Water Quality Assessment

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Scope: questions/ challenges the tool addresses

Some rural populations are heavily dependent on small reservoirs for their water supply, and are concerned about the quality of this water for direct consumption and other uses. Such concerns can be raised by what appears to be water pollution, or by disease symptoms perceived to be water related. In these cases, chemical and biological water quality measurements can be taken to ascertain the suitability of water for different uses. Water "suitability" of course, depends on the use for which it is intended. Brick making, livestock watering, fisheries or irrigation have different water quality requirements. These activities, in turn, can affect water quality (see a related tool on the impact of pesticides on water quality).

Reservoir users can assess water quality through simple methods such as observing its color, transparency, taste and smell. These methods require no financial resources and are within the reach of even the very poor.

More sophisticated technical methods can be used by water managers to monitor changes in reservoir water quality. These include analysis of biomedical (e.g. fecal streptococci, total coliforms, fecal coliforms, *Cryptosporidium*, *Giardia*); biological (e.g. chlorophyll as indicator of eutrophication); and physico-chemical (e.g. EC, pH, hardness, nitrate, chloride, phosphorus) parameters. It also helps to identify sources of pollutants and their loading. Changes in plankton diversity and abundance can be used as an indirect assessment of water quality, to ascertain how various land and water uses impact water quality. (See related tools on agricultural intensification and pesticides; and plankton diversity and abundance; and cyanobacterial proliferation).

Target group of the tool

Target groups for this tool include planners, designers, builders, managers, and users of small, multi-purpose reservoirs. Communities can use the methods that are based on perception while water managers or health professionals might prefer the more sophisticated technical methods.

Requirements for tool application

The tool requires personnel who can correctly perform observations or analysis and interpret results. Sample collection can be done by professionals or by water users, provided the procedures on sampling and preserving samples are properly followed.

Analysis of water quality requires more elaborate and expensive equipment and laboratory facilities. National institutes or private laboratories often have the expertise and material to carry water quality analyses. Community members with minimal knowledge and proper training can perform some simple water quality tests by assessing taste, smell and color, and by using simple field kits.

Tool: description and application

The tool takes a holistic approach to addressing water quality problems in small reservoirs. The first step is to select the reservoirs for which water quality is to be monitored, identify the main water uses, and determine key water quality parameters. Next, a qualitative survey on water quality is carried out to elicit peoples' perceptions (see Appendix). Dialogue between experts and community members is used to select parameters (Ait Lhaj and Laamrani 2007) after which systematic collection and analysis of water samples can be performed (see a related tool on health indicators). Water samples should be taken from different sources of water: reservoir, canals, wells, collected water at the site and in the household, drains; and so on.

In the following sections, a range of methods are described for measuring several well-known water quality indicators. Where possible, relatively simple protocols are selected that can be applied in the field with a simple laboratory. For chemical components, ready-made probes are typically used.

Parasite sampling (Shortt et al. 2006)

For parasite analysis, water samples are collected from the various water sources and filtered using a hand pump with a flow rate of approximately 5 liters per minute. For each sampling, 49 liters of water are pumped through a single cylindrical filter. A simple filtering apparatus can be made for this purpose out of an inlet hose and a plastic filter holder with a 25 cm long yarn-wound polypropylene filter (porosity 1µm, e.g. such as is manufactured by Triosin Corporation Mirabel[1], Québec). A concentrated specimen is obtained by washing the filter with distilled water in a squirt bottle and then scraping it with a scalpel. The filter does not have to be disassembled. (Note of course that some of the filter material will end up being scraped into the concentrated sample.) A concentrated specimen of 200 ml, recovered from filtering 49 liters of water, is then preserved in 10% formalin and kept for further analysis.

Concentrated specimens are stored at room temperature until they are processed for microscopic analysis. The specimens are further concentrated by centrifuge to a volume of 5 ml (containing all of the sediment visually detectable in the original 200 ml). Microscope

[1] Use of trade or company names is for information purposes only and does not imply endorsement of a product or company.

identification is suitable to classify the protozoa if special microscopes equipped with ultra-violet light are not available. These would allow the use of prepared kits for the specific detection of *Giardia* cysts and *Cryptosporidium* oocysts.

Giardia spp. analysis

The identification of *Giardia* spp. cysts can be done by light microscopy without staining. A Pasteur pipette is used to drop approximately 0.1 ml of the concentrated specimen across two microscope slides (0.05 ml per slide) (Ruest et al. 1998). A cover slip is placed over the specimens, which are examined with a light microscope at 400X magnification. The cysts appear as elongated structures with visible flagella inside. They have a mean size of 12µm. A total of 50 fields are examined on the two microscope slides. These fields cover the entire surface of both slides and represent 0.1 ml of concentrated specimen. Positive fields are registered, along with the total number of cysts counted in the 50 fields. The number of cysts is multiplied by 50 in order to correspond to the 5 ml centrifuged sample from the original 49 liters of raw water.

Cryptosporidium spp. analysis

For the identification of *Cryptosporidium* spp. oocysts, 5 ml of sucrose with a specific gravity of 1.103 is pipetted into a 16 ml glass centrifuge tube. Three ml of the concentrated water sample are layered on top of the sucrose solution. After centrifugation at 200g for 10 minutes, all oocysts are assumed to be in the 1 ml cloudy layer located at the interface. This cloudy layer is removed with a Pasteur pipette and washed 3 times in distilled water. A total volume of 0.1 ml is then dried on two microscope slides at room temperature (between 20 and 30 $^{\circ}$C), fixed with methanol and stained with a Ziehl Neelsen acid-fast stain. These are examined with a microscope at 1000X magnification (oil immersion). The oocysts appear in red and usually have dimensions of 5.0µm X 4.5µm. A total of 100 fields are examined, covering both slides and the entire 0.1 ml concentrated specimen. Positive fields are registered along with the total number of oocysts counted in the 100 fields. The number of cysts is multiplied by 50/3 in order to correspond to the 5 ml centrifuged sample from the original 49 liters of raw water.

Coliform sampling and analysis

Sampling for coliform bacteria should be done even more frequently than for parasites: for example, once a month for various seasons. For a given round of measurement, all selected water sites should be sampled within the same five to seven day period so that findings can be compared. At each site, three samples are taken. Various media can be used for sample collection. Plastic bags are one option, though sterile ones often need to be specially imported.

In the studies in Sri Lanka (Shortt et al. 2003) samples were always collected in the morning using sterile 200 ml plastic bags. Approximately 150 ml of water were collected per sample. For the control, one sample bag was filled with sterile dilution water and placed into the cool box before leaving the laboratory. This control sample was transported to the field without opening and then analyzed along with the other samples.

All samples are placed in a cool box filled with ice to keep them at 5 °C, and analyzed within 9 hours of collection. Immediately after a sample is collected, electrical conductivity and other parameters are measured in the water source, and again in the laboratory.

The water samples can be analyzed for the presence of thermotolerant coliform bacteria using the membrane filter technique as outlined by Csuros & Csuros (1999) and the American Public Health Association (1998). Briefly, this technique involves filtering water through a membrane (0.47 μm) that retains thermotolerant coliform bacteria, incubating this membrane on a growth promoting medium (e.g. GelmanSciences microbiological media product # 4390 M-FC broth with rosolic acid) for 24 hours at 44.5 °C and then counting the resultant colonies of thermo-tolerant bacteria. Plates are counted within one hour of being removed from the incubator. In case of (expected) high contamination levels, prior to filtration, dilutions of samples should be made with a sterile phosphate, magnesium chloride solution. Hence no more than 500 colonies per filter are used to calculate the concentration of colony forming bacteria per 100 ml.

Another way of analyzing water quality is to analyze composite samples. This can help improve precision and lower the variance of estimated average contaminant concentrations (Million 2008). In the laboratory, the three samples from each site should then be mixed into replicate samples of 10 ml each and subjected to membrane filter analysis of total coliforms, fecal coliforms and *Enterococcus*/fecal *Streptococcus*. The latter are important indicators for fecal contamination of animal origin.

The composite samples are then filtered under hood, using a membrane filtration apparatus with 47 mm diameter sterile and gridded membranes with pore size 0.45mm. The membranes are then transferred aseptically to glass petri dishes with different media: m-Endo Agar LES for total coliforms (TC), m-FC agar with rosolic acid for thermotolerant coliforms (TTC) and mEntrococcus agar media for fecal *Streptococcus* (FS). Prepared culture dishes are inverted and incubated for 24h at 35 °C (TC), 24h at 44.5 °C (TTC) and for 48h at 35 °C (FS). Upon completion of the incubation period, typical TC colonies (a pink to dark red color with sheen), blue colored for TTC and dark red colonies for FS on the surface of membrane filter can be counted using a low power binocular wide field dissecting microscope, with a cool white fluorescent light source for optimal viewing sheen. Buffer rinse water (APHA 1998) is used to rinse the funnel between each site sample filtration. Verification tests should be done by transferring growth from each colony and place it in lauryl tryptose broth at 35±0.5 °C for 48h. Gas formed in lauryl tryptose broth within 48h verifies the colonies as TC. Inclusion of EC broth for 44.5±0.2 °C incubation verifies the colonies as TTC/FC.

For isolation of *Enterococcus*/fecal *Streptococcus*, typical colonies from mEnterococcus agar membrane are streaked on the surface of brain-heart infusion agar plate and incubated at 35 °C for 24h. A successful growth from a well-isolated colony on brain-heart infusion agar then has to be transferred to brain-heart infusion broth tube and to each of two clean glass slides. The brain-heart infusion broth is incubated at 35 °C for 24h. Growth from the brain-heart infusion broth is in turn transferred to bile esculin agar (prepared according to APHA 1998) and incubated at 35 °C for 48h, and brain-heart infusion broth with 6.5%NaCl and incubated at 35°C for 48h. Typical colonies from mEntrococcus agar membrane are streaked, prepared for

epifluorescent microscope and then diploid and small chain coccid shape cells can be identified, which is a typical characteristic of the indicator group (*Enterococcus/Streptococcus*). Further identification of TC, TTC/FC and FS can be done by examining the colonies under an epifluorescence microscope attached to a digital camera.

Electrical conductivity

Electrical conductivity measurements can be made with standard conductivity meters, such as the UC-35 conductivity meter of Central Kagaku Corporation. This meter should be calibrated every morning before leaving the laboratory with HACH EC standard solution of 0.180 mS/cm. The reference temperature should be fixed at 25°C, reference for tropical waters.

Chemical characteristics

Samples for anion analysis can be collected in 100 ml polyethylene bottles and filtered using 0.20 μm cellulose acetate filters prior to the analysis (Rajasooriyar 2003). Samples for cation analysis can be collected in 200 ml polyethylene bottles and acidified to 4% (by volume) using nitric acid in the field. Before analysis, samples are filtered using 0.45 μm cellulose acetate filters. Samples can be analyzed for Na, K, Mg, Ca, Mn, Al and Si by spectrometry, e.g. using Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES – Varian Vista – axial system). Samples for Cl^-, NO_3^-, SO_4^{2-} and PO_4^{3-} can be analyzed by ion chromatography, e.g. using a DIONEX^{TM} series 4000 I instrument. The total alkalinity (HCO_3^-) is best determined by titration. Fluoride determinations can be made using a fluoride ion combination electrode (ORION – Model 96-09) and TISAB III buffer. Using these techniques, the reproducibility for duplicate samples is less than 2%.

To get an indication of the (seasonal variation in) concentration of fertilizer nutrients in water of reservoirs, samples can be collected from the middle of the reservoirs. This type of analysis usually can only be carried out in well-equipped water quality laboratories, like the one of Embrapa Cerrados, Brazil. The concentration of cations and anions is determined through ion chromatography (Metrohm) in column Metrosep A Supp5 -100 e Metrosep C2. Water quality samples should be taken at least once during the rainy and dry season, in reservoirs built in soils from different parent materials. In the Preto River Basin, the results demonstrate the influence of geology on the water quality and a low level of water contamination due to nutrients.

Data analysis

The pollution load (P_L) of the various pollutants (NO^-_3 hardness, EC, Cl^-, pH) in each stream that drains into each of the reservoirs is determined using the following equation:

$$\mathbf{P_L = kQC}$$

Where: $\mathbf{P_L}$ = pollutant loading (mg/s), **Q** = flow rate (m^3/s), **C** = level/concentration of pollutant (mg/*l*) and **k** =0.0001 unit conversion constant.

The difference in water quality for all the reservoirs can then be evaluated using χ^2 test.

Lessons learned

Results from water quality analysis can be explained in terms of reservoir water use, and land management practices in reservoir watersheds, taking account of non-point source pollution. Using this knowledge, water managers can develop management strategies aimed at maintaining water quality at satisfactory levels.

Water quality assessment is most accurate when all relevant parameters are analyzed. Looking only at physico-chemical parameters or biological parameters might give the false impression that water quality is good when in fact it is not.

Reservoirs from areas with different kinds of land use should be monitored in order to better understand the effect of land use on water quality. Reservoirs should also be monitored over long periods of time to account for temporal variation. Water quality in reservoirs may not suitable for all conceivable uses when different levels of water quality are required for different uses. Water quality standards should be consistent with the uses to which the water is to be put.

Recommendations

Managing water quality in reservoirs is only dimension of managing water quality at the level of a watershed. Research on groundwater quality, sediment quality, and non-point source pollution is needed to complement surface water quality studies.

Figure 1. Hazardous behavior: water collection for domestic use in the Pouytenga reservoir, Burkina Faso (Photo: Philippe Cecchi, April 2005)

Drinking untreated surface water is potentially hazardous, and risks increase as reservoir use intensifies (Figure 1). Where drinking water is sourced from small reservoirs undergoing intensification, alternative sources of drinking water should be sought. The Millennium Development Goals propose that, by 2015, we halve the proportion of people without sustainable access to safe drinking water and basic sanitation. Substantial financial and human resources have been mobilized in several countries to reach this goal. Some of these can be used for water resources development. Ideally, drinking water supplies should be separated from those used for other purposes. Water in reservoirs typically has numerous uses that conflict with the storage of quality drinking water. In particular, pollution from pesticides and cyanotoxins is not easily remedied (see related tools on the impacts of pesticides and cyanotoxins on water quality).

Other conflicts abound. Agriculture, livestock-watering, and brick-making generally require far more water than does direct human consumption. Certain domestic activities such as washing clothes are often more easily carried out at the water source than in the house. Tables 1 and 2 show minimum quantities and service levels for drinking water.

Table 1. Minimum daily water requirements (Gleick 1998) in liters per capita per day (lpcd)

Water use	**Quantity (lpcd)**
Drinking	5
Hygiene	20
Sanitation	15
Food preparation[2]	10
Total	**50**

Table 2. Water service levels (Howard & Bartram 2003) in liters per capita per day (lpcd).

Service level	**Access**	**Covered water needs**	**Health impact**
No access (< 5 lpcd)	> 1000 m or > 30 min	Insufficient for consumption No hygiene practice	Very high
Basic access (< 20 lpcd)	100 - 1000 m 5 - 30 min	Consumption assured Minimum hygiene needs covered Insufficient for bathing	High
Immediate access (around 50 lpcd)	Water point or tap at short distance (100m or < 5min)	Consumption assured Basic hygiene needs covered Bathing and washing possible	Weak
Optimum access (> 100 lpcd)	Multiple local access to tap water	All water needs covered	Very weak

Where small reservoirs have already been built, access to water can sometimes be improved by diversifying the community's water sources. Groundwater, for example, can be used for drinking and cooking, while surface water is used for other purposes. Areas around reservoirs can be "zoned" for different activities, such as livestock watering or laundry. Wells or boreholes can be constructed downstream of the dam. Because of horizontal filtration, seepage water into these wells may be of generally higher quality than water in the reservoir. Under some circumstances, rainwater harvesting can be used at the community (watershed) or individual household level. Vegetative cover can act as a buffer to influxes of pollutants into reservoirs, for which reason maintenance of vegetation along reservoir shores is highly recommended.

Safe storage of domestic water is critically important. Storage tanks should be properly cleaned and equipped with taps (Figure 2). Where necessary they can be combined with filtration and treatment facilities, such as rapid sand filters, charcoal or chlorination.

[2] This number excludes the quantity of water required to produce the ingredients of the meals, estimated at 2,700 lpcd (Gleick 1998).

Limitations of the tool

The simple act of testing surface water for drinking water quality might create the impression that reservoir water is suitable for direct consumption. However, freely accessible surface water can rarely if ever reach drinking water standards. Yet, many people living near small reservoirs often depend on that water source for all uses, including drinking. It is important that they have some indication of the quality of this water and how it changes over time, so that they "treat" water properly.

Figure 2. Safe water storage tank with simple tap in Kaya, Burkina Faso (Photo: Philippe Cecchi, December 2005)

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Selected Websites related to water quality

The Water Sanitation and Health (WSH) Programme of the World Health Organization
http://www.who.int/water_sanitation_health/en/

GEMSTAT: Global Water Quality Data and Statistics of the United Nations Global Environment Monitoring System Water Programme
http://www.gemstat.org/

JMP: Joint WHO and UNICEF Monitoring Programme for water supply and sanitation.
http://www.wssinfo.org/en/welcome.html

APPENDIX

Villagers' Water Quality Perception Survey

The aim of the survey is to obtain villagers' water quality perceptive of the reservoirs being studied, which will be correlated to the analyzed water quality results. Below is the version used in Avoca Growth Point, Limpopo Basin, Zimbabwe

Interviewer	Ward

Respondent Characteristics/Demographic data

Name				
Age				
Sex	1.Male		2.Female	
Marital Status	1.Single	2.Married	3.Divorced	4.Widowed
No of people in household		5(b) No. under 5 years		
Position in household				

A: WATER USE

1. What time of the year is water abundant in the reservoir (specify in months)_____
2. Where do you normally get your water from (D = dry season, W = wet season)

	Drinking		laundry		Dishes		Livestock watering		Irrigation	
	D	W	D	W	D	W	D	W	D	W
Borehole										
Open Well										
River										
Small reservoir and name										
Other (specify)										

3. How close is the water source to your homestead in the wet season for the following uses?

   Drinking_____

   Laundry_____

   Dishes_____

   Livestock watering_____

   Irrigation_____

4. How close is the water source to your homestead in the dry season for the following uses?

   Drinking_____

   Laundry_____

   Dishes_____

   Livestock watering_____

   Irrigation_____

B: SMALL RESERVOIR WATER USE PERCEPTIONS

1. During the wet season what is the water quality in small reservoirs like?

Name of reservoir	Water Quality Perceptions			
	colour	taste	soap consumption	Frothing when boiling
Bova				
Avoca				
Sifinini				
Siwaze				

2. During the dry season what is the water quality in the following small reservoirs like?

Name of reservoir	Water Quality Perceptions			
	colour	taste	soap consumption	Frothing when boiling
Bova				
Avoca				
Sifinini				
Siwaze				

C: WATER MANAGEMENT ASPECTS

1. Are there any rules and regulations regarding water quality in the reservoirs?

Yes ☐ No ☐

2. If yes name them_____

_____

_____

_____

3. Are there any conflicts related to the water quality of these reservoirs

Yes ☐ No ☐

4. If yes, who resolves them explain_____

_____

5. Who is responsible for resolving the water quality conflicts?

_____

_____

D: FARMING INFORMATION

1. What type of crops do you grow and fertilizers used

Crops Grown	Area	How much fertilizer do you use		
Maize		Basal	Top	Manure
Groundnuts				
Bambara nuts				
Rapoko				
Other				

Livestock ownership	Number	Housing
	Wet season	Dry season
Cattle		
Goats		
Sheep		
Donkey		
Chicken		
Others		

What livestock-watering source do you use in the wet season?

Small reservoir name ☐ Other Specify ☐

2. What livestock-watering source do you use in the dry season?

Small reservoir name ☐ Other Specify ☐

3. How often do you water your livestock, in the wet season _____

In the dry season _____

4. What is the distance of your homestead to the watering source, state units

_____

5. Are there any spillages that occur from the livestock housing?

☐ ☐

E: OTHER COMMENTS THAT MAY BE RELEVANT TO THE STUDY

_____

_____

_____