SW	6, plus 1	9	
Oyo	6	SW	3	1	5
Enugu	7	SE	1		
Kano	8	NW	3	4	2
Subtotals for technology type[a]			18, plus 1	20, plus 1	18
No. of water samples to be tested			665	499	437
Cluster size			35	25	25
Sampling interval[b]			127	861	1440
Random number[b]			77	715	459

Key:

- Field team 1 area (green: Kebbi, Kaduna)
- Field team 2 area (orange: Lagos, Oyo)
- Field team 3 area (yellow: Adamawa, Plateau, Kano)
- Field team 4 area (lilac: Benue, Rivers, Enugu)
- Additional cluster was to assess fluoride levels (from natural sources), and arsenic levels (possibly from mining activities in the area) (magenta: Plateau boreholes or tubewells; "20, plus 1")
- Additional cluster was to assess vehicle-tanker supply (red: Lagos piped water supply; "18, plus 1")

[a] The number of clusters for each technology type was calculated by dividing the number of water samples to be tested for the technology by the cluster size for the technology. For piped water supplies, for example, the calculation is: 665/35 = 19.

[b] The sampling intervals and random numbers for the technology types were derived as described in the RADWQ handbook (Howard, Ince & Smith, 2003).

Table 2.8 **Final allocation of clusters by proportional weighting**

Hydrological Area	State	No. of water-sampling points	No of clusters
HA 1	Kebbi	95	7
HA 2	Kaduna	185	3
HA 3	Adamawa	50	2
HA 4	Benue	135	5
HA 4	Plateau	50	2
HA 5	Rivers	110	4
HA 6	Lagos	395	13
HA 6	Oyo	330	12
HA 7	Enugu	35	1
HA 8	Kano	170	6
HA 8	Yobe (reassigned from Kano)	25	1
HA 8	Borno (reassigned from Kano)	60	2
Totals:		1640	58

Key:

(magenta) Additional cluster was to assess naturally occurring fluoride content, and arsenic levels (possibly from mining)

(red) Additional cluster was to assess vehicle-tanker supply

Table 2.9 **Define and select sampling units**

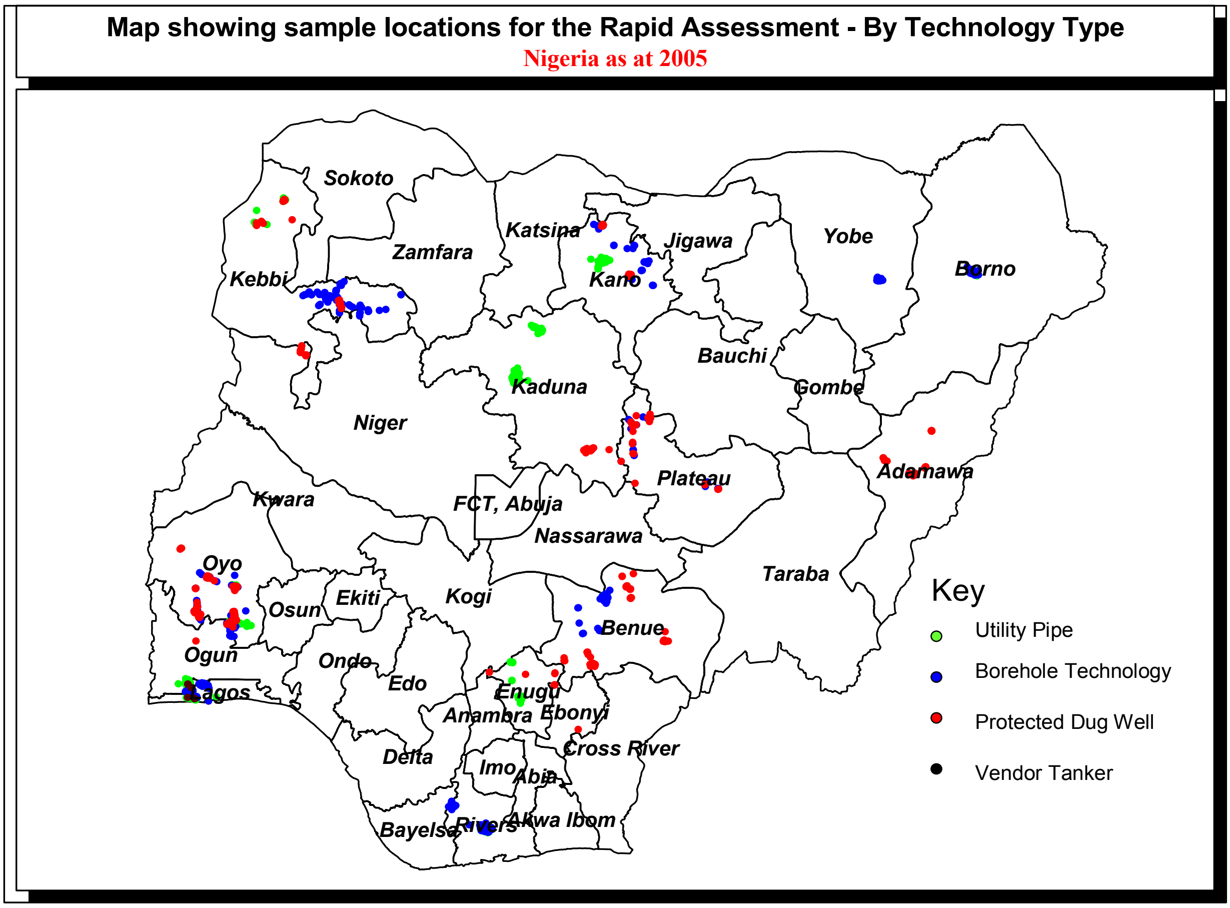
Hydrological Area	States included in the hydrological area	Technologies assessed in the states included in the RADWQ survey
HA 1	Kebbi	Piped water, boreholes, protected dug wells
HA 2	Kaduna	Piped water, boreholes, protected dug wells
HA 3	Adamawa	Piped water, boreholes, protected dug wells
HA 4	Benue and Plateau (F, As)[a]	Piped water, boreholes, protected dug wells, vehicle tanker
HA 5	Rivers	Piped water, boreholes, protected dug wells
HA 6	Lagos and Oyo[b]	Piped water, boreholes, protected dug wells, vehicle tanker
HA 7	Enugu	Piped water, boreholes, protected dug wells, vehicle tanker
HA 8	Kano (Borno and Yobe)[c]	Piped water, boreholes, protected dug wells, vehicle tanker

[a] One cluster in Plateau was assessed for fluoride and arsenic, since Plateau was considered to be more accessible than Benue. A choice needed to be made as there were not enough arsenators for all field teams.

[b] There were too few protected dug wells in Lagos, so Oyo State was added to Hydrological Area 6.

[c] To better represent the different technologies, some clusters were reassigned from Kano to Borno and Yobe States.

Figure 2.3 **Locations of sampling sites, by technology type**



Source: RADWQ Team, Nigeria. 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 frontiers or boundaries.

Table 2.10 **RADWQ parameters and frequency of testing in Nigeria**

Parameter[a]	Proportion of all types of water supplies tested for parameter (%)	Proportion of household water supplies tested for parameter (%)
Thermotolerant coliforms, turbidity, pH	100	100
Faecal streptococci	10	0
Free chlorine residual	100	100
Total chlorine residual	0	100
Appearance, conductivity	100	100
Arsenic, fluoride and iron	100	100
Nitrate	30	100
Copper	100	100

[a] Testing for copper in piped water supplies was only necessary if copper pipes were used. Total chlorine was tested only for household samples because there were a limited number of DPD3 tablets. Nitrate and arsenic were tested in 100% of the samples because the necessary consumables were available for a country-wide survey for these two chemicals.

Table 2.11 **Methods for testing water-quality parameters**

Parameter	Method[a]
Thermotolerant coliforms, faecal streptococci	Membrane filtration
Fluoride	Photometer
Iron	Photometer
Free and total chlorine	Photometer
Nitrate	Photometer
Copper	Photometer
pH	Photometer and pH meter
Arsenic	Visual
Turbidity	Turbidity meter
Conductivity	Conductivity meter
Appearance	Visual inspection on a 5-point scale

[a] All parameters were tested using Wagtech field kits, with the exception of Appearance, which was carried out visually.

Summary

The RADWQ survey methodology for Nigeria is summarized in Table 2.12, and the design parameters are listed in Table 2.13. The mean values for the water quality parameters are shown by broad area and technology type in Annex 8.

Table 2.12 **RADWQ survey design for Nigeria**

Step	Method in RADWQ handbook	Method used in Nigeria	Justification for not using RADWQ handbook method.
1	Calculate **sample size** required (= 1600).	According to survey design: • 1600 normal samples; • 268 quality-control samples; • 160 household samples.	After implementation: • 1608 normal samples; • 73 quality-control samples; • 160 household samples. The difference arose because one cluster was included to assess tanker supplies and one to assess the impacts of mining and natural fluoride. Other adjustments were made during the first weeks of implementation, and fewer quality-control samples were taken.
2	**Primary stratification**: proportional weighting by technology type (based on percentage of population served). NB: only include technologies serving at least 5% of population.	The survey was carried out across the whole country. The eligible technologies were: • piped water; • boreholes and tubewells; • protected dug wells. Stratification was by population served.	Primary stratification of the water sampling points for the included technologies was on the basis of the population (households) served by the technologies (a household was defined as having five members). This was necessary because the actual number of water supplies for each technology was unknown.
3	**Secondary stratification**: proportional weighting by broad areas (based on the number of water supplies across the country).	Secondary stratification was by population served, with hydrological areas selected as the broad areas.	The initial secondary stratification was by all states within each broad area (hydrological area). For logistical reasons, this was changed to one state within each hydrological area, selected as the state with the highest population and range of technologies in use. In some cases, more than one state was included in a hydrological area, to ensure that the data were representative of the broad area as a whole.
4	**Define clusters** (size and number): based on the number of water supplies that can be visited in one week by one team (cluster size).	Cluster size was determined on the basis of distances and travel times between state capitals or major towns and the sampling points (Table 2.6).	For some hydrological areas the cluster size was determined on the basis that microbiological samples could be taken and transported to the central location within the time allowed for such samples.
5	**Designate large area sampling units**: areas from which clusters are selected by proportional weighting.	States within each hydrological area were selected as the large area sampling units.	For logistical reasons, only one state was selected within each hydrological area, except to ensure that the data were representative of the entire broad area.
6	**Select clusters and individual water supplies**: identify supplies for water-quality assessment.	Clusters were selected by expert judgement, as recommended in the RADWQ manual. Individual water supplies were selected by field teams, with advice from local experts. There was not enough information to do this before starting field work.	Some clusters were reallocated to other states within a hydrological area, to ensure representative coverage of each technology type and to assess parameters of local concern. Selection of individual sites in the field was effective.

Table 2.13 **Summary of RADWQ survey parameters for Nigeria**

Parameter	Agreed values for Nigeria	Comments
Sample size.	1600 water-supply samples 160 household samples	One cluster of 30 vehicle tanker samples was added to the survey. One cluster of 25 borehole samples was included in the survey to assess fluoride levels and the impact of mining.
Broad area	8 hydrological areas	All geopolitical areas are covered.
Sampling units.	States, generally one per hydrological area.	Minimum of one state per hydrological area, and a minimum of one state in each geopolitical area.
Improved water-supply technologies (% of total households supplied).	• Piped water (19.6%); • Boreholes, tubewells (14.7%); • Protected dug wells (12.9%); • Tanker vendor (4.4%).	• Utility and community water supplies not separated; • Some may be piped water schemes; • Parameters assessed varied between states; • Tanker vendors were initially excluded because they served <5% of the population and because handcarts were often used, but one cluster was assessed in Hydrological Area 6 (Lagos) as urban coverage was reported to be >5%.
Unimproved water-supply technologies (% of total households supplied).	Streams/ponds/rainwater/ unprotected wells (48.5%).	The proportion of households supplied by unimproved technologies is 52.9% if vendor suppliers are included in the total.
Cluster size (the estimated number of water sampling points it is possible for one field team to visit in one week).	35 for piped water; 25 for boreholes; 25 for protected dug wells; 30 for tanker vendors.	
Cluster numbers	Piped water: 19 (18 piped water supplies and 1 vehicle tanker); Boreholes, tubewells: 20 (plus 1 in Plateau); Protected dug wells: 18.	One cluster was to assess water supplies of vehicle tanker vendors in Lagos. An additional cluster assessed the effects of mining and fluoride levels in boreholes.
Number of water-sampling points (based on the number of households supplied).	Piped water: 665; Boreholes, tubewells: 499; Protected dug wells: 437.	Totals: 1601 water supply samples; 160 household samples; Some additional blanks and duplicate samples.
Distribution of water-sampling points by technology type, after using proportional weighting to allocate clusters.	Piped water: 665; Boreholes, tubewells: 500 plus 25; Protected dug wells: 450.	Totals: 1640 water-supply samples; 160 household samples; Additional blank or duplicate samples and quality-control samples.

2.3 Field implementation and data recording

Field implementation

Field implementation was carried out from November 2004 to March 2005, with breaks during Ramadan and Christmas. The four field teams (Annex 1), each consisting of a chemist and a microbiologist, first underwent a series of training activities to adequately prepare them for the field work. An additional team was trained and put on standby. Each team then travelled to their assigned hydrological areas (Figure 2.4), to collect and analyse the water samples.

All the field teams also spent time in Hydrological Area 6, to facilitate information sharing and problem solving during the early stages of the field work. Initially, all the field teams worked on the same clusters, before separating and working on different clusters within Hydrological Area 6. The field teams later met to share experiences and lessons learned. This process was highly valued by the field team members and the field coordinator. It ensured that all the teams were following the same procedures during the rest of the field activities.

There were some problems with remote support by the consultant and the field coordinator from the Federal Ministry of Water Resources, because there was no reliable access to e-mail. Fortunately, the quality of the preliminary work carried out by the field teams in Hydrological Area 6 meant that urgent or routine requests for assistance were few.

Work plan

Before the field teams started their work, the approximate locations of clusters within the states were identified and recorded on a map, using information collected either by the Federal Ministry of Water Resources, or by a water supply specialist in each state. There were not enough data to determine the exact location of every water point within the clusters, especially for dug wells, boreholes and tubewells. When the locations of the sampling points were only approximate, the teams had to locate them during the field work. During the preparation of the work plan, the international consultant provided advice on selecting the final sampling point locations within the state, based on factors such as the proximity of the water point and ease of access to it, and whether additional sites were nearby (in case some wells turned out to be dry). The field teams then used this advice and the RADWQ handbook recommendations to select individual sampling points. The final choices of household sampling points were similarly based on ease of access and whether they represented social and economic differences in the state.

A draft work plan was developed by members of the steering committee, the field teams and the international consultant. Subgroups looked at individual hydrological areas (or states) and identified locations for the number of clusters required for each technology. The travel times between clusters were used to plan overnight accommodation stops and these were incorporated into the work plan. The final work plan is presented in Annex 4 and the budget in Annex 5.

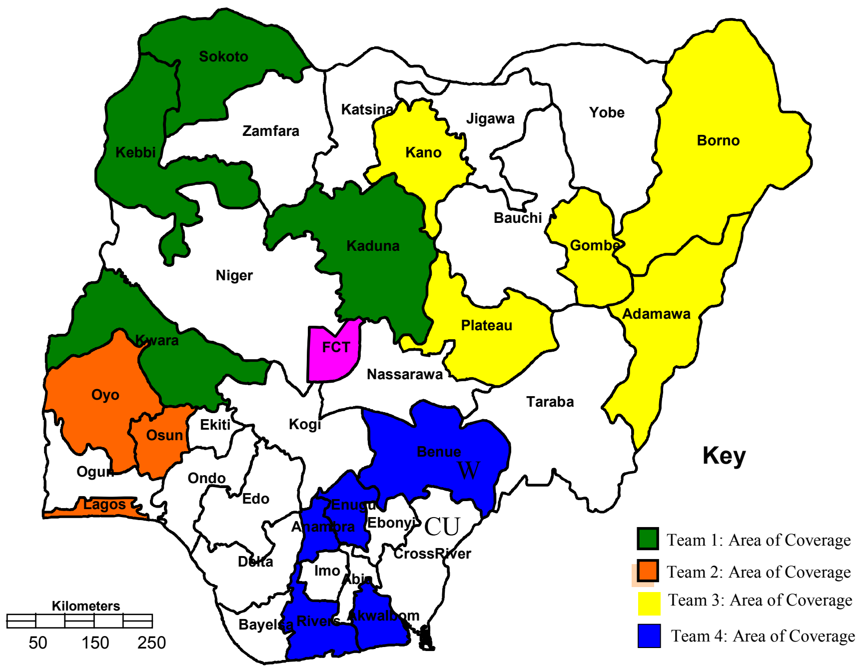
Data recording

Data were recorded on record sheets in the field (Annex 6) and copies were regularly sent to the data manager for entry into the data storage software (SanMan). The electronic data were then sent to the international consultant. In the SanMan database, each water sampling site was identified by a unique 8-digit code, or Water Supply Scheme Number (WSS No.). The following coding system was used for Nigeria:

- NGA (for Nigeria) was assigned to all non-household water samples (i.e. piped mains, dug wells, boreholes etc.);
- NHC was used in place of NGA for all household samples;
- One digit was used for each Hydrological Area (1-8), and the number 9 was used to indicate a quality-control sample;
- Two digits were used for the cluster number;
- Two digits were used for the sample number.

For example, NGA81702 indicates the water sample was non-household sample number 2, in cluster 17, Hydrological Area 8. NHC44623 indicates household sample number 23, in cluster 46, Hydrological Area 4; and NGA92209, the non-household quality-control sample from cluster 22 in Hydrological Area 9.

Figure 2.4 **Areas assessed by the four field teams**[a]



[a] Source: RADWQ Team, Nigeria. The divisions shown on the map of Nigeria represent political and administrative units. The designations do not imply any opinion whatsoever on the part of the World Health Organization concerning the legal status of any country, territory, city or area; or of their authorities; or concerning the delimitation of frontiers or boundaries.

2.4 Data analysis

Data collected for the water sampling points were stored in SanMan and exported to Microsoft Excel for analysis. Compliance of the water sources with WHO guideline and suggested values was determined for microbial, physical and chemical parameters. An overall compliance level was calculated for Nigeria, and the results were also disaggregated by technology type and by hydrological area. It was not possible to determine a compliance level for Nigerian national standards, because a decision as to which standards to use in the RADWQ project remained pending.

Household samples were also analysed for compliance with WHO guideline and suggested values for microbial, physical and chemical parameters. It was not possible to link the household data with the water sources, because not enough information was recorded on the household forms. Instead, the data were analysed using simple descriptive statistics, and average values, maximum and minimum values, and variability between the values were determined for each parameter.

In line with the WHO *Guidelines for drinking-water quality* (WHO, 2004), all the water sources included in the RADWQ survey (including household sources) were assessed for sanitary risk using a standard set of questionnaires developed for the RADWQ pilot project (Annex 6). The sanitary risk inspection results were then cross-checked with the microbiological data in a "risk-to-health" matrix, which gave an indication of the potential risk to health posed by the water source. The data were analysed by technology type, nationally, but were not disaggregated by hydrological area (e.g. Table 3.13).

Finally, the ability of water turbidity to act as a proxy parameter for bacterial contamination, as well as conductivity to act as a proxy for chemical contamination, was determined by calculating linear correlation coefficients (Pearson's *r*) for the data pairs. The calculation assumes the data are distributed normally, and the result is disproportionately influenced by outlier datum points. Spearman's *rho* is a more rigorous analysis, as it does not assume a normal distribution for the input data and it is more resistant to outlier data, but it is not easily calculated within Microsoft Excel. An outlier is a value far from most others in a set of data.

3. Results

The Level 1 parameters included in a RADWQ survey are described in Annex 7. For each parameter, the average, maximum and minimum values, and the variation were determined from the survey data (Annex 8). Compliance of Nigerian water supplies with WHO guideline values and suggested values for drinking-water was calculated with the SanMan software programme. It was not possible to determine compliance with Nigerian national standards for drinking-water quality, because at the time they had yet to be developed.

3.1 Bacteriological parameters

Thermotolerant coliforms

Thermotolerant coliforms were used as indicator bacteria to assay the level of bacteriological contamination of the water supplies. A total of 1608 water samples were analysed for thermotolerant coliforms and the results indicated that, with the exception of those in Hydrological Area 2, water supply sources in Nigeria were contaminated to a significant extent. The compliance of water supplies for thermotolerant coliforms and faecal streptococci is given by technology type for each hydrological area (Table 3.1), and the corresponding cumulative frequencies for bacteriological counts are listed in Tables 3.2 and 3.3 (see also Annex 9 for a graphical representation of the cumulative frequencies and sanitary risks, by technology type).

Nationally, the average compliance with the WHO guideline value for thermotolerant coliforms (<1 cfu/100 ml) was 77%, with the lowest (68%) compliance for water supplies in Hydrological Area 6 and the highest (98%) in Hydrological Area 2. Of the technology types assessed, protected dug wells had the lowest (56%) level of compliance nationally, while boreholes had the highest (94%). However, average compliance levels for protected dug wells ranged from 26% in Hydrological Area 6 to 100% in Hydrological Area 2 (Table 3.1).

The average level of thermotolerant coliform contamination ranged from 0 cfu/100 ml in Hydrological Area 2, to 17 cfu/100 ml in Hydrological Area 1, with a national average of 5 cfu/100 ml. Contamination was lowest for borehole water samples, but values for this technology varied within and between hydrological areas.

Faecal streptococci

In the RADWQ survey for Nigeria, 172 water samples from different parts of the country were also analysed for faecal streptococci. There was a low level of contamination in only four hydrological areas, with average counts of 2 cfu/100 ml for Hydrological Area 1; 4 cfu/100 ml for Hydrological Area 2; 2 cfu/100 ml for Hydrological Area 5; and 1 cfu/100 ml for Hydrological Area 6. In the other four hydrological areas no faecal streptococci contamination was found (mean value of 0 cfu/100 ml). Nationally, the average faecal contamination level was 1 cfu/100 ml. Some of the highest levels of contamination were found for boreholes (mean value of 8 cfu/100 ml) and protected dug wells (15 cfu/100 ml) in Hydrological Area 6, and for utility pipes in Hydrological Area 2 (42 cfu/100 ml). Vehicle tankers were not analysed for this parameter. Nationally, compliance with the WHO guideline value for faecal streptococci (<1 cfu/100 ml) was 78%.

The compliance levels of water samples for faecal streptococci did not mirror those for thermotolerant coliforms (Table 3.1). For faecal streptococci, protected dug wells had the highest compliance values (overall average of 85%), and boreholes the lowest (75%), which was the opposite of the results obtained for thermotolerant coliforms. A frequency analysis for thermotolerant coliforms and faecal streptococci showed that most samples fell in the <1 cfu/100 ml category, with few in the other three categories (Tables 3.2 and 3.3).

Table 3.1 **Compliance with WHO guideline values for bacteriological parameters, by technology type**[a]

HA	Boreholes, tubewells				Protected dug wells				Utility piped water			
	TCC		FS		TCC		FS		TCC		FS	
	N	Compl. (%)	*N*	Compl. (%)	*N*	Compl. (%)	*N*	Compl. (%)	*N*	Compl. (%)	*N*	Compl. (%)
HA 1	75	97	10	100	75	65	9	100	35	80	4	50
HA 2					25	100	3	100	70	97	7	57
HA 3					50	70	5	100				
HA 4	50	92	4	75	100	63	9	78	35	74	3	100
HA 5	75	84	10	50					35	77	8	50
HA 6	225	94	25	64	125	26	16	69	315	66	30	77
HA 7									35	77	2	100
HA 8	100	100	11	100	49	69	5	100	105	98	11	100
National	525	94	60	75	424	56	47	85	630	77	65	75

[a] HA = Hydrological Area; FS = faecal streptococci; TCC = thermotolerant coliforms; *N* = total number of water samples analysed; Compl. = compliance with WHO RADWQ guideline value (for TCC) or suggested value (for FS) of <1 cfu/100 ml.

3.2 Chemical parameters

Arsenic

Nationally, all samples tested for arsenic were in compliance with the WHO guideline value of 0.1 mg/l (Table 3.4), regardless of technology type used to deliver the water. Initially, there were concerns that water supplies in certain mining areas of Hydrological Area 4 (Plateau State) and Hydrological Area 6 (Oyo/Igbeti) might be contaminated by arsenic, but the results from clusters in these broad areas did not reflect this.

Fluoride

Fluoride was tested in 1595 samples from all eight hydrological areas and for all four technology options (Table 3.5). Nationally, compliance was high for all technology options, ranging from 94% for boreholes and tubewells, to 100% for vehicle tanker. Geographically, compliance for fluoride ranged from 91% to 100%, with a national average of 97%. The lowest average compliance recorded (78%) was for borehole and tubewell technology in Hydrological Area 4.

Measured fluoride levels were lowest in water from vehicle tankers, while borehole water had the highest content. Geographically, mean fluoride levels ranged from 0.20 mg/l in Hydrological Area 8, to a high value of 1.04 mg/l in Hydrological Area 1. Water from boreholes in Hydrological Area 4 had, however, the highest fluoride content, with an average value of 1.53 mg/l. This area covers Plateau State, which features fluoride containing rocks. There was little variation among fluoride values for individual water samples.

Table 3.2 National cumulative frequencies for thermotolerant coliforms[a]

Count category (cfu/100 ml)	**Boreholes, tubewells**			**Protected dug wells**			**Utility piped water**			**Vehicle tanker**			**Totals**		
	N	F (%)	∑ (%)	*N*	F (%)	∑ (%)	*N*	F (%)	∑ (%)	*N*	F (%)	∑ (%)	*N*	F (%)	∑ (%)
<1	494	94	94	239	56	56	488	77	77	18	62	62.0	1239	77	77
1–10	24	5	99	48	11	67	75	12	89	8	28	90.0	155	10	87
11–100	7	1	100	113	27	94	51	8	97	2	7	97.0	173	11	98
>100	0	0	100	24	6	100	16	3	100	1	3	100	41	2	100
Subtotals	525			424			630			29			1608		

[a] *N* = number of samples; F = frequency with which count category was seen in water samples; ∑ = cumulative frequency.

Table 3.3 National cumulative frequency for faecal streptococci[a]

Count category (cfu/100 ml)	**Boreholes, tubewells**			**Protected dug wells**			**Utility piped water**			**Vehicle tanker**			**Totals**		
	N	F (%)	∑ (%)	*N*	F (%)	∑ (%)	*N*	F (%)	∑ (%)	*N*	F (%)	∑ (%)	*N*	F (%)	∑ (%)
<1	45	75	75	40	85	85	49	75	75	0	0	0	134	78	78
1–10	15	25	100	6	13	98	15	23	98	0	0	0	36	21	99
11–100	0	0	100	1	2	100	1	2	100	0	0	0	2	1	100
>100	0	0	100	0	0	100	0	0	100	0	0	0	0	0	100
Subtotals	60			47			65			0			172		

[a] *N* = number of samples; F = frequency with which count category was seen in water samples; ∑ = cumulative frequency.

Table 3.4 Compliance of Nigerian water supplies with WHO guideline value for arsenic[a]

Hydrological Area	**Boreholes, tubewells**		**Protected dug wells**		**Utility piped water**		**Vehicle tanker**		**Totals**	
	N	Compl. (%)	*N*	Compl. (%)	*N*	Compl. (%)	*N*	Compl. (%)	*N*	Compl. (%)
HA 1	75	100	75	100	35	100			185	100
HA 2			25	100	70	100			95	100
HA 3			50	100					50	100
HA 4	50	100	100	100	35	100			185	100
HA 5	75	100			35	100			110	100
HA 6	225	100	125	100	315	100	29	100	694	100
HA 7					35	100			35	100
HA 8	100	100	49	100	105	100			254	100
National	525	100	424	100	630	100	29	100	1608	100

[a] *N* = number of samples; Compl. = compliance with WHO guideline value (0.01 mg/l).

Nitrate

A total of 613 samples were collected from all hydrological areas and technology options, and analysed for nitrate. Compliance levels ranged from 82% for boreholes and tubewells, to 100% for utility piped water and vehicle tanker (Table 3.6). Nationally, the average compliance for nitrate was 90%, with the lowest compliance level measured for borehole and tubewell technology in Hydrological Area 4 (47%).

Measured nitrate levels varied widely, both by hydrological area and by technology type. Nationally, average nitrate levels were lowest for the utility piped water supplies (1.67 mg/l) and highest for boreholes (35.32 mg/l), with an overall national average of 19.14 mg/l. Across hydrological areas, mean values ranged from 2.37 mg/l in Hydrological Area 8 to 68.98 mg/l in Hydrological Area 3.

3.3 Aesthetic parameters

Iron

All 1608 samples were analysed for iron, and compliance levels nationally ranged from 79% for vehicle tanker supplies to 96% for utility piped water supplies, with a national average compliance level of 91% (Table 3.7). Overall, the average compliance level was lowest in Hydrological Area 4 (77%) and highest in Hydrological Area 3 (100%). The lowest compliance level measured by the RADWQ survey in Nigeria was 70% and was for water samples taken from boreholes and tubewells in Hydrological Area 8.

Table 3.5 Compliance of Nigerian water supplies with WHO guideline value for fluoride[a]

Hydrological Area	Boreholes, tubewells		Protected dug wells		Utility piped water		Vehicle tanker		Totals	
	N	Compl. (%)	*N*	Compl. (%)	*N*	Compl. (%)	*N*	Compl. (%)	*N*	Compl. (%)
HA 1	75	100	75	100	35	100			185	100
HA 2			25	100	70	100			95	100
HA 3			50	100					50	100
HA 4	46	78	99	93	35	100			180	91
HA 5	74	100			35	100			109	100
HA 6	207	94	112	91	314	100	29	100	662	97
HA 7					35	100			35	100
HA 8	100	94	49	100	104	100			253	98
National	502	94	410	96	628	100	29	100	1569	97

[a] *N* = number of samples; Compl. = compliance with WHO guideline value (1.5 mg/l).

Table 3.6 Compliance of Nigerian water supplies with WHO guideline value for nitrate[a]

Hydrological Area	Boreholes, tubewells		Protected dug wells		Utility piped water		Vehicle tanker		Totals	
	N	Compl. (%)	*N*	Compl. (%)	*N*	Compl. (%)	*N*	Compl. (%)	*N*	Compl. (%)
HA 1	26	92	27	78	16	100			69	88
HA 2			9	100	21	100			30	100
HA 3			16	56					16	56
HA 4	34	47	34	85	12	100			80	71
HA 5	23	100			10	100			33	100
HA 6	100	85	59	83	139	100	18	100	316	92
HA 7					10	100			10	100
HA 8	32	97	14	100	31	100			77	99
National	215	83	159	82	239	100	18	100	631	90

[a] *N* = number of samples; Compl. = compliance with WHO guideline value (50 mg/l as NO_3).

Nationally, the overall mean level of iron measured in all water supplies was 0.11 mg/l, with the lowest mean level in water from utility piped supplies (0.03 mg/l), and the highest (0.34 mg/l) in water from boreholes. Geographically, mean iron levels ranged from 0 mg/l (for Hydrological Area 3) to 0.21 mg/l (Hydrological Area 8). Many individual water samples from nearly all hydrological areas and technologies had no measurable iron content; the highest individual value (13.5 mg/l) was measured in a borehole sample from Hydrological Area 6.

Table 3.7 Compliance of Nigerian water supplies with WHO suggested value for iron[a]

Hydrological Area	Boreholes, tubewells		Protected dug wells		Utility piped water		Vehicle tanker		Totals	
	N	Compl. (%)	*N*	Compl. (%)	*N*	Compl. (%)	*N*	Compl. (%)	*N*	Compl. (%)
HA 1	75	89	75	96	35	100			185	94
HA 2			25	96	70	100			95	99
HA 3			50	100					50	100
HA 4	48	75	100	72	35	94			183	77
HA 5	75	92			34	100			109	94
HA 6	224	93	125	100	315	93	29	79	693	94
HA 7					34	91			34	91
HA 8	100	70	49	98	105	99			254	87
National	522	86	424	92	628	96	29	79	1603	91

[a] *N* = number of samples; Compl. = compliance with WHO suggested value (0.3 mg/l).

Turbidity

Only 61% of all water supplies measured in Nigeria met the WHO suggested value of <5 NTU (Table 3.8). Water from protected dug wells was the most turbid, compared to water from the other technology options, and nationally only 35% of such wells was in compliance with the WHO suggested value. Extremely low compliance levels were seen for such wells in individual hydrological areas (e.g. 4% for Hydrological Area 2; 14% for Hydrological Area 4). However, a 6% compliance level was also measured for utility piped water in Hydrological Area 1. Water samples taken from vehicle tankers were the least turbid and 93% of these sources were in compliance. The measured turbidity values varied widely across all samples, ranging from 0 to 686 NTU, with a national mean value of 10.1 NTU.

pH

An analysis of pH compliance (pH range of 6.5–8.5) was included in the RADWQ assessment, because early in the fieldwork a large number of water samples were found to have a low pH. Nationally, the average compliance level for pH was only 56%, ranging from 42% for boreholes to 73% for utility piped water supplies (Table 3.9). Across hydrological areas, compliance levels varied from 7.3% (Hydrological Area 5) to 88% (Hydrological Area 3). In Hydrological Area 5, only 3% of borehole samples met the WHO suggested range for pH, the lowest compliance level measured in Nigeria.

The water supplies in Hydrological Area 5 were the most acidic overall, with a mean pH value of 5.4, while those in Hydrological Area 3 had a neutral pH. The most acidic sample measured (pH = 3.6) was taken from a borehole in Hydrological Area 4, and the most alkaline sample (pH = 9.3) from a utility piped water supply in Hydrological Area 6.

Table 3.8 **Compliance of Nigerian water supplies with WHO suggested value for turbidity**[a]

Hydrological Area	Boreholes, tubewells		Protected dug wells		Utility piped water		Vehicle tanker		Totals	
	N	Compl. (%)	*N*	Compl. (%)	*N*	Compl. (%)	*N*	Compl. (%)	*N*	Compl. (%)
HA 1	75	84	75	36	35	6			185	50
HA 2			25	4	70	54			95	41
HA 3			50	76					50	76
HA 4	50	78	100	14	35	43			185	37
HA 5	75	100			34	100			109	100
HA 6	224	90	125	33	315	64	29	93	693	68
HA 7					35	54			35	54
HA 8	100	79	49	55	105	33			254	56
National	524	87	424	35	629	55	29	93	1606	61

[a] *N* = number of samples; Compl. = compliance with WHO suggested value (<5 NTU).

Conductivity

Conductivity was measured for all 1608 water samples and in general compliance with the WHO suggested value of 1400 µS/cm was high, with national averages ranging from 95% for protected dug wells to 100% for utility piped water supplies and vehicle tanker supplies (Table 3.10). The overall national compliance level for conductivity was 98%, and ranged from 80% to 100% across the hydrological areas.

Nationally, the mean conductivity for all water supplies was 288 µS/cm, but conductivity was lower for utility piped water supplies (national average of 102 µS/cm) and higher for boreholes and dug wells (national averages of 338 µS/cm and 437 µS/cm, respectively). Geographically, the lowest average conductance value was recorded for Hydrological Area 7 (42 µS/cm), and the highest in Hydrological Area 3 (804 µS/cm). The lowest individual conductivity value (6 µS/cm) was measured for a water sample taken from a utility piped water supply in Hydrological Area 6. The highest value (6520 µS/cm) was recorded for a borehole sample in Hydrological Area 6.

Table 3.9 Compliance of Nigerian water supplies with WHO suggested range for pH[a]

Hydrological Area	Boreholes, tubewells		Protected dug wells		Utility piped water		Vehicle tanker		Totals	
	N	Compl. (%)	*N*	Compl. (%)	*N*	Compl. (%)	*N*	Compl. (%)	*N*	Compl. (%)
HA 1	75	88	75	57	35	23			185	63
HA 2			25	4	70	100			95	75
HA 3			50	88					50	88
HA 4	50	56	100	44	35	97			185	57
HA 5	75	3			35	17			110	7
HA 6	225	32	125	49	315	91	29	48	694	63
HA 7					35	49			35	49
HA 8	100	50	49	37	105	33			254	41
National	525	42	424	50	630	73	29	48	1608	56

[a] *N* = number of samples; Compl. = compliance with WHO suggested pH range of 6.5–8.5.

Table 3.10 Compliance of Nigerian water supplies with WHO suggested value for conductivity[a]

Hydrological Area	Boreholes, tubewells		Protected dug wells		Utility piped water		Vehicle tanker		Totals	
	N	Compl. (%)	*N*	Compl. (%)	*N*	Compl. (%)	*N*	Compl. (%)	*N*	Compl. (%)
HA 1	75	100	75	95	35	100			185	98
HA 2			25	100	70	100			95	100
HA 3			50	80					50	80
HA 4	50	92	100	97	35	100			185	96
HA 5	75	99			35	100			110	99
HA 6	225	97	125	98	315	100	29	100	694	99
HA 7					35	100			35	100
HA 8	100	100	49	98	105	100			254	100
National	525	98	424	95	630	100	29	100	1608	98

[a] *N* = number of samples; Compl. = compliance with WHO suggested value of 1400 µS/cm.

3.4 Overall compliance of Nigerian water supplies with WHO guideline values

Overall compliance of Nigerian water supplies with WHO guideline value for thermotolerant coliforms and chemical parameters of direct health concern (arsenic, fluoride and nitrate) is shown in Table 3.11 for each of the four technology types and eight hydrological areas. Compliance at the national level ranged from 51% for protected dug wells to 86% for borehole and tubewell technology, with an overall national average of 73% compliance. Geographically, overall compliance ranged from 58% in Hydrological Area 3 to 98% in Hydrological Area 2. The lowest overall level of compliance (22%) was registered for protected dug well technology in Hydrological Area 6.

3.5 Sanitary risk factors

The frequency of "yes" responses to the RADWQ sanitary risk inspection questions are given by technology type at national level in Table 3.12. The most frequent responses to questions, as well as responses given more than half of the time, are shown in bold font. The risk-to-health analysis at national level is given for each technology type in Table 3.13. Data for household samples are given in Tables 3.15 and 3.16.

Table 3.11 **Overall compliance of Nigerian water supplies with WHO guideline values for TCC, As, F and NO_3 [a]**

Hydrological Area	**Boreholes, tubewells**		**Protected dug wells**		**Utility piped water**		**Vehicle tanker**		**Totals**	
	N	Compl. (%)	*N*	Compl. (%)	*N*	Compl. (%)	*N*	Compl. (%)	*N*	Compl. (%)
HA1	75	95	75	61	35	80			185	78
HA2			25	100	70	97			95	98
HA3			50	58					50	58
HA4	50	72	100	53	35	74			185	62
HA5	75	84			35	77			110	82
HA6	225	84	125	22	315	66	29	62	694	64
HA7					35	77			35	77
HA8	100	93	49	69	105	98			254	91
National	525	86	424	51	630	77	29	62	1608	73

[a] *N* = number of samples. Compl. = compliance with WHO guideline values. TCC = thermotolerant coliforms.

Table 3.12 **Responses to RADWQ sanitary risk questions, by technology type**

Boreholes and tubewells (mechanical)			
	Sanitary risk inspection question	**Number of "yes" responses**	**Response frequency (%)**
1.	Is there a latrine or sewer within 100 m of the pumping mechanism?	115	34.5
2.	Is there a latrine within 10 m of the borehole?	45	13.5
3.	**Are there any other sources of pollution within 50 m (e.g. animal breeding, cultivation, roads, industry, etc.)?**	**133**	**39.9**
4.	Is there an uncapped well within 100 m?	15	4.5
5.	Is the drainage channel cracked, broken, or in need of cleaning?	103	30.9
6.	Can animals come within 50 m of the borehole?	115	34.5
7.	Is the base of the pumping mechanism permeable to water?	17	5.1
8.	Does water form pools within 2 m of the pumping mechanism?	24	7.2
9.	Is the well seal unsanitary?	41	12.3
10.	Is the borehole cap cracked?	28	8.4
	Total number of responses:	333	

Boreholes and tubewells (hand pump)			
	Sanitary risk inspection question	**Number of "yes" responses**	**Response frequency (%)**
1.	Is there a latrine within 10 m of the borehole?	14	7.3
2.	Is there a latrine uphill of the borehole?	32	16.7
3.	Are there any other sources of pollution within 10 m of borehole? (e.g. animal breeding, cultivation, roads, industry etc)	145	75.5
4.	Is the drainage faulty, allowing ponding within 2 m of the borehole?	88	45.8
5.	Is the drainage channel cracked, broken or in need of cleaning?	113	58.9
6.	**Can animals come within 10 m of the borehole?**	**157**	**81.8**
7.	Is the apron less than 2 m in diameter?	40	20.8
8.	Does spilt water collect in the apron area?	60	31.3
9.	Is the apron or pump cover cracked or damaged?	13	6.8
10.	Is the hand pump loose at the point of attachment?	11	5.7
	Total number of responses:	192	

Protected dug well		
Sanitary risk inspection question	**Number of "yes" responses**	**Response frequency (%)**
1. Is there a latrine within 10 m of the well?	84	19.8
2. Is the nearest latrine uphill of the well?	132	31.1
3. Is there any other source of pollution within 10 m of well (e.g. animal breeding, cultivation, road, industry, etc)?	**228**	**53.8**
4. Is the drainage faulty, allowing ponding within 3 m of the well?	174	41.0
5. Is the drainage channel cracked, broken or in need of cleaning?	185	43.6
6. Is the cement less than 2 m in diameter around the top of the well?	116	27.4
7. Does spilt water collect in the apron area?	158	37.3
8. Are there cracks in the cement floor?	166	39.2
9. Is the hand pump loose at the point of attachment? (Or, for rope-washer pump: is the pump cover missing?)	114	26.9
10. Is the well-cover absent or unsanitary?	172	40.6
Total number of samples:	424	

Utility piped water		
Sanitary risk inspection question	**Number of "yes" responses**	**Response frequency (%)**
1. Is the tap sited outside the house (e.g. in the yard)?	**510**	**81**
2. Is the water stored in a container inside the house?	312	49.5
3. Are any taps leaking or damaged?	169	26.8
4. Are any taps shared with other households?	**408**	**64.8**
5. Is the area around the tap unsanitary?	295	46.8
6. Are there any leaks in the household pipes?	64	10.2
7. Do animals have access to the area around the pipe?	298	47.3
8. Have users reported pipe breaks in the last week?	64	10.2
9. Has there been discontinuity in water supply in the last 10 days?	**413**	**65.6**
10. Is the water obtained from more than one source?	122	19.4
Total number of samples:	630	

Vehicle tanker		
Sanitary risk inspection question	**Number of "yes" responses**	**Response frequency (%)**
1. Is the source of water used by vendors unprotected and/or untreated?	0	0
2. Is the filling station/point unsanitary?	0	0
3. Is the pipe from the source used to fill the tanker (discharge pipe) dirty?	7	24.1
4. Can the discharge pipe touch the ground?	7	24.1
5. Is the tanker ever used to transport other material?	0	0
6. Is the inside of the tanker dirty?	3	10.3
7. Does the tanker leak?	**11**	**37.9**
8. Does the top of the tanker leak?	5	17.2
9. Is the pipe from the tanker used to fill the household container dirty?	**11**	**37.9**
10. Are the fittings on the tanker or household storage container unsanitary?	4	13.8
Total number of samples:	29	

3.6 Risk-to-health analysis

The risk-to-health matrices for water supplies at the national level were determined by cross-referencing the thermotolerant coliform counts with the corresponding sanitary inspection score, and classifying the matrix health risks as very low, low, medium or high, by technology type (Table 3.13). For all technology types, most samples fell into the low or very low risk category.

3.7 Analysis of proxy parameters

In general, there was little or no correlation between the selected pairs of water-quality parameters, although weak correlations were seen between thermotolerant coliforms and turbidity ($r = 0.56$), and between thermotolerant coliforms and faecal streptococci ($r = 0.56$) for protected dug wells (Table 3.14). Correlation coefficients for conductivity and nitrate, and for conductivity and fluoride were 0.38 and 0.44, respectively.

3.8 Household samples

Household samples were taken from household containers, not from taps in yards or households supplied by piped utility water. The latter samples were included in the analysis of utility piped water supplies.

Table 3.13 **Risk-to-health analysis at national level, by technology type**[a]

Sanitary inspection score (%)	Boreholes and tubewells: Thermotolerant coliform count (cfu/100ml) <1	1–10	11–100	>100
0–2 (0–20)	257	17	5	0
3–5 (30–50)	193	5	2	0
6–8 (60–80)	44	2	0	o
9–10 (90–100)	0	0	0	0

Sanitary inspection score (%)	Protected dug well: Thermotolerant coliform count (cfu/100ml) <1	1–10	11–100	>100
0–2 (0–20)	107	54	26	0
3–5 (30–50)	63	26	31	1
6–8 (60–80)	61	7	15	1
9–10 (90–100)	12	9	10	1

Sanitary inspection score (%)	Utility piped water: Thermotolerant coliform count (cfu/100ml) <1	1–10	11–100	>100
0–2 (0–20)	108	10	3	1
3–5 (30–50)	263	48	23	1
6–8 (60–80)	115	14	26	5
9–10 (90–100)	3	3	5	2

Sanitary inspection score (%)	Vehicle tanker: Thermotolerant coliform count (cfu/100ml) <1	1–10	11–100	>100
0–2 (0–20)	12	6	2	1
3–5 (30–50)	6	2	0	0
6–8 (60–80)	0	0	0	0
9–10 (90–100)	0	0	0	0

Sanitary inspection score (%)	Totals: Thermotolerant coliform count (cfu/100ml) <1	1–10	11–100	>100
0–2 (0–20)	484	87	36	2
3–5 (30–50)	525	81	56	2
6–8 (60–80)	220	23	41	6
9–10 (90–100)	15	12	15	3

[a] Risk-to-health categories:			
Very low	Low	Medium	High

Table 3.14 **Analysis of proxy parameters at national level**

Technology	Pearson's *r*			
	Thermotolerant coliforms *vs.*		Conductivity *vs.*	
	Turbidity	Faecal streptococci	NO_3	F
Boreholes and tubewells	-0.01	0.01	0.16	0.18
Protected dug well	0.56	0.56	0.38	0.44
Utility piped water	-0.01	-0.04	0.23	0.10
Vehicle tanker	-0.18		-0.01	-0.21

Thermotolerant coliforms and related parameters

The cumulative frequency diagram for household samples (Table 3.15) shows that 53 of 160 (33%) household samples tested had a thermotolerant coliform count of $\geq$1 cfu/100 ml. Only two samples were tested for faecal streptococci and they had counts of 0 and 6 cfu/100 ml.

Free chlorine

It is recommended that water supplies be tested for free chlorine residual, because the chlorine level directly influences the microbiological quality of the water. Very low chlorine residuals are cause for concern, as it implies a reduced protection against microbial contamination. In the RADWQ survey for Nigeria only 3 of the 71 samples tested had a free chlorine value >0.1 mg/l (0.26 mg/l, 0.88 mg/l and 0.42mg/l); in most, no free chlorine was detected.

Turbidity

Of all households tested, 26.8% had water samples with a turbidity >5 NTU and 7.9% of those had values >20 NTU. There was no correlation between turbidity and thermotolerant coliform counts: the sample with the highest turbidity (207 NTU) had a thermotolerant coliform count of zero.

Nitrate

Nitrate levels were generally low, although 13 of the 132 samples tested had high levels, ranging from 56 mg NO_3/l to 176 mg NO_3/l. Most of the samples with high nitrate levels had low thermotolerant coliform counts.

Fluoride

Only 5 household samples had fluoride concentrations >1.5mg/l (range: 1.75–6.8mg/l), one of which also had the highest nitrate concentration (176 mg/l). Only one of these samples had detectable thermotolerant coliforms (too numerous to count).

Arsenic, iron and copper

All water samples tested were in compliance with WHO guideline values for both arsenic and iron, and only 1 of the 36 samples tested for copper failed to comply with the WHO guideline value.

Sanitary risk for household samples

The greatest sanitary risk for household water samples was storing water in containers (57%, shown in bold font in Table 3.16), although service disruptions and pipe breaks were also important risks. One fifth of households reported obtaining water from more than one source, which can be a risk to water quality.

Quality of household water compared with source water quality

This analysis was not possible within the time-frame, because the data recording forms did not link household samples to water source samples.

Table 3.15 **Risk-to-health analysis for household samples**

Sanitary inspection score (%)	Totals: Thermotolerant coliform count (cfu/100 ml) <1	1–10	11–100	>100
0–2 (0–20)	68	16	8	4
3–5 (30–50)	38	11	6	3
6–8 (60–80)	1	0	4	0
9–10 (90–100)	0	0	0	1
	107	27	18	8

Table 3.16 **Sanitary risk factors for household samples**

Sanitary risk inspection question	Number of "yes" responses	Response frequency (%)
Household samples		
1. Is the tap sited outside the house (e.g. in the yard)?	2	1.2
2. Is the water stored in a container inside the house?	**94**	**57**
3. Are any taps leaking or damaged?	15	9.1
4. Are any taps shared with other households?	22	13.3
5. Is the area around the tap unsanitary?	35	21.2
6. Are there any leaks in the household pipes?	41	24.8
7. Do animals have access to the area around the pipe?	29	17.6
8. Have users reported pipe breaks in the last week?	45	27.3
9. Has there been discontinuity in the water supply in the last 10 days?	48	29.1
10. Is the water obtained from more than one source?	34	20.6
Total number of samples:	165	

3.9 Comments on quality-control procedures

Field teams followed the procedures suggested in the RADWQ project handbook (Table 3.17), and the quality-control sheet used can be found in Annex 6. Officers in charge of quality control checked the record sheets before passing them to the data manager. No data for suspect samples were recorded. Only 73 quality-control samples were entered into the SanMan database, each having a WSS No. with NGA9 as the first 4 characters, and all were for quality-control related to microbial parameters. Of the 73 samples, 11 had thermotolerant coliform counts greater than 1 cfu/100 ml.

Table 3.17 **Summary of quality-control procedures**

	Parameters: Bacteriological	Chemical
Frequency	Once per day	Once per week
Test	95% confidence interval	10% precision
Action	Sample marked suspect	Sample marked suspect

4. Conclusions and recommendations

4.1 General comments on water quality

The scarcity of reliable data from the national surveillance system, other than for aesthetic and physical parameters, meant that it was not possible to compare national data with the results from the RADWQ survey. In addition, no decision had been made on which of the two national standards for drinking-water quality to use in the RADWQ survey, and all compliance was measured against WHO guideline values or suggested values (Annex 3; WHO, 1997).

Overall compliance of Nigerian water supplies for WHO guideline/suggested values is given in Table 4.1 for each technology type studied. Water supplies from boreholes had the highest overall compliance (86%) and dug wells the lowest (51%). There were also variations in overall compliance between technology types within the broad areas. In Hydrological Area 2, for example, compliance for protected dug wells was 100%, but only 22% in Hydrological Area 6. It should be noted that Hydrological Area 6 (Lagos, Oyo, Osun, Ogun, Ekiti and Edo States) was the most densely populated hydrological area in the RADWQ survey and accounted for approximately 44% of all water samples taken. Consequently, the drinking-water quality in this area had a major impact on the final assessment of drinking-water quality for Nigeria. For some technologies, the pollution associated with a high population density can strongly impact the risks to drinking-water quality.

Overall compliance for each parameter is given in Table 4.2, by technology type. For the different parameters, compliance varied significantly by technology type and across hydrological areas.

Table 4.1 **Overall compliance of Nigerian water supplies with WHO guideline/suggested values, by technology type**

Hydrological Area	Boreholes and tubewells (%)	Protected dug wells (%)	Utility piped water (%)	Vehicle tanker (%)	All technologies (%)
National	86	51	77	62	73
HA 1	95	61	80		78
HA 6	84	22	66	62	64

Table 4.2 **Overall compliance of Nigerian water supplies with WHO guideline or suggested values, by parameter**[a]

Parameter	National (%)	Boreholes, tubewells (%)	Protected dug wells (%)	Utility piped water (%)	Vehicle tanker (%)
Thermotolerant coliforms	77	94	56	77	62
Faecal streptococci	78	75	85	75	
Arsenic	100	100	100	100	100
Fluoride	97	94	96	100	100
Nitrate	90	83	82	100	100
Iron	91	86	92	96	79
Turbidity	61	87	35	55	93
Conductivity	98	98	95	100	100
pH[b]	58	42	50	73	48

[a] Nigeria has two published national standards, one by the Federal Environmental Protection Agency in 1999, and the other by the Standard Organization of Nigeria in 2003, neither of which was acceptable to the majority of the sector stakeholders.

[b] Requested by the technical subcommittee.

4.2 Bacteriological Parameters

Both pathogenic and nonpathogenic microorganisms are found in water. Some nonpathogenic microorganisms may lead to problems with water supplies, such as a bad taste or odour, which can influence whether or not people use the water supply. However, the principal concern for microbiological quality is contamination by pathogens. Most water-borne pathogens are derived from faeces, and indicator organisms, usually bacteria, are used to analyse the microbiological quality of drinking-water. The most commonly used indicator organism is *Escherichia coli;* thermotolerant coliforms are sometimes used as a proxy for *E. coli.*

Thermotolerant coliforms

Thermotolerant coliforms are reliably correlated with the presence of faecal pathogens in the water supply and were detected in 371 of the 1608 samples (23.1%) tested in Nigeria. According to the WHO guideline value, none of the samples should have detectable levels of bacteria. Compliance varied significantly by hydrological area, with only 2.1% of the water samples tested in Hydrological Area 2 being potentially contaminated, while 32.3% of the samples were potentially contaminated in Hydrological Area 6. Of the technology types examined, water samples from boreholes were the least contaminated nationally, while those from protected dug wells were the most contaminated, presumably because boreholes were better protected against coliform contamination than protected dug wells. It is a matter of concern, however, that 23% of samples nationally from utility piped supplies were potentially contaminated, with the worst case in Hydrological Area 6 where 34% of the water samples were potentially contaminated. Contributing factors to this situation included a faulty network of pipes in this area, poor sanitation, inadequate protection of the water source and frequent leaks. Equally, the outcome that about 75% of all the water samples from protected dug wells in Hydrological Area 6 was potentially contaminated raises concern. There is an urgent need for authorities in Hydrological Area 6 to educate people on how to protect the dug wells against bacterial contamination, and to improve the water supply pipelines.

Faecal streptococci

Faecal streptococci were detected in 38 of 172 (22.1%) water samples tested, indicating that one fifth of all Nigerian water supplies are potentially contaminated. According to the WHO suggested value, none of the samples should have detectable faecal streptococci bacteria. The worst case was found in Hydrological Area 5, where 50% of the 18 water samples for boreholes and for utility piped water supplies was potentially contaminated. Nationally, 15% of the samples from protected dug wells was contaminated, while 25% of the water samples from boreholes and utility pipes was contaminated. The contamination could have resulted from poor sanitation, poor water handling and pipe leaks.

Free chlorine

Piped water systems (including water treatment plants) were the only technology tested for free chlorine. Of those tested (ca. 61%), 30% had ≥0.1 mg/l free chlorine and only ca. 14% had levels ≥0.2 mg/l. This low level of compliance could be due to poor/no dosing prior to distribution, or to loss of chlorine in the distribution system because of pollutants, or from increases in water temperature. This aspect of drinking-water quality needs to be addressed to increase the proportion of samples in the very low risk-to-health category.

Risk-to-health analysis

Approximately 77% of all samples had a coliform count <1 cfu/100 ml (Table 4.3; Annex 9). Only 30% of the water points had a very low risk, ca. 68% had a very low/low risk and ca. 11% a high risk. There were large differences in risk between technologies. Approximately, 21% of all samples from protected dug wells were classified in the high risk category, whereas <1% of samples from boreholes and tubewells fell into this category. The greater health risk for protected dug wells derived both from higher coliform counts and sanitary risk scores. Given the low compliance for turbidity and free chlorine, the high coliform counts were not surprising. On the other hand, protected dug wells had higher compliance rates for faecal streptococci than other technologies (85% v. 75–78%, respectively).

Table 4.3 **Overall risk-to-health results for Nigerian water supplies**[a]

Risk (%)	Thermotolerant coliform count (cfu/100 ml)				
	<1	1–10	11–100	>100	%
0–29	484	87	36	2	37.8
30–59	525	81	56	2	41.2
60–89	220	23	41	6	18.0
90–100	15	12	15	3	3.0
% of all samples	77.4	12.6	9.2	0.8	100.0

[a] Except for the percentage values, the table entries indicate the number of water samples for the given coliform count and risk.

4.3 Chemical parameters

Arsenic, fluoride and nitrate were included in the Level 1 RADWQ parameters because excessive levels of these chemicals are toxic and constitute a health hazard. Iron, turbidity, conductivity, pH and appearance were also included because these parameters can render the water objectionable and may result in consumers rejecting the water in favour of an alternative source that may be more microbiologically contaminated.

Arsenic

All samples were in compliance with the WHO guideline value (<0.1 mg/l), across all technology options. Initial concerns of excessive arsenic in mining areas of Hydrological Area 4 (Plateau State) and Hydrological Area 6 (Oyo/Igbeti) appeared unfounded and were not reflected in the results from clusters in these areas.

Fluoride

Nationally, overall compliance was 97%, and ranged from 94–100% across the technology options. However, there were some extreme values recorded. In Hydrological Area 8 (Pawari ward, Yobe State), a very high value of 22 mg/l was recorded (WHO guideline value is 1.5 mg/l) and the inhabitants complained to the field team of serious ailments, such as bone deformation and stunted growth, which were thought to result from ingesting the water. In Hydrological Area 6 (Eruwa, Oyo State), typical values recorded were 3.2 mg/l from a borehole and 5.0 mg/l from a protected dug well.

Nitrate

Nationally, compliance with the WHO guideline value for nitrate was 90% (range 82–100% across all technologies). A few cases of slightly high nitrate levels were recorded for protected dug wells in Benue State. In Hydrological Area 4, for example, a high value of 88 mg/l was recorded for Hausa Quarters and Katsina Ala town; 74.8 mg/l in Terver Orkuma compound, Central Ward and Katsina Ala town; and 83.6 mg/l for Ajila town and Ado LGA. The high nitrate levels measured in the area correlated with reports by the inhabitants of Hausa Quarters of a mysterious disease in 2004 that killed many babies under one-year old.

4.4 Aesthetic parameters

Iron

Nationally, the overall compliance was 91% and the range across technologies was 79–96%. The lowest compliance measured for the technological options was for vehicle tankers (79%), most likely due to the use of old and rusted tanks to collect water. Nationally, borehole compliance was 86%, ranging from 70% in Hydrological Area 8 to 93% in Hydrological Area 6, and for protected dug wells, national compliance was 92% (range 72–100%). Despite the relatively high compliance nationally, high iron concentrations were recorded in a number of areas, which indicates that iron may be a concern for boreholes and underground water sources generally. Extremely high levels of iron (12.8 mg/l) were measured in Hydrological Area 5 (Omu compound, Ogbobo Community, Okrika Island, Rivers State), and the highest value of 13.5 mg/l was recorded in Hydrological Area 6.

Turbidity

Nationally, compliance was 61% and the range across the technology options was 35–93%. Generally, the measured turbidity values are of serious concern because they may influence disinfection efficiency and microbial survival. The turbidity levels of water from treated utility piped supplies is particularly worrying, because a situation in which public utilities from two thirds of the hydrological areas fall short of delivering clear water may diminish public confidence in municipal water supplies and endanger public health.

pH

An analysis of pH compliance ($6.5 \leq pH \leq 8.5$) was included in the RADWQ survey, as early in the field work a large number of samples were found to have a low pH. National compliance was 56%, while the range across technology was 43–73%. The lowest compliance level was recorded in Hydrological Area 5 (7.3%), and the lowest pH value (3.6) was recorded for a protected dug well in Hydrological Area 4 at Wase, Plateau state. The inhabitants complained to the field team of prevalent stomach problems in the area. The results have revealed that there is a problem of low pH in the country.

Conductivity

Conductivity was included in the RADWQ assessment, because high values are associated with customer dissatisfaction and complaints, and changes in conductivity over time can indicate the water has become contaminated (e.g. saline intrusion, faecal pollution or nitrate pollution), and cause corrosion in rising mains and pipes. Nationally, compliance was 98% (range across the technologies was 95–100%). No unusual or extreme values were recorded.

4.5 Overall compliance

The overall compliance for technology options is given in Table 4.4, and compliance across hydrological areas is summarized in Table 4.5. Borehole technology, at 86.1% compliance, ranked the highest, while protected dug wells ranked last. In Nigeria, protected dug wells are normally managed by individual households and water-quality status is dependent on the hygiene practice of the individuals involved. In general, these figures are not satisfactory and there is a need to focus attention on improving water quality across the technologies by applying best management practices. This is particularly important for boreholes and utility pipes, the technology options the public considered to be the safest.

Table 4.4 **Overall compliance by technology option**

Technology	Average overall compliance (%)	Overall ranking
Borehole	86.1	1st
Protected dug well	50.7	4th
Utility piped water	77.3	2nd
Vehicle tanker	62.1	3rd

Vehicle tanker technology also ranked low in terms of average overall compliance. Since most of the vehicle tankers collect their water from boreholes and utility pipes, the operational practices of the tanker operators must be the source of contaminants to the water. The fact that one-in-three tankers cannot meet the WHO guideline/suggested values suggests the need for quality control measures.

Health officials need to initiate a targeted hygiene and sanitation education programme for users of protected dug wells and vehicle tankers, to improve the quality of drinking-water available to the population. The lowest ranked hydrological areas (HA3, HA4, HA6, HA7) require renewed intervention strategies to improve their water supply to the public.

4.6 Sanitary risk

The sanitary risk data for each of the technologies examined in the RADWQ survey are shown in Table 4.6. Only technologies with response frequencies of >33% were considered in the sanitary risk analysis. The questions used were the same for all countries in the RADWQ pilot studies and they were applicable in Nigeria. The cumulative frequencies for sanitary risk are shown in Annex 9 for the technology options assessed in the RADWQ survey.

Table 4.5 **Overall compliance by hydrological area**

Hydrological Area	Average overall compliance (%)	Overall ranking
HA1	78	4th
HA2	98	1st
HA3	58	8th
HA4	62	7th
HA5	82	3rd
HA6	64	6th
HA7	77	5th
HA8	91	2nd

The results of the sanitary risk analysis indicate that it is common for the environment around water points to be polluted, for all types of technology (Tables 3.12, 3.13 and 4.6). The sources of pollution include animals, as well as latrines and other sources of pollution such as industry (urban areas) that are situated too close to the water point. For piped systems, shared outside taps and supply interruptions are major additional factors. The quality of construction is a factor for boreholes with hand pumps and for dug wells. Many of the dug wells may have been incorrectly designated as protected, because the protective cover for the well was absent. This issue was discussed prior to fieldwork and the teams located protected dug wells whenever possible. In some locations (e.g. Hydrological Area 1) this was not always possible and unprotected dug wells were sampled. Drainage was a sanitary risk for dug wells and boreholes with hand pumps. For vehicle tankers, the sanitary status of the tankers was the greatest risk to water quality.

4.7 General comments on the RADWQ project for Nigeria

Methodology

The RADWQ methodology was clear and understood by both the steering committee and field teams, many of whose members had studied the method prior to the international consultant's visit. However, the presentation on survey design helped to further clarify the methodology considerably. Some variations in the methodology were introduced in response to the availability of data, and to ensure that the clusters covered areas where there were concerns about water quality for one or more of the parameters.

Table 4.6 **Most common sanitary risk factors, by technology type**

Technology type		**Sanitary risk inspection questions**	**Frequency of "yes" response (%)**
Borehole, tubewell (mechanical)	3.	Is there any source of other pollution within 50 m (e.g. animal breeding, cultivation, roads, industry etc)?	39.9
	1.	Is there a latrine or sewer within 100 m of the pumping mechanism	34.5
	6.	Can animal come within 50 m of the borehole?	34.5
Borehole, tubewell (hand pump)	6.	Can animals come within 10 m of the borehole?	81.8
	3.	Are there any other sources of pollution within 10 m of borehole? (e.g. animal breeding, cultivation, roads, industry etc.).	75.5
	5.	Is the drainage channel cracked, broken or need cleaning?	58.9
	4.	Is the drainage faulty allowing ponding within 2 m of the borehole?	45.8
Protected dug well	3.	Is there any other source of pollution within 10 m of well?(e.g. animal breeding, cultivation, road, industry etc)	53.8
	5.	Is the Drainage channel cracked, broken or in need of cleaning?	43.6
	4.	Is the Drainage faulty allowing ponding within 3 m of the well?	41.0
	10.	Is the well-cover absent or unsanitary?	40.6
	8.	Are there cracks in the cement floor?	39.2
	7.	Does spilt water collect in the apron area?	37.3
Utility piped supplies	1.	Is the tap sited outside the house (e.g. in the yard)?	81.0
	9.	Has there been discontinuity in water supply over the last 10 days?	65.6
	4.	Are any tap shared with other households?	64.8
	2.	Is the water stored in a container inside the house?	49.5
	7.	Do animals have access to the area around the pipe?	47.3
	5.	Is the area around the tap unsanitary?	46.8
Vehicle tanker	7.	Does the tanker leak?	37.9
	9.	Is the pipe from the tanker used to fill the household container dirty?	37.9
Household	2.	Is the water stored in a container inside the house?	57.0

The RADWQ Level 1 parameters were adequate for producing a good baseline assessment of the drinking-water quality and sanitary conditions in Nigeria, especially given the scarcity of reliable data at the start of the project. This will contribute to the development of national approaches for water-quality monitoring, as well as of intervention strategies to improve water safety. The scarcity of reliable data meant that it was not possible to assess any seasonality effects on water quality, and it would be beneficial for strategic planning to extend the RADWQ survey to address this issue.

The standard sanitary risk inspection questionnaires were generally applicable to the situation in Nigeria. There was a lack of familiarity with their use, which was eased by including a classroom session on the questionnaires, as well as field work during the training week. This was reinforced during the period when all field teams worked in Hydrological Area 6, as part of the training schedule prior to dispersing to their allocated areas.

There were few problems during field implementation, although field teams found the days to be long. One solution to try to alleviate the stress on team members was to reduce the time required for the daily analysis of thermotolerant coliforms and faecal streptococci. This was accomplished by collecting samples during the day and processing them at the overnight accommodation, rather than at each sampling point. This also helped to reduce the time in areas where the security of personnel was a concern (e.g. some urban areas).

Project management and implementation

In-country general management was through the Federal Ministry of Water Resources, with support from UNICEF. WHO was represented on the steering committee, and both WHO and UNICEF supported the international consultant during her visit. Planning of the RADWQ field implementation was made possible through the collaboration among national and state agencies. Different agencies provided staff, information and support during field implementation, and assistance with data collection, entry and analysis, and report writing.

One of the most difficult aspects of the project was planning the field work within the budget allocated. The original budget was too small, as it ignored the travel and subsistence costs for the field work. Although this issue was resolved in-country between the Federal Ministry of Water Resources and UNICEF, it delayed the start of the field work. The budget also did not provide funds to support the steering committee and technical committee in performing their duties. The funds were needed to pay for travel and subsistence; for committee meetings to ensure the data were clean; for data analysis; and to prepare a draft report. The budget shortfall was not helped by the cost overrun on the field work and by the inability of the international consultant to make a second visit owing to illness, although remote support was provided. These effects were further compounded by pressures on the central WHO budget for international inputs to all countries.

The training materials were much appreciated by the field teams and management personnel. The materials reinforced their understanding of water-quality and health issues, by explaining the reasoning behind the selection of the parameters. Copies of Microsoft PowerPoint presentations were left with the steering committee and field teams, in case ongoing support and training of additional personnel was required.

One problem in implementing the project was that some of the selected water sites did not have the technology that was allocated to them during the design of the RADWQ survey. In future, after the design and sampling sites are selected the sites should be visited, both to physically locate them and to verify that they have the assigned technologies.

Field kits

A one-week training programme for the field teams was held in Minna. Both the Wagtech staff member (Neil Wrigglesworth) and the international consultant were involved in the training, which covered equipment use, reporting and sanitary inspection forms. The initial training was carried out in a hotel conference room, rather than in a laboratory, but it also involved some field work to familiarize the teams with their responsibilities in planning, preparation and on-site analysis and recording. Teams worked hard during this period and helped to produce a checklist for the field work (Annex 6). This checklist was an essential component, because once on site field teams would be unable to do their work if they forgot to bring all of the equipment or consumables required. Aseptic technique forms (Annex 6) were used during training to check the performance of all team members in aseptic technique. Following the training and field work, the project team members were better qualified to analyse water quality, particularly in the use of the field equipment. The steering committee and the field teams also enhanced their skills in designing and implementing surveys for monitoring water quality.

In common with all other countries involved in the RADWQ pilot studies, there were shortages of consumables (notably for faecal streptococci), which constrained the number of analyses possible. In addition, some consumables were supplied for parameters not included within RADWQ Level 1 (e.g. ammonia). These were relocated to the regional laboratory at Minna, where they could be used in the water quality monitoring programme currently being developed. Also, the field teams reported that the field-kit photometer did not function well in high ambient temperatures, particularly in the dry months and in arid areas, and that the cuvettes supplied for the photometer were fragile and inadequate for the number of analyses. Nevertheless, the field kits were accepted for use in monitoring and at the end of the RADWQ project they were distributed to laboratories of the Federal Ministry of Water Resources and the National Water Resources Institute for use in water quality monitoring programmes and projects.

Data storage software

Entering data into SanMan was time consuming because the computers were not networked and much of the data had to be entered by one person. There were problems with updates to the programme and in ensuring that the in-country data manager was able to make the necessary adjustments. These updates were due to revisions requested by RADWQ international consultants during the project (some in response to comments from teams during training). Ideally, these issues should have been identified and resolved before starting in-country work. Training on the SanMan software was made easier by the fact that the user interface is in English, and by the video clips on different aspects of using SanMan that were provided during the project. Unfortunately, the value of SanMan in identifying samples from the same source (i.e. a water source and the corresponding household sample) was lost, as not enough data were entered on the record sheets (Annex 6) to allow this.

4.8 Suggestions for improving the RADWQ methodology

Based on experiences gained from the RADWQ project in Nigeria, the following revisions could be made to the handbook:

- Simplify the main text, and place much of the detailed statistical methodology in an annex.
- Include a CD that contains the PowerPoint presentation materials, as well as worked examples prepared by the international consultants.
- Review the impact of missing data on survey design. In Nigeria, for example, population data were used to select the technologies, because the information was more readily available than the actual number and location of water points. In turn, this affected the design of the RADWQ project for Nigeria, including development of the work plan.
- Include more guidance on the specifics of implementing a RADWQ-type project in large countries, such as Nigeria (and probably for small countries, too). The size of a country is an important determinant of the RADWQ budget, the cluster size and the timetable for project implementation.
- Review the sample size (1600) once data and comments from all countries are available. In Nigeria, the sample size meant that a minimum of five months was required for the field work, given the number of field teams and equipment available. However, this sample size provided a statistically representative baseline assessment of drinking-water quality.
- In future, after the design and sampling sites are selected, they should be visited to physically locate the actual sites and verify they have the assigned technology. In the RADWQ project in Nigeria, some of the sites visited did not have the technology allocated to them in the project design.
- Better communication and partnership with the community, local leaders and local government officials will improve the success of the programme in future exercises.
- Team leaders for the field teams should be selected based on field expertise.
- The experience gained in this assessment should be used as a platform to initiate a regular surveillance programme.
- There was concern that selecting only improved water sources for the RADWQ project neglected approximately 50% of the population without access to such sources. Whilst this approach reflects the requirements of the JMP, it could be of value to include some assessment of unimproved sources.

- The definition of household samples needs to be clarified. This led to some initial confusion in assessing household samples in Nigeria, as some of the piped-water samples were taken from household taps. Most household samples, however, were taken from storage containers in households without a connection to the piped system.
- The number of controls was adequate, but not all the controls for quality control and assurance purposes were recorded. This aspect needs to be more fully explained in the handbook.
- The sanitary risk inspection questionnaires were generally applicable to Nigeria, but there needs to be a review of the actual risk and weighting of questions (currently, they are given equal weighting in the RADWQ methodology). The questions will not be applicable in all countries.

4.9 General recommendations

1. Most of the water sources assessed by the RADWQ pilot project showed good compliance nationally for all the parameters tested. However, cases of extreme values were detected in certain locations, and it is recommended that the following areas be further investigated:
    - Barkinladi in Plateau State; Girei, Song and Unguwar Fulani in Adamawa State; Eruwa in Oyo State; Argungu in Kebbi State; Hausa Quarters in Katsina Ala; and Ajila town in Benue State had nitrate values well above the WHO guideline value of 50 mg/l (range: 83.6–246.4 mg/l). An in-depth study of water quality in the areas is recommended.
    - Fluoride levels in excess (range: 6.5–22 mg/l) of the WHO guideline value of 1.5 mg/l were recorded at Damaturu, Yobe State, St. Louis College, Jos, Wase, Langtang and Water Board Quarters in Pajat (all in Plateau State), and at Eruwa town in Oyo State. Most fluoride found in drinking-water is from natural sources. Excess fluoride is associated with dental and skeletal fluorosis that may cause deformation and disability in susceptible individuals. Consequently, an analysis of fluoride levels during the development of groundwater sources should be standard policy in such areas.
    - The assessment showed that water sources in many parts of the country had a low pH, and only 56% of the samples tested nationally were in compliance with the WHO suggested range (6.5–8.5). Extreme cases were recorded in Wase, Plateau State (Hydrological Area 4), where pH values as low as 3.6 was recorded for a handpump at Angwan Turawa, and 3.9 in a hand-dug well at a government secondary school. A pH value of 3.7 was also obtained in a mechanized borehole at Yaba, Lagos State. Further study is recommended to identify the causes of the acidic water.
2. The quality of the water supplied by the public water agencies is of serious concern. For turbidity, the national compliance level for water samples taken from utility pipes was only 55%, and those for coliforms and faecal streptococci were 77% and 75%, respectively. Moreover, in the majority of the samples, no free chlorine was detected – only 4% of the 71 samples tested had enough free chlorine to mitigate bacteriological risk. It is therefore recommended that a national regulatory agency with an effective enforcement mechanism be put in place to ensure the sanitary integrity of the water supply schemes.
3. It is recommended that external support agencies be partnered for future RADWQ exercises, owing to the huge amount of resources required to carry out a national survey, especially in a country as big as Nigeria, as well as the attendant costs implied for repeated exercises.
4. The results could not be compared with national standards for drinking-water quality, because they have yet to be agreed upon. Current efforts for establishing such standards should be accelerated.
5. The assessment was valuable and revealed unexpected results, such as the low pH values measured in some states, and the presence of arsenic. Consequently, it is recommended that this study should be used as a platform for further water quality surveillance and research.

References

FOS (2003). *Report of national modular child labour survey – Nigeria 2000/2001*. Abuja: Federal Government of Nigeria.

Howard G, Ince M, Smith M (2003). *Rapid assessment of drinking-water quality: a handbook for implementation (Draft).* Geneva: WHO/UNICEF.

Kehinde M (2003). *Nationwide rapid water quality assessment program: progress report*. Abuja, Nigeria: Federal Ministry of Water Resources.

MICS (1999). *Multiple indicator cluster survey 1999, Nigeria.* Lagos, Federal Office of Statistics and UNICEF.

NDHS (2003). *National demographic health survey, 2003*. Calverton, Maryland, USA: National Population Commission (Nigeria) and ORC Macro.

NWSSP (2000). *National water supply and sanitation policy 2000*. Lagos, Nigeria: Federal Ministry of Water Resources.

WHO (1993). *Guidelines for drinking-water quality, Volume 1: recommendations* (2nd ed.). Geneva: WHO. Available online at: (www.who.int/water_sanitation_health).

WHO (1997). *Guidelines for drinking-water quality, Volume 3: surveillance and control of community water supplies* (2nd ed.). Geneva: WHO. Available online at: (www.who.int/water_sanitation_health).

WHO (2004). *Guidelines for drinking-water quality, Volume 1: recommendations* (3rd ed.). Geneva: WHO. Available online at: (www.who.int/water_sanitation_health).

WHO/UNICEF (2000). *Global water supply and sanitation assessment 2000 report*. Geneva and New York: WHO and UNICEF

WHO/UNICEF (2005). *Water for life: making it happen*. Geneva and New York: WHO and UNICEF.

WHO/UNICEF (2006). *Meeting the MDG drinking-water and sanitation target – the urban and rural challenge of the decade*. Geneva and New York: WHO and UNICEF.

WHO/UNICEF (2006). *Core questions on drinking-water, sanitation and hygiene for household surveys*. Geneva and New York: WHO and UNICEF.

WHO/UNICEF (2008). *Progress on drinking water and sanitation*. Geneva and New York: WHO and UNICEF.

WHO/UNICEF (2010). *Progress on sanitation and drinking-water: 2010 update*. Geneva and New York: WHO and UNICEF.

Annex 1 In-country personnel

Steering Committee members

Name	Job title	Organization
Ogbe, A.O.	Deputy Director	Federal Ministry of Water Resources
Ikelionwu, C.O.	Assistant Director	Federal Ministry of Water Resources
Awe, E.O.	Chief Scientific Officer	Federal Ministry of Water Resources
Ogbechie, V.	Deputy Director	Federal Ministry of Water Resources
Ashiru, R.O.	Deputy Director	Federal Ministry of Environment
Bashir, D.	Deputy Director	National Water Resources Institute
Oni, O.O.O.	Chief Lecturer	National Water Resources Institute
Okpuruka, D.C.		Niger Delta River Basin Development Authority
Olufolabo, A.A.		National Bureau for Statistics
Monwuba, P.C		National Agency for Food and Drug Administration and Control
Hamidu, M.		Rural Water Supply and Sanitation Agency, Yobe
Owoso, E.		Water and Sanitation – Akure
Orkuma, A.	Managing Director	Rural Water-Supply and Sanitation Agency – Makurdi
Leo, M.		State Water Agency – Kaduna
Okoh, E.		State Water Agency – Enugu
Okonedo, J.		State Water Agency – FCT
Abubakar, I.	Head of Department	Amadu Bello University
Longe, E.		University of Lagos
Habila, O.A.	Project Officer, Water and Environmental Safety	UNICEF
Odunjinrin, S.		WHO
Okedi, S.		Water Aid
Akoh, D.A.	President	Institute of Public Analysts of Nigeria

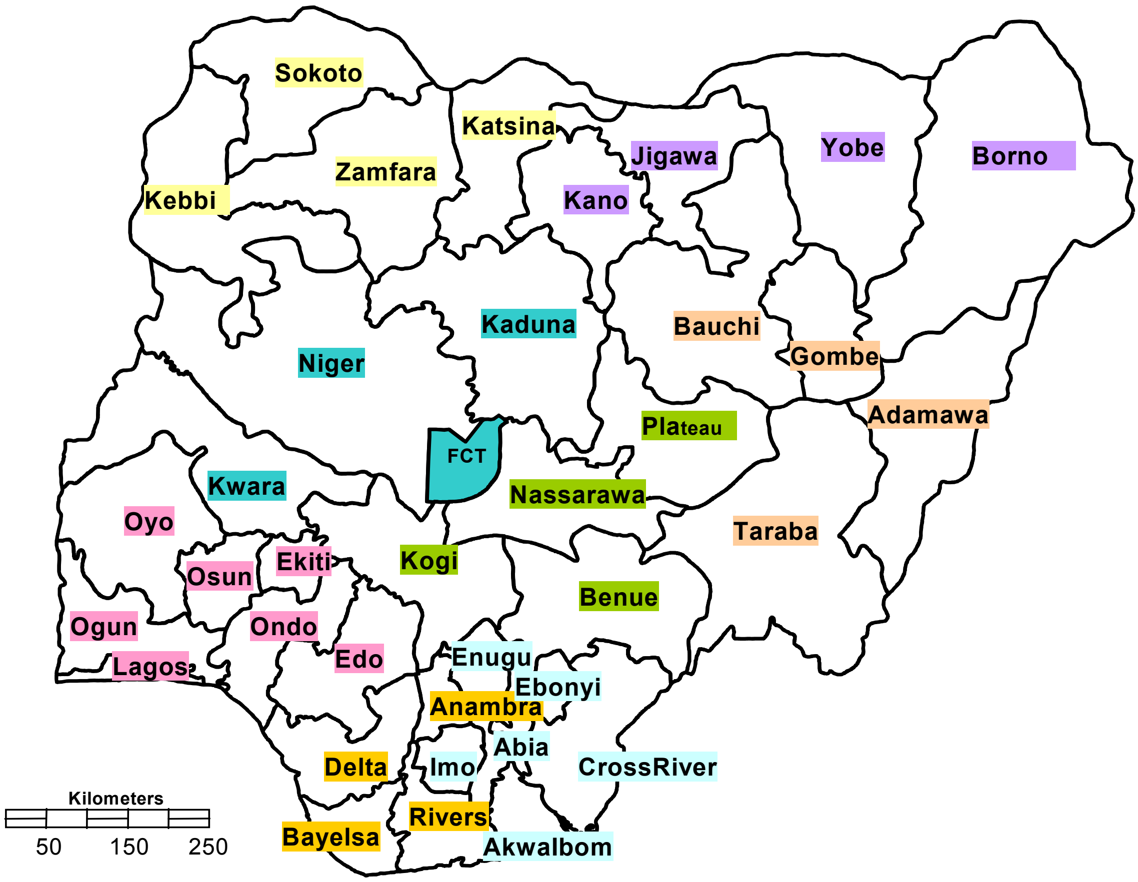
Technical Subcommittee members

Name	Organization/role
Bashir, D.	National Water Resources Institute, Kaduna
Oni, O.O.O.	National Water Resources Institute, Kaduna
Awe, E.O.	Federal Ministry of Water Resources, Abuja
Olokun, A.A.	Federal Ministry of Health, Abuja
Adeyinka, M.A.	Federal Ministry of Environment, Lagos
Olufolabo, A.A.	National Bureau for Statistics, Lagos
Korve, K.	UNICEF, Abuja
Ofordu, F.	Data Manager, Lagos.

Project team

Name	Role	Organization
Abubakar, M.A.K.	Project coordinator	Federal Ministry of Water Resources
Ince M.	Survey and work plan design	
Ogbe, A.O.	Field coordinator	Federal Ministry of Water Resources
Ince M.	Data analysis and report writing	
Olufolabo, O.O.	Statistician	National Bureau for Statistics
Ofordu, F.	Data manager	
Danjuma, D, Okafor; C, Jera, D, Hassan, H, Rilwan, R, Adeyemi, A, Kadiri, D, Egbulem, B, Asogwa, E, Ugoji, C, Sasere, O.	Field staff	Federal Ministry of Water Resources/National Water Resource Institute

Annex 2 Map of the political and administrative units of Nigeria



Source: RADWQ Team, Nigeria. 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.

Annex 3 WHO guideline values

Parameter	WHO guideline value
Arsenic	0.01 mg/l
Copper	2.0 mg/l
Fluoride	1.5 mg/l
Nitrate	50 mg/l (as NO_3)
Thermotolerant coliforms and faecal streptococci	Non detectable per 100 ml

Annex 4 Workplan and cluster allocation

The following table shows the locations of clusters by technology type and the allocation of sampling points within the clusters. The exact locations of the water points were decided in the field by the field teams, in consultation with local experts/guides, as there was not enough state information to allow the water-points to be located prior to commencing field work. The details of the final locations are stored on the SanMan data base.

Locations of clusters and sampling points											
Zones/Areas			**Piped water**			**Boreholes and tubewells**			**Protected dug wells**		
States of the Federation	HA[a]	Geopolitical zones	No. of clusters	No. of sampling points	Locations[b]	No. of clusters	No. of sampling points	Locations	No. of clusters	No. of sampling points	Locations
Adamawa	3	North-east	0	0	None	0	0	None	2	50	1. Yola (15) Numan (10) 2. Giei (15) Song (10)
Benue	4	North central	1	35	1. Makurdi	1	25	Katsina-Ala	3	75	1. Guma 2. Makurdi/Gwer 3. Ado/Oju/Obi
Enugu	7	South-east	1	35	1. Enugu 2. Nsukka (if boreholes feed a reticulated system)	0	0	None	0	0	None
Kaduna	2	North-west	2	70	1. Kaduna 2. Zaria	0	0	None	1	25	1. Kafanchan/Kagoro
Kano	8	North-west	3	105	1. Kano 2. Wudil 3. Gabasawa	4	100	1. Kano 2. Wudil 3. to Portiskum (Yobe) 4. to Auna (Borno)	2	50	1. Dabatta 2. Wudil
Kebbi	1	North-west	1	35	1. Kebbi (25) and Argungu (10)	2	50	1. Zuru 2. Dwasagu	4	100	1. Zuru 2. Dwasagu 3. Yauri + 1
Lagos	6	South-west	7	245	1–7 Lagos Island, Victoria Island, Ajegunle, Agege, Ikeja, Apapa and Surulere	9	225	1. Mainland 2. Ikorodu 3.Ikoyi/Obalende 4. Isolo 5. Shomolu 6. Mushin +1	0	0	None
Oyo	6	South-west	3	105	1 and 2 in Ibadan	1	25	1. Ibandan 2. Akinyele	5	125	1. Ibadan 2. Oluyole

					3. Oyo			3. Iseyin			3.Ibarapa 4. Oyo 5. Iseyin
Plateau	4	North-central			None	1	25	Jos (9) Jos (8 mining) Langtang (8 fluoride). This is an additional cluster	1	25	Jos (9) Jos (8 mining) Langtang (8 fluoride)
Rivers	5	South-south	1	35	1. Port Harcourt (25) and Eleme/Okrika (10)	3	75	1. Eleme 2. Okrika 3. Ahoada	0	0	None
Totals			19	665		21	525		18	450	

[a] HA = hydrological area.

[b] In some locations there were not enough sampling points to constitute a full cluster. In these instances, samples were taken from additional locations to constitute a full cluster. The numbers in parentheses following such locations indicate the number of samples taken at each location, and together they add up to a full cluster.

Annex 5 Final budget for the RADWQ pilot project in Nigeria

Team	Location	No of weeks	Team				Driver	Field coordinator				Local guide @ 1000 for a 5-day week	Courier @ 2500 / week	Communication @ 1000 / week
			DSA rate[b]	DSA / week	DSA total (x2)	Travel costs to Lagos[c]	DSA @ 3000 / day	Location	No of days	DSA	Travel costs (car hire)			
1	Adamawa	2 (14 days)	5 000	70 000	140 000	2 387	42 000	Kano	3	24 000	10 000	50 000	16 weeks	16 weeks
	Kano	6 (42 days)	5 000	210 000	420 000	14 000	126 000	Enugu	3	24 000	33 000		40 000	16 000
	Yobe	1 (7 days)	5 000	35 000	70 000		21 000	Kaduna	3	24 000	10 000			
	Borno	2 (14 days)	5 000	70 000	140 000		42 000	Lagos	3	33 000	38 000			
	Plateau	2 (14 days)	5 000	70 000	140 000		42 000							
	Lagos	3 (21 days)	8 000	168 000	336 000		63 000							
2	Benue	5 (35 days)	5 000	175 000	350 000	14 000	105 000					30 000	13 weeks	13 weeks
	Enugu	1 (7 days)	5 000	35 000	70 000	2 387	21 000						32 500	13 000
	Rivers(PH)	2 (14 days)	8 000	112 000	224 000		84 000							
	Rivers(Eleme/ Ahoada)	2 (14 days)	5 000	70 000	140 000									
	Lagos	3 (21 days)	8 000	168 000	336 000		63 000							
3	Kaduna	3 (21 days)	5 000	105 000	210 000	14 000	63 000					45 000	13 weeks	13 weeks
	Kebbi	7 (49 days)	5 000	245 000	490 000	15 092	147 000						32 500	13 000
	Lagos	3 (21 days)	8 000	168 000	336 000		63 000							
4	Lagos	4 (28 days)	8 000	224 000	448 000	14 000	84 000					40 000	16 weeks	16 weeks
	Oyo	12 (84 days)	5 000	420 000	840 000	14 000	252 000						40 000	16 000
				2 345 000	4 690 000	89 866	1 218 000			105 000	91 000	165 000	145 000	58 000
													Total cost	**6 561 866**

[a] All currency values are in Nigerian Naira.

[b] Daily subsistence allowance.

[c] Travel costs to Lagos for the RADWQ project members were calculated either on the basis of the cost of an air ticket to Lagos, or on the basis of the number of kilometres travelled (for personnel who travelled by road).

Annex 6 RADWQ forms for data recording

Quality control sheet for microbiological tests[a]

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

[a] For results between 0–100 cfu/100 ml, locate the value equal to the thermotolerant coliform count for the first sample in the Count 1 column. If the thermotolerant coliform count for the duplicate/split sample is within the range given in the Count 2 column, this indicates a 95% confidence in the results.

Chemical tests (once a week, 10% precision)

1. Calculate: Precision = $\dfrac{Count1 - \dfrac{Count1 + Count2}{2}}{\dfrac{Count1 + Count2}{2}} * 100$

2. If *Precision* > ±10%, then SUSPECT SAMPLE

Evaluation form for aseptic technique

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

Record sheet for individual water sampling point

WSS NO:	NGA________	Date	
Broad Area	HA	Time	
Zone/state		Analyst	
Village/Town		Analyst	
Technology category			
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/residual chlorine	mg/l		
Total chlorine	mg/l		
Nitrate	mg/l		
Arsenic	mg/l		
Iron	mg/l		
Fluoride	mg/l		
Copper	mg/l		

	PRINT NAME	SIGNATURE
Analyst 1		
Analyst 2		

Record sheet for sanitary risk inspection

Piped water: treatment processes

I. General information:

a. WSS No:.NGA………………………HA: ………..STATE:……………

b. Community Name:………………………………………………………..

c. Treatment processes used:..……………………………………………

d. Date of visit:…………………………………………………………..

e. Water Sample – TTC No:………………………………………………..

II. Specific diagnostic information for assessment

(Please indicate at which sites the risk was identified)

		Risk
1.	Are there evident cracks in the pre filters?	Y/N
2.	Are there leaks in the mixing tank?	Y/N
3.	Is the mixing tank in an unsanitary condition?	Y/N
4.	Are there evident hydraulic surges at the intake?	Y/N
5.	Is any sedimentation tank in an unsanitary condition?	Y/N
6.	Is the air and water supply distribution in any sand bed uneven?	Y/N
7.	Are there mud balls or cracks in any of the filters?	Y/N
8.	Are there evident cross connections between backwashed and treated water?	Y/N
9.	Is there evidence of insufficient coagulant dosing (e.g. alum)?	Y/N
10.	Are free residual chlorine concentrations (minimum 0.2 mg/l) not being achieved?	Y/N
	Total score of risks	**……./10**

III Results and comments:

a. Risk score (tick appropriate box):

9–10 = Very high	6–8 = High	3–5 = Medium	0–2 = Low

b. The following important risks were noted:

- list risk numbers 1–10
- additional comments (continue on back of form if necessary).

IV Names of analysts (print and sign):

Record sheet for sanitary risk inspection

Piped water with supply tanks: distribution system

I. General information:

a. WSS No: NGA………………… HA: ………………..STATE…………...

b. Community name:...……………………………………………………

c. Date of visit:………………………………………………………………..

d. Water sample – TTC No:…………………………………………………

II. Specific diagnostic information for assessment

Explanatory note: "Taps" refers to inspection taps or public taps (where directly connected to distribution system). A supply tank is a clean water/storage tank either at the WTW, or in the distribution system. (Please indicate at which sites the risk was identified)

		Risk
1.	Do any taps or pipes leak at the sample site?	Y/N
2.	Does water collect around the sample site?	Y/N
3.	Is there area around the tap unsanitary?	Y/N
4.	Is there a sewer or latrine within 30 m of any tap	Y/N
5.	Has there been discontinuity in the last 10 days?	Y/N
6.	Is the supply main exposed in the sampling area?	Y/N
7.	Do users report any pipe breaks within the last week	Y/N
8.	Is the supply tank cracked or leaking?	Y/N
9.	Are the vents and covers on the tank damaged or open?	Y/N
10.	Is the inspection cover or concrete around the cover damaged or corroded?	Y/N
	Total Score of risks	**………/10**

III Results and comments:

a. Risk score (tick appropriate box):

9-10 = Very high	6-8 = High	3-5 = Medium	0-2 = Low

b. The following important points of risk were noted:

- list risk numbers 1–10
- additional comments (continue on back of form if necessary)

IV Names of analysts (print and sign):

Record sheet for sanitary risk inspection

Household container

I. General information:

a. WSS No: NGA …………… ……..HA: ……..…….STATE:………………
b. Community name:...……………………………………………………….
c. Date of visit:……………………………………………………………..
d. Water sample – TTC No:………………………………………………….

II. Specific diagnostic information for assessment

(Please indicate at which sites the risk was identified)

		Risk
1.	Is the water storage container used for storing any other liquid/material?	Y/N
2.	Is the water storage container kept at ground level?	Y/N
3.	Is the water storage container lid/cover absent or not in place?	Y/N
4.	Is the storage container cracked or leaking or unsanitary?	Y/N
5.	Is the area around the storage container unsanitary?	Y/N
6.	Do any animals have access to the area around the storage container?	Y/N
7.	Is the tap/utensil used to draw water from the container unsanitary?	Y/N
8.	Is the water from the container also used for washing/bathing?	Y/N
9.	Has there been discontinuity in water supply in the last 10 days?	Y/N
10.	Is the water obtained from more than one source?	Y/N
	Total Score of risks	**………/10**

III Results and comments:

a. Risk score (tick appropriate box):

9–10 = Very high	6–8 = High	3–5 = Medium	0–2 = Low

b. The following important points of risk were noted:
- ☐ list risk numbers 1–10
- ☐ source of water
- ☐ additional comments (continue on back of form if necessary)

IV Names of analysts (print and sign):

Record sheet for sanitary risk inspection

Household piped water

I. General information:

a WSS No: NGA …………………… HA: ………..STATE:……………

b Community name:...…………………………………………………….

c Date of visit:…………………………………………………………..

d Water sample – TTC No:……………………………………………….

II. Specific diagnostic information for assessment

(Please indicate at which sites the risk was identified)

		Risk
1.	Is the tap sited outside the house (e.g. in the yard)?	Y/N
2.	Is the water stored in a container inside the house?	Y/N
3.	Are any taps leaking or damaged?	Y/N
4.	Are any taps shared with other households?	Y/N
5.	Is the area around the tap unsanitary?	Y/N
6.	Are there any leaks in the household pipes?	Y/N
7.	Do animals have access to the area around the pipe?	Y/N
8.	Have users reported pipe breaks in the last week?	Y/N
9.	Has there been discontinuity in water supply in the last 10 days?	Y/N
10.	Is the water obtained from more than one source?	Y/N
	Total Score of risks	**……../10**

III Results and comments:

c. Risk score (tick appropriate box):

9–10 = Very high	6–8 = High	3–5 = Medium	0–2 = Low

d. The following important points of risk were noted:

- list risk numbers 1–10
- source of water
- additional comments (continue on back of form if necessary)

IV Names of analysts (print and sign):

Record sheet for sanitary risk inspection

Deep borehole with mechanized pumping

I. General information:

a. WSS No: NGA …………………… HA: …………..STATE……………..

b. Community name:...……………………………………………………..

c. Date of visit:……………………………………………………………..

d. Water sample – TTC No:…………………………………………………

II. Specific diagnostic information for assessment

		Risk
1.	Is there a latrine or sewer within 100 m of the pumping mechanism?	Y/N
2.	Is there a latrine within 10 m of the borehole?	Y/N
3.	Is there any source of other pollution within 50 m (e.g. animal breeding, cultivation, roads, industry etc)?	Y/N
4.	Is there an uncapped well within 100 m?	Y/N
5.	Is the drainage channel cracked, broken or needing cleaning?	Y/N
6.	Can animals come within 50 m of the borehole?	Y/N
7.	Is the base of the pumping mechanism permeable to water?	Y/N
8.	Does water form pools within 2 m of the pumping mechanism?	Y/N
9.	Is the well seal unsanitary?	Y/N
10.	Is the borehole cap cracked?	Y/N
	Total Score of risks	**………/10**

III Results and comments:

a. Risk score (tick appropriate box):

9–10 = Very high	6–8 = High	3–5 = Medium	0–2 = Low

b. The following important points of risk were noted:

- list risk numbers 1–10
- additional comments (continue on back of form if necessary)

IV Names of analysts (print and sign):

Record sheet for sanitary risk inspection

Borehole with handpump

I. General information:

a. WSS No: NGA…………………… HA: ………..STATE:………

b. Community name:...……………………………………………………

c. Date of visit:……………………………………………………………..

d. Water sample – TTC No:……………………………………………….

□

II Specific diagnostic information for assessment

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

III Results and comments:

a. Risk score (tick appropriate box):

9–10 = Very high	6–8 = High	3–5 = Medium	0–2 = Low

b. The following important points of risk were noted:

- □ list risk numbers 1–10
- □ additional comments (continue on back of form if necessary)

IV Names of analysts (print and sign):

Record sheet for sanitary risk inspection

Dug well with handpump

I. General information:

a. WSS No: NGA ………………..… HA: ……..STATE:…………………..

b. Community name:...……………………………………………………

c. Date of visit:…………………………………………………………..

d. Water sample – TTC No:……………………………………………….

II. Specific diagnostic information for assessment

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

III Results and comments:

a. Risk score (tick appropriate box):

9–10 = Very high	6–8 = High	3–5 = Medium	0–2 = Low

b. The following important points of risk were noted:

- list risk numbers 1–10
- additional comments (continue on back of form if necessary)

IV Names of analysts (print and sign):

Record sheet for sanitary risk inspection

Tanker or bowser

I. General information:

a. WSS No: NGA ..……………..…....… HA: ..…..STATE:……..….………

b. Community name:...……………………………………………………

c. Date of visit:………………………………………………………………..

d. Water sample – TTC No:………………………………………………

II. Specific diagnostic information for assessment

		Risk
Source of water and filling station/point		
1.	Is the source of water used by vendors unprotected and/or untreated?	Y/N
2.	Is the filling station/point unsanitary?	Y/N
3.	Is the pipe from the source used to fill the tanker (discharge pipe) dirty?	Y/N
4.	Can the discharge pipe touch the ground?	Y/N
Tanker		
5.	Is the tanker ever used to transport other material?	Y/N
6.	Is the inside of the tanker dirty?	Y/N
7.	Does the tanker leak?	Y/N
8.	Is the top of the tanker uncovered?	Y/N
9.	Is the pipe from the tanker used to fill the household container dirty?	Y/N
10.	Are the fittings on the tanker or household storage container unsanitary?	Y/N
	Total Score of risks	**………/10**

III Results and comments:

a. Risk score (tick appropriate box):

9–10 = Very high	6–8 = High	3–5 = Medium	0–2 = Low

b. The following important points of risk were noted:

- list risk numbers 1–10
- additional comments (continue on back of form if necessary)

IV Names of analysts (print and sign):

Checklists for field teams

1. **General**
   - Cotton wool
   - Masking tape x 8
   - Marker x 8
   - Stapler (with pins) x 4
   - Biro
   - Extension rope x 4
   - Log book x 4
   - Wash bottle x 8
   - Distilled water
   - Soap solution
   - Brush (soft) x 8
   - Enough money for food and accommodation
   - Bowl x 4
   - Disposable hand gloves
   - Waste bag x 4
   - Administrative maps
   - Lighter x 8
   - Tissues
   - Hand towels x 16
   - Enough photocopies of sanitary inspection forms
   - Enough photocopies of daily report forms
   - Electric kettle x 4
   - Standard operating procedure for each parameter to be tested (sampling and analysis)

2. **Microbiology**
   - Methanol
   - 0.1% thiosulphate solution
   - Bleach (JIK) x 16
   - Filter membrane
   - Forceps
   - Petri dishes (TTC and FS plates)
   - Absorbent pad
   - Absorbent pad dispenser
   - Grease
   - Vacuum pump
   - Cool box x 4
   - Sample Bottles x 40
   - Prepared MLSB
   - Prepared FS media
   - Incubator
   - Incubator battery
   - Incubator connection cables

3. **Physiochemical**
   a. Screwdriver
   b. Plastic bottle/beaker
   c. Turbidity
      - Meter
      - Batteries (4)
      - Sample cell with cap
      - Calibration standard (4) of different grade
      - Silicon oil
   d. Conductivity
      - Tester
      - Probe remover tube
      - Batteries (4) + back-up

- Probe
- Calibration solution

e. pH
   - Tester with glass electrode
   - Buffer solutions (3) (acid, neutral, basic)
   - Batteries (back-up)

f. Photometric Analysis
   - Photometer
   - Batteries
   - Cells with cover (2) (10 ml and 20 ml)
   - DPD 1 and 3 tablets for residual chlorine
   - Fluoride 1 and 2 tablets
   - Iron tablet
   - Nitrate test powder
   - Nitrate test tablets
   - Copper 1 and 2 tablets

4. **Logistics**
   - Letter from the ministry introducing the team members to relevant agencies/communities/house holds where samples are to be taken
   - Local contact person that will aid the team to locating sampling points
   - Operational vehicles
   - Provision for fuelling and servicing of the vehicles.
   - Telephone to ease communication with the coordinators
   - How to send results
   - When to send results
   - To whom to send results

5. **Personal needs**

   These are optional items that may be carried by team members on a daily basis:
   - First aid
   - Drinking-water
   - Stipends for feeding during the field trip

Annex 7 Level 1 parameters for a RADWQ survey

Bacteriological parameters

A variety of microorganisms are found in water, including both pathogenic and nonpathogenic species. Some nonpathogenic microorganisms can cause problems with the taste and odour of water supplies, which consumers see as important indicators of water safety, and which may determine whether they drink the water. The principle concern for drinking-water quality, however, is contamination by pathogenic microorganisms, most of which derive from faeces. To determine whether drinking-water is contaminated by such pathogens, the levels of indicator microorganisms are usually measured. These indicator microorganisms are normally bacteria, and several types are used by programmes that monitor drinking-water quality. The most commonly used is *Escherichia coli*, but thermotolerant coliforms are also frequently used as a surrogate for *E. coli.*

In the RADWQ project for Jordan, thermotolerant coliform levels were used to assay drinking-water quality, rather than *E.* coli levels, because tests for the former microorganisms are rapid and widely used. Whenever possible, however, it is recommended that confirmatory tests for *E. coli* be undertaken for each type of water source. The usefulness of faecal streptococci as indicator microorganisms of drinking-water quality was also examined in a small-scale within-study investigation, by testing 10% of all water sources for these bacteria.

Thermotolerant coliforms

The thermotolerant coliforms are a group of coliform bacteria that grow at 44 °C, and they include *E. coli* as well as other species that may derive from environmental sources. Thermotolerant coliform analysis can be performed using a number of relatively inexpensive techniques, and the results can be obtained within 14–24 hours. In temperate climates, approximately 95% of thermotolerant coliforms are thought to be *E. coli*, but in tropical climates this proportion may be significant lower. This indicates that the results of a thermotolerant coliform analysis should be interpreted cautiously, and highlights the need for other assay methods.

E. coli contamination derives almost exclusively from human and animal faeces, and some strains of *E. coli* are pathogenic (e.g. *E. coli* O157:H7). There is evidence that *E. coli* can multiply in nutrient-rich tropical soils, although it is generally recognized that this ability is limited, and in most cases the indigenous bacteria would out-compete the *E. coli.* The identification of *E. coli* is simple, but time consuming, as it typically requires a two-stage process of presumptive and confirmative testing.

Faecal streptococci

Faecal streptococci may also be used as microbiological indicators of drinking-water quality. Evidence indicates that these bacteria have a stronger relationship to diarrhoeal disease than does *E. coli*, and a closer relationship to indicator bacteria known to derive from human faeces. Generally, faecal streptococci are more environmentally resistant than *E. coli* or thermotolerant coliforms, and it has been recommended that they be used to assay groundwater receiving contaminated recharge water, and to assay chlorinated distribution systems. Several simple methods are available for detecting faecal streptococci, but they are time-consuming and results cannot be obtained for 48 hours. This may limit the usefulness of faecal streptococci for routine monitoring, but it would have a limited impact on their value in assessments.

Free chlorine and chlorine residuals

It is recommended that assays of free chlorine, turbidity and pH are included in water-quality surveys, as these parameters directly influence the microbiological quality of the water supply.

Chemical parameters

The third edition of the WHO, *Guidelines for drinking-water quality*, lists many chemicals that are relevant to drinking-water quality, and guideline values are given for most of the chemicals. To test for all the chemicals listed in the guidelines would be difficult, prohibitively expensive and largely unnecessary, even within an assessment, and therefore the chemicals selected for analysis must be prioritized. Some chemicals are toxic (e.g. fluoride, arsenic and nitrate) and pose a health hazard when found in drinking-water, and should therefore be included in an assessment. Other chemicals are not toxic *per se*, but contribute to the palatability or appearance of drinking-water, and thus influence whether people use a water source. Examples include salts and iron (see following section, *Aesthetic parameters*). Water properties that lead consumers to reject a safe, though aesthetically unappealing, source pose an indirect health risk, because the consumers may instead use a microbiologically contaminated source. Besides the chemical composition of drinking-water, certain physical characteristics of water (e.g. turbidity) are often cited by consumers as indicators of a change in water quality and as reasons for rejecting a source. Factors that influence the aesthetic properties of drinking-water should therefore also be included in an assessment of water quality.

Groundwater contamination may be natural or anthropogenic, and the levels of contamination can vary over time and by location. Contamination levels tend to vary more over time for surface waters and shallow groundwater than for deep groundwater. However, the microbiological quality of shallow groundwater and surface water is often poor, and this is the principal concern. The levels of chemical contamination in shallow groundwater resources and surface waters tend to be related to human activity, but prevention measures are usually possible and the contamination may be relatively short-lived if there is a rapid flow of water in the shallow source. Naturally occurring chemicals in groundwater may affect the operational performance of drinking-water systems, but normally they do not pose an acute risk to health. Typically, long-term exposures to the low concentrations of the chemicals are required before clinical effects become apparent.

In deeper groundwater, the microbiological quality is often very good and therefore chemical quality is usually a higher priority. Furthermore, the chemical contamination is more likely to be natural, and therefore removal, rather than prevention, may be required. However, if the water flow-rate in the deep groundwater source is slow, this could lead to long-term problems with contamination. The quality of deep groundwater is generally stable, so that the required frequency of monitoring is lower than that for shallow groundwater and surface water sources, which are both prone to natural (e.g. erosion, run-off) and anthropogenic contamination.

Nitrate

Nitrate is one of the most ubiquitous chemical contaminants of water bodies worldwide, as it is derived from human sources, particularly human wastes and inorganic fertilizers used in agriculture. Nitrate is of concern because of its link to methaemoglobinaemia in "blue-baby" syndrome, although the actual health burden for this syndrome is often considered to be relatively insignificant because of breast-feeding practices. It is likely, however, that the health burden is underreported.

Nitrate is also a concern because once it has entered a water body in which oxidation is occurring, only dilution and hydrodynamic dispersion are likely to significantly reduce nitrate concentrations until the input load is reduced. If nitrate is allowed to increase in source waters, long-term resource problems may result, leading to costly investments later. It is expensive and difficult to remove nitrate during treatment, and blending nitrate-rich waters with low-nitrate waters may be the only viable option. In reducing or non-oxidizing waters nitrate may not be formed, as organic nitrogen would be converted to ammonia by denitrifying bacteria.

Fluoride

Excess fluoride is associated with dental and skeletal fluorosis, which may cause severe deformation and disability in susceptible individuals. If no fluoride data are available for water supplies, and people have mottled teeth or skeletal deformities, fluorosis should be suspected. At the other extreme, a lack of fluoride also carries health risks and is associated with dental caries. In some countries, fluoride is added to drinking-water to improve dental health, but this remains a controversial issue and may not be the most effective mechanism to reduce the incidence of dental caries. Although fluoride may be released by industrial pollution, most fluoride contamination in drinking-water supplies at levels that pose a health concern derives from natural sources. Fluoride should always be analysed during the development of a water source, particularly groundwater sources.

Arsenic

Most arsenic in water is naturally occurring and derives from the dissolution of arsenic-bearing minerals associated with volcanic activity, but it may also originate from anthropogenic sources, such as mining and other industrial activities. Arsenic accumulates in humans (and is amplified in the food chain) and is associated with skin disease and cancers. Drinking from a water source contaminated by low arsenic concentrations (≤50 μg/l) over many years can result in toxic concentrations in humans, and carcinogenic effects may develop in some individuals.

Arsenic became one of the principal water-quality issues in the late 1990s because of the rising levels of arsenic in groundwaters in Bangladesh and neighbouring countries. Prior to this, few data on arsenic levels in water supplies were available, mainly because of a lack of the laboratory equipment needed to assay arsenic at low concentrations. Recently, new laboratory and field methods have been developed and these are helping to clarify the extent of arsenic contamination in water bodies worldwide, which appears to be extensive in Asia and Latin America.

Copper

The most significant health effects from copper are gastrointestinal bleeding, renal failure and possibly liver failure at high doses, and nausea and diarrhoea at lower doses. Although ingestion of copper in drinking-water is the major pathway by which copper enters the body, significant amounts can also be ingested in food. Copper also imparts both taste and colour to water at concentrations >2.4 mg/l, and causes staining of laundry and sanitary waters at concentrations >1 mg/l, all of which influence the acceptability of the water by the consumer. Copper contamination usually derives from pipes used in household plumbing systems, and from copper-containing solders. However, there are natural sources of copper in groundwater and some industrial discharges may also contain copper. Copper concentrations in water supplies range from ≤0.0005 mg/l to >30 mg/l. The higher concentrations usually are associated with corrosion of interior plumbing. The WHO guideline value is 2.0 mg/l. A copper analysis is usually only included in RADWQ Level 1 parameters for water systems with copper piping.

Aesthetic parameters

Iron

Iron contamination of water sources is mainly of aesthetic concern, because in its oxidized ferric form iron can discolour clothes and sanitary ware, which may cause consumers to reject the water source. The ferric iron mostly comes from the oxidation of ferrous iron in the water itself, but it may also come from the corrosion of galvanized iron or cast-iron pipes, and from the action of iron bacteria (Howard, Ince & Smith, 2003; WHO, 2004). Iron contamination is a particular problem for groundwater supplies, but surface waters can also have iron problems, especially with colloidal iron.

Iron and manganese (which also causes discolouring problems with water supplies) are normally found together in nature, and if a water supply has an elevated level of one element this could indicate that the level of the other element is also high. Fortunately, treatments that remove iron from water also remove manganese. Given the impact of iron on the aesthetic quality of water, and the problems it can cause in rising mains and pipes, iron is a primary parameter for a RADWQ assessment.

Turbidity, pH and chlorine residuals

Turbidity is a key parameter for describing the microbiological quality of drinking-water, and it is recommended that this parameter, together with pH and chlorine residuals, be included in surveys of water quality, as they either directly influence microbiological quality (in the case of chlorine), or influence disinfection efficiency and microbial survival (pH and turbidity). Turbidity is also the key parameter in a minimal monitoring of water quality. Very high turbidity, even in the absence of faecal indicator bacteria, may be cause for concern, as it indicates that sanitary integrity has been compromised.

Conductivity

Conductivity, the ability of water to carry an electric charge, can be considered a proxy indicator of dissolved solids (a conductivity of 1400 μS/cm is equivalent to 1000 μg/l of dissolved solids) and is, therefore, an indicator of the taste and salinity of the water. Although there is little direct health risk associated with high conductivity values, such values are associated with poor-tasting water and customer dissatisfaction and complaints. Changes in conductivity with time, or high conductivity values, can both indicate that the water has become contaminated (e.g. from saline intrusion, faecal pollution, or nitrate pollution). Over time, the contamination can cause corrosion in rising mains and pipes.

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 consumers. The most effective way to undertake sanitary inspections is a semiquantitative, standardized approach using logical questions and a simple scoring system. Sanitary inspections complement water-quality analyses by providing a longer-term perspective on the risks of microbiological contamination, rather than the "snapshot" view of water-quality analyses, and there is an increase in the power of analysis when both types of data are available.

In the RADWQ survey in Nigeria, special questionnaires were used in the sanitary inspections of all water supplies (Annex 6). The questionnaires comprised sets of 10 questions with only "yes" or "no" responses allowed, which enabled the interviewer to quickly and easily mark the answer. Sanitary inspection scores were then derived from the results of the sanitary inspections.

Risk-to-health analysis

A relative health risk for a water supply can be calculated by combining the sanitary inspection score with data on thermotolerant coliform counts (e.g. see Table 3.12). The sanitary inspections provide a longer-term perspective on the risks of microbiological contamination, while the coliform data provide more of a "snapshot" of current conditions. Ranking water supplies in such a way allows interventions aimed at improving water safety to be prioritized, and supports effective and rational decision-making.

Analysis of proxy parameters

The purpose of a proxy analysis in a RADWQ survey is to quantify correlations between pairs of selected water-quality parameters, and determine if one parameter could be used to approximate the result that would be given by the direct measurement of a second parameter (which might be more difficult, expensive or time-consuming to measure). Most commonly, a proxy analysis is used to investigate the correlations between:

- faecal contamination (measured as the thermotolerant coliform count) and turbidity;
- thermotolerant coliform count and faecal streptococci level; and
- conductivity and nitrate, fluoride or arsenic.

The strength of association between two water-quality parameters in a RADWQ survey is measured by calculating Pearson's *r*, a linear correlation coefficient. If the paired data lie exactly along a straight line with a positive slope, then $r = 1$; if they lie exactly along a straight line with a negative slope, $r = -1$; and if there is no correlation, then $r = 0$. To interpret the RADWQ data, the following ranges of values for *r* were used to define the strength of the association between data pairs:

- -1.0 to -0.7 strong negative association;
- -0.7 to -0.3 weak negative association;
- -0.3 to +0.3 little or no association;
- +0.3 to +0.7weak positive association;
- +0.7 to +1.0strong positive association.

The main limitations of Pearson's *r* are that the method assumes a linear association between two variables, and would not approximate well a non-linear relationship; it assumes the data are distributed normally; and the value of *r* is disproportionately influenced by outlier data. The justifications for using Pearson's *r* are that it can be easily calculated in Microsoft's Excel spreadsheet, and that the snapshot nature of a RADWQ survey does not justify using a more complicated analysis, such as Spearman's *rho*.

Annex 8 Mean values for water quality parameters, by broad area (hydrological area) and technology option

Hydrological Area	Boreholes, tubewells		Protected dug wells		Piped utility supply		Vehicle tanker		Totals	
	No. of samples	TTC[a]	No. of samples	TTC	No. of samples	TTC	No. of samples	TTC	No. of samples	TTC
HA 1	75	4	75	23	35	25			185	17
HA 2			25	0	70	0			95	0
HA 3			50	6					50	6
HA 4	50	0	100	3	35	1			185	1
HA 5	75	2			35	2			110	2
HA 6	225	0	125	16	315	19	29	10	694	11
HA 7					35	1			35	1
HA 8	100	0	49	9	105	0			254	3
National	525	1	424	10	630	7	29	10	1608	5

[a] TTC = thermotolerant coliforms (cfu/100 ml).

Hydrological Area	Boreholes, tubewells		Protected dug wells		Piped utility supply		Vehicle tanker		Totals	
	No. of samples	FS[a]	No. of samples	FS	No. of samples	FS	No. of samples	FS	No. of samples	FS
HA 1	10	0	9	0	2	7			21	2
HA 2			3	0	7	7			10	4
HA 3			5	0					5	0
HA 4	4	1	9	0	3	0			16	0
HA 5	10	2			8	1			18	2
HA 6	25	1	16	2	30	0			71	1
HA 7					2	0			2	0
HA 8	11	0	5	0	11	0			27	0
National	60	1	47	0	63	2			170	1

[a] FS = faecal streptococci. (cfu/100 ml).

Hydrological Area	Boreholes, tubewells		Protected dug wells		Piped utility supply		Vehicle tanker		Totals	
	No. of samples	pH	No. of Samples	pH	No. of samples	pH	No. of samples	pH	No. of samples	pH
HA 1	75	6.9	75	6.5	35	5.8			185	6.4
HA 2			25	5.8	70	7.6			95	6.7
HA 3			50	7.0					50	7.0
HA 4	50	6.4	100	6.3	35	7.7			185	6.8
HA 5	75	5.0			35	5.7			110	5.4
HA 6	225	5.8	125	6.5	315	7.1	29	6.7	694	6.5
HA 7					35	6.5			35	6.5
HA 8	100	6.4	49	6.1	105	5.9			254	6.1
National	525	6.1	424	6.4	630	6.6	29	6.7	1608	6.4

Hydrological Area	Boreholes, tubewells	Protected dug wells	Piped utility supply	Vehicle tanker	Totals

	No. of samples	Cond.[a] (µS/cm)	No. of samples	Cond. (µS/cm)	No. of samples	Cond. (µS/cm)	No. of samples	Cond. (µS/cm)	No. of samples	Cond. (µS/cm)
HA 1	75	276	75	500	35	137			185	304
HA 2			25	174	70	94			95	134
HA 3			50	804					50	804
HA 4	50	560	100	322	35	79			185	320
HA 5	75	145			35	51			110	98
HA 6	225	436	125	475	315	180	29	309	694	350
HA 7					35	42			35	42
HA 8	100	274	49	346	105	134			254	251
National	525	338	424	437	630	102	29	309	1608	288

[a] Cond. = conductivity.

Hydrological Area	Boreholes, tubewells		Protected dug wells		Piped utility supply		Vehicle tanker		Totals	
	No. of samples	Turb.[a] (NTU)	No. of samples	Turb. (NTU)	No. of samples	Turb. (NTU)	No. of samples	Turb. (NTU)	No. of samples	Turb. (NTU)
HA 1	75	2.7	75	21.6	35	25.5			185	16.6
HA 2			25	24.7	70	6.1			95	15.4
HA 3			50	7.9					50	7.9
HA 4	50	18.4	100	34.9	35	10.0			185	21.1
HA 5	75	0.3			35	0.4			110	0.4
HA 6	225	2.2	125	15.4	315	5.4	29	1.8	694	6.2
HA 7					35	4.0			35	4.0
HA 8	100	3.9	49	10.9	105	13.6			254	9.5
National	525	5.5	424	19.2	630	9.3	29	1.8	1608	10.1

[a] Turb. = turbidity.

Hydrological Area	Boreholes, tubewells		Protected dug wells		Piped utility supply		Vehicle tanker		Totals	
	No. of samples	Free Cl_2 (mg/l)	No. of samples	Free Cl_2 (mg/l)	No. of samples	Free Cl_2 (mg/l)	No. of samples	Free Cl_2 (mg/l)	No. of samples	Free Cl_2 (mg/l)
HA 1					35	0.01			35	0.01
HA 2					70	0.11			70	0.11
HA 3										
HA 4					34	0.13			34	0.13
HA 5					35	0.12			35	0.12
HA 6					315	0.06			315	0.06
HA 7					31	0.07			31	0.07
HA 8					103	0.14			103	0.14
National					623	0.09			623	0.09

Hydrological Area	Boreholes, tubewells		Protected dug wells		Piped utility supply		Vehicle tanker		Totals	
	No. of samples	Total Cl_2 (mg/l)	No. of samples	Total Cl_2 (mg/l))	No. of samples	Total Cl_2 (mg/l)	No. of samples	Total Cl_2 (mg/l)	No. of samples	Total Cl_2 (mg/l)
HA 1					10	0.08			10	0.08
HA 2					35	0.25			35	0.25
HA 3										
HA 4					10	0.32			10	0.32
HA 5					8	0.17			8	0.17
HA 6					81	0.19			81	0.19
HA 7					8	0.11			8	0.11
HA 8					20	0.41			20	0.41
National					172	0.22			172	0.22

Hydrological Area	Boreholes, tubewells		Protected dug wells		Piped utility supply		Vehicle tanker		Totals	
	No. of samples	NO_3 (mg/l)	No. of samples	NO_3 (mg/l)	No. of samples	NO_3 (mg/l)	No. of samples	NO_3 (mg/l)	No. of samples	NO_3 (mg/l)
HA 1	26	12.84	27	35.93	16	0.86			69	16.54
HA 2			9	29.90	21	0.12			30	15.01
HA 3			16	68.98					16	68.98
HA 4	16	21.45	34	38.84	12	0.10			62	20.13
HA 5	23	8.49			10	6.03			33	7.26
HA 6	100	20.88	59	29.33	139	1.73	18	9.49	316	15.36
HA 7					10	2.37			10	2.37
HA 8	32	12.92	14	8.95	31	0.48			77	7.45
National	197	15.32	159	35.32	239	1.67	18	9.49	613	19.14

Hydrological Area	Boreholes, tubewells		Protected dug wells		Piped utility supply		Vehicle tanker		Totals	
	No. of samples	As (mg/l)	No. of samples	As (mg/l)	No. of samples	As (mg/l)	No. of samples	As (mg/l)	No. of samples	As (mg/l)
HA 1	75	0	75	0	35	0			185	0
HA 2			25	0	70	0			95	0
HA 3			50	0					50	0
HA 4	50	0	100	0	35	0			185	0
HA 5	75	0			35	0			110	0
HA 6	225	0	125	0	315	0	29	0	694	0
HA 7					35	0			35	0
HA 8	100	0	49	0	105	0			254	0
National	525	0	424	0	630	0	29	0	1608	0

Hydrological Area	Boreholes, tubewells		Protected dug wells		Piped utility supply		Vehicle tanker		Totals	
	No. of samples	Fe (mg/l)	No. of samples	Fe (mg/l)	No. of samples	Fe (mg/l)	No. of samples	Fe (mg/l)	No. of samples	Fe (mg/l)
HA 1	75	0.34	75	0.03	35	0.00			185	0.12
HA 2			25	0.05	70	0.00			95	0.03
HA 3			50	0.00					50	0.00
HA 4	50	0.34	100	0.23	35	0.03			185	0.20
HA 5	75	0.22			35	0.00			110	0.11
HA 6	225	0.25	125	0.00	315	0.07	29	0.18	694	0.13
HA 7					35	0.06			35	0.06
HA 8	100	0.54	49	0.02	105	0.06			254	0.21
National	525	0.34	424	0.06	630	0.03	29	0.18	1608	0.11

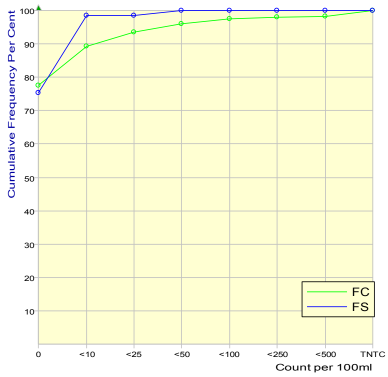
Hydrological Area	Boreholes, tubewells		Protected dug wells		Piped utility supply		Vehicle tanker		Totals	
	No. of samples	F (mg/l)	No. of samples	F (mg/l)	No. of samples	F (mg/l)	No. of samples	F (mg/l)	No. of samples	F (mg/l)
HA 1	75	0.96	75	1.00	35	1.16			185	1.04
HA 2			25	0.49	70	1.01			95	0.75
HA 3			50	0.91					50	0.91
HA 4	50	1.53	100	0.84	35	0.25			185	0.87
HA 5	75	0.09			35	0.21			110	0.15
HA 6	225	0.63	112	0.78	315	0.41	29	0.26	681	0.52
HA 7					35	0.20			35	0.20
HA 8	100	1.06	49	0.34	105	0.70			254	0.70
National	525	0.85	411	0.73	630	0.56	29	0.26	1595	0.64

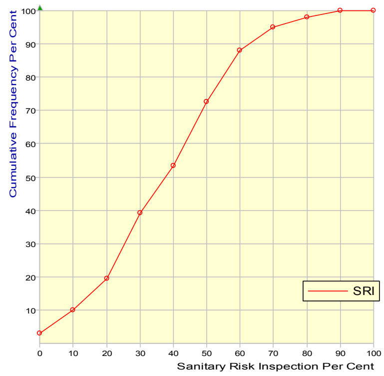
Hydrological Area	Boreholes, tubewells		Protected dug wells		Piped utility supply		Vehicle tanker		Totals	
	No. of samples	Cu (mg/l)	No. of samples	Cu (mg/l)	No. of samples	Cu (mg/l)	No. of samples	Cu (mg/l)	No. of samples	Cu (mg/l)
HA 1					33	0.00			33	0.00
HA 2					63	0.10			63	0.10
HA 3									0	
HA 4					35	0.23			35	0.23
HA 5										
HA 6										
HA 7					24	0.13			24	0.13
HA 8					103	0.00			103	0.00
National					258	0.09			258	0.09

Annex 9 National cumulative frequency diagrams for thermotolerant coliforms and sanitary risk, by technology type[a]

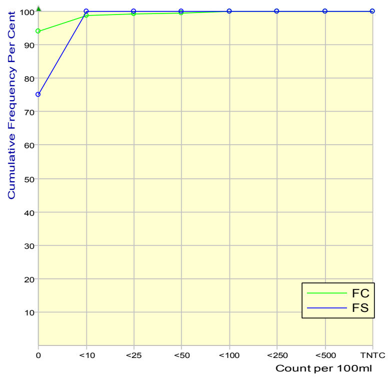
Category	Cumulative frequency diagram for thermotolerant coliforms	Cumulative frequency diagram for sanitary risk

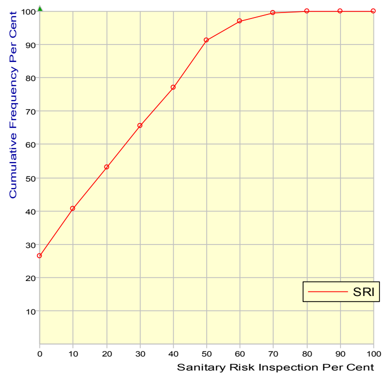
UP



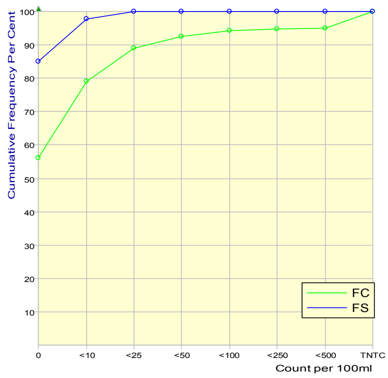


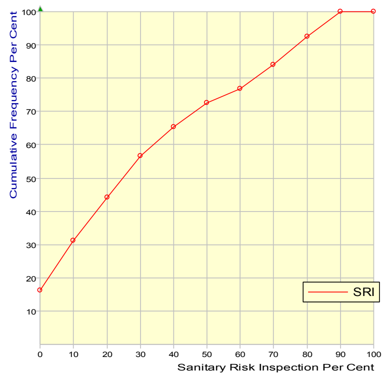
BT





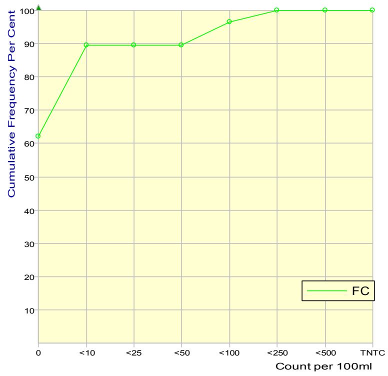
PDW

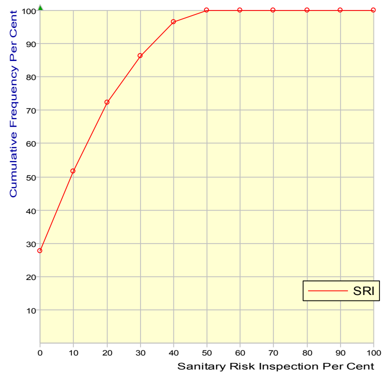




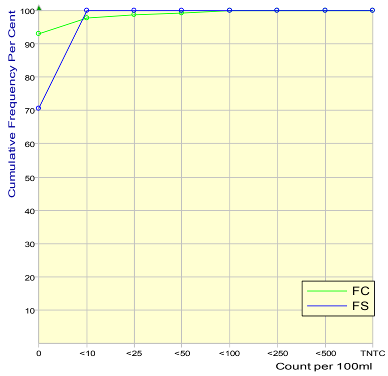
Category	Cumulative frequency diagram for thermotolerant coliforms	Cumulative frequency diagram for sanitary risk

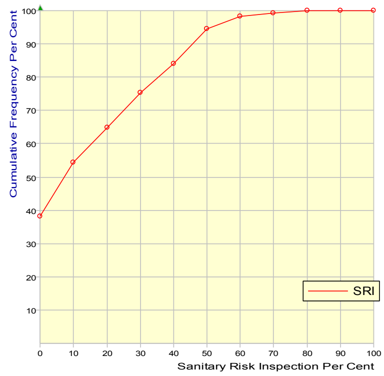
VT



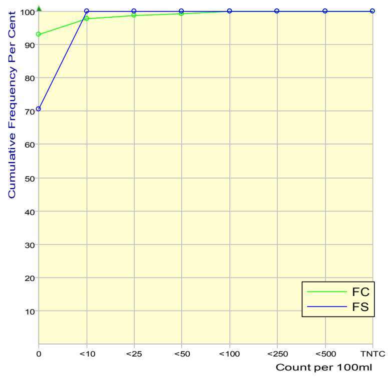


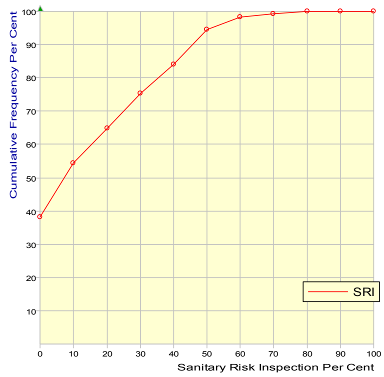
BHMECH





BHHAND





[a] The diagrams show the outputs from the SanMan software. UP = unprotected dug well; BT = borehole, tubewell; PDW = protected dug well; VT = vehicle tanker; BHMECH = borehole with mechanized pump; BHHAND = borehole with hand pump. FC = faecal coliform; FS = faecal streptococci; SRI = sanitary risk inspection score.

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