A PROTOTYPE WATER SELF-ASSESSMENT TOOL FOR RURAL COMMUNITIES

DEVELOPMENT OF A PROTOTYPE WATER SECURITY SELF-ASSESSMENT TOOL FOR RURAL, REMOTE, AND OTHERWISE MARGINALIZED COMMUNITIES

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ABSTRACT

The majority of people in the world that lack access to safe, adequate, and reliable water supplies reside in the rural regions of low- and middle-income countries (LMICs). Lacking this access they depend on unprotected surface water sources that are contaminated from environmental factors and poor land-use practices. Access to safe water is a key determinant of public health, and hence rural, remote, and otherwise marginalized (RRM) communities suffer high rates of waterborne disease that consequently deteriorates their quality of life.

The sustainability of water supply in RRM communities is greatly influenced by the level of community participation. Practically speaking, a community must have legitimate decision-making authority over development choices to increase the likelihood that the development benefits will be sustained. Furthermore, the sustainability of rural water supplies further depends on an holistic array of issues that correspond to the challenges faced by RRM communities.

The purpose of this research is to develop a prototype computer-based tool to support RRM communities in an holistic self-assessment of their water security. The aim of this assessment is (1) to facilitate a systematic consideration of a community's water security issues and (2) to consolidate the results into key graphics that could help the user identify relative strengths and threats. This tool intends to serve communities by bringing awareness to the holistic nature of water security and by acting as a front-end for decision support.

The development of this tool was achieved through three objectives. First, a literature review was conducted on water security indicators and indices relevant to RRM communities, which resulted in a water security framework and indicator database (n=285). Second, the Community Self-Water Assessment Tool (Community-SWAT) was developed based on the water security framework. It was designed to meet some of the unique needs of RRM communities through minimal reliance on historical data, the use of qualitative response options, and flexible parameter selection options. Community-SWAT employs the use of composite indicators, or indices: a mathematical model which is commonly used to simplify the representation and communication of complex realities.

Third, Community-SWAT was beta-tested to demonstrate its ability to differentiate challenges between communities having similar contexts, identify water security challenges within a community, and visualize heterogeneity in water point security. The sensitivity analysis demonstrated that dimension scores are generally more sensitive to the inputs when there are fewer responses. It was also shown that, upon the removal of a single question within a dimension, the majority of changes in that dimension's scores were small (less than 5) when at least half of its questions were answered.

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PREFACE

This thesis has been prepared according to McMaster University's regulations for theses consisting of material that has been previously published or is planned for publication. Chapters 2 and 3 are planned for publication in refereed journals. As such, the material in Chapters 2 and 3 was co-authored. The original contributions made by the thesis author are as follows:

Chapter 2

Title: Water security indicators: the rural context
Authors: Jesse J. Newton, Sarah E. Dickson and Corinne J. Schuster-Wallace
Prepared for: *Water Resources Management*

The literature review was conceived and conducted by J.J. Newton. Literature identification was conducted by J.J. Newton. The list of indicators was compiled by J.J. Newton. The water security framework was developed by J.J. Newton in consultation with S.E. Dickson and C.J. Schuster-Wallace. The text was written by J.J. Newton and edited by C.J. Schuster-Wallace and S.E. Dickson.

Chapter 3

Title: A new water security self-assessment tool for rural communities

Authors: Jesse J. Newton, Corinne J. Schuster-Wallace and Sarah E. Dickson.
No journal has yet been identified for publication

The Community Self-Water Assessment Tool was conceived by J.J. Newton, C.J. Schuster-Wallace, and S.E. Dickson. The Tool was designed and developed by J.J. Newton. The indicators used for evaluation were selected by J.J. Newton. Analysis of water quality data, sanitary inspection data, and household questionnaire data was conducted by J.J. Newton. The text was written by J.J. Newton and edited by C.J. Schuster-Wallace and S.E. Dickson.

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CHAPTER 1

INTRODUCTION

1.1. Water Security in Rural Communities

Approximately 780 million people do not have access to improved drinking water sources, and over 2.6 billion people are without access to improved sanitation (WHO and UNICEF, 2012a). The majority of these people live in rural, remote, and otherwise marginalized (RRM) communities in low- and middle-income countries (LMICs). Access to safe water is a key determinant of public health (Schuster-Wallace et al., 2008), hence making the prevalence and burden of waterborne disease greatest in LMICs (WHO, 2011). RRM communities face economic, environmental, institutional, technical, and sometimes social restraints to improving their access to secure water resources, to such a degree that they cannot meet these challenges on their own; these challenges are compounded by having limited access to services and support networks (Mahmud et al., 2007; McCommon et al. 1990). RMM communities typically have a population of less than 5000 (McCommon et al., 1990).

Water security is defined as the sustainable access to affordable and reliable quantities of water, of suitable quality to enable all persons to lead healthy, dignified, and productive lives, including neighbours and future users (Calow et al., 2010; Cook and Bakker, 2012; MacDonald and Calow, 2009). Secure water supply depends on and impacts many physical, social, economic, political, and institutional factors both in the community and the broader context in which they are found. Therefore, an holistic orientation to the assessment, development, and management of water supply is required for solutions to be sustainable.

Experience has shown that the sustainability of water supply in RRM communities is further influenced by community participation (Katz and Sara, 1998; MacDonald et al., 2005; McCommon et al., 1990; Narayan, 1995; UNICEF, 1999). There is some disagreement on the kind of participation necessary; the critical issue however is that the decision-making authority rests with the community (Harvey and Reed, 2006; MacDonald et al., 2005; McCommon et al., 1990). One effective way to empower communities for decision-making is to support them through the generation of their own knowledge rather than simply providing it to them (Narayan, 1993). This process, referred to as participatory evaluation, promotes a better internalization of the results, which can empower community members to make informed decisions and take action (Levison et al., 2011; Narayan, 1993).

Indicators are parameters that simplify the representation of a phenomenon and/or environment. Indices are composites of indicators, and are used for the same purpose. Both indicators and indices are used for evaluating complex realities and communicating the results (OECD, 2003; Sullivan, 2002). They are particularly useful for communicating to non-technical audiences and the wider public (Streeten, 1994). Their ability to simplify the evaluation and communication processes has been harnessed little, if at all, for use in and by RRM communities to analyze their water resource security.

1.2. Scope and Objectives

The purpose of this research is to develop a prototype computer-based program, **'Community Self-Water Assessment Tool'** (Community-SWAT), to support RRM communities in an holistic self-assessment of their water security. The following objectives were designed to meet this goal:

1. Develop a framework of critical elements for water security in RRM communities populated with indicators and standards used for evaluation;

2. Develop Community-SWAT in Microsoft® Excel; and

3. Beta-test Community-SWAT using three RRM Kenyan communities to assess its ability to differentiate water security issues within and between communities.

Objective 1 was achieved through a review of pertinent literature on water security indicators and indices in RRM communities. The key outputs were a consolidated list of relevant water security indicators and their standards for evaluation within a framework for water security for RRM communities.

A literature review was conducted to identify relevant indices at the community and basin levels within the Engineering Village database for articles written in English from 1990-2012 with various permutations of key terms[1] in the subject, title, and abstract. Literature was selected for: 1) its relevance to RRM communities, which was determined by its geographical context being in a LMIC at watershed or sub-watershed scales; and 2) its use of an organizational framework. Outside this scope, a broad reading of other water sustainability literature was incorporated for a fuller representation of the dimensions and types of measures used to evaluate rural water supply sustainability. Additionally, the present author together with his supervisors have included additional indicator suggestions to fill any information gaps. A summary of the references used is provided in Table 1.

[1] Key terms included: water; index; security, sustainability, vulnerability; rural, community, watershed.

Table 1 Summary of references identified from literature search

Reference	Name of index	Context*	No. of dimensions	No. of components	No. of parameters
Sullivan et al., 2003	Water Poverty Index	Index	5	-	22
Giné and Pérez-Foguet, 2010	Water Poverty Index (modified)	Index	5	-	25
Pérez-Foguet and Giné, 2011	Enhanced Water Poverty Index	Index	5	13	42
Chaves and Alipaz, 2007	Watershed Sustainability Index	Index	4	-	15
PRI, 2007	Canadian Water Sustainability Index	Index	5	-	15
Alessa et al., 2008	Artic Water Resource Vulnerability Index	Index	2	9	25
Vishnudas et al., 2008	No name	Index	4	-	18
Xiao et al., 2007	No name	Index	4	8	21
Henriques and Louis, 2011	Critical Factor Analysis	Index, decision-support	8	-	30
Garfi and Ferrer-Martí, 2011	n/a	Decision-making criteria guide	4	12	33
Baguma et al., 2010	n/a	Predictive variable modelling	-	-	16
Davis et al., 2008	n/a	Predictive variable modelling	-	-	41
Hoko and Hertle, 2006	n/a	Water project assessment	6	-	21
Narayan, 1993	n/a	Participatory assessment guide	3	10	33

* All “index” references were identified within the scope of the literature search. Other references in this table were incorporated based on a broader reading of water sustainability literature. Additionally, other literature were used to expand on a single indicators: Alkire and Santos, 2010; Guo and Baetz, 2007; WHO and UNICEF, 2012b; WHO, 2011.

Objective 2 was achieved through specifying design criteria, adapting the framework and indicators resulting from Objective 1, and developing the program in Microsoft® Excel. The key output was the Community-SWAT program in prototype form that was designed to meet the unique needs of RRM communities.

- Specific design criteria include a minimal reliance on historical data, the use of qualitative response options, a systematic assessment, simplicity of use, transparency of the processes, meaningful and interactive outputs, and flexibility so as to maximize its usefulness for RRM communities around the world.

- Two suites of indicators are used for a two-part assessment to represent the broader environmental, institutional, and health resources of the community (Part 1: Community Assessment) as well as the individual locations where community members collect water (Part 2: Water Points Assessment). The Community Assessment is divided into six dimensions: water resources, environment, health and hygiene, community capacity, water committee, and external support. The Water Points Assessment is also divided into six dimensions: quantity, quality, reliability, operation and management, distance to water points, and access. These dimensions are further divided into components (and subcomponents for the Community Assessment portion), which are populated with indicators, each being represented by a question in the assessment tool.

- A flexible parameter list allows users to skip irrelevant or unanswerable questions. A dynamic weighting system is thus employed to calculate aggregation weights based on the number of actual responses.

- As the quality of data used for the assessment will vary, Community-SWAT allows users to assign a confidence rating to each question, which is then presented as a part of the output so that the quality of data can be considered in the interpretation of output.

- An interactive dashboard displays the results and allows users to query different aspects of the assessment.

Objective 3 was achieved through the collection and analysis of data relevant to water security in three RRM communities and using it within Community-SWAT. The key outputs were beta-test results and a sensitivity analysis.

- The primary sources of data for Community-SWAT were collected through a household questionnaire and water point surveys, which included geocaching, sanitary inspections, and testing for several microbiological parameters.

    - Samples were collected from community water sources during the September-October dry season in 2011 and analyzed for microbiological parameters. Sanitary inspections were completed at each water point visited. The results were analyzed using Statistical Analysis Software (SAS) and Microsoft® Excel.

    - A household questionnaire was designed to survey women responsible for providing water in their home to gauge water collection and storage practices, hygiene, health, and preferences for future water sources at the household level. The survey results were entered into a database twice by independent parties. An electronic line-by-line comparison was conducted, and discrepancies were resolved by consulting the original questionnaires.

  - Other data included community documents and a key informant questionnaire that was designed to survey community persons knowledgeable in community water affairs, including raising livestock, agriculture, seasonal characteristics and community water needs.

- For the beta-test, data were entered into Community-SWAT by the thesis author. Questions for which information was unavailable were left unanswered. Questions for which limited information was available were answered and assigned a low confidence rating. For the Water Points Assessment, some household questionnaire responses were unusable based on missing responses or contradictory information; a low confidence rating was assigned accordingly to indicate that the data may not be representative.

- A two-stage sensitivity analysis was conducted using the beta-test data.

  - The first stage consisted of calculating and plotting the theoretical dimension weight calculations for various permutations of the number of resident components, subcomponents, and questions. The purpose of this was to demonstrate possible values of the weights according to different scenarios (since these values can vary) and to derive a rule of thumb to suggest a number of questions that should be answered by users.

  - The second stage consisted of the systematic omission of individual responses and recording the resulting change in dimension scores, which examined the effect of the flexible question list on the output.. The following iterative procedure was used for each response within each of the eight dimensions. First, an answered question was targeted. Second, the targeted question's score (x_{ijkl}) and dimension weight (w_{ijkl}) were recorded. Third, the question's response was removed and the resulting dimension score (x_i*) was recorded. Fourth, the targeted question's response was re-entered.

This research is in partnership with the United Nations University Institute for Water, Environment and Health (UNU-INWEH) through the collaborative graduate programme *Water Without Borders* (WWB). Community-SWAT was designed as a front-end piece to *HydroSanitas*, a web-based knowledge portal and decision-support system that will allow stakeholders to access and exchange information related to their experience with water and sanitation solutions.[2] Both

[2] More information is available at http://inweh.unu.edu/Health/SafeWaterProvisioning.htm.

Community-SWAT and *HydroSanitas* build upon an ongoing research initiative within UNU-INWEH to examine local linkages between water, environment and health.

1.3. Structure of Thesis

This thesis has been prepared according to McMaster University's regulations for theses consisting of material that has been previously published or is planned for publication. Chapters 2 and 3 each consist of a paper that is planned for publication in a refereed journal. Each paper includes relevant introduction and background sections.

Chapter 2 reviews pertinent literature for water security indicators in RRM communities and organizes the indicators and the standards for their evaluation into a framework consisting of nine dimensions. Chapter 3 discusses the development of Community-SWAT and the results from an applied case study in three communities. Chapter 4 summarizes the conclusions to this research and recommendations for further development of Community-SWAT.

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CHAPTER 2

WATER SECURITY ASSESSMENT INDICATORS: THE RURAL CONTEXT

The contents of this chapter are planned for submission in *Water Resource Management* as: Newton, J.J., Dickson, S.E., Schuster-Wallace, C.J. 2013. Water security assessment indicators: the rural context.

Abstract

An increasing number of factors pose challenges to the development and management of water resources in rural, remote, or otherwise marginalized (RRM) communities. Indicators and indices have been developed for evaluation, prioritization, and decision-making at local and supra-local scales. Indicators and indices are useful assessment tools as they simplify the modeling process and provide results in an accessible format. The purpose of this paper is to consolidate a list of indicators (n=289) from a review of community- and basin-level indices and a selection of other literature within a water security framework for RRM communities. A detailed discussion of each of the nine dimensions within the framework is provided. This paper concludes with some general remarks on the standards used for evaluation, the reliance upon historical and measured data, suggestions for improving the descriptive clarity where it is lacking, and the prospect of the use of these indicators by community members.

2.1. Introduction

In 2010, the Millennium Development Goal (MDG) to halve the number of people without access to improved drinking water was achieved five years ahead of schedule (WHO and UNICEF, 2012a). However, over 780 million people remain without access to improved drinking water, and the sanitation target is highly unlikely to be met by 2015, leaving 2.5 billion people without improved sanitation. Those left without improved access tend to be poor or live in rural areas, or both, mostly in low- and middle-income countries (LMICs) (WHO and UNICEF, 2012a).

Although development has been significant in recent decades, rural, remote, and otherwise marginalized (RRM) communities pose several challenges which have resulted in mixed success in providing improvements to water supply and sanitation services. These communities tend to be dispersed agricultural populations with 5000 or fewer members; have reduced access to infrastructure, services, and external support; and face severe technical, economic, and institutional constraints to improving water supply (McCommon et al., 1990). In addition, data in these communities are typically sparse.

One approach to understanding water issues is to use indices. Indices are useful because they attempt to simplify complex realities, measured by different indicators, into a single index or several sub-indexes. When applied to several geographic areas at once, they offer an objective method for distinguishing between regions of high and low need (Sullivan et al., 2003). In general, indicators and indices have been developed to facilitate assessment, track progress, prioritize need, and inform decisions. More specifically, indices have been developed to assess water security at the community scale (Alessa et al., 2008; Giné and Pérez-Foguet, 2010; PRI, 2007; Sullivan et al., 2003) and the basin scale (Chaves and Alipaz, 2007; Pérez-Foguet and Giné, 2011; Vishnudas et al., 2008; Xiao et al., 2007).

At supra-local scales, the use of indices and indicators is common and diverse enough to warrant the writing of several reviews and inventories. Brown and Matlock (2011) trace the historical development of water scarcity indices, while Walmsley et al. (2001) reviewed indicators used by organizations for evaluating catchment management. Detailed reviews and inventories of water-related indicators have been compiled and used at regional and national scales (Dunn and Bakker, 2009; EPA, 2002, 2008). In addition, the fourth edition of the *World Water Development Report* (UNESCO, 2012) offers a revised set of 52 global water indicators, and a set of key environmental indicators has been published by the Organization for Economic Cooperation and Development (OECD, 2004). While these reviews and inventories are helpful, their scale of application makes them of marginal relevance to RRM communities.

Seeing that the use of community-level water vulnerability indices has grown in use, there is a need for a review, particularly with respect to the indicators. Recently Plummer et al. (2012) reviewed the scales, contexts, and comprehensiveness of water vulnerability assessment tools at multiple scales. This paper embarks on a complementary task to Plummer et al. (2012) through a detailed review of the specific indicators used in community-level indices. Specifically, this paper provides an organized review of these indicators, how they are being measured, and the standards by which they are evaluated. The key output of this review is a comprehensive and flexible list of indicators to serve as a reference for selecting parameters for future studies and tools. The review was achieved by compiling a list of indicators that have been used in community water security assessments, together with standards for evaluating them on the security-vulnerability continuum, organizing the indicators into a framework to capture an holistic understanding of water security in RRM communities, and discussing the results.

This paper is organized as follows. Section 2.2 discusses water security and presents the framework used in this review. A summary of the methods is described in Section 2.3. A brief background to indicators is given in Section 2.4. A review of indicators used in water security assessments is presented in Section 2.5. Finally, Section 2.6 concludes with some overall observations on indicator use and evaluation in general, and concerns that are specific to RRM communities.

2.2. Water Security: A Comprehensive Framework

The state of water resources has been framed through the use of terms such as "sustainability", "vulnerability", "stress", "scarcity", and "poverty". The term "water security" has also grown in use. Cook and Bakker (2012) document its growing and broad application in the natural and social sciences. Various definitions of water security exist in the literature, each reflecting the perspective and purpose of their different applications.

Cook and Bakker (2012) identified four complementing themes in water security frameworks: availability; water-related hazards and vulnerability to those hazards; human needs; and, environmental sustainability. They argue for a conceptual framing that is comprehensive and integrative, which by definition requires consideration not only of environmental, but social and economic conditions. Partly as a result of the large number of prospective variables, Cook and Bakker (2012) identify the "operationalization" of this framework as a significant drawback. Therefore, when it comes to application, they suggest narrowing the definition of water security to focus on issues of relevance.

A comprehensive conceptual framing applies to the scale of analysis as well. Some water security frameworks aim for relevance at all scales (Witter and Whiteford, 2007 as cited in Cook and Bakker, 2012; Global Water Partnership, 2000), while others use the watershed scale (Norman et al., 2010). The watershed scale is increasingly popular because it provides a well-defined system for balancing availability and demand from an hydrological perspective. However, watershed boundaries rarely align with jurisdictional boundaries, invoking challenges of transboundary water management.

In RRM communities, local level assessments are warranted for two reasons. First, decision-making in RRM communities must happen at this level and include community participation in order for any water supply scheme or intervention to be sustainable (Katz and Sara, 1998; MacDonald and Calow, 2009; McCommon et al., 1990; Narayan, 1995; UNICEF, 1999; WELL, 1998). Second, large variations in physical and socio-economic factors can exist between nearby communities which can be hidden in regional averages (Sullivan et al., 2003).

From the user's perspective, water sources can vary in five quasi-independent ways: quantity, quality, accessibility, affordability, and reliability (MacDonald and Calow, 2009; WHO, 2011). A working definition of **water security** for RRM communities, then, requires **sustainable access to affordable and reliable quantities of water, of suitable quality, to enable all persons to lead healthy, dignified, and productive lives, including neighbours and future users.**

The framework for RRM water security that resulted from the indicator review is provided in Table 2. The key elements are divided into dimensions, which focus on water security from a particular perspective. Each dimension is likewise divided into components and sub-components, where each sub-component is made up of one or more indicators from the literature (Table 3). Where available, the standards used for evaluation are also included.

Table 2 Framework used in the review of community water security assessment index indicators

Dimension	Symbol	Perspective	Components
Water Resources	R	The natural, raw water resources available to the community.	R1 Quantity R2 Variability R3 Quality
Developed Sources	S	The state of water resources currently accessed by the community.	S1 Supply S2 Reliability S3 Quality
Infrastructure Appraisal	I	The infrastructure through which water is protected, treated, and/or supplied.	I1 Appropriateness for community I2 Impact on community
Operation and Management	M	The systems and institutions in place for the operation and development of community water sources.	M1 Capacity M2 Administration M3 Community involvement M4 Miscellaneous social factors
Access and Equity	A	The ability of current water users to access sufficient quantities of water.	A1 Physical A2 Social
Environment	E	The mutually dependent relationship between water and the natural environment.	E1 Aquatic E2 Terrestrial
Health and Hygiene	H	Household knowledge and behaviours related to water and hygiene, including access to support resources.	H1 Health H2 Knowledge H3 Behaviour H4 Access
Community Capacity	C	The human capital and resources within a community that are available for water resource management.	C1 Knowledge capital C2 Financial capital C3 Social capital
External support	X	The greater social and political context in which the community is situated.	X1 Government and policy X2 Linkages

2.3. Methods

The indicators and organizational framework presented in this paper (Table 2 and Figure 1) resulted from an investigation of the pertinent literature on water security indicators and indices in RRM communities. A literature review was conducted to identify relevant indices at the community and basin levels within the Engineering Village database for articles written in English from 1990-2012 with various permutations of key terms[3] in the subject, title, and abstract. Literature was selected for: 1) its relevance to RRM communities, which was determined by its geographical context being in a LMIC at watershed or sub-watershed scales; and 2) its use of an organizational framework. Outside this scope, a broad reading of other water sustainability literature was incorporated for a fuller representation of the dimensions and types of measures

[3] Key terms included: water; index; security, sustainability, vulnerability; rural, community, watershed.

used to evaluate rural water supply sustainability. Additionally, the authors have suggested additional indicators to fill information gaps (Figure 1 and Table 3).

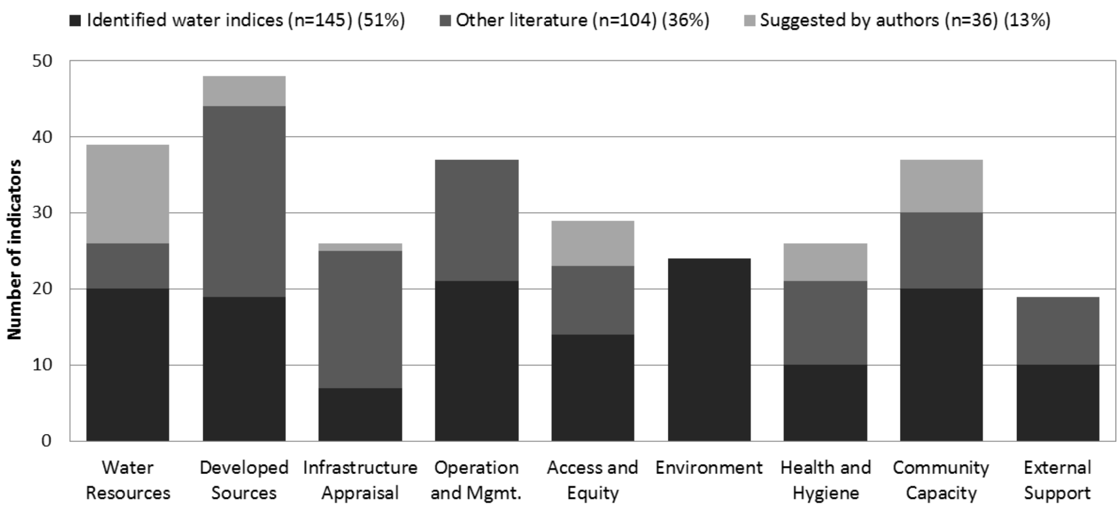

Figure 1 Identified RRM water security indicators (n=285), by dimension and source. Indicators from "Identified water indices" are those within the scope of the literature selected, while those from "Other literature" were based on a broad reading of water sustainability literature, as described in the text.

As the frameworks differed for each reference, the following changes assisted the organization of the indicators. First, the indicators are organized into the framework proposed in this paper. Second, a few indicators were originally used as proxies to measure a parameter for which limited data were available; some of these have been included without reference to the parameter they were approximating. For example, Alessa et al. (2008) used the existence of water quality data as a proxy to evaluate water quality; this has not been included under water quality, but rather operation and management. Finally, some indicators were very similar with subtle variations between sources; in some cases these have been given identical names, with the subtleties retained in the evaluation standards.

2.4. Indicator Background

An indicator can be defined as "a parameter, or a value derived from parameters, which points to, provides information about, [or] describes the state of a phenomenon/environment/area, with a significance extending beyond that directly associated with a parameter value" (Organization for Economic Cooperation and Development (OECD), 2003, p. 5). The first purpose of indicators is to simplify model complexity by reducing the number of measurements and mathematical processes that would ordinarily be used to develop a more precise representation (Norman et al., 2010; OECD, 2003). Second, indicators serve to simplify communication to end-users or the general public (Norman et al., 2010; OECD, 2003), which is arguably their ultimate purpose. Indicators can therefore be useful for bridging the science-policy and science-society gaps, which are often cited as one of their major uses (Alessa et al., 2008; Chaves and Alipaz, 2007;

Giné and Pérez-Foguet, 2010; Pérez-Foguet and Giné, 2011; PRI, 2007; Sullivan et al., 2003; Xiao et al., 2007).

Standards are needed to select appropriate indicators. OECD (2003) offers three basic criteria. First, indicators should be relevant and useful for both users and policy. Specifically, they should be easy to interpret, representative of the bigger picture, respond to and reflect changes in the system, and have an associated reference value or benchmark for interpreting what the values mean. Second, they should be analytically sound, meaning that they are well-defined, based on standards and/or consensus, and can be linked to economic models and forecasting. Third, indicators should be measureable, meaning that data are available (or reasonably attainable), properly documented, and easily updated. Although OECD works at large scales and is interested in international comparisons, these criteria are useful for critiquing water security indicators when viewed through the lens of RRM communities (cf. Dunn and Bakker, 2009). In reality, these standards compete with one another and thus compromise should be expected in evaluating and choosing an indicator (or indicator set) (OECD, 2003). In the RRM community context, because data tend to be scarce, the choice in some cases may be between one indicator and none.

2.5. Indicator Compilation and Review

Dimension 1: The first dimension identified was **water resources** which is subdivided into quantity, variability and quality components.

The **quantity (R1)** of available natural water resources should consider surface water, groundwater, and precipitation. Many indices combine water quantity measures into a single indicator, either for simplicity or because they cover large geographic areas and multiple sources (Chaves and Alipaz, 2007; Sullivan et al., 2003; Xiao et al., 2007). Alessa et al. (2008) evaluated surface water by accounting for river flows and surface water storage, with the latter approximated by the proportion of area that is surface water. PRI (2007) emphasises the assessment of the total *renewable* availability to account for environmental water needs (cf. Dimension 6). In data-limited regions, the mean annual precipitation and aridity indexes (a measure of climate dryness) have been used as proxies for total availability (Pérez-Foguet and Giné, 2011), as has a qualitative five-point scale (Henriques and Louis, 2011). Groundwater in RRM communities is often more reliable than precipitation and surface water sources and less susceptible to contamination, as the subsurface material provides some degree of protection, particularly for confined aquifers, and is therefore less likely to require treatment (MacDonald and Calow, 2009). Groundwater availability can be quantified from yield, hydraulic conductivity, and hydraulic gradient measurements.

Several authors apply Falkenmark's Water Stress Indicator to define upper and lower score bounds. Falkenmark states that water resources are stressed below 1700 m^3/capita/year, scarce below 1000 m^3/capita/year, and the principal livelihood constraint when below 500 m^3/capita/year (Falkenmark, 1989 in PRI, 2007). The application of this indicator has varied, however. PRI (2007) evaluated the lower and upper scores between the 500 and 1700 m^3/capita/year benchmarks, respectively, whereas others (Chaves and Alipaz, 2007; Pérez-Foguet and Giné, 2011) have evaluated the same upper and lower bounds between 1700 and 6800 m^3/capita/year – four times Falkenmark's stressed level.

Variability (R2) of available quantities is often accounted for in these indices. Variability can be accounted for in quantity measurements (e.g. by a strict use of annual average values). Sullivan et al. (2003), for example, used only dry season data for seasonally variable indicators. This approach allows water stress to be more representative, while it also risks overlooking its significance of variability as its own issue.

Water availability may vary on both seasonal and inter-annual scales, however most references include only one of these scales. A simple seasonal measure is the number of months per year with water (Giné and Pérez-Foguet, 2010), that can be evaluated by precipitation patterns (i.e. wet and dry seasons), river flows (i.e. flowing or not), or groundwater yields. Stream flow variations can be evaluated by the difference between the maximum and minimum monthly flows, normalized by the annual average. Environments with high variability indicate less stable and dependable resources and therefore higher vulnerability (Alessa et al., 2008). Alternatively, a runoff ratio (Q_5/Q_{95})[4] can be used as in PRI (2007). Gleick (1995) suggests that values greater than 3 indicate vulnerability, although this threshold is based upon an evaluation of major US water systems and therefore may not be hold true in LMIC contexts.

An ideal inter-annual variability measure is the per capita water availability relative to the long-term average (Chaves and Alipaz, 2007). The variance in annual averages of precipitation, river flows, and surface water storage (approximated by change in surface water area) over a 30-year period were used by Alessa et al. (2008), with lower values indicative of a more stable (and dependable) climate. Although any of these indicators would be insightful, data requirements will limit their use in the RRM context. As data are more likely to be available at the basin rather than the community level, such data should be used cautiously. Using historical satellite imagery, Alessa et al.'s (2008) surface water storage proxy may find more use. On a shorter time scale, change in groundwater levels may be evaluated using a simple function that rewards levels that are increasing or stable (PRI, 2007).

Extreme hydrological events should be considered explicitly, although they are arguably a subset of inter-annual variability. Traditionally, extremes are statistically defined as outliers and/or the upper n^{th} percentile of events. Where data exist, extreme events should be evaluated. Alternatively, personal recall may be used as a surrogate, whereby a community can incorporate an unusually extended and/or devastating event into their assessment.

[4] Q_5 and Q_{95} represent the rates of flow at the fifth and ninety-fifth percentile, respectively, for a given time series.

The **quality (R3)** of natural water resources should be assessed in terms of contaminants and pollution sources. Knowing the quality of all available water sources can determine their best combined use and treatment needs. The WHO's (2011) *Guidelines for Drinking Water Quality* offers evidence-based guidelines for physical, biological, chemical, and radiological contaminants that pose risks to human health. Faecal pathogens from humans, animals, and birds cause the most acute health effects and therefore present the greatest microbiological risk. In fact, a mere five pathogens are responsible for most of the waterborne and hygiene-related illnesses around the world: *Cryptosporidium parvum*, *Giardia*, *Campylobacter*, *Salmonella*, and *E. coli* O157:H7 (WHO, 2012). The most common indicators of faecal contamination are *E. coli* and thermo-tolerant coliforms (WHO, 2011). Other pathogens associated with water include viruses and helminthes (WHO, 2011). Chlorine-resistant organisms (e.g. *Cryptosporidium*) are of notable concern, as chlorine is widely employed as a disinfectant.

Health risks from chemical contaminants are generally due to long-term exposure at unsafe levels, and may be anthropogenic or occur naturally. As the number of potential pollutants in this category is numerous, the selection of specific parameters will be context-dependent. Arsenic, fluorides, nitrite, nitrate, and manganese are of notable concern due to their effects on human health. In some situations radiological parameters, most notably radon, are also important for consideration (WHO, 2011).

Turbidity (a measure of suspended solids content) affects disinfection efficiency and so its removal is an important consideration in treatment technology options (WHO, 2011). Turbidity is a useful water quality proxy, particularly against chlorine-resistant pathogens, as microorganisms often attach to suspended particles (WHO, 2011). The cloudiness of turbid waters may also reduce consumer acceptability. WHO advises that limited-resource communities aim for turbidity values <5 NTU, and <1 NTU where possible. Effective disinfection requires that turbidity be <1 NTU.

Depth to water table can be used as a proxy indicator for groundwater vulnerability and/or quality. Shallow or unconfined aquifers are the most susceptible to contaminants, whereas deep and/or confined aquifers are more protected from contamination. There are exceptions, however. Wells or boreholes with poor sanitary completion, or improper construction, can short-circuit this natural protection (Howard et al., 2003), as can fractures and root holes in consolidated media.

Pollution sources present contamination hazards and their proximity to water resources can be used to identify approximate risks, particularly when contaminant-specific data are unavailable. Upstream development includes any type of human interaction, including industry and other settlements. Other indicators include livestock and wildlife population densities, the proportion of the community practicing open defecation, and contaminants resulting from agricultural practices.

Dimension 2: Developed sources are water points that are accessed by community members and may have some level of physical infrastructure designed to protect, treat, store, and/or distribute water. The level of water point development may be very simple, and includes hand-dug wells and springs that are merely fenced. This dimension is subdivided into supply, reliability, and quality components.

The primary indicator for evaluating **supply (R1)** is the daily per capita quantity accessed. A demand-based approach should be used to evaluate supply adequacy (Katz and Sara, 1998), which includes water for drinking, food preparation, hygiene, washing, and productive uses (e.g. agriculture, livestock, or other industry). Evaluation will depend on the water usage norms within the country, as higher quantities are used in higher-income countries (e.g. PRI, 2007; Alessa et al., 2008) than typical LMICs (e.g. Henriques and Louis, 2011). The internationally recognized minimum standard for basic access is 20 L/capita/day (Lpcd) to meet consumption and basic hygiene needs (WHO and UNICEF, 2012a). This can be further disaggregated into a minimum of 7.5 Lpcd for consumption (drinking and food preparation); 20 Lpcd for consumption and basic hygiene; 50 Lpcd for consumption, basic hygiene, laundry, and bathing; and 100 Lpcd to meet all domestic and productive water needs (Howard and Bartram, 2003; cf. Gleick, 1996). While these values are helpful for assessing domestic water requirements, the quantities actually accessed by households are strongly linked to the distance between household and source (Howard and Bartram, 2003) (see Dimension 5, Access). A qualitative evaluation based on levels of supply adequacy has also been used (Giné and Pérez-Foguet, 2010).

The potential for rainwater harvesting must also be considered (cf. Dimension 1, Water Resources). The storage required is a function of local precipitation characteristics, demand, and desired reliability (Guo and Baetz, 2007). Where rainwater harvesting is practiced, storage facilities can be benchmarked against an external standard or against the community's expectations.

Losses to the system are a function of the age, type of material, construction quality, and unaccounted withdrawals (i.e. illegal connections), which may find use as proxies to estimating losses. The simplest means of assessing losses due to infrastructure is through leaks, whether they are observed (Davis et al., 2008) or recorded (PRI, 2007). Although centralized systems, and therefore the potential for illegal connections, are not as common in RRM communities, they should be considered with a complete analysis.

The capacity of water points should consider the number of users and the expected infrastructure lifetime. The maximum number of users per water point is a function of flow rate, queuing, and seasonal variations in supply and demand (SCHR, 2004). Maximum users for different types of water points have been previously approximated (SCHR, 2004). Infrastructure lifetime is measured by the number of years before either demand exceeds supply capacity, or the infrastructure is expected to fail, with the population growth rate and system age as key parameters respectively (PRI, 2007). Less technical, yet perhaps an insightful approach is to survey the community's opinion of the system's expected lifetime (Davis et al., 2008). Through polling both households and water committees, Davis et al. (2008) found that household members are generally more optimistic on this front.

Reliability (S2) measures the variability of supply. These indicators are influenced by factors related to operation and management, storage capacity, and the variability of the water resource. Key indicators include the proportion of facilities currently operational (Davis et al., 2008; Giné and Pérez-Foguet, 2010; Pérez-Foguet and Giné, 2011) and historical supply disruptions (Davis et al., 2008; Giné and Pérez-Foguet, 2010; Hoko and Hertle, 2006; PRI, 2007). Breakdowns can result from missing parts, depleted resources, insufficient operating budgets, or user disinterest and neglect, and may be investigated through a questionnaire developed by Howard (2002). Acceptable levels of non-operationality differ in the literature. Giné and Pérez-Foguet (2010) assign a perfect score if it is less than 5% of the time (17 days/year), while others suggest a maximum of 2% (7 days/year) based on field experience (Carter, 1996 as cited in in Hoko and Hertle, 2006). When estimating breakdown histories, the source of information is important to consider. Davis et al. (2008) compared questionnaire answers from operators, households, and women's focus groups, and found that the latter two groups reported greater breakdown frequencies and durations, possibly due to different perceptions of what constitutes as a 'breakdown'.

Reliability is also a function of source type diversity and storage. Alessa et al. (2008) considered communities to be less vulnerable to supply variability if they used a greater diversity of sources, both in number and type (i.e. surface, groundwater, or rainwater), as they would have other alternatives if facing breakdowns or resource variability. A suggested system storage parameter is the tank capacity per capita. This is particularly important where supply is highly variable, as it enables RRM communities to regulate natural water supply (see also Guo and Baetz, 2007).

One of the main reasons for developing water points is to improve drinking water **quality (S3)**. WHO (2011) recommends a multiple-barrier approach to ensuring safe drinking water quality. A barrier provides either protection to reduce the risk of contamination, or treatment for contaminant removal. The use of multiple barriers reduces the overall risk of contamination that leads to waterborne illnesses. Unless treated, WHO (2011) recommends against consuming surface water and shallow groundwater sources as they are highly susceptible to contamination. Sanitary inspection forms can be used to evaluate the number and type of hazards and pathways that increase the risk of contamination (e.g. lack of fencing, faulty diversion ditches, faeces in area, compromised construction) (WHO and UNICEF, 2012b). At minimum, water points in RRM communities should have a fence or other physical barrier to restrict people and animal access. Howard et al. (2003) modelled microbial water quality against sanitary risk assessment parameters and found that the faecal contamination of protected springs was primarily caused by rapid recharge through localized pathways following rainfall events (see also Godfrey et al., 2006). Furthermore, one index evaluated barriers based on a combination of protection and treatment (Giné and Pérez-Foguet, 2010).

The level of water and wastewater treatment is also important to water quality. Alessa et al. (2008) rated community resilience based on the combination of available drinking water and wastewater treatment processes. Their evaluation approach is useful for communities that have centralized treatment systems, particularly for wastewater, however it requires modification for communities where decentralised solutions are more prevalent. Another approach is to evaluate the treatment technologies themselves in terms of their ability to treat raw water of differing qualities (Garfì and Ferrer-Martí, 2011). The necessity of treatment should also be considered, as it is not required for some developed groundwater sources that are well maintained.

Ideally, appropriate biological and chemical parameters would be monitored on a routine basis to assess the water quality. Faecal indicators are the most important parameters to monitor, as faecal contamination is responsible for the majority of acute illnesses (WHO, 2011). In communities that have multiple developed sources, the percentage of systems that test positive for faecal contamination should be evaluated (WHO, 2011; Pérez-Foguet and Giné, 2011). In resource-limited areas, inexpensive and reliable rapid-assessment techniques exist for measuring faecal contamination (Chuang et al., 2011; McMahan et al., 2011; WHO, 2002), that are accessible to community members (Silliman et al., 2009).

Where applicable, agricultural water quality should be considered (Garfì and Ferrer-Martí, 2011). The standards differ from that of drinking-water, and notable concerns include salinity, ion toxicity, excess nitrogen, abnormal pH, and salt deposition (FAO, 1994). Due to higher nutrient content, domestic grey or black wastewater may be desirable for crop irrigation. This practice may, however, present a health risk, the magnitude of which will depend on farming, hygiene, and food preparation practices.

If drinking water from developed sources are unacceptable, users may seek out other more traditional sources that are at much higher risk for faecal loading. Physical parameters, including taste, appearance, and odour are the primary indicators used to evaluate a source from a consumer's perspective (Garfì and Ferrer-Martí, 2011; Hoko and Hertle, 2006; WHO, 2011). Hardness is another consideration and can be a barrier to community hygiene as soap will lather poorly. Hoko and Hertle (2006) use community perceptions of soap use in the community as a proxy for hardness; soap use however is likely to depend on too many factors (e.g. availability, affordability, perception, education) to be considered a reasonable proxy. Temperature is an important indicator for palatability, bacterial growth, and some treatment processes (WHO, 2011).

Dimension 3: Infrastructure appraisal evaluates the **appropriateness (I1)** of any infrastructure of Developed Sources (Dimension 2), and its **impact (I2)** on the community. To be sustainable, water points must be suitable to the local economic, social, and environmental context. Failure to recognize this has contributed to the high failure rates of water supply interventions in the past (Katz and Sara, 1998; McCommon et al., 1990).

Operating costs must be fully accounted for and affordable. Otherwise service will be erratic at best, and community members will resort to using sources that are unprotected yet more reliable. The revenue sufficiency ratio (RSR) is useful for assessing the appropriateness of operating costs. Due to data constraints, Davis et al. (2008) approximated this using the water committee's judgment of the revenue being 90 percent sufficient or better. Alessa et al. (2008) used the hydraulic gradient as an operating cost proxy, as it is proportional to the energy required for pumping (Alessa et al., 2008).

From a societal perspective, the most important impact to be assessed is the change in health. This can be measured through questionnaires (e.g. Hoko and Hertle, 2006), or through pre- and post-intervention clinic visit trends. The proportion of members benefitting from improvements can be assessed as a measure of positive societal impact (cf. Garfì and Ferrer-Martí, 2011). The economic impacts resulting from infrastructure development include changes in income, changes to the cost of water, and employment opportunities (Table 3).

In addition to the net benefits of improving water supply, technological interventions can have unforeseen consequences, including conflict between different groups, loss of social networks, and environmental impacts (see also Dimension 6: Environment). Communities must also recognise that more accessible water may lead to increased waste and pollution, including wastewater, treatment by-products, solid waste, emissions, noise, and landscape impacts (Garfì and Ferrer-Martí, 2011). Some technologies and pricing structures may encourage poor water conservation, particularly when free or heavily subsidised.

Dimension 4: Community **management** of water supplies is recognized by some as an integral component for long-term sustainability (MacDonald et al., 2005; McCommon et al., 1990). Others have debated this given the number of failures and offer alternatives for management by the household, small-groups, and private entities (Harvey and Reed, 2006). For the purpose of this paper, the important message is that communities vary in their **capacity (M1)** for management, and this should be assessed prior to investing them with responsibility (Harvey and Reed, 2006). An innovative approach is seen in Henriques and Louis (2011), where various community capacities are modelled against the those required by proposed water services. Where capacity is sufficient, communities still require support from local government or agencies to ensure the long-term, satisfactory operation of water services (Davis et al., 2008; Harvey and Reed, 2006). Two of the most common reasons for failed community management are a lack of remuneration and loss of institutional memory through employees leaving or dying (Harvey and Reed, 2006; cf. Davis et al., 2008).

Water supplies managed at the household level are a viable alternative for communities lacking community-level management capacity (Harvey and Reed, 2006). While not always feasible, households can be more willing to contribute more finances to household supplies than to community-shared supplies (Sutton, 2003 as cited in Harvey and Reed, 2006). Indicators to assess the household management are absent in current water vulnerability indices, however. One study indicated that training and the availability of operating instructions were statistically important factors for the sustainability of household-managed rainwater harvesting (Baguma et al., 2010).

Once in place, ongoing **administration (M2)** activities are necessary. Specifically, policies are required to define roles, responsibilities, and procedures. Indicators include the presence of a community water action plan (Alessa et al., 2008), the level of community legislation (Henriques and Louis, 2011), the extent of record-keeping (e.g. meeting minutes, financial records, repairs; Hoko and Hertle, 2006), and the existence of water quality records (Alessa et al., 2008). Vishnudas et al. (2008) used community-member ratings to assess administrative capacity regarding items such as policy appropriateness and governance efficiency. Interestingly, Davis et al. (2008) found that the most helpful type of postconstruction support was related to addressing administrative needs.

Opportunities for **community involvement (M3)** are integral for long-term sustainability (Garfì and Ferrer-Martí, 2011) and exist throughout the planning and construction phases and ongoing operation and maintenance. Members can contribute time, money, labour, or materials (Hoko and Hertle, 2006; Vishnudas et al., 2008). Indicators for long-term community involvement include community membership (Baguma et al., 2010; Sullivan et al., 2003), community contributions toward maintenance costs (Hoko and Hertle, 2006), and the quality of community participation with the water committee (Vishnudas et al., 2008).

Social factors (M4) are also important. One of the most common reasons for failed community management is that the water committee loses the community's trust (Harvey and Reed, 2006). This is often related to a lack of transparency, accountability (perceptions of which can be solicited from community members, e.g. Davis et al., 2008) and poor representation as priorities differ among individuals and groups, as do their influence on community affairs (MacDonald et al., 2005). Generally, the interests of women, children and the poor are most likely to be overlooked (MacDonald et al., 2005) and thus representation of gender, class and caste as suggested by Vishnudas et al. (2008) are useful indicators. Other indicators include mutual respect, common goals, and the legitimacy of the water committee's authority (Narayan, 1993).

Dimension 5: Access and equity evaluates the ability of the community to obtain sufficient quantities of water, and the extent to which this varies in different cross-sections of the community. The Joint Monitoring Programme (JMP) for water supply and sanitation measures access by the availability of 20 litres per person per day from an improved[5] source within one kilometer of their home (WHO and UNICEF, 2012a). This indicator should be commended, as it provides

[5] An improved source is one that is likely to protect against faecal contamination through protective works. These include piped water into dwelling or to yard/plot, public taps, tube wells or boreholes, protected dug wells, rainwater, protected springs, and bottled water only when a secondary source of improved water is available (WHO and UNICEF, 2012a)

consistency across large geographic scales, insight at regional and national scales, and has been improved in recent years. It has, however, several shortcomings. First, quality and variability are admittedly not addressed because of the burden of data that would be required to assess these parameters (WHO and UNICEF, 2012a). Potable water quality is instead approximated by the source being ‘improved’ or ‘unimproved’ (WHO and UNICEF, 2012a, 2012b). Seasonal variations can significantly affect the total collection time, and the type and quality of sources being used (Calow et al., 2010). Second, the relationship between total collection time (travel plus queue) and quantity of water collected, which drastically decreases beyond a distance of 100 m or five minutes travel, is ignored (Devi and Bostoen, 2009; Howard and Bartram, 2003). Third, it only deals with domestic water needs, while water for food security is also important (Sullivan et al., 2003), particularly in RRM communities. If these shortcomings were incorporated, the number of people considered to be without access would certainly be greater.

The relationship between collection distance and quantity of water collected has been thoroughly investigated (Howard and Bartram, 2003), and it has been suggested that there are three distance thresholds at which collected quantities are likely to increase (1000 m, 100 m, on-property). Distance may also be assessed qualitatively through a questionnaire with possible responses such as near, moderate, and far (Hoko and Hertle, 2006). Other indicators include the relative accessibility to improved versus unimproved sources (Giné and Pérez-Foguet, 2010), terrain characteristics (as they can prolong travel time or prevent access altogether), danger from wild animals (Sullivan et al., 2003), and the fear/threat of physical or sexual violence.

The **effort (A1.2)** required to collect a given volume of water includes trips per day, queue times, and operational ease. Time spent at the source, either in queue or on water withdrawal can significantly prolong collection time (Sullivan et al., 2003) and may be due to low flow rates, operational difficulties, or high demand. SCHR (2004) recommends a maximum queue time of 15 minutes, while Giné and Pérez-Foguet (2010) use <30 and >120 minutes as upper and lower scoring limits, respectively. Water vulnerability indices do not appear to consider the number of trips per day, although there is some evidence that the number of trips per day reduces to one even just beyond a distance of 100 m (Howard and Bartram, 2003). Hoko and Hertle (2006) assessed the number of strokes required for the borehole or well to discharge. The present authors observed a RRM village that lost its middle generation to HIV/AIDS, and saw a significant collection burden on the grandparents, many of whom were physically incapable of working a hand or foot pump. Therefore, physical health and age must be considered together with effort.

As clean water almost always costs money, **affordability (A2.1)** and willingness to pay are economic measures of access. Affordability may be evaluated by considering the proportion of household income spent on water. Some literature suggests that water becomes unaffordable when it is between 3 and 7 percent of a household’s income (Al-Ghuraiz and Enshassi, 2005; Fitch and Price, 2002; Garfì and Ferrer-Martí, 2011). Other indicators of affordability include a qualitative evaluation through a questionnaire (Vishnudas et al., 2008) measuring the proportion of households in arrears and/or disconnected for late payment (Davis et al., 2008), and the proportion of households that are purchasing water (Baguma et al., 2010).

In this paper we take **equity (A2.2)** to be the fair distribution of both resources and responsibilities. While fair does not necessarily mean identical, with respect to basic access it does mean that no subset of the community should be favoured or disadvantaged due to gender, age, caste, tribe, race, disability, family relation, religion, political alignment, economic status, or other social influence. The burden borne by water collectors can significantly reduce the quality of their life through time and energy requirements and the associated lost opportunity costs (UNICEF, 1999). Gender and responsibility are two pertinent equity issues in RRM communities. In sub-Saharan African households without piped water service, 62% of water is collected by women (WHO and UNICEF, 2012a). While there is nothing inherently wrong with a division of labour, involving women in any and all community water decisions becomes critical for equity and improving the livelihoods of women and girls (UNICEF, 1999).

While widely discussed, measures of social equity are used infrequently in water security indices. Specific measures that have been identified include the percent of water collected by females (Sullivan et al., 2003), an inequality index comparing access levels between families having different housing quality (Pérez-Foguet and Giné, 2011), a discrimination indicator (Garfì and Ferrer-Martí, 2011), and conflict, whether between people or people and animals (Giné and Pérez-Foguet, 2010; Sullivan et al., 2003). Other measures could include the proportion of children less than 15 years of age who are collecting water, and the competing priorities for water use in a community by different user groups.

Dimension 6: The natural **environment** has its own water needs. Water is necessary for ensuring environmental integrity and providing critical ecosystem services, such as storage and filtration, which improve both the quality and quantity of water available for human use. Regarding the **aquatic (E1)** environment, the "criticality ratio" (CR; the ratio of mean annual withdrawals to water availability) indicates the potential for water shortages during low flow periods. A water shortage is considered severe if CR exceeds 0.4 (Alcamo et al., 2000). On a global scale, environmental integrity is threatened when more than 40% of the available freshwater is abstracted (OECD, 2004). Other research indicates that it is difficult to predict environmental responses to changes in natural flow regimes (Bunn and Arthington, 2002). Water quality is also important to support aquatic habitats. Indicators that have been used include the five-day biochemical oxygen demand (BOD_5) (Chaves and Alipaz, 2007), fish populations (Alessa et al., 2008; PRI, 2007), and the more complex and data intensive Water Quality Index (CCME, 2001; as used by PRI, 2007).

Terrestrial (E2) indicators include the integrity of elements that humans depend on for livelihoods, as well as the impact of human development on the environment. Protected status of land is a common terrestrial indicator (Chaves and Alipaz, 2007; Pérez-Foguet and Giné, 2011), which can also be applied to institutional capacity (Alessa et al., 2008). Land cover metrics such as the proportion of area with natural vegetation (Chaves and Alipaz, 2007; Pérez-Foguet and Giné, 2011), the proportion of arable land (Pérez-Foguet and Giné, 2011), and land cover availability that is necessary for subsistence of wild and domestic animals (Alessa et al., 2008; Pérez-Foguet and Giné, 2011; Xiao et al., 2007) are also common indicators. Drought, flooding, and permafrost are land characteristics that increase a community's vulnerability to extreme water-related events. Permafrost is a unique factor for northern communities to consider (Alessa et al., 2008). Other terrestrial indicators include soil erosion and changes in crop yields (Sullivan et al., 2003; Vishnudas et al., 2008). More broadly, Chaves and Alipaz (2007) apply a basin Environmental Pressure Index (EPI) related to changes in agricultural area and urban population for the basin.

Dimension 7: Health and hygiene includes explicit health indicators, knowledge and practices associated water and hygiene at the household level, and access to related resources. In their review of water terminology used in UN declarations, Mount and Bielak (2011) point out that hygiene and sanitation tend to be neglected when grouped with water, for example, in the popular catchphrase "water, sanitation, and hygiene". Acknowledging them in their own category can help draw attention to this important issue within water security.

The most frequent indicators are related to **health (H1)** (e.g. prevalence of waterborne illness) and access to sanitation facilities, where some have included these as measures for access, capacity, or use (Giné and Pérez-Foguet, 2010; Pérez-Foguet and Giné, 2011; PRI, 2007). 'Acceptable' rates of water-related disease incidence and child mortality are difficult to identify and will vary from context to context. Research in Canada defines an annual incidence rate for waterborne illnesses greater than 1 in 1000 as the upper acceptable limit (PRI, 2007), but LMIC thresholds do not exist (e.g. Sullivan et al., 2003). Perhaps a better approach, particularly within RMM communities, is the rate of change in incidence based upon clinic records.

Understanding the link between environment, water quality, hygiene, and health can lead a community to desire to improve their status with respect to water security. This is not always the case, as **knowledge (H2)** is tempered by perceptions based on prior experiences and world view, as well as the means and willingness to undertake change. However, this individual understanding can be measured using questionnaires or focus groups that explain knowledge, attitudes, and practices (Levison et al., 2011). **Behaviour (H3)** can be measured in various ways, including use of household water treatment, transport, storage practices and hygiene practices (Howard, 2002; Narayan, 1993; WHO and UNICEF, 2006). Key indicators including proper hand-washing practices (widely recognized as the single most effective practice for preventing illness), use of improved sanitation facilities, and proper disposal of infant faeces (WHO and UNICEF, 2006).

While sanitation practices are an indicator of behaviour, they have further reaching consequences as faeces are a vector for individual and family disease transmission as well as a source of water contamination. Thus, improperly treated or disposed faeces pose an elevated risk of community exposure to waterborne disease, and an increased burden (technological and financial) for treatment. Both open defecation and disposal in locations near water sources present a greater risk for water contamination than an open pit, particularly when these practices are conducted in close proximity to shallow groundwater wells (Howard et al., 2003). JMP (WHO and UNICEF, 2012a) definitions and data for access to improved sanitation facilities[6] have been used directly in indices (Giné and Pérez-Foguet, 2010; Sullivan et al., 2003); another approach is to use the annual change in access (Pérez-Foguet and Giné, 2011).

Dimension 8: Equally important as individual and household behaviour is the overall **community capacity**. This can be measured by examining the knowledge, financial, and social capitals available within a community. It is essential for sustainable decision-making that these capacities are understood and worked within as changes are made to improve water security and community capacity.

Regarding **knowledge capital (C1)**, education is often used as an indicator for evaluating community capacity, particularly within the context of managing water resources, understanding the links between health and environmental issues, ability to petition for improvements or assistance as well as to approximate household well-being (Davis et al., 2008; PRI, 2007; Pérez-Foguet and Giné, 2011; Sullivan et al., 2003). This may not always be the case, as Baguma et al. (2010) acknowledged the importance of education but found it to be statistically insignificant for household water management. Special considerations could be given to child enrolment (Alkire and Santos, 2010), the number of college degrees per capita (Alessa et al., 2008), and professional human resources within the community (Henriques and Louis, 2011). Moreover, education, particularly child enrolment, can be an indicator of future capacity and well-being, as well as poverty and low levels of access to water resources, as it costs money to attend school and water collection is prioritized over school attendance. Traditional knowledge (i.e. longitudinal information about community water resources) contributes to a community's capacity to deal with water resources and their changes. This can be measured by the proportion of indigenous people older than 50 years of age or by the proportion of people who have lived in the community longer than 30 years (Alessa et al., 2008).

Financial capital (C2), whether it's monetary or through another means of trade, plays a role in household access and ability to participate in water development and management. When evaluating the financial capacity of households in RRM communities, indicators must capture both forms of capital. Various indicators of household income have been used in indices (Alessa et al., 2008; Sullivan et al., 2003) and as parameters in statistical models (Baguma et al., 2010; Davis et al., 2008), usually based on mean annual values. Microfinance and rotating savings and credit

[6] Improved sanitation facilities include flush or pour flush to a piped sewer system, septic tank, or pit latrine; ventilated improved pit (VIP) latrines; pit latrine with slab; or composting toilet. Unimproved sanitation methods include flush or pour-flush to elsewhere; pit latrine without slab; open pits; buckets; hanging toilets/latrines; shared or public facilities of any type; and open defecation (no facilities) (WHO and UNICEF, 2012a).

associations (ROSCAs) are other ways in which community groups could access funds. Eligibility for subsidies provides another measure of a community's access to funds (Vishnudas et al., 2010). The existence of a tracking external auditing program for the community's financial activities may indicate capacity to handle new funds or assets (Henriques and Louis, 2011). Other approximations of financial capital include the ownership of durable items (Alkire and Santos, 2010; Davis et al., 2008; Sullivan et al., 2003), type of cooking fuel (Alkire and Santos, 2010), ownership of different livestock, and type of housing material (Pérez-Foguet and Giné, 2011).

Social capital (C3) can be accounted for through solidarity measures of help, sharing resources, fairness, caste influences, and trust (Davis et al., 2008; Henriques and Louis, 2011; Vishnudas et al., 2008). The existence of social constraints may hinder a community from working together, and often need to be dealt with when they are severe. Low self-esteem, distrust of leaders, financial fears, and fears of criticism or 'losing face' are some examples (UNICEF, 1999). These indicators are usually qualitative and need to be evaluated by members based on their experiences and the perceptions of community members. The roles, responsibilities, and dignity of women within a community are equally important indicators of social capital (e.g. Henriques and Louis, 2011; Pérez-Foguet and Giné, 2011; Vishnudas et al., 2008). Evaluation standards are vague in the literature. Suggested standards include the proportion of women involved in a women's group, the proportion of women attending community meetings (including level of participation), and the ratio of female to male board members on community committees.

Solidarity and cohesion lead to and require strong institutional support, and this institutional capacity is the measure of its ability to organize and take collective action on the community's behalf. Many of the parameters used to evaluate the operation and management of water resources (Dimension 4) are relevant for measuring institutional capacity, as are the number of community-based organizations (CBOs) and the number of funding proposals for community development, both submitted and realized. Without institutional capacity, it is unlikely that community involvement will succeed.

Dimension 9: The final dimension captures the **external support** available to a community. Consideration of external support is rarely addressed, if at all, in water security indices, though it is recognized to be important in other water security literature. Different **government (X1)** levels play important roles in supporting integrated water resource management (IWRM), creating and enforcing water policy, developing plans for management, analyzing the state of water resources, and providing support programmes. McCommon et al. (1990) suggest that a key role of governments is to help develop and support the conditions necessary for community-based action. The knowledge of rights, grants and other opportunities are essential for community empowerment and the self-management of water systems.

Other **linkages (X2)**, including nongovernmental support, are important for community management (Davis et al., 2008; McCommon et al., 1990; Narayan, 1993). Postconstruction support (PCS) in particular is important for the sustainability of water developments in RRM communities and is often overlooked (Davis et al., 2008). Davis et al. (2008) distinguished between three types of PCS visits, and found that those related to administrative needs (e.g. support with record keeping, finances) contributed the most significantly to operational status of water service sites. Larger social networks may increase access to information, partnerships, and sharing of resources. This can be evaluated through network diversity (Alessa et al., 2008), external involvement (Vishnudas et al., 2008), scale of supply chain (Henriques and Louis, 2011), or distance to nearest urban centre or trading locale. From the point of view of maintaining physical infrastructure, third party management may be more appropriate in some RRM communities, particularly where the capacity for management does not exist, and this point is often ignored (Harvey and Reed, 2006).

2.6. Conclusions

As one of the primary functions of indicators and indices is simplified modeling and communication, the clarity of these indicators is critical. Yet numerous indicators and standards uncovered through this review lacked clarity in one or more of three ways. First, in some cases indicator names needed to be more precise, as either the name or abbreviation was unclear or misleading. Sometimes after reading the authors' discussion, one may learn that the indicator is a measure of something quite different than was suggested by the shorthand terminology found in a table, particularly when proxy indicators were used. Second, evaluation standards, which are used for normalizing the measured indicator into a score within a standardized range, were also absent in some cases (see Table 3). Third, and most frequently, the rationale behind particular evaluation criteria were missing from the discussion. Articulating both the evaluation criteria and associated rationale results in greater transparency, and provides insight into the particular physical, social, or economical context. It would also be insightful to learn how others have dealt with data limitations, which is a particular issue in RRM contexts. It is acknowledged, however, that these apparent omissions may in fact be due to space restrictions of the journals in which the indicators were published.

For the indicators included in this review, scoring standards were set in one or more of four ways. One method was the judgment and experience of the authors. Another method was to ground standards in the findings of relevant literature. A third method was to rate indicators by community member responses through questionnaires. The fourth method, in multi-community assessments, was to calculate indicator scores relative to the other communities in the assessment according to equation [1]:

$$score(x_i) = (x_i - x_{min})/(x_{max} - x_{min}) \quad [1]$$

where x_i represents the value of indicator x for community i, and x_{min}, and x_{max}, represent the minimum and maximum values respectively for all communities within the study. In one respect, comparing one community with another is inescapable: even in the referencing of other literature, these standards are the result of previous research and experience. One further consideration is to evaluate an indicator's change over time, which essentially establishes a baseline conditions against which future conditions can be compared. Strictly speaking this would delay the assessment until at least a second round of data could be collected.

The application of indicators and indices tends to focus on comparisons between localities rather than within a single locale. When used to assess need for a single community, the focus often shifts to drawing comparisons between the dimensions of the index. While some multi-community index assessments have given attention to the relative needs of individual communities (Alessa et al., 2008; PRI, 2007), their concerns are not specific to RRM communities and their leaders in LMICs. Moreover, the construction of their indicators ofen leans heavily upon historical data records (see also Chaves and Alipaz, 2007). This reliance on historical data limits the usefulness of these indices in the data scarce context of many RRM communities. Where data scarcity exists, indicators and indices that use qualitative and/or respondent-based evaluation means can provide a starting point for a water security assessment. With this in mind, attention must be given to the development of qualitative and respondent-based scoring standards.

The aim of this review was to create a comprehensive and flexible list of indicators for a water security assessment of a RRM community (Table 3). The holistic nature of RRM community water security has made indicators and indices a frequent choice for assessments. However, the use of indicators has typically been restricted to researchers and policy makers. However, due to their value as an accessible assessment tool, possibilities for the use of indicators by RRM communities should be explored. Simplifying the description of a RRM community's water security through indicators and indices is one way in which a community could engage with and internalize the data, thus contributing to the community's empowerment (see also Levison et al., 2011). Therefore, the comprehensive list of indicators and indices compiled in this paper is one tool by which a community could undertake a preliminary and meaningful assessment to begin or support development change.

Table 3 List of water security indicators by dimension

Component		Sub-component		Indicator		Evaluation*	Reference
1 WATER RESOURCES							
R1	Quantity	R1.1	Surface water	R1.1a	Mean annual river flow	Rated (from <0.01 to ≥10 cms/km²)	Alessa et al., 2008
				R1.1b	Proportion of surface water area to total area (storage proxy)	Rated (from ≤0.1 to >20%)	Alessa et al., 2008
		R1.2	Groundwater	R1.2a	Yield	-	Suggested by authors
				R1.2b	Hydraulic conductivity	-	Suggested by authors
				R1.2c	Hydraulic gradient	-	Suggested by authors
		R1.3	Other	R1.3a	Combined renewable surface water and groundwater	Prorated (Falkenmark indicator; from <500 to >1700 m³/capita/yr)	PRI, 2007
				R1.3b	Combined surface water and groundwater	Rated (Falkenmark indicator; from <1700 to >1700*4 m³/capita/yr)	Chaves and Alipaz, 2007
						Unclear (use hydrological and hydrogeo-logical techniques)	Sullivan et al., 2003
						Relatively prorated	Xiao et al., 2008
				R1.3c	Mean annual precipitation	Rated (from <100 to ≤750 mm/yr)	Alessa et al., 2008
						Rated (Falkenmark indicator; from <1700 to >1700*4 m³/capita/yr)	Pérez-Foguet and Giné, 2011
				R1.3d	Qualitative ranking of available quantities	Rated (from "very low" to "very high")	Henriques and Louis, 2011
				R1.3e	Aridity Index	Rated (hyper-arid, arid, semi-arid, semi-humid, humid)	Pérez-Foguet and Giné, 2011
R2	Variability	R2.1	Seasonal	R2.1a	Months per year with water	Rated (from <7 to 11-12)	Giné and Pérez-Foguet, 2010
				R2.1b	River flow variations	Rated (monthly means, $(Q_{max} - Q_{min})/Q_{mean}$; from >8 to <1)	Alessa et al., 2008
						Prorated (Q_5/Q_{95}; from >5 to 1; Gleick, 1990)	PRI, 2007
				R2.1c	Groundwater resources reliable year-round	Report (respondent: no, yes)	Hoko and Hertle, 2006
		R2.2	Inter-annual	R2.2a	Per capita quantity variation in comparison with long-term mean	Rated (from >20% to <-10%)	Chaves and Alipaz, 2007
				R2.2b	Annual precipitation variance	Rated ($\sigma/\bar{x}$ over 30 years; from >0.5 to <0.1)	Alessa et al., 2008

Component		Sub-component		Indicator		Evaluation*	Reference
				R2.2c	River runoff variance	Rated ($\sigma/\bar{x}$ over 30 years; from >0.5 to <0.1)	Alessa et al., 2008
				R2.2d	Change in storage: % surface water area variance	Rated ($\sigma/\bar{x}$ over 30 years; from >±10 to 0%)	Alessa et al., 2008
				R2.2e	Change in groundwater levels	Prorated (% wells rising + 0.5* % wells stable)	PRI, 2007
		R2.3	Extreme events	R2.3a	Drought events	Qualitative (historical records, personal recall)	Suggested by authors
				R2.3b	Flood events	Qualitative (historical records, personal recall)	Suggested by authors
				R2.3c	Other extreme hydrological events	Qualitative (historical records, personal recall)	Suggested by authors
R3	Quality	R3.1	Contaminants	R3.1a	Suite of microbiological parameters for drinking water quality	See reference	WHO, 2011
				R3.1b	Suite of chemical parameters for drinking water quality	See reference	WHO, 2011
				R3.1c	Groundwater: Depth to water table		Suggested by authors
				R3.1d	Surface water: Turbidity	<1 NTU ideal; <5 NTU acceptable	WHO, 2011
				R3.1e	Suite of radiological parameters for drinking water quality	See reference	WHO, 2011
		R3.2	Pollution sources	R3.2a	Upstream development sites	Rated (from >10 to 0)	Alessa et al., 2008
				R3.2b	Pollution sources near water source	Option comparison (qualitative; proximi-ty)	Garfì and Ferrer-Martí, 2011
						Rated (from >2 to 0)	Giné and Pérez-Foguet, 2010
				R3.2c	Livestock densities	Qualitative scale	Suggested by authors
				R3.2d	% pop. practicing open defecation	Prorated (%)	Suggested by authors
				R3.2e	% using grey water for agriculture	Rated (from "none" to "all" HHs)	Suggested by authors
				R3.2f	% using pesticides for agriculture	Rated (from "none" to "all" HHs)	Suggested by authors
				R3.2g	% using fertilizers for agriculture	Rated (from "none" to "all" HHs)	Suggested by authors
				R3.2h	Wildlife pop. densities	Qualitative scale	Suggested by authors
2 DEVELOPED SOURCES							
S1	Supply	S1.1	System capacity	S1.1a	Service levels	Rated (from <10 to >500 L/capita/day; reservoir and well yields)	Alessa et al., 2008
						Rated (not sufficient for humans, only for humans, human + livestock, always)	Giné and Pérez-Foguet, 2010

Component		Sub-component		Indicator		Evaluation*	Reference
						Rated (domestic consumption; from <10 to >40 L/capita/day)	Giné and Pérez-Foguet, 2010
						Rated (from <20 to >80 L/capita/day)	Henriques and Louis, 2011
						Prorated (from <50 to >150 L/capita/day; infrastructure, water trucks, wells)	PRI, 2007
						Unclear	Sullivan et al., 2003
						Relatively prorated	Xiao et al., 2008
				S1.1b	Rainwater harvesting potential	Function of storage, water use rate, reliability, local climate characteristics	Guo and Baetz, 2007
		S1.2	Losses	S1.2a	Age of system	Regression var. (mean)	Davis et al., 2008
				S1.2b	System material and construction quality	-	Suggested by authors
				S1.2c	Illegal connections	-	Suggested by authors
				S1.2d	Leaks	Categorical var. (observed: no, yes)	Davis et al., 2008
						Prorated (recorded losses: from >25 to 0%)	PRI, 2007
		S1.3	Limits	S1.3a	Maximum number of people per water source	Option comparison (250, 400, 500 people per tap, hand pump, open well, respectively; SCHR, 2004)	Garfi and Ferrer-Martí, 2011
				S1.3b	Time before water service capacities are exceeded by pop. growth	Prorated (from 0 to >50 yrs; function of pop. growth rate, system capacity, # currently serving)	PRI, 2007
				S1.3c	Perceived future (1, 5, 10 years) functioning of piped water systems	Categorical var. (HH and WC respondents: no, yes, unsure)	Davis et al., 2008
S2	Reliability	S2.1	Source diversity	S2.1a	Water source diversity (# and type)	Rated (from "1 surface or 1 ground" to ">2 of each")	Alessa et al., 2008
		S2.2	Operationality	S2.2a	Present operational state	Regression var. (% of HH taps functioning)	Davis et al., 2008
						Prorated (%)	Giné and Pérez-Foguet, 2010
						Report (respondent: not functioning, satisfactory, good)	Hoko and Hertle, 2006
						Prorated (% systems in good condition)	Pérez-Foguet and Giné, 2011

Component		Sub-component		Indicator		Evaluation*	Reference
				S2.2b	Historical disruption frequency (#, duration, % time)	Regression vars. (HH respondent: # and duration in last 6 months)	Davis et al., 2008
						Regression vars. (operator respondent: # and duration in last 6 months)	Davis et al., 2008
						Regression vars. (women's focus group: # and duration in last 6 months)	Davis et al., 2008
						Option comparison (min. favoured)	Garfì and Ferrer-Martí, 2011
						Rated (from >25% to <5%)	Giné and Pérez-Foguet, 2010
						Report (respondent: max. of 2% or 7 days/yr; Carter, 1996)	Hoko and Hertle, 2006
						Prorated (of those having access, % having continual access)	Pérez-Foguet and Giné, 2011
						Prorated (equation; disruption days per person)	PRI, 2007
		S2.3	System storage	S2.3a	Tank capacities	Function of water use rate, reliability, and inflow characteristics	Suggested by authors
				S2.3b	# tanks per capita	-	Suggested by authors
S3	Quality	S3.1	Barriers	S3.1a	Sanitary inspection risk score	Rated (based on total number of hazards)	WHO and UNICEF, 2012
				S3.1b	Source type as water quality proxy	Rated (open + untreated, open + local treatment, open + treated, protected)	Giné and Pérez-Foguet, 2010
				S3.1c	Water point protection (fencing, access restriction)	Prorated (% fenced)	Giné and Pérez-Foguet, 2010
						Report (respondent: fencing: no, yes, unsure)	Hoko and Hertle, 2006
				S3.1d	Treatment technology scale at point of extraction	Rated based on combined treatment levels of water (none, filtered, chlorinated) and wastewater (none, 1°, 2°, 3°)	Alessa et al., 2008
				S3.1e	Flexibility for treating raw water of different qualities	Option comparison	Garfì and Ferrer-Martí, 2011
		S3.2	Contaminants	S3.2a	Suite of drinking water quality parameters	see WHO, 2011 (updated)	Garfì and Ferrer-Martí, 2011
				S3.2b	% water systems with faecal contamination	Prorated (% without coliforms)	Pérez-Foguet and Giné, 2011

Component		Sub-component		Indicator		Evaluation*	Reference
				S3.2c	Suite of agricultural water quality parameters	see FAO (2004)	Garfì and Ferrer-Martí, 2011
				S3.2d	Water point cleanliness	Report (researcher observed: no, yes)	Hoko and Hertle, 2006
		S3.3	User acceptability	S3.3a	Taste, appearance, odour	Option comparison (qualitative; most appropriate favoured)	Garfì and Ferrer-Martí, 2011
						Report (respondent: acceptable, not acceptable, unsure)	Hoko and Hertle, 2006
				S3.3b	HH use of secondary water source, when developed source is accessible	Categorical var. (no, yes)	Davis et al., 2008
						Report (respondent: no, yes)	Hoko and Hertle, 2006
				S3.3c	HHs providing additional ("unnecessary") drinking water treatment	Report (respondent: no, yes)	Hoko and Hertle, 2006
				S3.3d	Perception of soap use in community (hardness proxy)	Report (respondent: no, yes, unsure)	Hoko and Hertle, 2006
3 INFRASTRUCTURE APPRAISAL							
I1	Appropriateness for Community	I1.1	Society	I1.1a	Respect for local culture	Option comparison (e.g. working hours; max. favoured)	Garfì and Ferrer-Martí, 2011
				I1.1b	Level of operation required by technology	Rated (water use, pumping water, control water quality, monitor systems, control pipes, monitor pipes network, monitor treatment)	Henriques and Louis, 2011
				I1.1c	Level of maintenance required by technology	Rated (none, cleaning, minor repair, major repair, maintain systems, maintain pipes, check/maintain network and meter and IT systems)	Henriques and Louis, 2011
				I1.1d	Required level of operation and maintenance	Option comparison (qualitative; most appropriate favoured)	Garfì and Ferrer-Martí, 2011
		I1.2	Environment	I1.2a	Suitable to local geographic conditions	Rated (respondent: from "bad" to "good")	Vishnudas et al., 2008
				I1.2b	Non-renewable energy consumption	Option comparison (min. favoured)	Garfì and Ferrer-Martí, 2011

Component		**Sub-component**		**Indicator**		**Evaluation***	**Reference**
		I1.3	Economy	I1.3a	Perceived revenue sufficiency for operation and maintenance	Categorical var. (<90% sufficient, >90% sufficient)	Davis et al., 2008
				I1.3b	Daily or weekly operation costs		Suggested by authors
				I1.3c	Per capita cost of water system	Regression var. (mean)	Davis et al., 2008
				I1.3d	Construction, maintenance, and labour costs	Rated (respondent: from "bad" to "good")	Vishnudas et al., 2008
				I1.3e	Energy costs	Rated (% of budget; from "very high" to "none")	Henriques and Louis, 2011
						Rated (proxied by hydraulic gradient between water source and destination; from <-100 to >10.0)	Alessa et al., 2008
I2	Impact on Community	I2.1	Society	I2.1a	Reduction of water borne disease incidence after project	Report (respondent: no, yes, unsure)	Hoko and Hertle, 2006
				I2.1b	Percent of beneficiaries	Option comparison (max. favoured)	Garfi and Ferrer-Martí, 2011
				I2.1c	Project avoided conflict between different groups (e.g. men and women) and arising from new income differences	Option comparison (qualitative; max. favoured)	Garfi and Ferrer-Martí, 2011
		I2.2	Environment	I2.2a	Water consumption required by technology	Option comparison (preservation considerations; min. favoured)	Garfi and Ferrer-Martí, 2011
				I2.2b	Contaminated water generated	Option comparison (quantity and quality; min. favoured)	Garfi and Ferrer-Martí, 2011
				I2.2c	Solid waste generated (ton/yr)	Option comparison (min. favoured)	Garfi and Ferrer-Martí, 2011
				I2.2d	Atmospheric emissions	Option comparison (greenhouse gases, particulate matter, sulphur oxides; min favoured)	Garfi and Ferrer-Martí, 2011
				I2.2e	Noise generation (decibels)	Option comparison (min. favoured)	Garfi and Ferrer-Martí, 2011
				I2.2f	Changes in landscape due to human use	Option comparison (qualitative; min. favoured)	Garfi and Ferrer-Martí, 2011
				I2.2g	Amount of land used	Option comparison (qualitative; min. favoured)	Garfi and Ferrer-Martí, 2011
		I2.3	Economy	I2.3a	Rate of increase in beneficiaries' income, including savings	Option comparison (max. favoured)	Garfi and Ferrer-Martí, 2011

Component		Sub-component		Indicator		Evaluation*	Reference
				I2.3b	Increased income generation	Rated (respondent: from "bad" to "good")	Vishnudas et al., 2008
				I2.3c	# locals employed from water project	Option comparison (max. favoured)	Garfì and Ferrer-Martí, 2011
4 OPERATION AND MANAGEMENT							
M1	Capacity	M1.1	Personnel	M1.1a	Water operator(s) level of training	Rated (no training, other training, industry certified)	PRI, 2007
				M1.1b	Skilled labour and maintenance personnel availability	Rated (none, mechanic, maintenance technician, laboratory technician, water systems operator, health inspector, admin. assistant, water meter leader, IT technician)	Henriques and Louis, 2011
						Report (respondent: no, yes, unsure)	Hoko and Hertle, 2006
				M1.1c	Unskilled labour types and availability	Rated (craftsman, clerk, mechanic assistant, water meter reader, water systems worker)	Henriques and Louis, 2011
						Rated (respondent: from "bad" to "good")	Vishnudas et al., 2008
				M1.1d	Unskilled and illiterate personnel availability	Rated (caretaker)	Henriques and Louis, 2011
		M1.2	Administrative structures	M1.2a	Facilities managed and/or owned by local and/or legally registered WCs (%)	Prorated (%)	Giné and Pérez-Foguet, 2010
				M1.2b	Tariff structure	Rated (none/irregular period, flat (bi)monthly rate, single block rate, increasing block rate)	Henriques and Louis, 2011; Davis et al., 2008
				M1.2c	Level of administration	Unclear; rated (none, basic, intermediate, complete, advanced)	Henriques and Louis, 2011
				M1.2d	Level of governance	Rated (none, national, regional, state, local)	Henriques and Louis, 2011
		M1.3	Finances	M1.3a	WC pays members for services	Regression var. (% WCs that pay)	Davis et al., 2008
		M1.4	Household	M1.4a	Rainwater harvesting experience	Regression var. (years since installation)	Baguma et al., 2010
				M1.4b	Availability of usage instructions for HH systems (incl. waterborne health risks)	Categorical var. (HH respondent: no, yes)	Baguma et al., 2010

Component		Sub-component		Indicator		Evaluation*	Reference
				M1.4c	Received operation and maintenance training for HH systems	Categorical var. (no, yes)	Baguma et al., 2010
M2	Administration	M2.1	Meetings	M2.1a	WC meets regularly	Report (proxied by respondent: no, yes, unsure)	Hoko and Hertle, 2006
				M2.1b	WC holds regular monthly meetings with community members	Regression var. (% WCs)	Davis et al., 2008
		M2.2	Accountability	M2.2a	Regulation and accountability	Unclear; rated (none, basic, intermediate, complete, advanced)	Henriques and Louis, 2011
						Rated (respondent: from "bad" to "good")	Vishnudas et al., 2008
		M2.3	Policies	M2.3a	Community water action plan	Rated (None, draft, approved, implemented)	Alessa et al., 2008
				M2.3b	Level of legislation	Unclear; rated (none, basic, intermediate, complete, advanced)	Henriques and Louis, 2011
				M2.3c	Policies correspond with rules, customs, property rights, land tenure	Rated (respondent: from "bad" to "good")	Vishnudas et al., 2008
				M2.3d	Efficiency of governance structure	Unclear; rated (respondent: from "bad" to "good")	Vishnudas et al., 2008
		M2.4	Documentation	M2.4a	WC keeps written records (e.g. minutes, finances, repairs, water quality)	Report (proxied by literacy rate in area)	Hoko and Hertle, 2006
				M2.4b	Proportion of watershed (or streams) with water quality data not older than 10 years (%)	Rated (from 0 to ≥90%)	Alessa et al., 2008
M3	Community involvement	M3.1	Short-term	M3.1a	% of local pop. involved	Option comparison (max. favoured)	Garfì and Ferrer-Martí, 2011
				M3.1b	Indigenous technology was considered	Rated (respondent: from "bad" to "good")	Vishnudas et al., 2008
				M3.1c	Construction contributions	Report (money, unskilled labour, local materials)	Hoko and Hertle, 2006
						Rated (local and unpaid labour; respondent: from "bad" to "good")	Vishnudas et al., 2008
		M3.2	Long-term	M3.2a	Membership of WC	Categorical var. (no, yes)	Baguma et al., 2010
						Unclear	Sullivan et al., 2003

Component		Sub-component		Indicator		Evaluation*	Reference
				M3.2b	Maintenance cost contributions	Report (respondent: no, yes)	Hoko and Hertle, 2006
				M3.2c	Community's participation with WC	Rated (respondent: from "bad" to "good")	Vishnudas et al., 2008
M4	Social factors	M4.1	Trust	M4.1a	HH satisfaction with WC	Categorical var. (from "very dissatisfied" to "very satisfied")	Davis et al., 2008
				M4.1b	HH satisfaction with operation and maintenance of water systems	Categorical var. (from "very dissatisfied" to "very satisfied")	Davis et al., 2008
				M4.1c	Supportive leadership	Respect other's opinions, decisions made through consensus, available, shared vision, team spirit, decentralized control	Narayan, 1993
		M4.2	Representation	M4.2a	Social equity (representation of gender, class, caste)	Rated (respondent: from "bad" to "good")	Vishnudas et al., 2008
5 ACCESS AND EQUITY							
A1	Physical access	A1.1	Supply	A1.1a	Access to improved water supply (%: HHs, pop.)	Prorated (% HHs within 100, 1000, >1000 m)	Based on Howard and Bartram, 2003
						Prorated (% HHs)	Giné and Pérez-Foguet, 2010
						Prorated (% access; JMP definitions and data)	Pérez-Foguet and Giné, 2011
				A1.1b	HHs w/ piped supply (%)	Prorated (%)	Sullivan et al., 2003
				A1.1c	Human-wildlife conflict over water sources	Prorated (% facilities)	Giné and Pérez-Foguet, 2010
				A1.1d	Access to unimproved water source (%: HHs, pop.)	Prorated (% HHs within 100, 1000, >1000 m)	Based on Howard and Bartram, 2003
		A1.2	Effort	A1.2a	Distance from HH to water source (aerial and ground) (km, min)	Option comparison (min. favoured); 500 m max. (SCHR, 2004)	Garfì and Ferrer-Martí, 2011
						Rated (from >5 to <1 km)	Giné and Pérez-Foguet, 2010
						Report (respondent: near, moderate, far)	Hoko and Hertle, 2006
				A1.2b	Queue time at source	Option comparison (min. favoured); 15 minutes max (SCHR, 2004)	Garfì and Ferrer-Martí, 2011
						Rated (from >120 to <30 minutes)	Giné and Pérez-Foguet, 2010
				A1.2c	Total collection time (travel + queue)	Relatively prorated (per HH per day)	Sullivan et al., 2003

Component		Sub-component		Indicator		Evaluation*	Reference
				A1.2d	Trips per day per HH	Rated (<1, 1, 2, 3, >3); also used to estimate collection burden	Suggested by authors
				A1.2e	Ease of operating water points	Index based on pump type, well diameter, and depth	Suggested by authors
						Report (respondent: strokes required before discharge at borehole/well)	Hoko and Hertle, 2006
A2	Social access	A2.1	Affordability	A2.1a	Ability and willingness to pay	HH water costs should be ≤5% income; case-specific	Garfì and Ferrer-Martí, 2011
						Rated (respondent: from "bad" to "good")	Vishnudas et al., 2008
				A2.1b	Actual cost	Regression var. (monthly fee for users paying flat charges)	Davis et al., 2008
						Rated (from <1 to >5 Ksh. per 20 L container)	Giné and Pérez-Foguet, 2010
				A2.1c	HHs that purchase water (%)	Categorical var. (no, yes)	Baguma et al., 2010
				A2.1d	% of HHs in arrears, fined for late payment, and/or disconnected for non-payment	Regression var. (mean)	Davis et al., 2008
		A2.2	Equity	A2.2a	% water carried by women	Prorated (%)	Sullivan et al., 2003
				A2.2b	% water carried by children <15 years of age		Suggested by authors
				A2.2c	Accessibility for all groups of community (free from discrimination)	Option comparison (qualitative; discrimination based on gender, ethnicity, disability, etc.)	Garfì and Ferrer-Martí, 2011
				A2.2d	User and type of use given access priorities		Suggested by authors
				A2.2e	Human-human conflict over water sources	Prorated (% facilities in conflict)	Giné and Pérez-Foguet, 2010
						Prorated (% HHs not experiencing conflict)	Sullivan et al., 2003
				A2.2f	Human-livestock conflict over water sources	Prorated (% facilities in conflict)	Giné and Pérez-Foguet, 2010
				A2.2g	(% non-durable dwellings with access) ÷ (% improved housings with access)	Prorated (from >0.50 to <0.05)	Pérez-Foguet and Giné, 2011

Component		Sub-component		Indicator		Evaluation*	Reference
6 ENVIRONMENT							
E1	Aquatic	E1.1	Quality	E1.1a	Water Quality Index (WQI) for the protection of wildlife	Prorated (WQI value)	PRI, 2007
				E1.1b	BOD_5, basin long term mean	Rated (from >10 to <1 mg/L)	Chaves and Alipaz, 2007
				E1.1c	BOD_5, variation in basin, relative to the long-term mean (%)	Rated (from >20% to <-10%)	Chaves and Alipaz, 2007
				E1.1d	Subsistence fish	Rated (from <0.05 to >0.5 recruiting streams/km)	Alessa et al., 2008
						Prorated (% species with increasing pops. + 0.5 * % species with stable pops.)	PRI, 2007
		E1.2	Quantity	E1.1a	Ratio of annual water consumption to renewable surface flow	Prorated (equation based on 60% renewable flow required; OECD, 2004)	PRI, 2007
E2	Terrestrial	E2.1	Characteristics	E2.1a	% area under protected status (including areas with BMPs)	Rated (from <5 to >50%)	Alessa et al., 2008
						Prorated (%)	Pérez-Foguet and Giné, 2011
				E2.1b	% change in protected areas (including those with BMPs)	Rated (from <-10% to >20%)	Chaves and Alipaz, 2007
				E2.1c	% area with natural vegetation	Rated (from <5 to >40%)	Chaves and Alipaz, 2007
						Prorated (%)	Pérez-Foguet and Giné, 2011
				E2.1d	% arable land	Prorated (proportion of suitable to actual arable land)	Pérez-Foguet and Giné, 2011
				E2.1e	% area available for subsistence animals	Rated (from <20 to ≥80%; caribou and moose habitat, tundra and boreal forest, respectively)	Alessa et al., 2008
						Prorated (livestock grazing)	Pérez-Foguet and Giné, 2011
						Relatively prorated (livestock grazing)	Xiao et al., 2008
		E2.2	Stressors	E2.2a	Soil erosion	Prorated (% of surface with severe erosion)	Pérez-Foguet and Giné, 2011
						Prorated (% HHs not experiencing)	Sullivan et al., 2003

Component		Sub-component		Indicator		Evaluation*	Reference
						Rated (respondent: from "bad" to "good")	Vishnudas et al., 2008
				E2.2b	Crop yield changes	Prorated (% cultivators reporting losses in last 5 years)	Sullivan et al., 2003
						Rated (respondent: from "bad" to "good")	Vishnudas et al., 2008
				E2.2c	Basin Environmental Pressure Index (EPI)	Rated (% change in basin agricultural area + % change in basin urban pop.)/2	Chaves and Alipaz, 2007
		E2.3	Other	E2.3a	% area subject to drought	Relatively prorated	Xiao et al., 2008
				E2.3b	% area subject to flooding and waterlogging	Relatively prorated	Xiao et al., 2008
				E2.3c	% area subject to permafrost (PF)	Rated (from >25% discontinuous PF to >75% PF-free)	Alessa et al., 2008
7 HEALTH AND HYGIENE							
H1	Health	H1.1	Illness	H1.1a	Water-related disease incidence	Prorated (from 0 to > 0.001)	PRI, 2007
						Prorated (% HHs not experiencing illness perceived to be related to water)	Sullivan et al., 2003
		H1.2	Mortality	H1.2a	Child mortality rate	Deprived if any child has died in the family	Alkire and Santos, 2010
						Relatively prorated (under-five mortality rate)	Sullivan et al., 2003
H2	Knowledge	H2.1	Water and health	H2.1a	Perceived link between poor quality DW and negative health effects	Report (respondent: no, yes, unsure)	Hoko and Hertle, 2006
				H2.1b	% community trained in water, sanitation, and hygiene issues	Option comparison (max. favoured)	Garfì and Ferrer-Martí, 2011
				H2.1c	Perceived need for further health and hygiene training	Report (respondent: no, yes, unsure)	Hoko and Hertle, 2006
H3	Behaviour	H3.1	Water practices	H3.1a	Home practices to improve water quality	Prorated (% HHs boiling)	Giné and Pérez-Foguet, 2010
						Heating, boiling, chemical treatment, sedimentation, filtration	Narayan, 1993
						Prorated (% HHs chlorinating + 0.75 * % HHs boiling)	Pérez-Foguet and Giné, 2011
				H3.1b	Water transport and storage practices	Routes of contamination (containers and ladles, presence/use of covers, storage place, contact with hands/objects)	Narayan, 1993

Component		Sub-component		Indicator		Evaluation*	Reference
				H3.1c	Water quality at home (all containers used for drawing, carrying, storing, drinking)	Combination of faecal coliform counts, smell, taste, turbidity, chemical quality	Narayan, 1993
		H3.2	Hygiene	H3.2a	Personal hygiene practices	Hand-cleaning, infant faeces handling, body cleansing	Narayan, 1993
						Prorated (% pop. with water-related illnesses); discarded due to lack of data	Pérez-Foguet and Giné, 2011
				H3.2b	Site and home cleanliness	Proper excreta disposal, HH waste disposal, presence of animals and fences, presence of rodents/flies/mosquitos/other vectors	Narayan, 1993
H4	Access	H4.1	Sanitation	H4.1a	Access to improved sanitation facilities (%: HHs, pop)	Prorated (% HHs)	Giné and Pérez-Foguet, 2010
						Prorated (% access; JMP definitions and data)	Pérez-Foguet and Giné, 2011
						Prorated (% pop.)	Sullivan et al., 2003
				H4.1b	Annual variation in access to improved sanitation	Prorated (from <0 to >3 % change in access; JMP definitions and data)	Pérez-Foguet and Giné, 2011
		H4.2	Clinics	H4.2a	Distance from HH to health clinic (km)	Rated (based on travel time required by most HHs to reach clinic)	Suggested by authors
				H4.2b	Treatment affordability	% income	Suggested by authors
				H4.2c	Nurse availability	# per capita; wait time; hours of operation	Suggested by authors
		H4.3	Resources	H4.3a	Availability of health and hygiene workshops	Rated (from “never” to “always”)	Suggested by authors
				H4.3b	Awareness of health and hygiene workshops	Report (respondent: no, yes, unsure)	Hoko and Hertle, 2006
				H4.3c	Perception of health and hygiene workshop benefits	Report (respondent: no, yes, unsure)	Hoko and Hertle, 2006
				H4.3d	School health clubs	Existence, enrolment, activities	Suggested by authors
8 COMMUNITY CAPACITY							
C1	Knowledge capital	C1.1	Schooling	C1.1a	Education level	Rated "deprived" if no HH member has completed 5 years	Alkire and Santos, 2010
						Categorical var. (junior, high school and beyond)	Baguma et al., 2010
						Regression var. (mean)	Davis et al., 2008

Component	Sub-component	Indicator	Evaluation*	Reference
			Prorated (% of HH heads completed high school; from 0 to >50%)	Pérez-Foguet and Giné, 2011
			Prorated (% pop. aged 20-64 completed high school, relative to region)	PRI, 2007
			Prorated (% HHs having ≥ 1 member matriculated)	Sullivan et al., 2003
		C1.1b Child enrolment	Rated "deprived" if any school-aged child is out of school in years 1-8	Alkire and Santos, 2010
		C1.1c # college degrees per capita	Rated (from <20 to ≥250 per 1000)	Alessa et al., 2008
		C1.1d Professional human resources	Rated (none, admin. supervisor, health scientist, engineer, lawyer, public relations manager)	Henriques and Louis, 2011
	C1.2 Indigenous	C1.2a Traditional knowledge (# indigenous people 50+ years of age)	Rated (from <10 to ≥200 per 1000)	Alessa et al., 2008
		C1.2b Residency time (# people with 30+ years residence)	Rated (from <50 to ≥500 per 1000)	Alessa et al., 2008
C2 Financial capital	C2.1 Household	C2.1a HH income	Rated (mean; from <$5,000 to >$50,000 USD)	Alessa et al., 2008
			Regression var. (mean)	Baguma et al., 2010
			Regression var. (mean)	Davis et al., 2008
			Prorated (% HHs having ≥ 1 member with any sort of income)	Sullivan et al., 2003
		C2.1b Access to capital	ROSCA and Microfinance availability and eligibility	Suggested by authors
		C2.1c Ownership of durable items	Deprived if do not own more than one of: radio, TV, telephone, bike, motorbike	Alkire and Santos, 2010
			Regression var. (for each, % with: radio, television, automobile or tractor, improved sanitation facilities, telephone service access, electricity in home)	Davis et al., 2008
			Unclear	Sullivan et al., 2003
		C2.1d Ownership of subsistence animals	Based on # and type of animal	Suggested by authors
		C2.1e Housing material type	Index based on quality and durability	Suggested by authors
			Prorated (% pop. living in non-durable dwellings; from >8 to <1 %)	Pérez-Foguet and Giné, 2011

Component		Sub-component		Indicator		Evaluation*	Reference
				C2.1f	Cooking fuel	Rated "deprived" if HH uses wood, charcoal, or dung	Alkire and Santos, 2010
		C2.2	Community	C2.2a	Budget characteristics	Rated (none, basic accounting, annual, tracked annually, tracked quarterly)	Henriques and Louis, 2011
				C2.2b	Asset values	Rated (none, real estate, equipment, cash, stocks)	Henriques and Louis, 2011
C3	Social capital	C3.1	Women	C3.1a	Women's participation	Proportion involved in women's group; proportion attending and contributing to community meetings	Suggested by authors
						Unclear; rated (from "very low" to "very high")	Henriques and Louis, 2011
				C3.1b	Women's empowerment	Ratio of female to male members on community committee(s)	Suggested by authors
						Rated (respondent: from "bad" to "good")	Vishnudas et al., 2008
				C3.1c	Equity in education index	Prorated (harmonic mean of male and female HDI-education sub-indices; from <0.01 to <0.001)	Pérez-Foguet and Giné, 2011
		C3.2	Solidarity	C3.2a	Members share environmental resources with one another	Rated (respondent: from "bad" to "good")	Vishnudas et al., 2008
				C3.2b	Equity	Unclear; rated (from "very low" to "very high")	Henriques and Louis, 2011
				C3.2c	Existence and influence of castes	Rated (from "very high" to "very low")	Henriques and Louis, 2011
				C3.2d	Community trust	Regression var. (% saying "many people will help you if you need it")	Davis et al., 2008
				C3.2e	Stability	Unclear; rated (from "very low" to "very high")	Henriques and Louis, 2011
		C3.3	Institutions	C3.3b	# of community-based organizations	Consider both the # and level of activity	Suggested by authors
				C3.3c	# of submitted funding proposals	Consider both # submitted and # realized	Suggested by authors
9 EXTERNAL SUPPORT							
X1	Government and Policy	X1.1	Right to water	X1.1b	Does the state's constitution, bill of rights, or other statute recognise the right to water?	No, yes	Adapted from Backman et al., 2008

Component	Sub-component	Indicator		Evaluation*	Reference
	X1.2 Jurisdiction	X1.2a	Consensus between administrative and watershed boundaries	Rated (respondent: from "bad" to "good")	Vishnudas et al., 2008
	X1.3 IWRM support	X1.3a	Change in basin's water resource management expenditures (%)	Rated (from <-10 to >20%)	Chaves and Alipaz, 2007
		X1.3b	Has the state undertaken a comprehensive national situational analysis?	No, in progress, complete	Adapted from Backman et al., 2008
		X1.3c	Is there a published national water policy?	No, yes	Adapted from Backman et al., 2008
		X1.3d	Adequacy of programmes to support IWRM	Rated (none, in policy, project anticipated, plans exist, projects are funded and executed)	Pérez-Foguet and Giné, 2011
		X1.3e	Suitability of catchment management plan	Rated (none, plan exists, critical points identified, institutional capacity exists, plan is operational)	Pérez-Foguet and Giné, 2011
		X1.3f	Water law adequacy and implementation	Rated (from "very poor" to "excellent")	Chaves and Alipaz, 2007
		X1.3f	Smallest scale of administrative agencies	Rated (none, national, regional, state, local)	Henriques and Louis, 2011
X2 Linkages	X2.1 Relationships	X2.1a	Network diversity	Rated (quotient of the no. of external community linkages and $\log_{10}$(pop.);from <5 to ≥20)	Alessa et al., 2008
		X2.1b	Involvement of project implementing agency	Rated (respondent: from "bad" to "good")	Vishnudas et al., 2008
	X2.2 Accessibility and remoteness	X2.2a	Distance to municipality (km or hours)	Regression var. (mean)	Davis et al., 2008
		X2.2b	Distance to main road	Regression var.	Baguma et al., 2010
	X2.3 Postconstruction support	X2.3a	# administrative-related visits from external organization(s)	Categorical var. (None, solicited, unsolicited)	Davis et al., 2008
		X2.3b	# engineering-related visits from external organization(s)	Categorical var. (None, solicited, unsolicited)	Davis et al., 2008
		X2.3c	# enrolment of system operator in training workshop	Categorical var. (None, solicited, unsolicited)	Davis et al., 2008
		X2.3d	Extension officer visit (government or NGO)	Categorical var. (HH respondent: no, yes)	Baguma et al., 2010

Component	Sub-component	Indicator		Evaluation*	Reference
		X2.3e	Access to info. from technical experts	Rated (respondent: from "bad" to "good")	Vishnudas et al., 2008
		X2.3f	Scale and accessibility of supply chain	Rated (none, national supplier, regional supplier, national manufacturer, local supplier)	Henriques and Louis, 2011

HH(s) = Household(s); Ksh. = Kenyan Shilling; NTU = Nephelometric Turbidity Units; pop. = population; var(s). = variable(s); yr(s). = year(s)
*Authors often used different standards in their evaluation. The details of these differences are preserved in the following key words. Further details on the values or items used for evaluation are found in parentheses within this column.

- Rated: indicator values were grouped into a range or category (typically five) and assigned a score (e.g. 0, 0.25, 0.50, 0.75, 1);
- Prorated: indicator values were scored on a continuous standardized scale between 0 and 1;
- Relatively prorated: indicator values for each locale were scored relative to the others in the assessment, using the formula $(x_i – x_{min})/(x_{max} – x_{min})$
- Regression variable: the indicator was used as a numerical variable in a regression model;
- Categorical variable: the indicator was used as a categorical variable in a regression model;
- Option comparison: the indicator compared features of water supply or sanitation solutions against another (e.g. Garfì and Ferrer-Martí, 2011);
- Report: the reference used the indicator in a topical analysis and not in an index or model (e.g. Hoko and Hertle, 2006);
- Respondent: the indicator was measured or evaluated by community respondents through questionnaires, interviews, or focus groups;
- Unclear: information regarding the indicator's evaluation is vague or missing.

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CHAPTER 3

A NEW WATER SECURITY SELF-ASSESSMENT TOOL FOR RURAL COMMUNITIES

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Abstract

Access to sustainable water supply and sanitation can provide immediate health and livelihood benefits for households in rural, remote, and otherwise marginalized (RRM) communities. Both acquiring and sustaining these benefits depends on, and impacts, a host of physical, social, and economic factors within the community. The sustainability of solutions is also dependent on the nature of decision-making by the community itself. This paper introduces the Community Self-Water Assessment Tool (Community-SWAT) as a participatory evaluation tool for RRM communities. Community-SWAT provides a systematic avenue for RRM community leaders to evaluate their community's needs through meaningful indicators within a water security framework. The results are presented in an interactive dashboard using an index approach to simplify their representation and communication. Community-SWAT has several features to accommodate both the challenges of such an assessment in RRM communities and the shortcomings of traditional indices. A beta-test was conducted with data from three neighbouring RRM communities in Kenya to demonstrate the ability of Community-SWAT to differentiate water security challenges between co-located communities, and to visualize the heterogeneity of water point security within a community. The sensitivity analysis illuminated limitations with respect to the flexible question list, and demonstrated the conditions under which Community-SWAT is likely to provide reasonably consistent results.

3.1. Introduction

Despite the global achievement of the Millennium Development Goal target to reduce by half the number of people without access to improved drinking water, not all countries have achieved their national goals. Today, 780 million people remain without access to safe, affordable, and reliable water (WHO and UNICEF, 2012a). In low- and middle-income countries (LMICs), progress in rural areas significantly trails their urban counterparts.

Improving access to water and sanitation can have immediate benefits for individuals and households in rural, remote, and otherwise marginalized (RRM) communities, the most notable of which are improved health and reduced mortality rates, especially among children. Other benefits include time and energy savings, particularly for women and children, which can then be put towards family, education, and other productive activities, and financial savings due to reduced healthcare costs and reduced dependency on expensive water vendors (MacDonald et al., 2005a; UNICEF, 1999).

However, water supply depends on and impacts many physical, social, and economic factors within a community, all of which can vary over space and time. Also subject to variance are the five key indicators of water supply security: quantity, quality, accessibility, affordability, and reliability (MacDonald and Calow, 2009; WHO, 2011). For water interventions to be sustainable, they must be undertaken holistically by accounting for the interplay of issues between water point security and the broader community itself.

Experience has demonstrated that the sustainability of rural water supply schemes is significantly influenced by community participation (Katz and Sara, 1998; MacDonald and Calow, 2009; McCommonet al., 1990; Narayan, 1995; UNICEF, 1999; WELL, 1998). While a distinction is sometimes made between community *participation* and community *management*, generally in favour of the latter (MacDonald and Calow, 2009; McCommon et al., 1990), the necessity of community-managed water supplies has been debated (Harvey and Reed, 2006). Both sides, however, agree that the critical issue for sustainable development is empowering communities with legitimate decision-making authority for the changes affecting them.

RRM communities face several challenges for water resource development and management. Specifically, RMM communities tend to be dispersed agricultural populations with 5000 or fewer members; have reduced access to infrastructure, services, and external support; face technical, economic, and institutional constraints to improving water supply; and have limited or no access to expertise and support networks (Mahmud et al., 2007; McCommon et al., 1990). These challenges make it difficult for a community to affect change independently and thus they require external support from agencies and government. A key issue then becomes one of roles and authority. Water supply decisions made by agencies and government prior to, or without, community engagement are likely to overlook socio-cultural perspectives and compromise the likelihood of sustained benefits. Decisions driven by technology and water availability alone (a typical approach to developing water resources) are likely to neglect the preferences and demands of users, which are required for solutions to be sustainable and affordable (Katz and Sara, 1998). If the decision-making authority is to rest with communities, government and other agencies must recognize and support communities in their role as decision-maker. This can be achieved through sharing ideas, merging expertise with community knowledge and wisdom, and helping a community to consider options (Narayan, 1993).

Community decision-making can be facilitated through not only the provision of knowledge, but by supporting the generation of knowledge by community members, which enhances knowledge internalization. This process of collaborative evaluation based on the knowledge assembled is referred to as participatory evaluation (Narayan, 1993). Narayan (1993) further noted that stakeholders who are involved in the process of knowledge gathering and analysis are far more likely to come to their own conclusions and respond to their findings (see also Howard, 2002). For the community, the assessment process itself becomes an opportunity to build local capacity for informed decision making, and thus developmental change (Narayan, 1993).

Community members with little or no technical training can enhance resource evaluation by participating in several ways including data collection, providing tacit and experiential knowledge, and basic data analyses. Community members have collected reliable groundwater quality data (Silliman et al., 2009), recalled historical groundwater levels (Lightfoot et al., 2009), and complemented quantitative measures in a biophysical land quality assessment based on embedded familiarity with the environment (Messing and Fagerström, 2001). Community perceptions have been used to assess the sustainability of watershed projects (Vishnudas et al., 2008) and Arctic community members have been engaged in analyzing and verifying the results of a water resource vulnerability assessment (Alessa et al., 2008). Messing and Fagerström (2001) noted that involving community members in their work at an earlier stage would have reduced the amount of data collection required.

Thus, there is great potential for a community desiring to enhance their water security to benefit from evaluating the security of water resources *themselves*. Such an exercise is one way in which a community can identify and prioritize both opportunities and needs while gaining knowledge of how the key elements interact. This then provides the community with better insight to their situation, is likely to equip and inspire members to improve communication with external partners and authorities, and can empower them to make change.

This paper introduces the Community Self Water Assessment Tool (Community-SWAT) as an holistic participatory evaluation program designed to strengthen the role of RRM communities in developing secure water supplies. Community-SWAT is intended to precede the development of a Water Safety Plan (WSP), which is a risk-based approach to ensuring safe water quality advocated by the World Health Organization (WHO, 2011). Implementing a WSP remains a challenge for RRM communities because they often need support in developing their water resources, or lack the infrastructure necessary for implementation. WSPs seek to ensure proper sanitary conditions of water supply infrastructure; however, if a community does not practice good hygiene, remedying this ought to be a first step (WHO, 1999). The intention of Community-SWAT is to guide a community through an holistic gathering of water security related data, and to increase their awareness of these issues in the process.

3.2. The Community Self-Water Assessment Tool

The development of Community-SWAT consisted of four major stages. First, the overall concept and design criteria were established. Second, the relevant parameters for assessing water security, and the standards by which to evaluate them, were established. Third, the computer application was developed. Finally, a beta-test and sensitivity analysis was conducted using information from three RRM communities in Kenya.

The design criteria were established through a consideration of the potential challenges to be faced by a RRM community undertaking a water security assessment. In order to maximize usability, these challenges and resulting design criteria formed the decision-making basis for the development of Community-SWAT (Table 4).

Table 4 Design criteria for Community-SWAT

Challenges for a water security assessment in a RRM community	Corresponding design criteria for Community-SWAT
Data are limited, incomplete, non-existent, or otherwise unreliable	Minimal reliance on historical data records and use of qualitative response options
Limited and inaccurate knowledge of the links between water, environment, health, and hygiene	Systematic presentation, enabling users to learn while using the tool
Limited capacity for development and informed decision-making	Designed for participatory use; systematic; clear and interactive outputs
Non-technical audience	Simple to use; qualitative response options; water security modelled using an index approach
No two RRM communities are the same	Flexible, scalable, and transferable for use in many RRM contexts

Community-SWAT was developed as a Microsoft® Excel application. It has been designed to be used by community water leaders with an assumption of basic computer training and computer access. Where this assumption is not met, external agencies could provide assistance. Microsoft® Excel was chosen because it is widely available, relatively simple to use, has aesthetic potential, and is capable of meeting all design criteria (Table 4).

The relevant parameters for assessing water security, and the standards by which to evaluate them, were established based on a literature review (Newton et al., 2013). Indices (or composite indicators) were chosen to model water security; they are organized into eight dimensions, which are further organized into components and subcomponents within each dimension (see Table 5). The indices were divided into two parts for assessment purposes. The Community Assessment (Part 1) is used to evaluate the broader context of water and environmental resources and the socio-economic status of a community, while the Water Points Assessment (Part 2) is used to evaluate individual water points (e.g. springs, boreholes). The Water Points Assessment implicitly recognizes that a RRM community may have several points of collection, and that even when a safer source is available some may choose to use unprotected sources for various reasons (e.g. tradition, convenience, cost, preferred taste; see Bhandari and Grant, 2007; Davis et al., 2008; UNICEF, 1999; WHO, 2011). Each water point is to be assessed individually, which is necessary for a thoughtful, rigorous analysis. After completing the required assessments, users are can view the overall results, or details, that pertain to either of the results for Part 1 or 2.

Table 5 Overview of the Community-SWAT framework (Newton et al., 2013)

Dimension	Component	Subcomponent details	# indicators
Water Resources	Quantity	Surface water, groundwater, precipitation, climate	5
	Variability	Seasonal, inter-annual, extreme events	7
	Quality	Potential pollution sources	6
Environment	Land	Natural vegetation, erosion, drought, flooding	5
	Water	Environmental water quality indicators	3
Developed Sources*	Quantity*	Sufficiency of household collected quantities (wet and dry seasons)	2
	Reliability*	Frequency of supply interruptions (weekly and seasonal)	2
	Quality*	Sanitary conditions (from WHO and UNICEF, 2012b), level of treatment, *E. coli* levels, user acceptability (taste, odour, clarity)	10 sanitary, 5 other
Access*	Distance*	No. of households having water point within 100 m, 1000 m, beyond 1000 m, or on property (cf. Howard and Bartram, 2003) (wet and dry seasons)	2
	Affordability*	Proportion of users burden by water costs	1
	Competition*	Frequency of domestic water needs being outcompeted	2
	Ease of use*	Queue time at source, withdrawal effort, safety	3
Water Management	Administration	Documentation and planning	8
	Finances	Financial structures in place	3
	Representation	Community satisfaction, equity	3
	Water point operation*	Fund sufficiency, inspection frequency, water conservation	3
Community Capacity	Knowledge capital	Schooling, special training, indigenous knowledge	6
	Financial capital	Household and community assets	6
	Social capital	Women, institutions, solidarity	9
Health and Hygiene	Knowledge and health	Community understanding of water-health link, incidence of diarrhoea	4
	Water practices	Storage and preparation	5
	Hygiene	Hand-cleaning practices, sanitation facilities	4
	Access	Proximity to and affordability of clinics and other resources	5
External Support	Government	Water policies, plans, the right to water	4
	Linkages	Accessibility, relationships, support-related visits	4

* indicates sections belonging to Part 2: Water Points Assessment. All others belong to Part 1: Community Assessment.

Each indicator in Community-SWAT is represented by a question and a response. The response to each question is scored and normalized to a value between 0 and 100, with higher values being indicative of greater water security. Specific indicators within each dimension were chosen for their relevance to RRM community water issues, minimal reliance on historical records which may or may not exist, and ease of information collection. In recognition of the scarcity of historical data records in RRM communities, qualitative response options are used extensively in Community-SWAT. Also known as Likert scales, these response options form an ordered list (lowest to highest water security) with a numerical score associated with each choice. With a few exceptions, a five-point scale was chosen with values of 0, 25, 50, 75, and 100 as the associated scores. Table 6 shows three examples employed in Community-SWAT. While scales with fewer than ten points may slightly inflate the mean (Dawes, 2008), the effect is minor, and other water security indices of relevance have used four-point (e.g. Giné and Pérez-Foguet, 2010) and five-point scales (e.g. Alessa et al., 2008; Chaves and Alipaz, 2007; Henriques and Louis, 2011; Vishnudas et al., 2008).

Table 6 Examples of qualitative responses

Score	How frequently do farmers use pesticides or herbicides on their crops?	How engaged are women at community meetings?	What best describes the colour of the water?*
0	Always	Women do not attend community meetings	Dirty and/or opaque
25	Often	Through listening	Cloudy
50	Sometimes	Through listening, and asking questions	Slightly cloudy
75	Rarely	Through listening, asking questions, and being asked questions	Clear but coloured
100	Never	Through listening, asking questions, being asked questions, and giving presentations	Clear

*Based on WHO (2011)

Water security is modelled in Community-SWAT through indices. Indices have been used to simplify the representation and communication of complex issues (e.g. OECD, 2003; Sullivan et al., 2003). Indices simplify by reducing the number of input parameters, normalizing parameter scores, and aggregating scores into a single value or several sub-values. Relevant to water security, indices can combine different types of measurement units through normalization and weighting methods. As a result, relevant issues that are not easily quantified can be evaluated by using either qualitative or other surrogate variables. The resulting index value(s) can be used to prioritize the needs between communities (e.g. Giné and Pérez-Foguet, 2010; PRI, 2007; Sullivan et al., 2003) or within a community (e.g. Alessa et al., 2008; PRI, 2007) according to the components of the index.

Indices are not without limitations, however. In their criticism, Molle and Mollinga (2003) note several drawbacks, including: the use of poor quality data; the designation of equal, and therefore arbitrary, weightings; loss of information through aggregation (e.g. complexities, extreme values); different standards of evaluation for different parameters; and the potential to be misleading through the lack of transparency in the assumptions and calculations. While these limitations are acknowledged deficiencies, they also call for cautious, conscientious use. Indices therefore ought to be thoughtfully applied and not used to replace a more detailed analysis when required. In Community-SWAT, indices provide a place to start the analysis and a tool for summarizing areas of concern.

Community-SWAT is adaptable to different RRM communities through a flexible question list, made possible by a dynamic weighting system. The aggregation weights are calculated based on the number of actual responses as opposed to the total number of questions. This method ensures that questions that are either not answerable or not applicable do not artificially lower the overall score. Furthermore, as Table 5 shows, the number of indicators, subcomponents, and components varies for each dimension. Within each of these layers, an equal weighting scheme was applied to each of its constituents. With each level, aggregation increases from indicator to dimension and weightings are calculated as:

$$x_{ijk} = \frac{1}{n_{ijk}} \sum_{l=1}^{n_{ijk}} x_{ijkl} \qquad [1]$$

$$x_{ij} = \frac{1}{n_{ij}} \sum_{k=1}^{n_{ij}} x_{ijk} \qquad [2]$$

$$x_{i} = \frac{1}{n_{i}} \sum_{j=1}^{n_{i}} x_{ij} \qquad [3]$$

where *i*, *j*, *k*, *l* are the dimension, component, subcomponent, and question indexes respectively; n_{ijk} is the number of responses in subcomponent *ijk*; n_{ij} is the number of subcomponents (with at least one response) in component *ij*; n_i is the number of components (with at least one response) in dimension *i*; and *x* is the score of the question, subcomponent, component, or dimension as noted. Finally, for questions belonging to the Water Points Assessment, the dimension, component, and subcomponent scores are the average of individual water point scores, weighted by the number of households using each point.

Like other water vulnerability indices (e.g. Alessa et al., 2008; Chaves and Alipaz, 2007; PRI, 2007; Sullivan et al., 2003), Community-SWAT uses an equal weighting scheme within each framework layer, but it differs by incorporating a flexible question list and additional framework layers (e.g. the component and subcomponent grouping of questions within each dimension). The dynamic calculation of the weight is the mechanism that allow the question list to be flexible, permitting users to omit questions without artificially lowering scores. The flexible question list and framework layers do result in a degree of implicit weighting. For example, within the Water Resources dimension, if one Quantity and four Quality questions are answered, the dimension weight of the quality questions will be four times smaller than the one quantity question, in order to have both quantity and quality issues equally represented in Water Resource's score. However, the identified eight key dimensions together with the sub-dimension structure was designed to give an equal representation of each issue within each layer of the framework (Table 5), provided that at least one question is answered in each (compare with Sullivan et al., 2003).

There are two exceptions to these weighting calculations. The Distance and Quantity components (see Table 5) of the Water Points Assessment are scored based on level of access according to Howard and Bartram's (2003) literature review of service levels and health (Table 7). Water availability and accessibility can also fluctuate significantly throughout the year (Calow et al., 2010), as extended dry periods are common for many RRM communities. While others have accounted for this by using dry season values as the worst case scenario (e.g. Sullivan et al., 2003), Community-SWAT incorporates seasonal variation in access directly by soliciting responses for both wet and dry periods for each water point. Specifically, for both wet and dry periods, information is solicited on the number of households living within the four distance increments defined by Howard and Bartram (2003), and the average volume of water collected by households within each increment (Table 7). The resulting seasonal subcomponent scores for both Distance and Quantity are then averaged and weighted by the number of households. Likewise, the overall Distance and Quantity component scores (accounting for both seasons) are the household-weighted averages of their respective parameters.

Table 7 Water service levels in relation to household distance from source (after Howard and Bartram, 2003)

Access level	Distance	Equivalent return trip	Score (distance)	Quantities likely to be collected	Water needs likely to be satisfied	Score (quantity)
Optimal	On property	-	100	100 Lpcd[1]	All domestic needs likely to be met; water available for productive use	100
Intermediate	<100 m	<5 min.	75	50 Lpcd	Drinking, cooking, all personal hygiene, possibly laundry	75
Basic	100-1000 m	5-30 min.	50	20 Lpcd	Drinking, basic cooking, hand washing	50
Minimum	>1000 m	>30 min.	0	7 Lpcd	Drinking and basic cooking	25
				< 7 Lpcd	Minimum needs likely unsatisfied	0

[1] Lpcd = L/capita/day

Nine different types of water points are common to RRM communities as indicated in Table 8. For improved water sources, sanitary inspections assess the risk of faecal contamination by the presence or absence of hazards, pathways, and indirect factors (WHO and UNICEF, 2012b). Sanitary inspections are used to assess water point sanitary conditions, one of the four components of the Quality dimension (Table 5). Unprotected sources and water vendors, for which there are no forms, are assigned a sanitary score of 0. In cases where the water vendor is known and trusted for providing water from protected sources, the user can select the appropriate source and complete a sanitary inspection.

Table 8 Types of water sources (adapted from WHO and UNICEF, 2012b)

Type of source	Sanitary inspection form?
Surface water	No
Unprotected spring	No
Protected spring	Yes
Borehole with mechanized pump	Yes
Borehole with handpump	Yes
Dug well with handpump	Yes
Rainwater harvesting tank	Yes
Household piped water	Yes
Other water vendor	No

The Water Points Assessment can be adapted to unique situations by grouping or disaggregating entities. For example, homes with piped water on premises may be grouped together under one water point. To evaluate distance, only the number of households having piped water would be entered in the "on premise" distance section along with the needs that they are able to satisfy. The same could be done if a community only had piped water during the dry season, for example, and used other sources during the wet season. If there were water shortage (or other) problems for only some of the households with piped water, the homes could be split into two water points and assessed separately.

Community-SWAT also enables users to rate the confidence that they have in each of their responses. These "confidence scores", ranging from 1 (low) to 10 (high), are intended to capture the level of uncertainty for each answer provided. These uncertainties are preserved and displayed to the user as an aid for interpreting the results. While not a perfect measure, this provides a starting place for assessing the quality of the results, and may reveal areas of significant uncertainty and motivate a more thorough investigation. Confidence scores for subcomponents, components, and dimensions are aggregated using equations [1], [2], and [3].

While data and information availability have been accounted for in the design of the indicators, Community-SWAT will only be used if it is user-friendly for both data entry and output displays. A review of water, sanitation, and health resources found that user interfaces are often ineffective (Palaniappan et al., 2008). Therefore, several features have been added to Community-SWAT to improve its ease of use, including: a user guide; a main menu to track progress; links to navigate between forms; simple aesthetics; consistent colour schemes; and greyed out response boxes for inapplicable questions. The results are displayed as tables and graphs in an interactive dashboard format that enables users to drill down into the details of the aggregation. The interactive outputs were designed not only for ease of comprehension, but to increase the level of user engagement and therefore internalization of the results.

The assessment results are presented using several tables and charts with interactive elements. The results section is organized into a primary page containing the overall results, and two supplementary pages containing extra details for both Parts 1 and 2. Since six of the eight dimensions belong to Part 1, there is some overlap between the presentation of the overall results and the extra details for Part 1. Across all three result pages, there are common elements which include: a main table and bar chart for presenting dimension scores; and the option to toggle between the main bar chart and a bubble chart, where the diameter of the bubble represents the aggregated confidence score (see Figure 3). Each of the three result pages also contains a set of unique elements, which are listed in the following points.

- The **overall results page** includes the option to sort the eight dimensions within the main table and chart by one of four criteria: default, highest score, highest confidence, and highest combined score and confidence. This page also includes a larger chart that illustrates the component scores for each of the eight dimensions.

- The **Part 1 details page** includes the option to focus on a dimension of the user's choice via a dropdown list selection, which highlights the respective dimension in the main table and chart and shows its component scores in a smaller chart. This page also includes two pie charts with the option to illustrate any question that required a percentage input[7]. Finally, there is a bar chart for precipitation with the option to view average monthly rainfall depths and/or a bar chart representation of wet, dry, and mixed wet and dry months.

- The **Part 2 details page** includes the option to focus on a component[8] of the user's choice via a dropdown list selection (similar to Part 1 details), which highlights the respective component in the main table and chart, shows its subcomponent scores in a smaller chart, and ranks all water points according to the selected component in an additional table. This page also includes the option to select and compare scores for an individual water point against the community average on the main table and chart. Final-

[7] For example, for the question, "Approximately what percent of households have reliable income throughout the year?", the pie chart would consist of two pieces: households with reliable income, and households without.

[8] Since the Water Points Assessment has only two full dimensions, the main table and bar chart instead display the eight related components (see Table 5).

ly, there is a pie chart summarizing the distance access levels for the whole community, as per Table 7, with the option to view by season (wet, dry, or average)[9].

As noted above, indices have several limitations (Molle and Mollinga, 2003). Community-SWAT addresses these issues in several ways. First, it is a participatory tool designed with the intent of supporting a deeper understanding of water security issues at the community level. Second, there is no final index value: the eight dimensions remain disaggregated to highlight pertinent issues within the local context. Third, qualitative response options are frequently used to bypass some of the dependence on historical data records, particularly when they are of poor quality. Fourth, the quality of information entered is evaluated by the "response confidence" feature, as some questions may require the use of poor quality data or users may be otherwise uncertain. This allows the users to consider the results together with their reliability. Finally, the results are interactive and allow users to query into different levels of the aggregation. These features position Community-SWAT to act as a starting point for dialogue, visioning, and decisions around all aspects of water security.

3.3. Beta-Test Case Study

Community-SWAT was beta-tested by running it with data collected from three neighbouring RRM communities in Kenya.

Community-SWAT was beta-tested by entering data collected from three neighbouring RRM communities in Kenya. The data were used to test whether the tool could provide a realistic representation of community water security; demonstrate differences between water points; and present data in a user-friendly format.

The beta-test discussion focuses on both the index scores and examples of the interactive features that enable users to query into the details of the aggregation. Since six of the eight dimensions belong to Part 1, the discussion of the overall results and details from Part 1 will be combined. Detailed results for the Water Points Assessment will be discussed separately. For the sake of brevity, a selection of the interactive elements will be included. Discussion of the results are followed by a sensitivity analysis.

3.3.1. Data collection

During the period of September 2011 to March 2012, data representing the dimensions of water security were collected in three neighbouring RRM communities in Kenya. The primary sources of data were a household questionnaire and water point surveys. Information on the component Water Point Operation was not available and has therefore been omitted.

[9] This figure is included because research by the World Health Organization suggests that household to water point distance is the single most important indicator regarding access and household health (Howard and Bartram, 2003).

The questionnaire was designed to gauge water collection and storage practices, hygiene practices, health, and preferences for water sources at the household level. The questionnaire was developed based on that of Levison et al. (2011) together with a literature review on water- and health-related knowledge, attitudes, and practices (KAP) in RRM communities. Written in English, it was translated into Swahili, and administered in either Swahili or Maa according to respondent preference. Six community members were hired and trained to administer the survey over three weeks in 2012 between late January and the middle of February.

An informal stratified sampling process was used to identify households representative of both as many water points as possible, and the diverse socioeconomic backgrounds (education, family size, age, socioeconomic status, and health) within each community. Coverage of these two criteria was verified by mapping the participants' household locations, the number of water points reported in each community, and the diversity of responses to the socioeconomic questions of the questionnaire. This sampling process was informal as it was based on the local surveyors' knowledge of their community (as opposed to demographic information which was previously non-existent). Interviewees were females having either partial or full responsibility for providing water in their home. Participants were approached in their homes, informed of the survey's purpose and given an opportunity to decline. Ethics approval was provided by McMaster University. In total 139 surveys were completed in three different communities (Community 1: n=75; Community 2: n=40; Community 3: n=24). Household locations were geocached and assigned a unique code for mapping and spatial analyses. The survey results were entered into a database twice by independent parties. An electronic line-by-line comparison was conducted, and discrepancies were resolved by consulting the original questionnaires.

The water point surveys included geocaching, sanitary inspections, and limited microbiological analyses. Geocaching was conducted using the same method as the household surveys, described above. The sanitary inspections were completed at each water point visited according to the method described by Howard (2002). The microbiological analyses involved collecting samples from each water point visited (Community 1: n=15; Community 2: n=7; Community 3: n=17) during the dry season (September and October). Samples (1 to 5 mL) were drawn directly from the source using a sterile syringe, transferred into sterile bottles containing an inoculation solution (ECA Check Easygel® Plus, Micrology Laboratories, IN, USA) and kept on ice until end of day. Water sources were sampled in duplicate (75%) or triplicate (25%) with field and sample blanks (33%). At the end of the day each sample was poured onto a pre-treated plate (ECA Check Easygel® Plus, Micrology Laboratories) and incubated at 37 °C for approximately 48 hours. At 24 hours, plates were inspected under a UV light for the presence of *E. coli* (faecal). At 48 hours, plates were inspected under tungsten light for the presence of *E. coli* (total), *Salmonella spp., Aeromonas spp.,* and other generic coliforms, each differentiated by coloured dyes that differ according to the metabolism of the organisms.

3.3.2. Combined Overall Results and Details from Part 1: Community Assessment

The final index scores for all eight dimensions are presented in the bubble plots in Figure 2 (which can also be viewed as a bar chart) along with the component scores for the Community Capacity dimension. Since the three communities are co-located, they have several environmental and institutional characteristics in common and also share certain collective resources. As expected, significant similarities were found for the Water Resources, Community Capacity and External Support dimensions (Figure 2). However, drilling down into the individual elements begins to demonstrate nuances between the locations. For example, reported income and education varied between communities and this provides the variation in component scores seen in the output charts (Figure 2). The benefit of viewing component score details is that a community can better pinpoint both their strengths and priority issues that would be otherwise be hidden in a higher level of aggregation and explore ways of improving scores in these individual categories. If a community was expecting a higher score than calculated (e.g. the Water Management score for Community 1, whose members are relatively proactive), they may be motivated by the difference between actual and expected values to investigate the reason. Users could then identify specific items to be addressed through the breakdown of component scores and tracing the results back to specific questions.

When interpreting these results, it is important to distinguish between that which a community can control, and that which it cannot. A community cannot, for instance, exercise control over the availability of water resources or external support. Items of this sort indicate some of the *constraints* within which they must work. Although a community may not be able to alter these constraints, they can benefit from their identification. For example, RRM communities may be unaware of government water policies or assistance available to communities to improve water security. However, through answering the questions posed in Community-SWAT, communities may become sensitised to these possible external supports and/or research them in order to complete the assessment. Identifying constraints and finding new information to complete the assessment may also reveal *opportunities*. There are many variables, however, for which Community-SWAT solicits a response that a community can exercise some form of control over. Of these, Community-SWAT suggests to a user that water security *strengths* are indicated by variables receiving high scores, while low scores indicate both *threats* and *opportunities* for improvements. Through a thoughtful consideration of the results, distinguishing *limitations* from *strengths*, *threats* and *opportunities* is one step in removing fatalistic attitudes and empowering communities to realize their ability to exercise control over their environment and health (MacDonald et al., 2005; UNICEF, 1999).

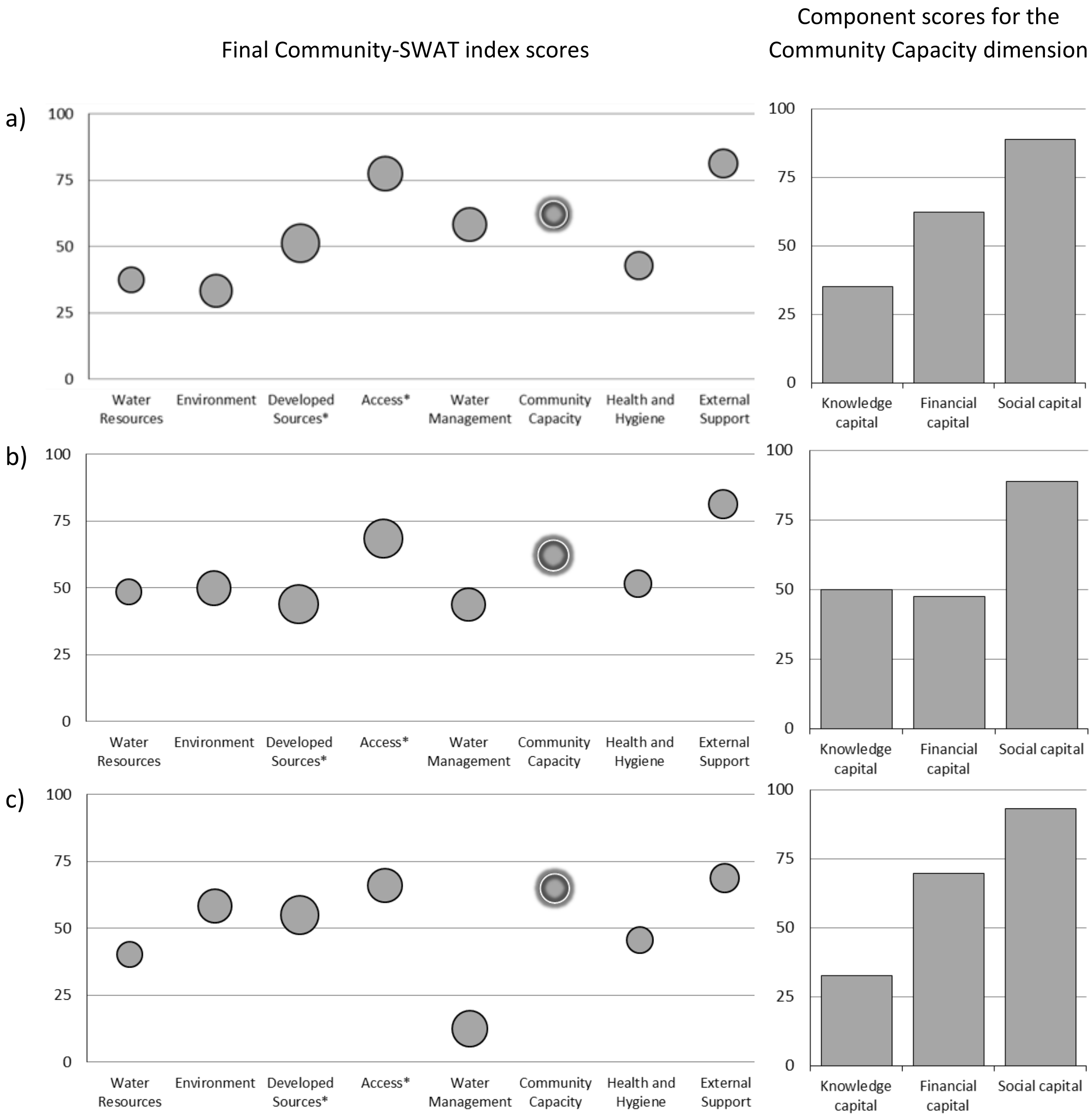


Figure 2 Final Community-SWAT index bubble plots and component scores for the Community Capacity dimension for (a) Community 1, (b) Community 2, and (c) Community 3. The diameter of the bubble indicates the response confidence for a particular dimension, with smaller bubbles indicating greater response confidence. The * indicates dimensions that are based upon results from the Water Points Assessment (see Table 5 above and the discussion below). Note that the selected dimension for viewing component score details is highlighted in the main chart.

3.3.3. Detailed Results from Part 2: Water Points Assessment

A comparison of three options for displaying the results of the Water Points Assessment is shown in Figure 3. The overall aggregation of all water points (Figure 3a) is useful for gauging the state of water point security within a community, as well as for inter-community comparisons. There is, however, a unique feature in Community-SWAT that allows scores for individual water points to be compared against the overall averages (Figures 3b and 3c). This comparison enables users to visualize any heterogeneities in water point security that exist within a community. Users can also integrate the response confidence scores by viewing bubble plots instead of bar graphs (Figure 3c). Rather than providing a separate bar graph to view either confidence scores or individual water point scores, the comparative bubble plot shown in Figure 3c condenses several layers of information into a single visual display, and therefore greatly eases the interpretation of results.

The confidence score of any dimension is indicated by the diameter of the circle in the bubble plots (Figures 3c and 4). Smaller circles focus on a smaller area of the graph and therefore represent a greater degree of certainty. Likewise, larger circles cover more area and represent greater degrees of uncertainty. Visually speaking, this representation is comparable to error bars. In this beta-test, confidence values were notably low for the Quantity component in the Water Points Assessment (Figures 3c and 4) as a result of missing data and mixed responses to the questionnaire. The Competition and Ease of Use components also received relatively low confidence ratings to reflect the approximations made in translating related questionnaire results to Community-SWAT inputs (as the design of certain questions differed between the household questionnaire and Community-SWAT). In the first case, these low confidence ratings indicate that, while based on collected data, the results were not conclusive and therefore may not be representative, while in the second case they reflect the approximations or assumptions in converting data from one format or context to another. Thus, two options are presented through these results. Community-SWAT users could choose to improve the reliability of low-confidence dimension inputs through additional data collection or consultations, or make an assessment based on their current knowledge. This enables users to proceed with the assessment despite data limitations, while the limitations may be acknowledged through confidence ratings that are visually embedded in the results.

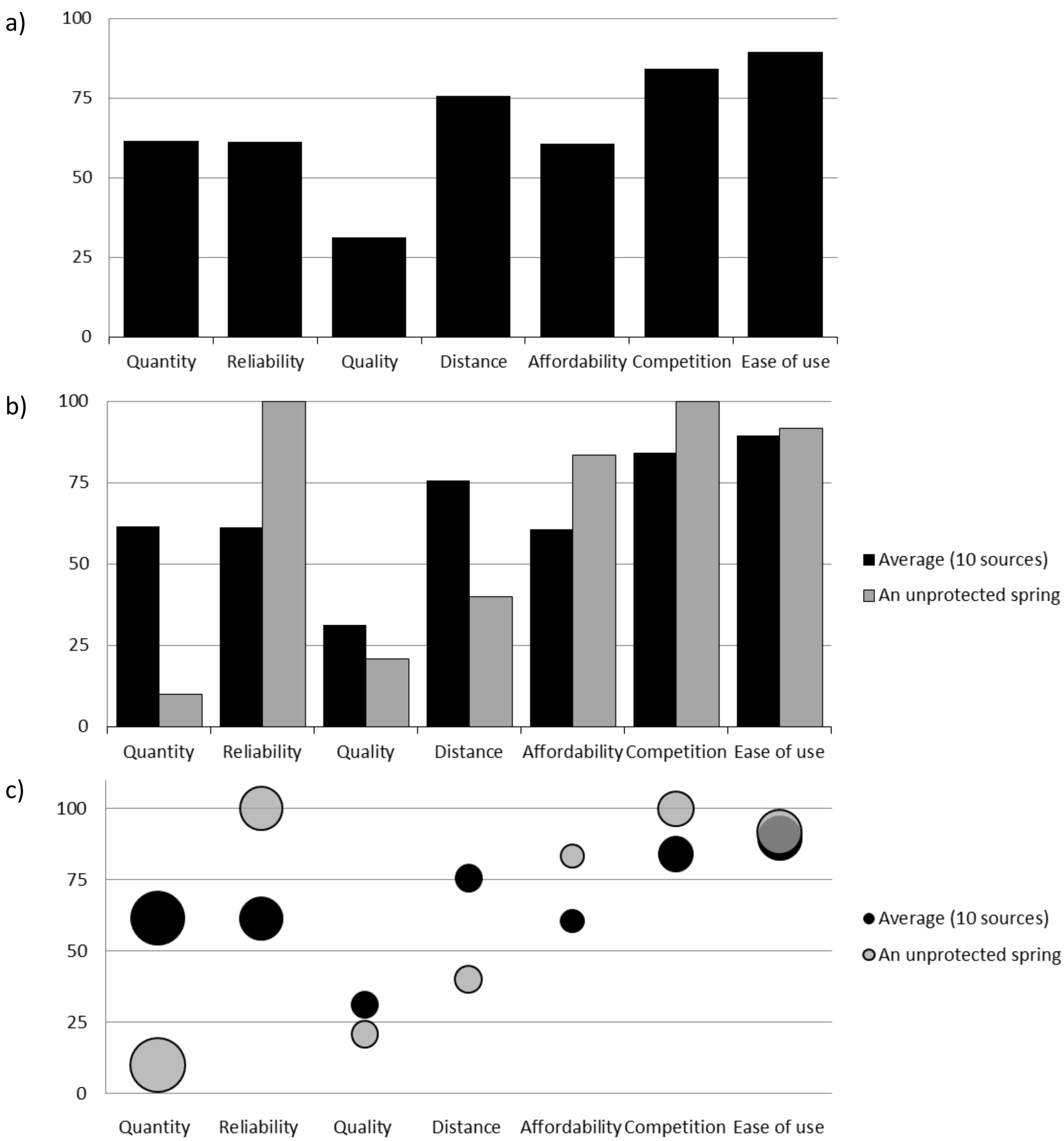


Figure 3 Comparison of result presentation of Water Points Assessment using data from Community 1: (a) bar graph of a typical aggregated index; and (b) bar graph and (c) bubble plot comparing dimension scores between values for the overall average and a user-specified water point. The diameter of the bubbles indicate the response confidence for a particular component, with smaller bubbles indicating greater response confidence. In Community-SWAT users can toggle between graphs (a), (b), or (c).

Aggregated water point scores can quickly communicate to Community-SWAT users the main water point issues(s) facing their community in relative priority. The importance of examining the results from each individual water point must be emphasized, however, so as not to give the false impression that challenges faced by households are homogeneous. Challenges at the household level are clearly not homogeneous, as illustrated by Figures 3c, 4a, and 4b which compare scores for individual water points against a community average.

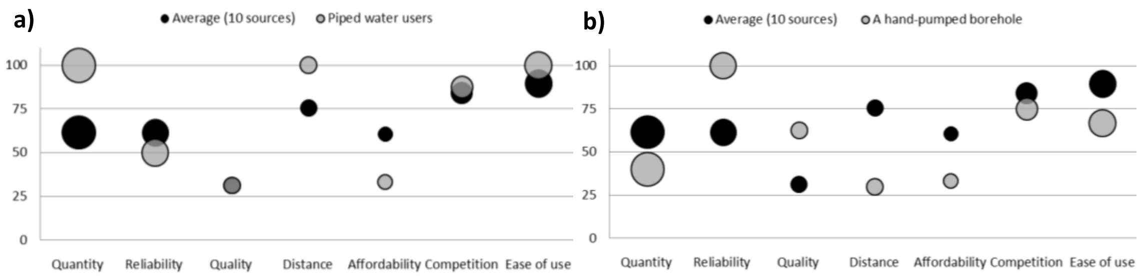


Figure 4 Water Points Assessment results for Community 1, comparing the average score for all sources and the scores for: a) homes with piped water; and b) a hand-pumped borehole

These three examples from Community 1 illustrate how needs (and subsequent priorities) may vary for different cross-sections of a community. These examples also demonstrate Community-SWAT's ability to visualize and highlight such heterogeneities in water point security within a community. For Community-SWAT users, this feature may also foster a greater appreciation for the different advantages and challenges faced by different households within their community, and consequently be informative for decision-making.

Community-SWAT disaggregates the components of water point security in order to assess them independently of one another. For example, the measures of distance, quantity, and quality are separated to assist community leaders in identifying improvements that could be made to existing water points. Conversely, the Joint Monitoring Programme's (JMP) access indicator[10] combines distance, quantity, and quality measures into a single value. While separating water point components for assessment purposes is useful, it also demonstrates that Community-SWAT's results require thoughtful interpretation.

3.4. Sensitivity Analysis

Sensitivity analysis (SA) is used in modeling in order to understand how model outputs are influenced by the inputs, construction, and assumptions (Saltelli et al., 2004). Since indices are typically used as a policy instrument to rank regions of interest, SA is used to quantify the uncertainty in the rankings (OECD, 2008). For large-scale indices, a typical input is a highly aggregated value (e.g. the arithmetic mean) of a dataset that is also characterized by other statistical properties (e.g. variance, skewness). Other assumptions include the choice and calculation of weights (particularly when using preference or expert opinion) and the method used for aggregating the inputs (e.g. arithmetic mean, geometric mean). For these types of indices, variance-based sampling techniques can be used to run model simulations under alternative, randomly chosen as-

[10] The percentage of households having access to 20 L/person/day from an improved source within 1 km of a person's dwelling (WHO and UNICEF, 2012a)

sumptions which are used to assess changes in regional rankings (OECD, 2008; Saltelli et al., 2004).

The Community-SWAT index differs from larger scale indices in that there is no final index value, and it was designed for use by a single community (i.e. there are no inter-regional rankings). More importantly, the majority of inputs are not drawn from aggregated datasets, and several scores are discrete numbers resulting from the five-point list selections. For these reasons, a different, two stage approach was implemented. The first stage provided a theoretical basis by modeling weight calculations under different conditions. This was complemented, in the second stage, by the systematic omission of individual responses and the resulting change in dimension scores, which provided a practical test of the flexible question list. It was unnecessary to test the outputs resulting from grossly erroneous data, as all inputs have restrictions on the type (and for numerical data, the range) of input to prevent entry error.

Theoretically, the sensitivity of Community-SWAT outputs to changes in the inputs is determined by how the inputs are weighted. By substituting equations [1] and [2], the score for dimension *i* (equation [3]) can be re-written as follows:

$$x_i = \frac{1}{n_i}\sum_{j=1}^{n_i} x_{ij} = \frac{1}{n_i}\sum_{j=1}^{n_i}\left(\frac{1}{n_{ij}}\sum_{k=1}^{n_{ij}} x_{ijk}\right) = \frac{1}{n_i}\sum_{j=1}^{n_i}\left(\frac{1}{n_{ij}}\sum_{k=1}^{n_{ij}}\left(\frac{1}{n_{ijk}}\sum_{l=1}^{n_{ijk}} x_{ijkl}\right)\right) \qquad [4]$$

for all *j*, *k*, *l* belonging to *i*. Since the weights for the components, subcomponents, and questions are represented by the inverses of n_i, n_{ij}, and n_{ijk}, respectively, the dimension weight (w_{ijkl}) for question x_{ijkl} is equal to:

$$w_{ijkl} = \frac{1}{n_i n_{ij} n_{ijk}} \qquad [5]$$

Therefore, the dimension weight of a question is a function of: the number of components and subcomponents within that dimension; and the number of answered questions belonging to the same subcomponent. The weights for various configurations of n_i, n_{ij}, and n_{ijk}, are depicted in Figure 5 (right axis). This allows the change in a dimension's score (Δx_i) resulting from a change in a single question's score (Δx_{ijkl}), with all else held constant, to be calculated as:

$$\Delta x_i = \frac{1}{n_i n_{ij} n_{ijk}} \Delta x_{ijkl} \qquad [6]$$

A plot of the change in a dimension's score (Δx_i) resulting from a 25-point change[11] in a single question's score (Δx_{ijkl}) is illustrated in Figure 5 (left axis). In general, Figure 5 illustrates the mechanics of how influential a question will be on a dimension score. The factors affecting a dimension scores are the number of answered questions, the score of all answered questions, and how the questions are organized within the framework (Table 5; equation [4]). Figure 5 demonstrates that questions becomes more influential, and the results more sensitive to individual responses, when there are fewer responses and when fewer sub-dimension sections have responses.

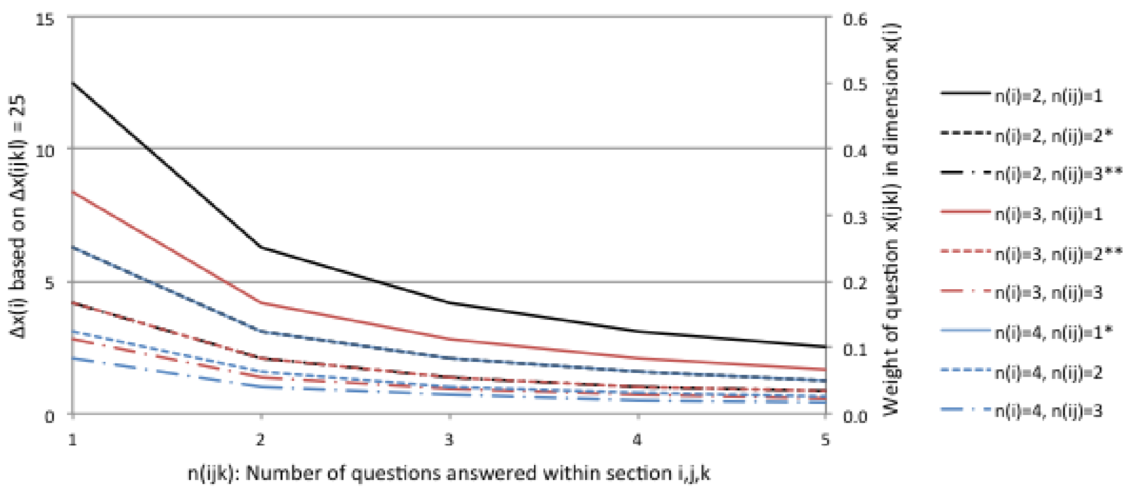
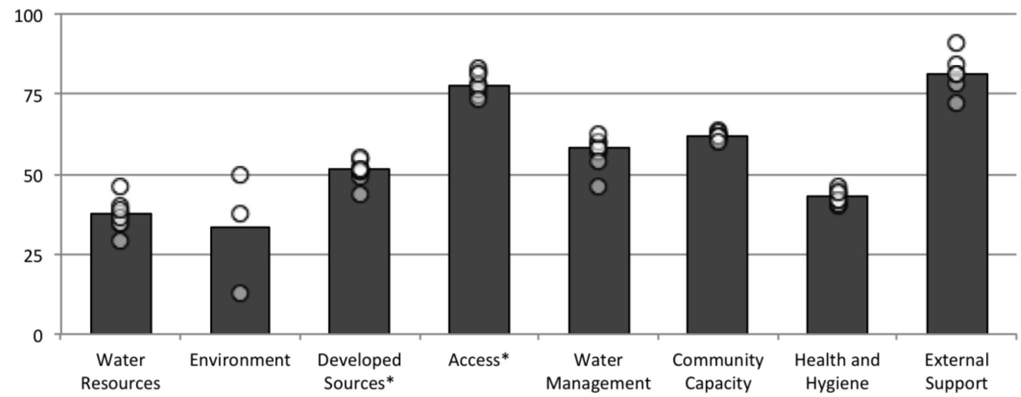


Figure 5 Change in a dimension's score (Δx_i) based on an incremental change in a question's score (Δx_{ijkl}). The asterisks in the legend identify coincident lines.

The second stage of the SA was to investigate change in dimension scores resulting from unanswered questions. This was accomplished by systematically removing individual responses from a completed assessment. The beta-test results for Community 1 were used in this analysis. The following iterative procedure was used for each response within each of the eight dimensions. First, an answered question was targeted. Second, the score (x_{ijkl}) and dimension weight (w_{ijkl}) of this targeted questioned were recorded. Third, the question response was removed and the resulting dimension score (x_i*) was recorded. Finally, the original response was re-entered. The results of the simulation, along with the proportion of questions answered in the original beta-test, are displayed in Figure 6.

[11] Twenty-five was chosen because it is the size of the scoring increment for the five-point qualitative response options



	Water Resources	Environment	Developed Sources*	Access*	Water Management	Community Capacity	Health and Hygiene	External Support
responses / total questions	9 / 18	3 / 8	10 / 10	8 / 8	9 / 14	11 / 20	10 / 17	6 / 8
% answered	50%	38%	100%	100%	64%	55%	59%	75%
largest absolute difference	8.3	20.8	8.0	5.6	12.5	1.9	2.9	9.4

Figure 6 Resulting dimension scores from the systematic omission of single responses using data from Community 1. The original dimension scores (x_i)are represented by the bars; the new dimension scores (x_i*) are represented by the circles. The number and percent of responses are based on the original dimension score.

Figure 6 shows the practical outworking of what could be expected based on Figure 5: generally, a dimension score is more sensitive to changes when fewer of its questions are answered. There is no strict relationship, as dimensions that had similar proportions of questions answered differed with respect to their largest absolute difference (e.g. Water Resources and Community Capacity), as did dimensions having similar largest differences with respect to the proportion of answered questions (e.g. Water Resources, Developed Sources, and External Support).

Additional diagnostic tests were run to investigate any relationships underlying the change in dimension scores. In this respect, there were three independent variables of concern: the weight of the removed question (Figure 7a); the score of the removed question (Figure 7b); and the proportion of questions answered (Figure 8).

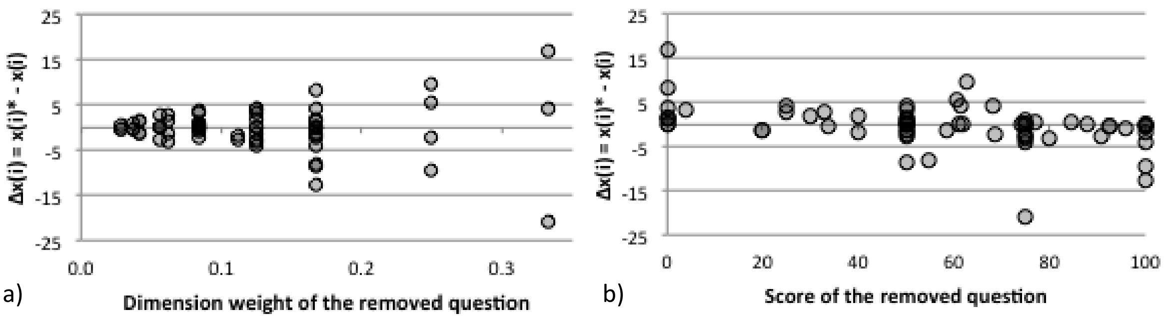


Figure 7 Diagnostic figures showing the relationship between the change in dimension score against (a) the dimension weight of the removed question and (b) the score of the removed question. These figures appear essentially identical when plotted against the relative change (i.e. $\Delta x_i/x_i$) instead (not shown).

Figure 7a demonstrates the expected envelope shape for the change in dimension score (Δx_i) when plotted against dimension weight, since questions with larger weights have more potential to influence change in a dimension's score. Driving the degree to which this potential is realized (i.e. where a question landed within the envelope) is the difference between the question's score and its dimension score. Figure 7b at best demonstrates a weak and slightly negative relationship between the score of the removed question and the change in dimension score, while more clearly it shows that there was no direct relationship (particularly when extreme scores of 0 and 100 are not considered).

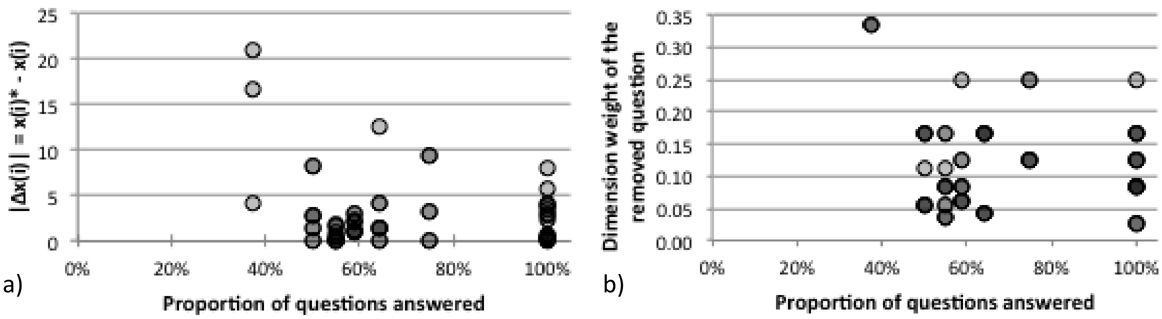


Figure 8 Diagnostic figures showing (a) the absolute difference in a dimension's score versus the proportion of questions answered, and (b) the dimension weight of the removed question versus the proportion of questions answered. Points that are darker indicate instances of coincidence.

Figure 8a demonstrates that there was no clear relationship between the relative completeness of a dimension's assessment and the change in score. Similar to Figure 7a, however, there is evidence of an envelope that narrows as the proportion of answered questions increases, though it is much less defined. Figure 8b shows that, although dimension weights are a function of the number of questions answered (equation [5] and Figure 5), there is no clear or linear relationship between the two. Also evident is the implicit weighting of the individual questions (cf. Figure 7a) that results from how the questions are organized and aggregated in Community-SWAT's framework. The reader is reminded that although there is implicit weighting at the question level, it is the result of the framework's design to give equal representation to water security issues within the framework.

There are two key limitations of the Community-SWAT index that can be identified from the SA. The first is that a dimension score is more sensitive to individual responses when a low proportion of its questions are answered. This was demonstrated theoretically in Figure 5, and practically in the changes in the Environment dimension score in Figure 6, which is further supported by noting that two of the Environment dimension's three points in all diagnostic plots (Figure 7 and Figure 8) were extreme values. Positively, the SA simulation also demonstrated that 86% of dimension score differences were less than 5, and 56% were less than 2 (Figure 9). Combined with the fact that seven of the eight dimensions had at least half of their questions answered, this SA has demonstrated that Community-SWAT provided reasonably consistent dimension scores when there were responses to at least half of a dimensions assessment questions.

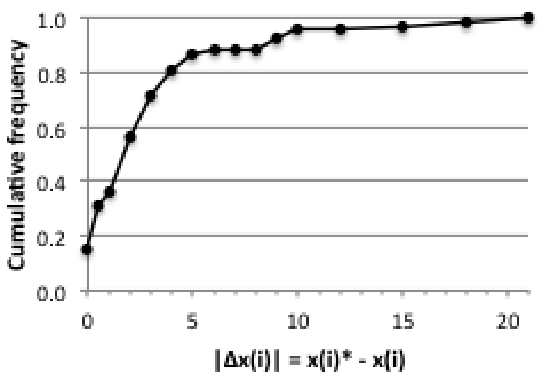


Figure 9 Cumulative frequency diagram of the absolute changes in dimension score (n=67).

The second limitation is the framework organization itself, in that the usefulness of the results largely depend on the degree to which the framework presented in Table 5 represents the reality of a RRM community's water security issues. Practically, the framework is expressed in the equal weighting of issues within each layer, and the resulting implicit weighting of individual questions. This limitation and the issue of weights is not unique to Community-SWAT, however, but is common to all indices.

3.5. Conclusions

Community-SWAT addresses several challenges associated with assessing water security in RRM communities. Community-SWAT is intended to support community leaders in individual RRM communities to evaluate the dimensions of water security with relevant indicators and to learn about the holistic nature of water security and its links to health and livelihoods in the process. Community-SWAT is unique because it has been developed to support change at a local scale; a scale at which decision-making is critical for sustainable change. The strengths of Community-SWAT, as presented here, are that it combines an holistic suite of physical and social indicators; it does not depend on, though is greatly helped by, historical and other data records; and it is flexible in terms of the selection of relevant indicators. Community-SWAT employs a participatory approach to quantifying development indices in RRM communities. Although indices have been used to simplify the measurement and communication of complex issues, they do not tend to be developed for use by local leaders for local decisions in RRM communities.

The beta-test demonstrated that Community-SWAT enables the visualization of key dimensions of water security, both between communities and within a community. For co-located communities, Community-SWAT solicits responses that identifies them within, while also differentiating them from, their broader environmental, social, and political context. By appraising water points currently in use, community leaders can use the results to inform priorities for future improvements. The average water point dimension scores quickly summarize a community's most pressing issues. Comparing the average with individual water point scores allows users to visualize heterogeneity in water point security within a community, as was shown in the beta-test. The results demonstrated that the water security challenges faced by groups of households are not necessarily those of the aggregated community. By highlighting the advantages and challenges of different water points in comparison with the community average, Community-SWAT can help community leaders appreciate how the needs differ within their community and be informative for decision-making. The confidence ratings and bubble plots as presented offer an enhancement to traditional index results and a common issue of data reliability. As was encountered in the beta-test, other RRM context water indices have acknowledged data issues related to representation (Giné and Pérez-Foguet, 2010), the adaption of previously collected information (Pérez-Foguet and Giné, 2011), or the absence of information altogether (Sullivan et al., 2003). Community-SWAT's confidence ratings allow users to assess the quality of their information so that it can be considered during the interpretation of the results.

Through the sensitivity analysis (SA), it was demonstrated that dimension scores are generally more sensitive to the inputs when there are both fewer responses, and fewer sub-dimension sections having responses. It was shown that a question's potential to influence a dimension's score is proportional to its weight, and that the degree to which this potential is realized is driven by the difference between the scores of the question and its dimension. Through the SA it was also shown that the majority of changes in dimension scores were small (less than 5) when at least half of a dimension's questions were answered.

Community-SWAT may not necessarily provide new information to a community, but combines this information to facilitate a systematic consideration of water-related issues to highlight needs. Community-SWAT is built upon key dimensions of water security relevant for RRM communities (Newton et al., 2013), supporting communication of the local context within a standardized and globally recognised framework which promotes and improves not only local understanding and communication but external communication with government, and other partners. Through use of the confidence response ratings, Community-SWAT is also intended to help leaders and decision-makers in a community assess the reliability of their understanding of the actual conditions of their community. In this manner, Community-SWAT is also a means for data advocacy, especially to fill gaps and/or improve confidence in responses.

The next step is for Community-SWAT to be piloted in several additional RRM communities to evaluate its transferability, usability, appropriateness, and usefulness as perceived by RRM community leaders, both in general and in regards to its specific features. The usefulness of the response confidence scores should be assessed in particular, as well the effect is has upon the users, specifically, whether it is actually taken into account when they are interpreting the results, and if it encourages users to seek out more reliable information.

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CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

4.1. Conclusions

The following conclusions were drawn from this work:

1. The major dimensions of a water security assessment that are relevant to rural, remote, and otherwise marginalized (RRM) communities are:
    a. Water resources
    b. Developed sources
    c. Infrastructure appraisal
    d. Operation and management
    e. Access and equity
    f. Environment
    g. Household health and hygiene
    h. Community capacity
    i. External support
2. Indicators and the standards by which they are evaluated require greater clarity in peer-reviewed published literature, regarding either their definition, the standards by which they are evaluated, and/or a justification for the standards used. This would achieve a greater level of transparency, provide further insight into the particular physical, social, and environmental context of application, and allow for learning on how others have dealt with poor quality or unavailable data.
3. Indices may provide a means for simplifying the calculation and presentation of a water security assessment in a RRM community. Index calculations are simple and therefore transparent which allows non-technical audiences to connect the inputs and outputs with greater ease. Indices provide a means for combining indicators with different units of measurement, which is important given the breadth of parameters necessary for a holistic assessment of water security. Index use has not been explored as a means to simplify and communicate otherwise complex assessments for RRM communities, yet they have been used for these very purposes in many other contexts.

4. The limitations of indices may be compensated for in several ways:

    a. A flexible parameter list permits users to skip questions/indicators that are irrelevant or unanswerable. This is enabled by a dynamic weighting system that uses the number of actual responses to calculate weights for each level of aggregation.

    b. A user-specified confidence rating for each response can provide a means of compensating for the use of poor quality data, which enables users to account for uncertainty when interpreting the results of Community-SWAT. Additionally, this approach enables community leaders to consider the quality of available information regarding the different dimensions of water security. Finally, this approach provides the community with a means for data advocacy, as it may prompt community leaders to obtain more reliable information where possible.

    c. Qualitative response options can reduce a community's dependence on historical records and numerical data and therefore opens Community-SWAT for use in more communities that would be otherwise prevented from this limitation.

    d. Result interaction whereby users can drill down into the aggregation details increases transparency and helps to prevent information loss by enabling users to view extreme values that may otherwise be hidden. For the Water Points Assessment, the heterogeneity of water point security can be visualized by comparing dimension scores for individual water points against the overall averages.

5. Through the beta-test and sensitivity analysis, it was demonstrated that:

    a. Community-SWAT highlights sub-dimension (i.e. component) score variations by displaying the associated scores in a secondary graph.

    b. Confidence scores allowed the certainty of the dimension scores to be assessed. Confidence scores enabled the assessment to proceed despite deficiencies within the data, while also acknowledging these deficiencies and embedding them as a visual queue within the results through the use of bubble plots.

    c. The average water point dimension scores presented an overall summary of the community, while comparing the dimension scores for individual water points against the average enabled a visualization of intra-community heterogeneity in water point security.

    d. Dimension scores are generally more sensitive to the inputs when there are both fewer responses, and fewer sub-dimension sections having responses. It was shown that a question's potential to influence a dimension's score is proportional to its weight, and that the degree to which this potential is realized is driven by the difference between the scores of the question and its dimension. It was also shown that, upon the removal of a question, the majority of changes in dimension scores were small (less than 5) when at least half of a dimension's questions were answered.

4.2. Recommendations

Several recommendations for future development of Community-SWAT were identified as follows:

1. Pilot Community-SWAT in several RRM communities to evaluate its usefulness and appropriateness as perceived by community leaders. Based on the findings from the pilot tests, Community-SWAT should be modified to enhance its usability and transferability to the great number of RRM communities that exist. With respect to the features of Community-SWAT, the following questions should be investigated:

    a. *Framework*. Are the water security dimensions organized meaningfully for communities? Do communities have concerns that are not represented within this framework?

    b. *Input parameter flexibility (Part 1: Community Assessment).* Does having the option to omit parameters dissuade users from seeking out more information?

    c. *Qualitative response options*. Are the available options appropriate? Where possible, would users prefer the five-point scale to be extended to include more options? Would users prefer to have this feature used more extensively throughout Community-SWAT?

    d. *Response confidence scores*. Do the users perceive them as useful? What effect do they have upon the user when interpreting the results? (Specifically, are the confidence scores considered at all, and do they encourage users to seek out more reliable information?)

2. Translate the outputs of Community-SWAT into meaningful inputs for *HydroSanitas*. This research is part of a larger initiative to create a web-based knowledge portal (known as *HydroSanitas*) on water, sanitation, and hygiene solutions to support lesson-learning, networking, and solution identification. Linking Community-SWAT to *HydroSanitas* will support more explicit decision-making for identifying appropriate solutions.

3. Expand Community-SWAT to include an additional section entitled, "Part 3: Looking Forward" (note that a beta version of this section is currently included in the Community-SWAT application file). The purpose of this section would be to help a community

begin thinking about their next steps and points of action. This section would require additional user input, as well as the re-use of some of the information entered into the Community Assessment and Water Points Assessment. Possible components to this section could include:

   a. Identifying barriers to future development as perceived by community members and leaders. Even if they exist only in the mind, barriers bring resistance to change, an unwillingness to participate, or otherwise slow progress.

   b. Identifying community preferences for future water development with regards to the dimensions of water security for water points: travel distance, affordability and willingness-to-pay, quantity, and quality. It may also include evaluating preferences for particular technologies.

   c. Identifying roles and responsibilities for beginning the post-assessment steps.

4. Enhance the potential for education through use of Community-SWAT. A User Manual was developed to provide support. However, there may be potential to include a more detailed manual that would provide greater background depth regarding each dimension of water security, as well to each question. Alternatively, there is potential for Community-SWAT to be integrated into an existing participatory assessment program, or for one to be designed for Community-SWAT.

5. Enhance the input of household to water point distance measurements. It is expected that this will be among the assessment's most difficult questions. Challenges for evaluating distance measures include homes using more than one water point, and some water points being seasonally-dependent. With these in mind, the following are potential solutions to be explored:

   a. Enable GIS-support for easier evaluation of household to water point distances.

   b. Reducing the number of distance thresholds to be evaluated for each water point. (This should be evaluated after piloting the community

   c. Removing this measure from the Water Points Assessment and evaluating it more generally within the whole community

6. Explore possibilities for alternative and possibly more accurate scoring and weighting schemes. Currently, qualitative response options assume an equal distance between each option (e.g. responses converted to scores of 0, 0.25, 0.5, 0.75, and 1). Some response options may be more accurately portrayed with unequal distances. Likewise, some subcomponents or components may better represent reality by having larger or smaller weightings. The risk with any such "improvements", however, is that Communi-

ty-SWAT becomes less transparent, unless the scores associated with each option are presented to the user during data entry.

7. Water for food security could be more explicitly accounted for. While it is implicitly considered in the standard for evaluating accessed water quantities (Water Points Assessment), as well as parts of the Environment dimension (Community Assessment), some communities may wish to consider this issue in more detail on its own.

APPENDIX 1

Community Self-Water Assessment Tool Application File

The enclosed CD contains the Microsoft® Excel application file for the Community-SWAT program. It was developed using Microsoft® Excel 2010 and requires Macros to be enabled.

APPENDIX 2

Community-SWAT User Guide

The following pages contain the User Guide that was written for Community-SWAT users, and is also accessible through the application file. Some formatting has been changed to be in agreement with McMaster University's guidelines for the publication of theses.

Community Self-Water Assessment Tool

USER GUIDE

The purpose of this tool

Community-SWAT is an analysis tool that was designed to help you evaluate the status of your community's water resources. Using the Community-SWAT application file has two stages:

1. Completing the assessment questions, and
2. Viewing, interpreting, and interacting with the assessment results.

Both of these stages were designed to support you, community-leaders, in learning more about the holistic nature of water security, and to facilitate a systematic assessment of your community water resources.

Community-SWAT is not an explicit decision-support tool. However, as an analysis tool, Community-SWAT supports decision-making by helping to identify key water issues in a community.

Contents

PREAMBLE

Community-SWAT was created as part of a Master's research project and presented in its first complete form in June 2013. This research was undertaken at McMaster University in conjunction with the *Water Without Borders* graduate programme of the United Nation University Institute for Water, Environment, and Health (UNU-INWEH), both located at Hamilton, Ontario, Canada.

Software used

Community-SWAT was developed using Microsoft® Excel 2010 on the Windows 7 operation system. The tool was coded through a combination of MS Excel's spreadsheet functions, features, and code that was written in the Visual Basic for Application language.

Versions and compatibility

This tool was designed to be run on 2007 and 2010 versions of MS Excel. In testing Community-SWAT on MS Excel 2007, an issue was found that affected certain charts in the Results section. This issue was due to the use of an advanced feature in MS Excel, which is less stable in the 2007 version. While this issue has been resolved, please keep this in mind if you experience problems using MS Excel 2007.

At present, Community-SWAT is not compatible with any version of the "Office for Mac" software on Apple computers designed for the OS X operating system.

What you need to run Community-SWAT

1. MS Excel (version 2007 or later) installed on your Windows computer.
2. A PDF viewer installed on your computer (e.g. Adobe Acrobat, www.adobe.com/reader/).
3. Macros settings enabled within MS Excel.

To enable macros, upon opening Community-SWAT, a warning will appear informing you that "This file contains macros." Select "Enable content" or "Enable macros". Additionally, you can click the *File* tab (MS Excel 2010) or *Microsoft Office* button (MS Excel 2007) and then select: *Excel Options* → *Trust Center Settings* → *Macro Settings* → select the option to enable macros.

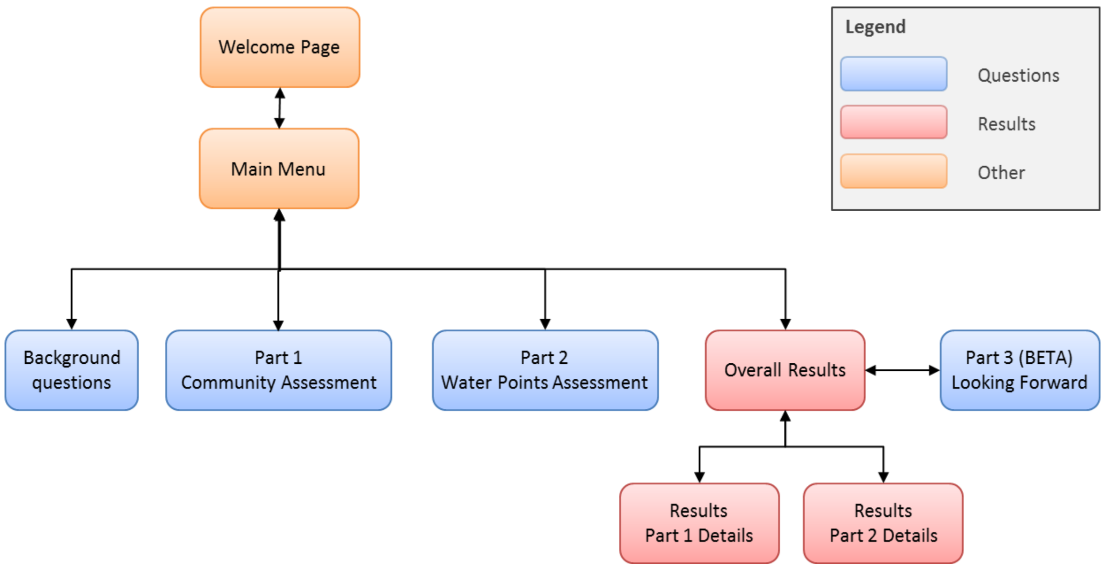
THE BASICS OF COMMUNITY-SWAT

The assessment in Community-SWAT is made up of eight major themes, each being divided into several sub-themes. Each theme represents a key water security issue for rural communities. The assessment is split into two parts. The table below shows how the eight themes are divided between the two parts of the assessment:

- **Part 1: Community Assessment** focuses on the broader community factors, such as water and environmental resources and socio-economic status.
- **Part 2: Water Points Assessment** focuses on individual water points.

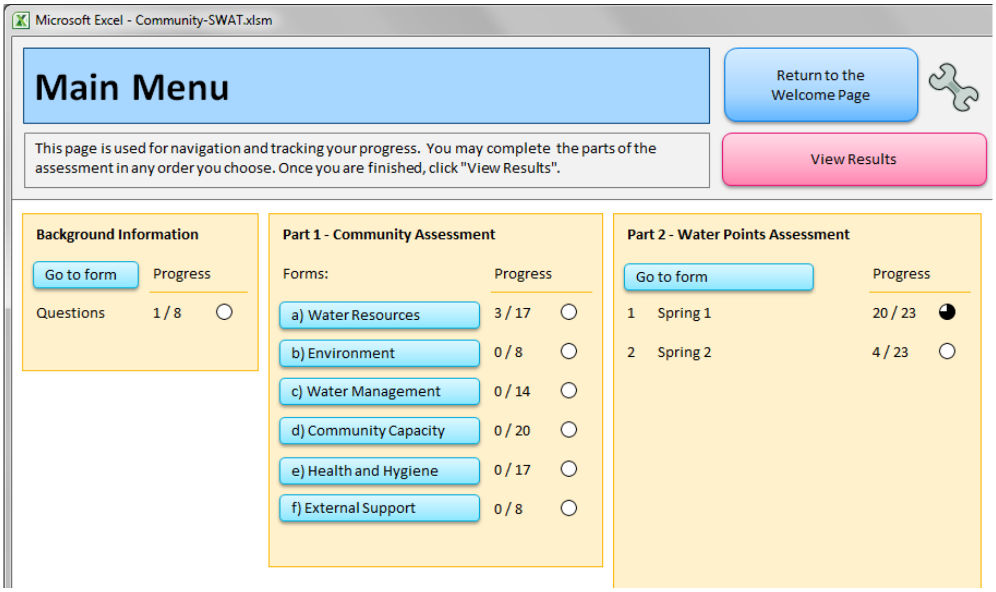
Theme	What is assessed in this theme?	Sub-themes
Water Resources	The natural, raw water resources available to the community.	• Quantity • Variability • Quality
Environment	The mutually dependent relationship between water and the natural environment.	• Land • Water
Developed Sources	The state of water resources that are currently accessed by community members.	• Quantity • Reliability • Quality
Access	The ability of community members to access sufficient amounts of water.	• Distance • Affordability • Competition • Ease of use
Water Management	The systems in place for the operation and management of community water resources.	• Administration • Finances • Representation
		• Water point operation
Community Capacity	The social and economic resources within a community.	• Knowledge capital • Financial capital • Social capital
Health and Hygiene	Household knowledge and behaviours related to water and hygiene, including access to support resources	• Knowledge and health • Water practices • Hygiene • Access
External Support	The greater social and political context in which the community exists.	• Government • Linkages

Community-SWAT contains several pages with different kinds of information. Below is a flowchart showing how these pages are organized. The arrows indicate how you can navigate between different pages through the buttons on each page. When you open a Community-SWAT file, you will always begin at the Welcome Page.

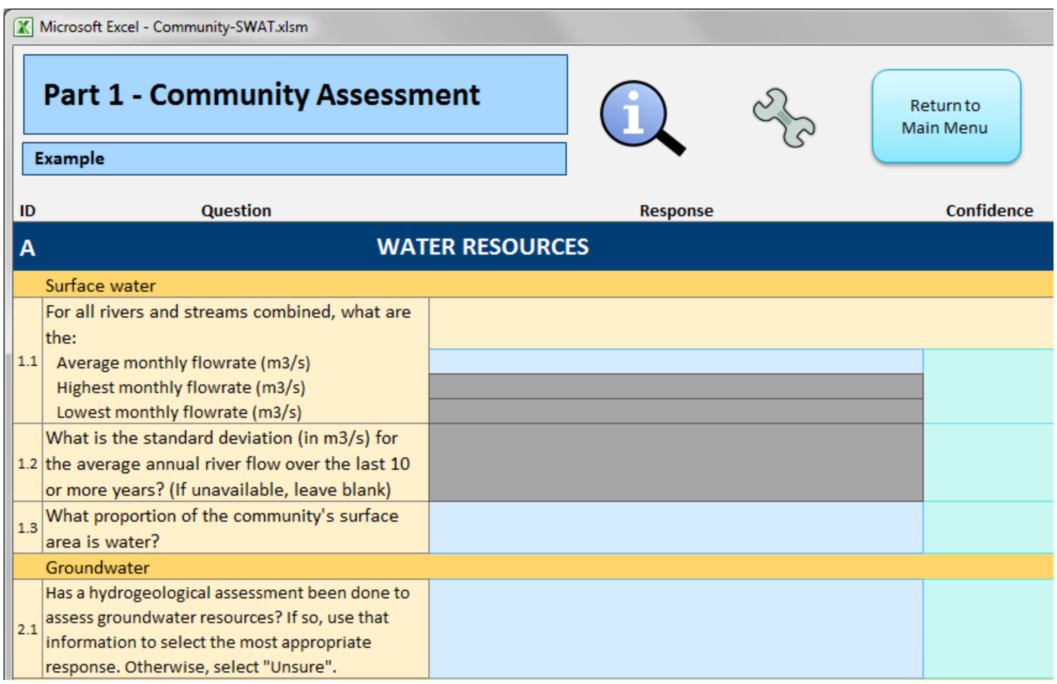


UNDERSTANDING THE INTERFACE

A screenshot of the Main Menu is shown below. You will note that it has two functions. First, from the Main Menu you can access every section of the program by clicking on the buttons. Second, the Main Menu is used to track your progress as you complete different sections. You can therefore complete the assessment in any order you like, or save and close the file and return to it at another time.



A screenshot of the interface for Part 1: Community Assessment is shown below.



In the figure above, please note the following:

- **Light blue cells**: These are answer cells, where you will enter your answers. In some cases, once you select a cell, a small yellow note will appear to offer further guidance. Some questions require you to enter a number, while for others you will need to select an option from a dropdown list. To view the dropdown lists, first select the cell, then click on the arrow that appears to the right.

- **Light green cells**: These are confidence cells, where you can rate your confidence in the response on a scale of 1 to 10 for each question. A score of 1 means that you are very unsure about your answer, and a score of 10 means that you are extremely confident (more information below).

- **Grey cells**: These cells indicate questions that are not applicable. Do not answer these questions. Some questions depend on others, meaning that they will become applicable or not applicable based on your answers to other questions.

-  Clicking this button will display any relevant instructions. This button appears throughout Community-SWAT.

-  Clicking this button will display a dialogue box with several different options that allow you to save, save as, or show or hide MS Excel's ribbon.

COMPLETING THE ASSESSMENT

Community-SWAT was designed so that it may be used in communities that have limited data records. The following three features are intended to help you deal with data limitations:

1. **Qualitative answers:** You will answer several questions by selecting an option from a list. While some questions do require a number, the reliance on numerical data has been minimized as much as possible.

2. **Confidence ratings:** To deal with the quality of your data, you can rate your confidence in your responses in the light green cells next to each question. As mentioned above, rate each response on a scale of 1 to 10, where 1 means that you are very unsure, and 10 means that you are extremely confident. These ratings will be integrated into the final results. Please note that 10 should only be entered if you are using measured, verified data.

3. **Not applicable questions:** You should leave any question that does not apply or that you cannot answer blank. Community-SWAT's scoring system accounts only for answered questions. However, please note that leaving questions unanswered will increase the influence of the answered questions in the final scores for each theme. In general, it is recommended that at least half of the questions per section are answered to increase the reliability of the results.

Background Information

Prior to the actual assessment questions, this small section asks you to provide general information about your community. This provides important data that are required for some of the background calculations. You must enter the population of your community before you proceeding to Part 1 or 2. Once you are finished, return to the Main Menu to continue the assessment.

Part 1 – Community Assessment

As mentioned, this section looks at broader community factors that influence water security. There are six sections to Part 1, which correspond to the six themes for Part 1 listed in the table above. You can access each of these six sections from the Main Menu. To complete each section, answer the relevant questions while also rating your confidence for each of your responses. You may leave any questions that do not apply or that you cannot answer blank. However, as mentioned above, it is recommended that at least half of the questions per section are answered to increase the reliability of the results. As you complete each section, return to the Main Menu to continue the assessment.

Part 2 – Water Points Assessment

A water point is any place that community members collect their water from. Some water points are very simple, and include hand-dug wells and springs. Other water points may have physical infrastructure designed to protect, treat, store, or distribute water.

This section asks questions related to water points that are used by your community. You can assess up to 23 different water points. The questions are organized according to Part 2's sub-themes listed in the table above. To complete this section, answer the questions for each water point while also rating your confidence for each question, while noting the following:

1. You may leave any questions that do not apply or that you cannot answer blank. *However, the questions that you answer or omit must be consistent for each water point.* For water points 2 and beyond, please answer/omit the same questions as you did for Water Point 1. Distance and quantity questions are omitted from this rule (questions 1.1 and 1.2).

2. For each confidence rating (light green cells), the rating you enter will apply to every water point. Therefore, your confidence rating for a particular question should reflect your confidence for that question for all water points.

The Water Points Assessment can be accommodated to unique situations. Below are two examples.

Example 1: If your community has many households with piped water service, you can group all of these households together and answer the questions as if they were one water 'point'. When evaluating distance, enter only the number of households having piped water in the 'on property' section (question 1.1d and 1.2d) along with what water needs they can satisfy. For all other distance entries, enter 0 or leave blank. Answer the remaining questions as usual.

Example 2: As in the example above, if your community has many households with piped water service, but some households receive less water than others, you can group these households under *two* water 'points'. Then, follow the instructions for Example 1 above.

Where will I find the information to answer the questions?

There are several areas for you to explore:

1. Your own personal knowledge
2. Community information records
3. Local water resource authorities
4. Formal and informal household surveys
5. Speak with both members and leaders of the community
6. Google Maps and/or Google Earth - You can use these programs to estimate the size of community, the size of water bodies within community, and environmental conditions such as the extent of erosion
7. Measure something for the first time

Please note that while these data are useful in this analysis, they are not essential, and will not prevent you from completing this assessment. However, the more information you have, the more reliable the results will be. The process of undertaking this assessment may provide insight into useful data that you may want to collect in the future. Community-SWAT can be used as often as you like and will provide more rigorous results each time you improve data. Remember also that with the confidence rating feature, you can rate the quality of the information that is represented in your answer.

What If I don't know the answer or if a question doesn't apply?

You may encounter questions that you do not have answers for. When this happens, it is best to skip the question temporarily, make a note, and research the answer to the best of your ability. This may mean talking with members of your community and your colleagues. Remember to speak to people of different genders, ages, and backgrounds.

The questions are not only meant to get an answer, but to help you discover something new that might be important to the sustainability of your community's water supply.

UNDERSTANDING THE RESULTS SECTION

How responses are scored

First, each question is scored between 0 and 100: Higher scores indicate water security, and lower scores indicate water vulnerability. Questions that are answered by selecting one of five options from an ordered list assign associated scores of 0, 25, 50, 75, or 100. Questions that are answered by entering a number or percent are then converted into a score between 0 and 100.

Second, each question belongs to a sub-theme and a theme (see the table above on page 89). The theme and sub-theme scores result from an averaging process that depends on: the number of answered questions; the scores of those answers; and how the Community-SWAT themes have been structured (e.g. the number of sub-themes within a theme). At the basic level, all questions have an equal weight. Additionally, all sub-theme scores are equally weighted. (For example, the Water Resources theme consists of three sub-themes: Quantity, Variability, and Quality. The scores for each of these will be equally weighted in calculating the Water Resources score.)

This applies to both Parts 1 and 2, with two exceptions for Part 2: Water Points Assessment. First, for a single water point, the scores for the Quantity and Distance sections are weighted by the number of households. Second, for the overall water point scores, the score of each theme is the average for all water points weighted by the number of households using each water point. (This means that water points having fewer households will have less influence on the overall score, while water points with more households will have a larger influence.)

Viewing the results

The results from both Parts 1 and 2 have been combined on the Overall Results page. From the Overall Results page, you can also view more score details for Parts 1 and 2. The result pages have been designed so that you can interact with results. By clicking the Information button at the top, pop-up notes will appear to help you identify where you can adjust the settings so that you can customize how the information is displayed. More instructions about the result pages are available by clicking the Information button.

A note on indices: the modelling method used in Community-SWAT

Community-SWAT attempts to represent water security in your community by using an index. An index is a mathematical model that attempts to simplify complex situations according to one or several themes. It does this by scoring different inputs on a scale between 0 and 100, and averaging these scores in one of several ways (as discussed above). Because indices (the plural of index) have the ability to simplify, they are widely used. Indices are especially useful in communicating the state of a complex situation to non-technical audiences and/or the general public.

As indices simplify the issue being represented, these very simplifications (including the scoring methods described above) are also limitations. Community-SWAT should be used thoughtfully, and is not intended to replace a more detailed analysis when required. For some communities, Community-SWAT provides a place to start the analysis and a tool for summarizing areas of concern.

If after reading this manual you would like more information about Community-SWAT, please refer to the Master's thesis by J.J. Newton completed at McMaster University in Hamilton, Ontario, Canada: *Development of a Prototype Community Water Security Self-Assessment Tool for Rural, Remote, and Otherwise Marginalized Communities* (2013).

APPENDIX 3

Community-SWAT Developer Guide

The following pages contain the Developer's Guide that was written for Community-SWAT developers. Some formatting has been changed to be in agreement with McMaster University's guidelines for the publication of theses.

Community Self-Water Assessment Tool

DEVELOPER'S MANUAL 1.0

The Community Self Water Assessment Tool (Community-SWAT, also the 'Tool') has been developed to assist rural community leaders evaluate the state of community resources related to water.

Community-SWAT was created as part of a Master's research project and presented in its first complete form in June 2013. This research was undertaken at McMaster University in conjunction with the *Water Without Borders* graduate programme of the United Nation University Institute for Water, Environment, and Health (UNU-INWEH), both located at Hamilton, Ontario, Canada.

Community-SWAT was developed using Microsoft® Excel 2010 on the Windows 7 operation system. The tool was coded through a combination of MS Excel's spreadsheet functions, features, and code that was written in the Visual Basic for Application language.

This manual is intended to assist future Community-SWAT programmers by providing additional notes and rationale to that which is already providing within the Tool application file itself.

This Developer's Manual assumes a working knowledge of the Community-SWAT application file and the User's Manual. For a more detailed introduction, please refer to the User Manual. An overview of the Key Functions and Features of MS Excel used in Community-SWAT is provided in the Appendix. When referenced, some key terms have been *italicized*.

SUPPORT FOR THE PROGRAMMER

In addition to this Manual, the Tool has several features that were developed to aid future programmers. These were created to make the Tool easier to navigate and manipulate during development.

1. **Quickly switch between Administrator Mode and User Mode** – *Macros* have been written to prepare the file for users (which includes protecting user forms and hiding worksheets with code, the Excel ribbon and the formula bar) or for administrators (a.k.a. programmers; this undoes the protection and hiding of user mode). To do this, simply go to the bottom of the Main Menu, and click the button labeled "For Administrators Only". Then,

    a. To enter Administrator Mode, type "Admin";

    b. To enter User Mode, type "User".

2. **Enhanced navigation for programmers** – A menu page has been created that summarizes the hidden calculation worksheets (Figure 1) that contains hyperlinks and an explanation of prefixes used in the *named* variables (see also Table 4). All calculation worksheets also contain hyperlinks to other relevant worksheets. You are automatically taken to this menu upon entering Administrator Mode.

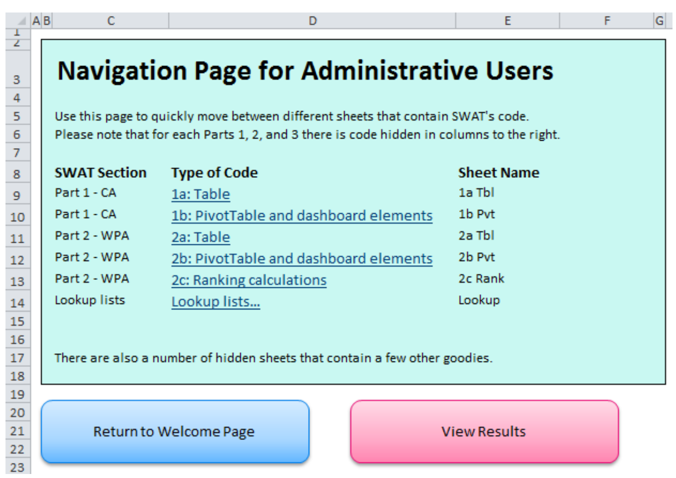


Figure 1 Screenshot of navigation menu for administrative users

3. **Extensive comments** – Comments, labels, and other information have been added to both worksheets and *VBA* subroutines to help explain what is there. These are sometimes relied upon throughout this Manual.

4. **Show/hide hidden sections of code** – Parts 1 and 2 contain large sections of code that is hidden from the user. In Administrator Mode, buttons are available that allow you to view or hide these sections easily.

Overview

Workbook Structure

Figure 2 contains a schematic overview of the main worksheets used in the Tool. The figure indicates both how the user will navigate between worksheets (solid 2-way arrows) and the flow of user input to results (dashed 1-way arrows).

Figure 2 Flowchart showing the navigation between worksheets and the flow of information from user entry to results. Except where noted, each shape denotes a separate worksheet.

From Figure 2, please note the following items with regards to the Tool's layout and structure:

1. The *Main Menu* is the main navigation portal.

2. The worksheet structure from user input to results follows the same general flow and layout:

   User entry worksheet → Scoring and weight calculation worksheet → Dimension aggregation and dashboard calculation worksheet → Dashboard presentation (see Figure 6)

3. The worksheet *'1b Pvt'!* contains dashboard elements for both *'Results'!* and *'Results p1'!*. This was done since Part 1 contains six of the eight dimensions, and there is considerable overlap between the Overall Results and Part 1 Detailed Results. Therefore, it was necessary to include information from Part 2 on Part 1's calculation worksheets, as follows:

   a. From *'2 WPA'!* and *'2a Tbl'!* to *'1 CA'!* – The Water Management dimension is comprised of inputs from both Part 1 and Part 2 (this is unique amongst the eight dimensions). Therefore, the aggregated scores are passed from *'2a Tbl'!* to the hidden calculation section on *'1 CA'!* at the end of the Water Management section (rows 216:219; see Figure 6).

   b. From *'2a Tbl'!* to *'1b Pvt'!* – *PivotTables* summarizing the results from *'2 WPA'!* (calculated in *'2a Tbl'!*) are passed to *'1b Pvt'!* for aggregating the results of the Developed Sources and Access dimensions to be included in the Overall Results section.

The Nested Structure of the Index Framework

The index used in Community-SWAT is organized into a multiple-layered framework. The category names and their nested relation to one another are illustrated in these bullets:

- Dimension (Level 4, highly aggregated)
  - Component (Level 3)
    - Subcomponent (Level 2)
      - Questions / Indicators (Level 1, basic inputs)

Table 1 presents an overview of the framework and its relation to assessments/user forms Part 1 and 2. Besides organization, this nested-framework is used for aggregation. Details about this are given below in the section: Converting responses to numerical scores (p. 109).

Table 1 Overview of the Community-SWAT framework. The colours indicate the appropriate user form: Yellow for Part 1: Community assessment, Light blue for Part 2: Water points assessment

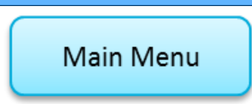
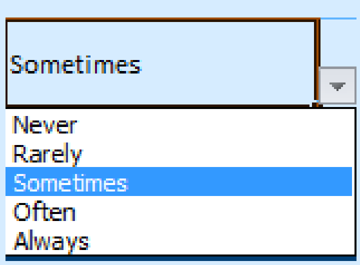
Dimension	Component	Subcomponents	(#)	# indicators
Water Resources	Quantity	Surface water, groundwater, rain/climate	3	5
	Variability	Seasonal, inter-annual, extreme events	3	6
	Quality	Pollution sources	1	6
Environment	Land	Land	1	5
	Water	Quality, quantity	2	3
Developed Sources	Quantity	Sufficiency for: wet season, dry season	2	2
	Reliability	Frequency of interruptions: weekly, seasonal	2	2
	Quality	Sanitary conditions, treatment level, *E. coli* levels, user acceptability	4	10 sanitary, 5 other
Access	Distance	Wet season, dry season	2	2
	Affordability	Cost burden	1	1
	Competition	Disputes, domestic needs prioritized	2	2
	Ease of use	Queue time, withdrawal effort, safety	3	3
Water Management	Administration	Documentation, planning	2	8
	Finances	Financial structures in place	1	3
	Representation	Equity, satisfaction, service	3	3
	Water point operation	Inspection frequency, water conservation, fund sufficiency	3	3
Community Capacity	Knowledge capital	Schooling, special training, indigenous knowledge	3	6
	Financial capital	Household, community	2	6
	Social capital	Women, solidarity, institutions	3	9

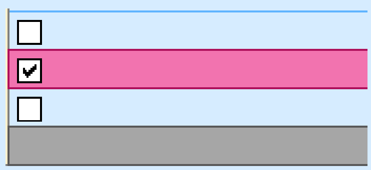
Dimension	Component	Subcomponents	(#)	# indicators
Health and Hygiene	Knowledge and health	Health, knowledge	2	4
	Water practices	Preparation, storage	2	5
	Hygiene	Practices, facilities	2	4
	Access	Clinics, resources	2	5
External Support	Government	Water plans, water policies	2	4
	Linkages	Accessibility, support	2	4

User Forms

This section details any code or special features used in coding the user entry forms. Commonly used items are explained in Table 2.

Table 2 Features commonly used within the Tool's user forms

Item	Note
	All **'buttons'** are shapes that have been assigned a *VBA*-coded *macros*. Upon clicking, the *macro* is run.
	The **option button** appears throughout Tool. The *macro* assigned to this image initializes a User Form (developed in the *Visual Basic Editor*) that allows the user to save, show or hide the MS Excel ribbon, or view the user manual.
	The **information button** appears throughout sections of the Tool. These images have assigned *macros* based on their location, which initializes a User Form or Message Box with instructions.
	All **dropdown lists** were coded using Excel's *Data Validation* feature. The validation allows 'lists', the source is a *named* range (located on the *'Lookup'!* worksheet). Each list is housed in one of several *tables*. The *defined name* of that list refers to the column in the appropriate *table*. * This was done to allow these lists to be easily extended to more options. By increasing the number of rows in the corresponding *table*, the *named* array is automatically increased as well.

<table>
<tr><th>Item</th><th>Note</th></tr>
<tr><td>
</td><td>All numerical inputs have restricted ranges and types (e.g. whole number or decimal), coded using Excel's Data Validation feature. This includes the input of Confidence Ratings as well, which are further restricted by requiring the user to enter a response first.</td></tr>
<tr><td></td><td>Checkboxes are linked to the cell that they occupy. Linked values are 0 (unchecked) and 1 (checked). The cells are formatted such that the text is always the background colour, so that it appears invisible to the user. This is accomplished using cell styles and conditional formatting.

For questions that are dependent on the response of another question, and are not applicable in accordance with that response, the response fields are greyed out using conditional formatting.</td></tr>
</table>

Main Menu

The first purpose of the Main Menu worksheet (Figure 3) is for user navigation. As shown in Figure 2, users access the main forms from here, through buttons. When taken to each form, there is another button for them to return to the Main Menu. As the entire Part 1 form is much longer, there are six buttons that are linked to those specific sections. In addition, when accessing sections of Part 1, the *macro* that is run initializes a scroll-lock, so that users can only view one section at a time. When the Part 1 worksheet is deactivated, the `Worksheet_Deactivate()` event is triggered and contains code to remove the scroll-lock.

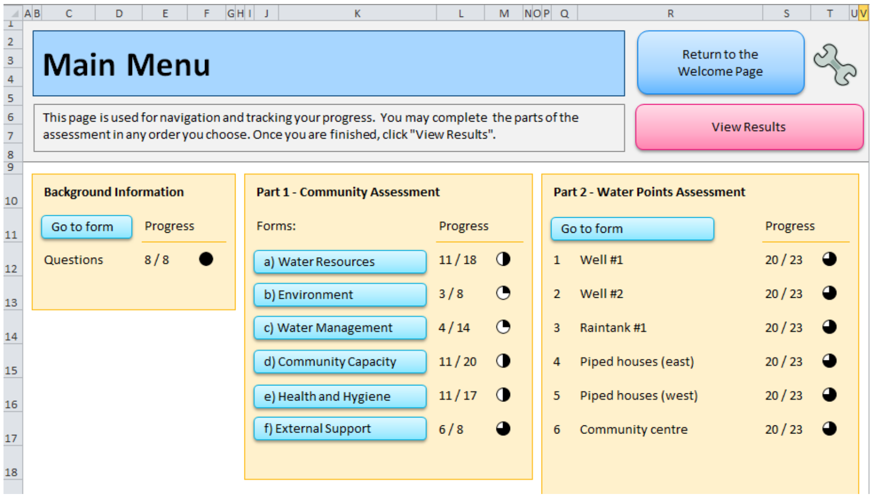


Figure 3 Screenshot of Main Menu

The second purpose of the Main Menu is for tracking progress. A fraction (with numerator and denominator) and a pie chart are used to this end, using *defined names* that have `COUNT()`, `COUNTIF()`, and `COUNTA()` functions to count the total number of questions and user responses. The numerator counts actual responses, while the denominator counts the total number of possible responses. (Some questions, e.g. Months with water in Part 1a, require multiple responses. However, answering this question counts as one response.) The pie chart is simply the calculated percent of questions answered, with *conditional formatting* that displays one of five pie chart images instead.

Part 1: Community Assessment

The worksheets of both user forms (*'1 CA'!* and *'2 WPA'!*) contain code that is hidden from the user (Figure 4 and Figure 6). On these worksheets, each question also contains corresponding code, located on the same row. These hidden sections of code 'pass' the information in these rows to the scoring and housing calculation tables (*'1a Tbl'!* and *'2a Tbl'!*) through simple formulas. Both user forms (*'1 CA'!* and *'2 WPA'!*) contain the following kinds of information in the hidden section for each question (see Figure 4):

- **Framework structure** (dimension, component, and subcomponent labels), ultimately used for aggregating scores using PivotTables. **All changes to the dimensional framework must be made here**
- **Score calculation code** (check for user response; function to convert response to score; confidence score). These cells are coloured light grey with orange text.
- **Additional information** (indicator label, ID, text of question, and any applicable references, equations, and dropdown list names) included as extra reference material for completeness.

This is also very useful for publishing summary tables by easily copying, pasting, and formatting relevant sections.

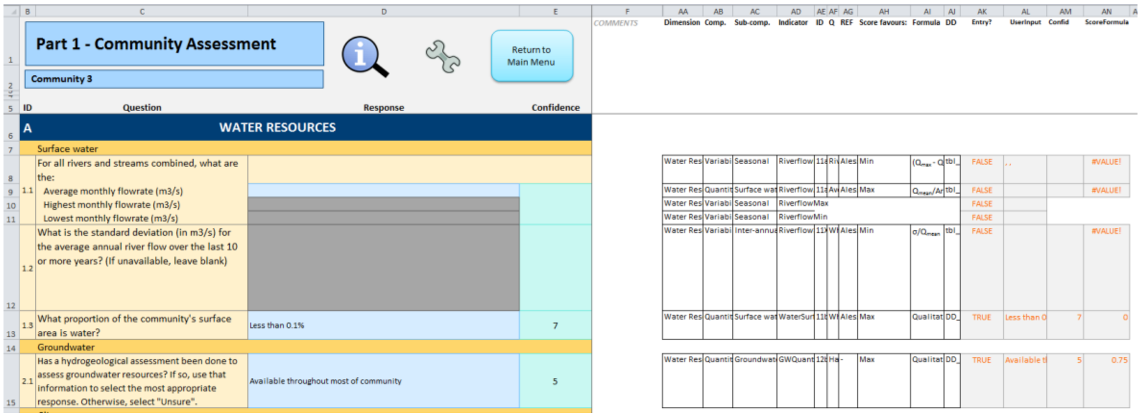


Figure 4 Screenshot showing the user form and the hidden on-sheet code section for Part 1 (sheet '1 CA'!*)*

Part 2: Water Points Assessment

Please note that information regarding the user form for Part 2 was mentioned on the previous page regarding the user form for Part 1, as both the user forms for Part 1 and Part 2 have the same basic common structure.

In addition, because Part 2 allows multiple water points to be assessed, and that the water points may be one of several types, the following items required special coding:

1. **Navigation buttons** – Located at the top, these allow the user to jump to different sections of the Part 2 assessment.

2. **Add/remove a water point** – Users have the option to evaluate up to 23 water points. To accommodate this, 23 input columns (C:Y) were developed. Those that are not in use are simply hidden. The *macros* assigned to the 'Add' and 'Remove' buttons will show or hide the columns when invoked. Note that the 'remove' a water point merely hides it. Users are notified that they must manually delete any entries. This was done so that users would not lose data by mistakenly pressing the remove button.

3. **Sanitary inspection questions** (section 4) –These depend on the type of water source. Lists of the questions for each source are located on the *'Lookup'!* worksheet. The questions are only populated if 1) the type of source is selected, and 2) a sanitary inspection has been completed (response = `TRUE`). If a sanitary inspection has not been completed, the questions are not populated. See Figure 5.

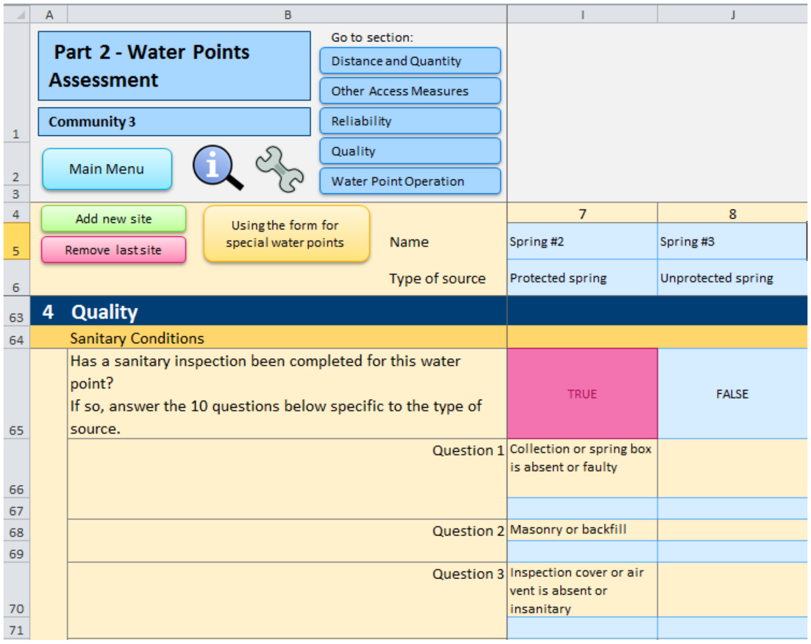


Figure 5 Screenshot of worksheet for Part 2: Water Points Assessment

CONVERTING RESPONSES TO NUMERICAL SCORES

An overview of the worksheet structure and scoring process is illustrated in Figure 6 (compare Figure 2). The scoring process is detailed in Figure 7. Please note that there are comments, labels, and explanations directly on the calculation and aggregation worksheets as well (e.g. see Figure 8). Both Figure 6 and Figure 7 pertain to calculating scores and confidence ratings.

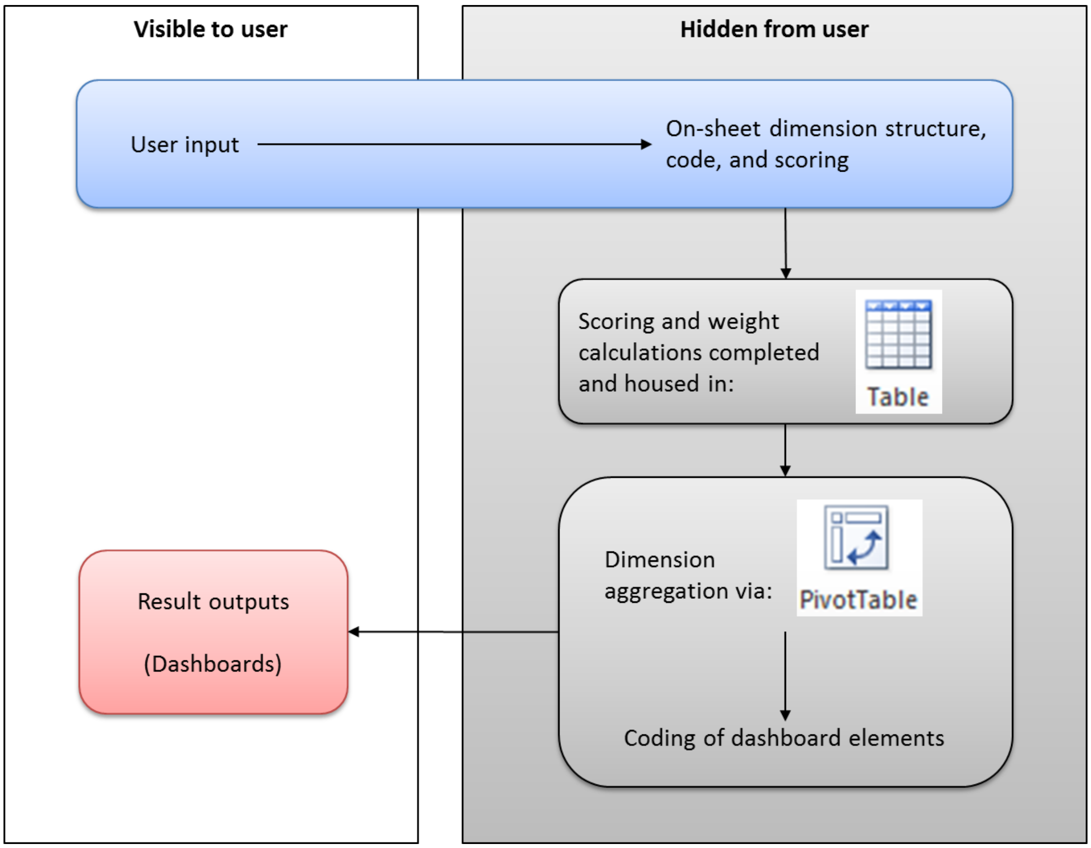


Figure 6 Flowchart showing the steps used to convert user input into results. Each rounded rectangle represents one worksheet. The arrows indicate the direction of information flow.

As mentioned, the nested nature of Community-SWAT's framework (Table 1) is also used for aggregation. It is important to understand that **within each layer (or nest level), its constituent layers are equally weighted.** For example:

- The **dimension** Water Resources has 3 components: the scores for Quantity, Variability, and Quality will equally contribute to Water Resources score (i.e. each component is weighted by 1/3).

- Furthermore, the Quantity **component** has 3 subcomponents: the scores for Surface water, Groundwater, and Rain/climate subcomponent scores will equally contribute to Water Resource's Quantity score (i.e. each component is weighted by 1/3).
  - The Surface water **subcomponent** under Quantity consists of two questions: the scores for Annual average river flow, and Surface water storage will, again, equally contribute to Quantity's Surface water score (i.e. each question is weighted by 1/2).
    - Finally, technically speaking, there are no "mandatory" **questions**: *all weights for all components, subcomponents, and questions account only for those which have a response.* Continuing with the example, if only 1 of the 2 Surface water subcomponent questions were answered, the answered question receives a weight of 1 for the Surface water subcomponent score.

This also applies for dimensions and components. (In the example above, if *both* Surface water subcomponent questions were unanswered, then Water Resource's Quantity component score would consist only of the Groundwater and Rain/climate subcomponents, each weighted by 1/2 as opposed to 1/3). This makes the Tool flexible by not artificially lowering scores due to unanswered, inapplicable questions.

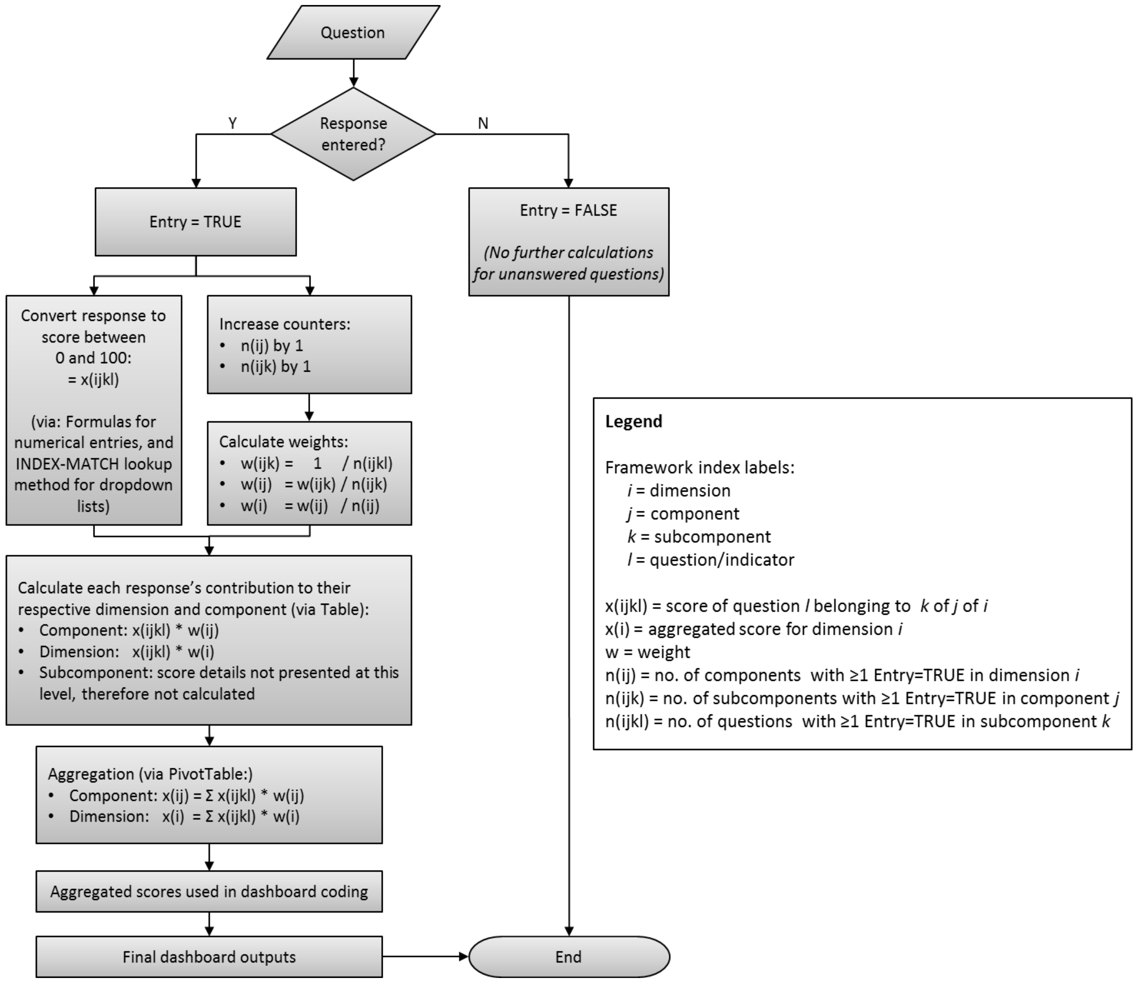


Figure 7 Flowchart showing the scoring and aggregation process in detail. The same process is used for aggregating Confidence Ratings.

Additional Remarks on Part 1 Scoring

A screenshot of the scoring and weight *table* is shown in Figure 8. Please also note that there are additional comments and guidance embedded within the spreadsheet code.

	A	B	C	D	R	S	T	U	V	W	X	Y	Z	AA	AB	AC
1																
2		CA: 1a - Table														
3		Return to Admin. Nav.														
4		Go to 1b: PivotTable and dashboard elements														
5																
6		Framework columns (used for weight calcs)			Actual inputs		From Input to Score		Counters (see comment		Dynamic weights for aggregation			Score parts, summed in PivotTable		
7		Form	Form	Form	Form	Form	Form	Calc'd here	Calc'd here	Calc'd here	Calc'd here	Calc'd here	Calc'd here	Calc'd here	Calc'd here	Calc'd here
8		Dimension	Comp	Subcomp	UserInpu	Confid	ScoreForm	Score	NumComp i	NumSubcom	wtDim	wtComp	wtSubcomp	scoreDim	scoreComp	scoreSubcon
9		Water Resources	Quality	Pollution sources			#N/A		3.00	1.00						
10		Water Resources	Quality	Pollution sources			#N/A		3.00	1.00						
11		Water Resources	Quality	Pollution sources			#N/A		3.00	1.00						
12		Water Resources	Quality	Pollution sources			#N/A		3.00	1.00						
13		Water Resources	Quality	Pollution sources	Open ar	10	0.00	0	3.00	1.00	0.17	0.50	0.50	0.00	0.00	0.00
14		Water Resources	Quality	Pollution sources	Sometin	8	0.50	50	3.00	1.00	0.17	0.50	0.50	8.33	25.00	25.00
15		Water Resources	Quantity	Groundwater	Availabl	5	0.75	75	3.00	3.00	0.11	0.33	1.00	8.33	25.00	75.00
16		Water Resources	Quantity	Rain/Climate	640	5	0.75	75	3.00	3.00	0.06	0.17	0.50	4.17	12.50	37.50
17		Water Resources	Quantity	Rain/Climate	Arid	6	0.25	25	3.00	3.00	0.06	0.17	0.50	1.39	4.17	12.50
18		Water Resources	Quantity	Surface water			#VALUE!		3.00	3.00						
19		Water Resources	Quantity	Surface water	Less tha	7	0.00	0	3.00	3.00	0.11	0.33	1.00	0.00	0.00	0.00
20		Water Resources	Variability	Extreme events	2 - Mod	8	0.50	50	3.00	2.00	0.17	0.50	1.00	8.33	25.00	50.00
21		Water Resources	Variability	Extreme events			#N/A		3.00	2.00						
22		Water Resources	Variability	Extreme events			#N/A		3.00	2.00						
23		Water Resources	Variability	Inter-annual			#VALUE!		3.00	2.00						
24		Water Resources	Variability	Inter-annual			#VALUE!		3.00	2.00						
25		Water Resources	Variability	Seasonal	, ,		#VALUE!		3.00	2.00						
26		Water Resources	Variability	Seasonal	5	7	0.42	42	3.00	2.00	0.17	0.50	1.00	6.94	20.83	41.67
27		Water Managemen	Administratio	Documentation			#N/A		3.00	1.00						
28		Water Managemen	Administratio	Documentation			#N/A		3.00	1.00						
29		Water Managemen	Administratio	Documentation			#N/A		3.00	1.00						

Figure 8 Screenshot showing a portion of the table used to complete and house score calculations for Part 1 (sheet '1a Tbl'!*). Note the additional comments both above the table and prefixed to the table headings.*

Additional Remarks on Part 2 Scoring

As mentioned above, Part 2 allows users to assess up to 23 water points. This, in addition to some unique indicators, required exceptions to be made and subsequent extra coding:

1. **Scoring the Distance parameters** (questions 1.1, 1.2): For both the wet and dry seasons, users input the number of households that have water points within 100 m, 1000 m, beyond 1000 m, or directly on their property. (Hence, 4 distance inputs per season x 2 seasons = 8 inputs total per water point.) The associated scores for each distance are listed in Table 3. **The score for Distance: Wet season is the average of the scores *weighted by the number of households***, and likewise for the Dry season score. Since this weighting scheme could not be done using *PivotTables*, these values needed to be averaged *separately and outside the main calculation and housing* Table *(`TBL_p2_ANS_MASTER`, worksheet ‘2a Tbl’!)*, with the resulting score directly fed into Part 2’s main calculation Table. (Comments and colour-coded rows help to identify these rows in the Tool. See Figure 9.)

   Another issue was aggregating the Distance subcomponent scores (Wet season, Dry season) into a single score. Since the score is to be weighted by households, again, a workaround was needed because of how the *PivotTable* is set up. Because *PivotTables* combined information based on labels, a unique label was needed to keep the Wet and Dry season scores separate from total Distance score. Therefore, a flag was used. Stored as the *named* variable `BC_p2_FLAG` (currently set to: ***), this flag is attached to the dimension label (located in the hidden section of worksheet *‘2 WPA’!*, rows 108:109). When the values are pulled from the *PivotTables*, formulas are used to identify the flag and remove it so that it remains hidden from the user. Compared with other approaches that were considered, this extra step was the best option for reduced potential programming error and allowed for easy reorganization and updating.

Table 3 Water service levels in relation to household distance from source (after Howard and Bartram, 2003)[1]

Access level	**Distance**	**Approx. return trip**	**Score (distance)**	**Quantities likely collected**	**Water needs likely to be satisfied**	**Score (quantity)**
Optimal	On property	-	100	100 Lpcd	All domestic needs should be met; water available for productive use	100
Intermediate	< 100 m	< 5 min.	75	50 Lpcd	Drinking, cooking, all personal hygiene, possibly laundry	75
Basic	100 - 1000 m	5 - 30 min.	50	20 Lpcd	Drinking, basic cooking, hand washing	50
Minimum	> 1000 m	> 30 min.	0	7 Lpcd < 7 Lpcd	Drinking and basic cooking Minimum needs are likely unsatisfied	25 0

2. **Scoring the Quantity parameters** (questions 1.1, 1.2): Water quantity inputs accompany each of the 8 distance inputs discussed above. (Hence, there are also 8 quantity inputs in total for each water point.) The associated scores for quantity inputs are listed in Table 3. Quantity indicators (Wet season, Dry season, and combined) are aggregated identically to the Distance indicators, as discussed above. (Comments and colour-coded rows help to identify these rows in the Tool. See Figure 9.)

3. **Biological water quality** (question 4.3): Users will answer 1 of 2 questions according to which is more applicable. Similarly to Distance and Quantity, scores are calculated outside the main calculation *table* (`TBL_p2_ANS_MASTER`, worksheet *'2a Tbl'!*) and then retrieved

[1] Howard, G., and Bartram, J. (2003). *Domestic Water Quantity, Service Level and Health*. Geneva: World Health Organization.

and stored in a single row (as opposed to one row for each of the possible two questions). (Comments and colour-coded rows help to identify these rows in the Tool. See Figure 9.)

4. **The "Match Type" column**: This column, found in the hidden section of the user form (sheet *'2 WPA'!*, column AL) is used to support score-related function and formula consistency in the calculation table (`TBL_p2_ANS_MASTER`, worksheet *'2a Tbl'!*), specifically regarding the Lookup values. In this column each cell contains either a 0 (lookup exact value), 1 (look up approximate value, less than or equal to), or 2 (display user input). The formulas in which these values are used are located in the main calculation *table* (`TBL_p2_ANS_MASTER`, worksheet *'2a Tbl'!*) in columns Score01:Score23.

5. **Omitting unanswered questions**: Users still have the option of omitting questions that do not apply or that they cannot answer. *The same weighting structure is used as depicted in Figure 7, with the one difference being that the check for a user response is based upon the responses to the first water point.* Therefore, answered/omitted questions must be consistent with each water point. This coding was because the results of all water points are aggregated into overall scores.

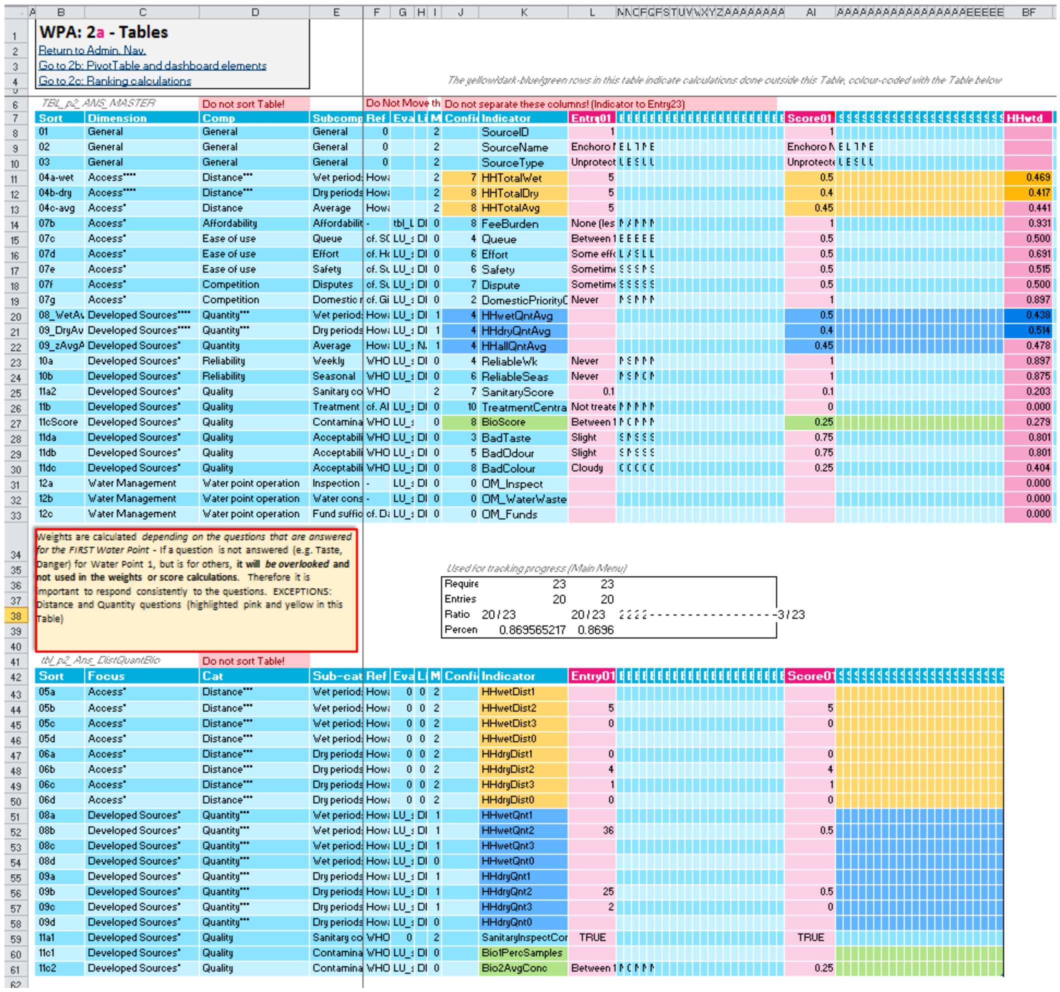


Figure 9 Screenshot of worksheet '2a Tbl'!, showing a portion of the main calculation and housing table (TBL_p2_ANS_MASTER) and the supporting calculation table (TBL_p2_Ans_DistQuantBio).

DASHBOARD CODE

Once scores are calculated, they are aggregated (using *PivotTables*) coded for an interactive display (i.e. the dashboard elements; see Figure 2). The results are presented to the user in different levels of detail on three worksheets (or three separate dashboards).

The dashboard code for the three result pages is contained in two worksheets, *'1b Pvt'!* and *'2b Pvt'!*, with the first containing code for both *'Results'!* and *'Results p1'!*. This discussion will begin with elements common to all dashboards, and then walk through the code as it is presented in the worksheets *'1b Pvt'!* and *'2b Pvt'!*.

It should be further noted that 'hard-coding' sections has been avoided as much as possible. Many of the extra (and sometimes complicated) steps taken have been done to allow for the Tool to be modified (e.g. the organizational framework, adding new questions) while maintaining the features of the results display intact.

Screenshots are included here solely as a visual aid to you, the programmer, so that you can quickly identify which sections are being discussed.

Features Common to All Three Dashboard Result Worksheets

1. **First-time activation and Instruction message boxes**: The first time each of the three result pages are activated by the user, the instruction menu appears allow with pink callout shapes that point to the interactive features. This is accomplished using a short *VBA macro* via the event `Worksheet_Activate()`. The code checks whether or not if this is the first time the user has accessed this page(through a publicly defined variable, which is set to `TRUE` upon opening the file through the event `Workbook_Open()`), and if so, it calls the function that displays the Instructions dialogue box.

2. **Toggling confidence bubbles on/off the charts**: The bar graphs and bubble plots are actually two separate graphs. Clicking the button (Figure 10) runs a *VBA macro* that alternates between the bubble plot being hidden or unhidden. The charts are linked to the same data.

Figure 10 Button that allows users to switch between bar graphs (confidence values off) and bubble plots (confidence values on)

3. **Dropdown lists**: Several features throughout the dashboards enable users to select an option from a list, and their selection results in the dashboard elements being updated. The dropdown cells have all been given *defined* names that are prefixed with BC_ (for "base cell"). Each list is also *defined*, usually prefixed with `DD_` ("dropdown") or sometimes `LU_` ("lookup"). These BCs and DDs/LUs are the 'keys' that drive the dashboard displays, and around which the functions and formulas for the dashboard elements have been written.

Worksheet '1b Pvt'! – Code for Dashboards "Main Results" and "Part 1 Details"

1. **Main chart (Part 1 details)**: This section contains *PivotTables*, a formatted table of the overall scores, and helper code for charting purposes. The formatted table section is displayed on *'Results p1'!*. The confidence bars within this table are simple formulas that use the `REPT()` function and formatted with the Playbill font style. Other comments are included on the sheet.

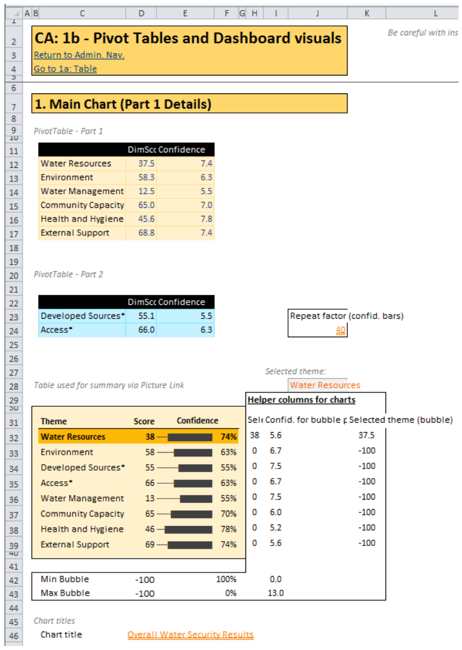


Figure 11 Screenshot of coded section for Main chart (Part 1 details)

2. **Main chart (Overall section – sort by chosen order)**: The chart that allows users to sort the dimensions by 1 of 4 orders (default, high score, high confidence, combined score and confidence) is built by:

    a. **Ranking the dimension scores according to these orders** – accomplished using `RANK()`, `INDEX-MATCH` lookup, and *Tables*. You will notice something special with the "Unique rank" columns: The `RANK()` function allows ties, which are a potential problem for ordering the dimensions. To ensure that all numbers are unique, a very small unique number (on the order of 10^{-8}) was added to ensure all scores are unique. Note that this is only used for the ordering of the dimensions on the chart.

    b. **Updating the chart based on the selected order** – accomplished using the user-selected order (*defined name*), `OFFSET()`, `MATCH()`, and *array* functions. It is tied to the order of the ranking scheme selected by the user.

    c. **Maintaining the unique colour of each dimension for visual pairing with component detail charts** – accomplished by creating individual chart series for each of the 8 dimensions, assigning the appropriate colour to each, and formulating the entries such that the score value is displayed only for the user-selected rank position with all other entries `=-100`, which will not show up on the chart. (Thus, 8 dimensions x 8 possible ranks = 64 individual bars; only 8 will show, in their position according to their rank, as previously calculated and selected by the user.)

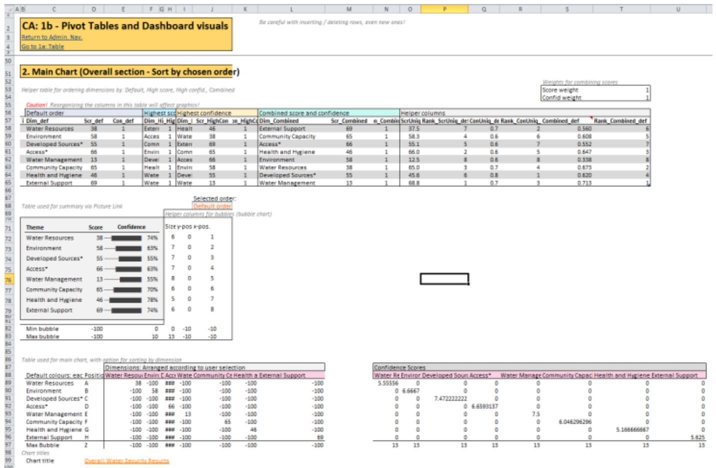


Figure 12 Screenshot of coded section for Main chart (Overall section - sort by order)

3. **Pie charts (Part 1 details)**: All responses that required a percentage input are linked to this location. The base data are pulled from the hidden code section of Part 1's user form. The tricky part of this code is that only those questions that have been answered should be displayed in the dropdown list for the user. To do this, a helper column (column "Count") counts the number of actual responses, and is used to make a second list that lists only those that have a response. The *defined list name* uses a combination of `OFFSET()` and `COUNT()` functions to create a variable-sized list array.

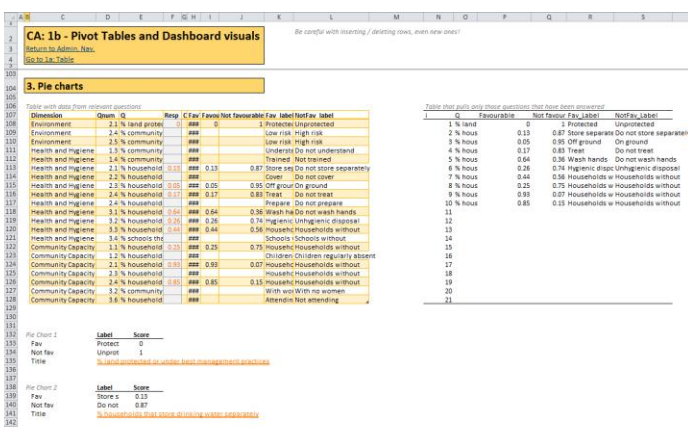


Figure 13 Screenshot of coded section for Pie charts (Part 1 details)

4. **Component chart FULL details (Main results page)**: This section is self-explanatory. Results from the *PivotTables* are pulled into a larger section, forming the basis for the chart's source data. These data are also used for the smaller, focused component score chart on Part 1's results page (point 5 below).

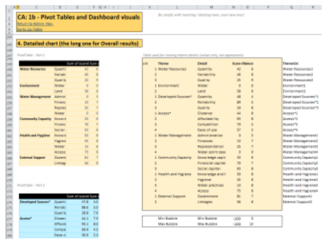
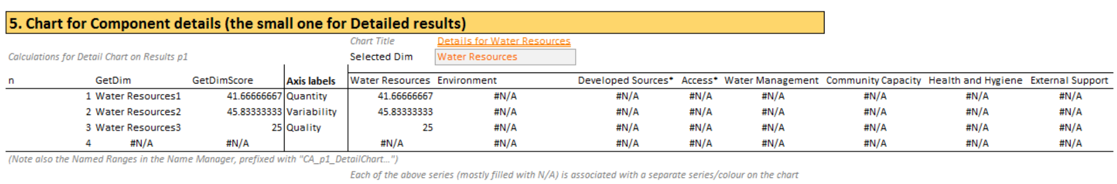


Figure 14 Screenshot of coded section for Component chart FULL details (Main results page)

5. **Component chart details (Part 1 details page)**: This section is very similar to point 2 above, except that rather than displaying the component scores for every dimension, they are displayed for only the one chosen. Similar challenges were presented (e.g. keeping colours coordinated – done again by creating 8 separate series). This chart is unique in that every series used in this chart is a *defined name* which uses a combination of `OFFSET()` and `COUNT()` functions to dynamically adjust the length of the chart's y-values and the labels for the horizontal category axis. These *names* are prefixed with `CA_p1_DetailChart`. Other comments are available on the worksheet.



5. Chart for Component details (the small one for Detailed results)

Chart Title Details for Water Resources

Calculations for Detail Chart on Results p1 Selected Dim: Water Resources

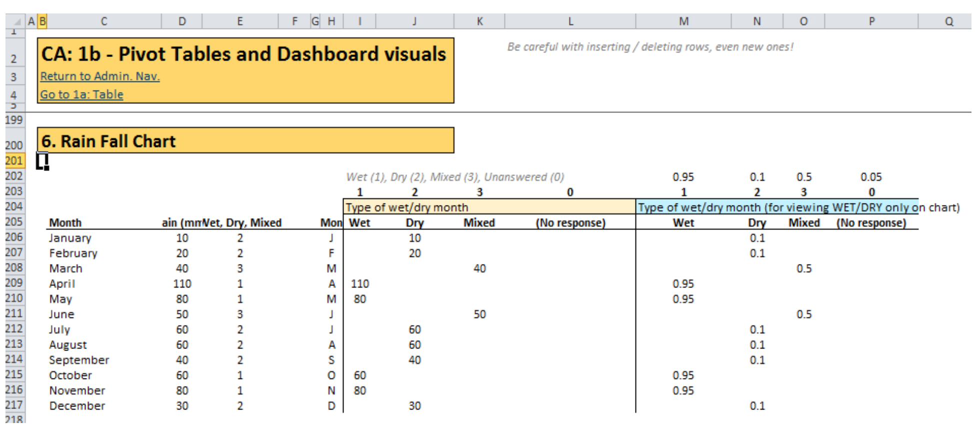
n	GetDim	GetDimScore	Axis labels	Water Resources	Environment	Developed Sources*	Access*	Water Management	Community Capacity	Health and Hygiene	External Support
1	Water Resources1	41.66666667	Quantity	41.66666667	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2	Water Resources2	45.83333333	Variability	45.83333333	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
3	Water Resources3	25	Quality	25	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
4	#N/A	#N/A		#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

(Note also the Named Ranges in the Name Manager, prefixed with "CA_p1_DetailChart...")

Each of the above series (mostly filled with N/A) is associated with a separate series/colour on the chart

Figure 15 Screenshot of coded section for Component chart details (Part 1 details page)

6. **Rain fall chart**: This section pulls rainfall data and wet/dry month data from the Part 1 user form and uses it to build the two charts: a) Average monthly rainfall amounts (mm), and b) Representation of wet, dry, and mixed months. Within the charts, multiple series are used to accord with the type of month the user identified (wet, dry, mixed). Toggling the charts on/off is done using a simple *VBA macro* that uses a counter located in cell `N30`.



CA: 1b - Pivot Tables and Dashboard visuals

Return to Admin. Nav.

Go to 1a: Table

Be careful with inserting / deleting rows, even new ones!

6. Rain Fall Chart

Wet (1), Dry (2), Mixed (3), Unanswered (0)

				1	2	3	0	1	2	3	0
								0.95	0.1	0.5	0.05
				Type of wet/dry month				Type of wet/dry month (for viewing WET/DRY only on chart)			
Month	ain (mm	Wet, Dry, Mixed	Mon	Wet	Dry	Mixed	(No response)	Wet	Dry	Mixed	(No response)
January	10	2	J		10				0.1		
February	20	2	F		20				0.1		
March	40	3	M			40				0.5	
April	110	1	A	110				0.95			
May	80	1	M	80				0.95			
June	50	3	J			50				0.5	
July	60	2	J		60				0.1		
August	60	2	A		60				0.1		
September	40	2	S		40				0.1		
October	60	1	O	60				0.95			
November	80	1	N	80				0.95			
December	30	2	D		30				0.1		

Figure 16 Screenshot of coded section for Rain fall charts

Worksheet '2b Pvt'! – Code for Dashboards "Part 2 Details"

As stated, the main difference in Part 2 is the potential to evaluate multiple water points. Not only did this require extra coding, but it results in extra data, which present different options.

Some of these sections are similar to the Overall and Part 1 details dashboards.

1. **Main chart**: Identical code logic to the main chart for Part 1 details, with the exception that an extra series is added that allows the user to view the results of an individual water point as well as the overall average.

    a. The list of water point names (`LU_p2_WaterPointNames`) is a row array of cells, the length of which is equal to the number of water points. This variable array uses `OFFSET()` and `MATCH()` functions.

    b. Extra columns were required in the main calculation table (`TBL_p1_ANS_MASTER`, worksheet *'2a Tbl'!*) and have the suffix `_SelectedSite`.

    c. The user-selected water point (`BC_p2_SelectedSite`) is the key that drives many of the water point-related functions. Because this variable updates the *PivotTable* cache, it needs to be refreshed. Refreshing *PivotTables* is separate from MS Excel's automatic calculation (which allows cell contents to be updated automatically), and can only be done manually or through *VBA* code. To automate this, a separate worksheet was created (*'2d WP change'!*). The variable `BC_p2_SelectedSite` is assigned to a cell (which will change with the user's selection). The event `Worksheet_Calculate()` is then triggered, which contains a short *macro* to refresh all data in the workbook. (A separate worksheet was used for this because: a) changing the dropdown list on the actual results page did not trigger the `Worksheet_Calculate()` event; and b) to isolate the refresh data action to a single variable, so as to not run it unnecessarily, as on slower computers the refresh action may take longer than desired.)

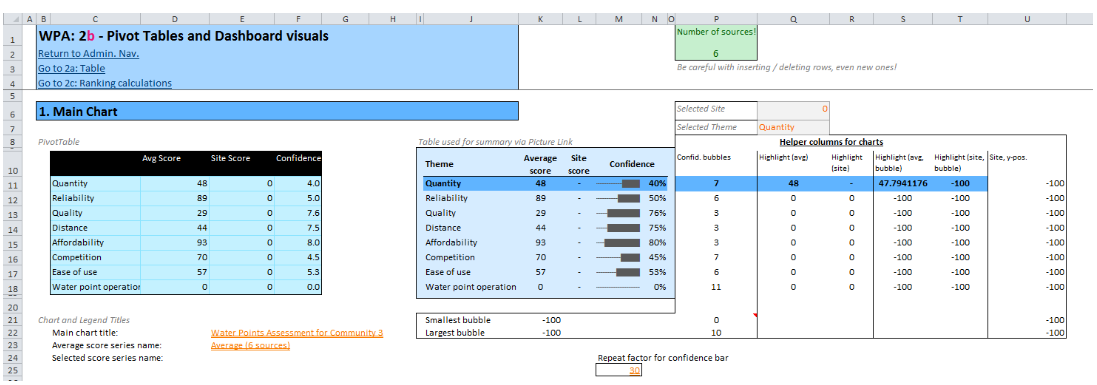


Figure 17 Screenshot of coded section for Part 2 detail's Main chart

2. **Pie chart (Access levels)**: The data from this chart are linked to the summed totals of households within each distance increment, located on worksheet *'2a Tbl'!*. The actual series used in the chart will update based on the season selection (`BC_p2_SelectedSeason`) of the three options (wet, dry, average) stored in the array *named* `RA_p2_SeasonLabels`. The chart's source data are made dynamic through the use of `CHOOSE()` and `MATCH()` functions.

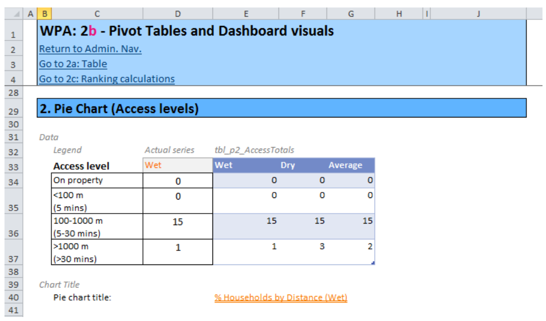


Figure 18 Screenshot of coded section for Part 2 detail's access level pie chart

3. **Component score charts**: The code and logic is identical to points 4 and 5 in the previous section: Worksheet '1b Pvt'! – Code for Dashboards "Main Results" and "Part 1 Details" (p. 116).

   The one difference is that in the extra coding in range K48:K66 (column labeled "Comp"). The need for a flag variable was mentioned above to deal with the weighted average calculations for Distance and Quantity scores (section "Additional Remarks on Part 2 Scoring", p. 112). This is the section that it affects, and this is where it is checked, and removed, using `IF()`, `RIGHT()`, `LEFT()`, and `LEN()` functions. Note that the flag variable (`BC_p2_FLAG`) may be modified without having to recode this section.

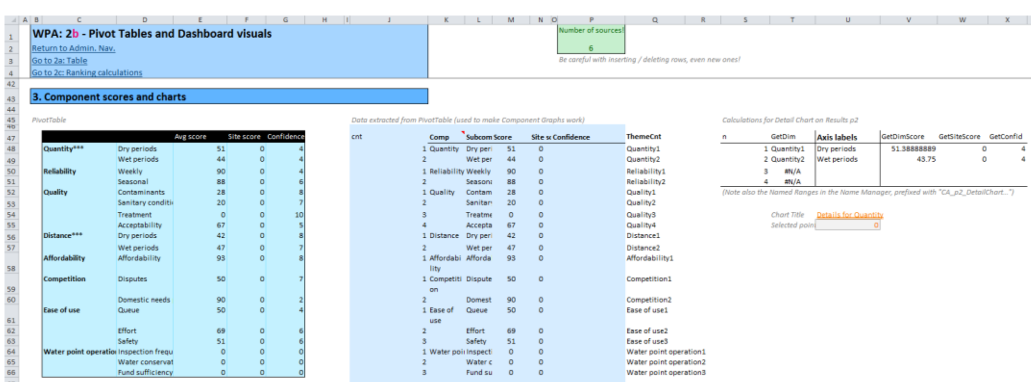


Figure 19 Screenshot of code for Part 2's Component scores and charts

Worksheet '2c Rank'! – Code for Dashboards "Part 2 Details"

This section codes for the ranking of water points according to the user-selected theme. Using the `RANK()` function, some of the Part 1 Overall Results main chart logic is used (p. 117, point 2.a). The key variables that drive the dynamic portion of the code are the user-selected theme (`BC_p2_SelectedDim`) and its position within its source array `LU_p2_Dimensions`.

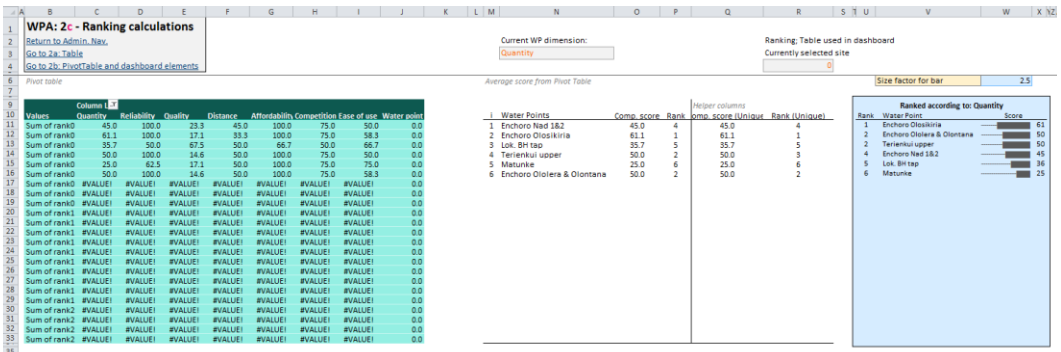


Figure 20 Screenshot of coded section for Part 2's water point ranking

Worksheet '3 Future'! – Code for Part 3 "Looking Forward (BETA)"

This section can only be accessed from the Overall Results worksheet. Upon clicking the designated button, users are prompted asking if they wish to go to this section, and encouraged to spend time analyzing the results of the main assessment first. The code for this section is quite basic. The user input sections and the result charts are located on the same page and can be navigated to using *macro*-assigned arrow shapes.

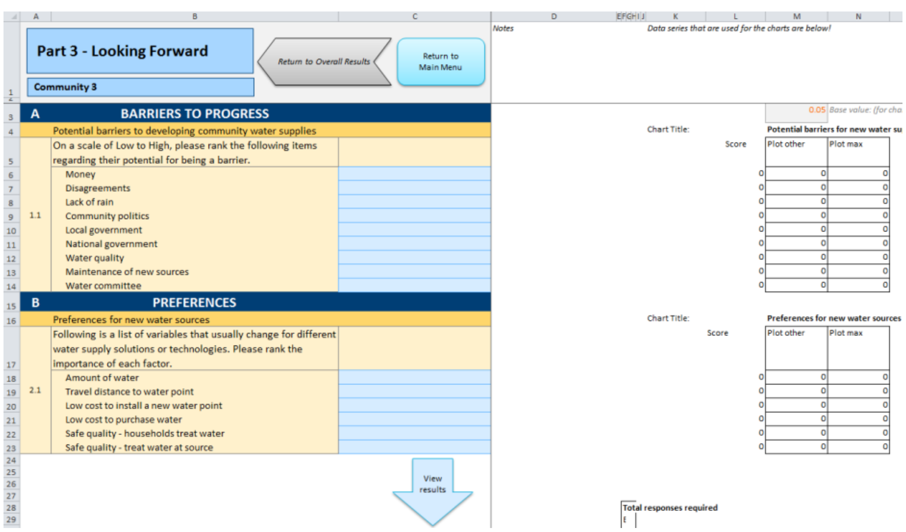


Figure 21 Screenshot of user form and hidden code for Part 3 Looking Forward (BETA)

NAMING CONVENTION FOR DEFINED NAMES

The Tool contains a large number of defined names. The following prefixes were used for organization.[2]

Table 4 Prefix convention used in naming variables

Prefix	Description
BC	base cell (single cell references)
CA	column array
DD	dropdown list
LU	lookup
p0	Part 0 (Background questions)
p1	Part 1 (Community Assessment)
p1a	Part 1a: Water Resources
p1b	Part 1b: Environment
p1c	Part 1c: Health and Hygiene
p1d	Part 1d: Community Capacity
p1e	Part 1e: Water Management
p1f	Part 1f: External Support
p2	Part 2 (Water Points Assessment)
RA	row array
RespEnt	number of responses entered
RespReq	number of responses required
tbl	table
yRef	reference material
z	discarded (but kept for possible future needs)

[2] Some prefixes were adopted from the Spreadsheet Standards Review Board's (SSRB) *Best Practice: Spreadsheet Modelling Standards*, available at http://www.ssrb.org/.

KEY FUNCTIONS AND FEATURES OF MS EXCEL

List of MS Excel Functions

The Tool's calculations and charts are programmed exclusively using MS Excel spreadsheet functions. The functions used in the Tool are grouped below by those used extensively (Table 5) and less extensively (Table 6) throughout the Tool. Hyperlinks are provided for further information.

Table 5 Frequently-used functions throughout Community-SWAT

Function	Type	Description*
AND()	Logical	Returns TRUE if all its arguments evaluate to TRUE; returns FALSE if one or more arguments evaluate to FALSE.
IF()	Logical	Returns one value if a condition you specify evaluates to TRUE, and another value if that condition evaluates to FALSE.
IFERROR()	Logical	Returns a value you specify if a formula evaluates to an error; otherwise, returns the result of the formula. Use the IFERROR function to trap and handle errors in a formula.
INDEX()	Lookup and reference	Returns a value or the reference to a value from within a table or range. There are two forms of the INDEX function: the array form and the reference form.
INDEX(MATCH())	Lookup and reference	Search for a value in any column of a table and return the value from another column in the same row. See: [1], [2].
MATCH()	Lookup and reference	Searches for a specified item in a range of cells, and then returns the relative position of that item in the range.
OFFSET()	Lookup and reference	Returns a reference to a range that is a specified number of rows and columns from a cell or range of cells. The reference that is returned can be a single cell or a range of cells. You can specify the number of rows and the number of columns to be returned.
OR()	Logical	Returns TRUE if any argument is TRUE; returns FALSE if all arguments are FALSE.

* Adapted from Microsoft® Excel help files.

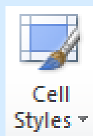
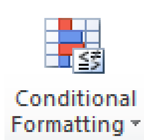
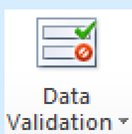
Table 6 Other functions used throughout Community-SWAT

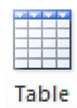
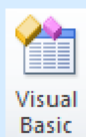
Function	Type	Description*
CHOOSE()	Lookup and reference	Return a value from the list of value arguments. Use CHOOSE to select one of up to 254 values based on the index number.
COUNT()	Statistics	Counts the number of cells that contain numbers, and counts numbers within the list of arguments.
COUNTIF()	Statistics	Counts the number of cells within a range that meet a single criterion that you specify.
COUNTIFS()	Statistics	Applies criteria to cells across multiple ranges and counts the number of times all criteria are met.
INDIRECT()	Lookup and reference	Returns the reference specified by a text string. References are immediately evaluated to display their contents. Use INDIRECT when you want to change the reference to a cell within a formula without changing the formula itself.
ISNUMBER()	Information	Collectively, the IS functions check the specified value and return TRUE or FALSE depending on the outcome.
LARGE()	Statistics	Returns the k^{th} largest value in a data set.
LEFT()	Text	Returns the first character or characters in a text string, based on the number of characters you specify.
LEN()	Text	Returns the number of characters in a text string.
RANK()	Statistics	Returns the rank of a number in a list of numbers.
VLOOKUP()	Lookup and reference	Looks in the first column of an array and moves across the row to return the value of a cell.
SMALL()	Statistics	Returns the k^{th} smallest value in a data set.
SUM()	Math	Returns the sum of the arguments.
SUMPRODUCT()	Math	Returns the sum of the products of corresponding array components.

* Adapted from Microsoft® Excel help files.

List of MS Excel Features

The following table lists the main features that were used in Tool development, and are used during operation. Hyperlinks are included for more information.

Feature	Description*	Tool Uses
Arrays	A collection of items, typically cell addresses.	Various
Cell styles 	A defined set of formatting characteristics, such as fonts and font sizes, number formats, cell borders, and cell shading. Key benefit: Quickly apply *and* modify formats	Formatting of User Forms
Conditional formatting 	Change the format of a cell based on conditions or formulas.	Checkboxes; Dashboard
Data validation 	Use to define restrictions on what data can or should be entered in a cell. You can configure data validation to prevent users from entering data that is not valid. Key benefits: Easy dropdown lists, restrict range or type of data entered	User Forms (dropdown options, restricted ranges); Dashboard
Defined names 	Make formulas easier to understand and maintain. You can define a name for a cell range, function, constant, or table.	Throughout. See *Naming Conventions* below.
Form controls 	Form controls are the original controls that are compatible with earlier versions of Excel. Key benefit: Insert buttons, check boxes, etc.	User Forms

Feature		Description*	Tool Uses
Linked Picture		Paste a dynamic image of a cell range. The picture will update when the contents of the cell(s) change. (Note: Less stable in MS Excel 2007 versions.)	Dashboard
PivotTables		An interactive way to quickly summarize large amounts of data. Key benefit: Quick data aggregation	Calculation worksheets: *'1b Pvt'!* + *'2b Pvt'!* + *'2c Rank'!*
Tables		Useful for managing and analyzing a group of related data easier. You can turn a range of cells into an Excel Table. Key benefit: Structured referencing	Calculation worksheets: *'1a Tbl'!* + *'2a Tbl'!* + *'Lookup'!*
VBA		Excel VBA is a programming application that allows you to use Visual Basic code to run the many features of the Excel package, thereby allowing you to customize your Excel applications.	Navigation and Information buttons Worksheet event subroutines (selection change, open, close)

* Adapted from Microsoft® Excel help files.

Helpful References

1. Microsoft® Excel Help files – Available both within Excel and online.
   Excel functions (by category)
   Excel functions (alphabetical list)

2. Chandoo.org – A very helpful, cutting-edge website that the original developer, Jesse Newton, used often: http://chandoo.org/wp/.

APPENDIX 4

List of Community-SWAT Questions and Possible Answers

The following table contains the questions, formulas (where applicable), and qualitative response options (where applicable) used in the Community-SWAT application file.

Table 9 Questions, scoring logic, and qualitative response options for Parts 1 and 2 of Community-SWAT (items marked with a * belong to Part 2: Water Points Assessment)

Component	**Sub-component**	**Question**	**Formula**	**Opt 1 (0.00)**	**Opt 2 (O.25)**	**Opt 3 (0.50)**	**Opt 4 (0.75)**	**Opt 5 (1.00)**	**Reference**
Dimension 1: Water Resources									
Quantity	Groundwater	Has a hydrogeological assessment been done to assess groundwater resources? If so, use that information to select the most appropriate response. Otherwise, select "Unsure".	Qualitative	Groundwater is not available for development	Available but significantly limited in either location, quantity, or by government policy	Available but limited in either location, quantity, or by government policy	Available throughout most of community	Abundant throughout the community	-
	Surface water	Average monthly flowrate (m3/s)	Q_{mean} / $Area_{Village}$	0	1	0.2	500	10.001	Alessa et al., 2008
		What proportion of the community's surface area is water?	Qualitative	Less than 0.1%	Between 0.2 and 1%	Between 2 and 10%	Between 11 and 20%	More than 20%	Alessa et al., 2008
	Rain/Climate	Average monthly rainfall (mm)	Annual mean	0	100	250	500	750	Alessa et al., 2008
		What is the Aridity Index for this region?	Qualitative	Hyper arid	Arid	Semi-arid	Dry sub-humid	Humid	Perez-Foguet and Gine, 2011

Component	Sub-component	Question	Formula	Opt 1 (0.00)	Opt 2 (O.25)	Opt 3 (0.50)	Opt 4 (0.75)	Opt 5 (1.00)	Reference
Variability	Seasonal	Variability in monthly river flow (calculated from other inputs)	$(Q_{max} - Q_{min}) / Q_{mean}$	8.001	4	2	1	0	Alessa et al. , 2008
		"Dry periods" are times of the year with less than average precipitation, "Wet periods" are those with higher than average precipitation. Please select the appropriate circle for each month (options are: wet, dry, mixed)	[(# wet months) + 0.5*(# mixed months)] /12						cf. Gine and Perez-Foguet, 2010
	Inter-annual	What is the standard deviation (in m3/s) for the average annual river flow over the last 10 or more years? (If unavailable, leave blank)	σ/Q_{mean}	0.5	0.3	0.2	0.1	0	Alessa et al., 2008
		What is the standard deviation (in mm) for annual rainfall over the last 10 or more years?	σ/Annual mean	0.5	0.3	0.2	0.1	0	Alessa et al., 2008

Component	Sub-component	Question	Formula	Opt 1 (0.00)	Opt 2 (O.25)	Opt 3 (0.50)	Opt 4 (0.75)	Opt 5 (1.00)	Reference
	Extreme events	In the past 30-50 years, have any extreme events affected the community's access to water? (Extreme events typically occur no more than once every 10 years.) Extreme dry season impact	Qualitative	4 - Devastating: Also caused human deaths	3 - Significant: Also caused families to relocate	2 - Moderate: Animal deaths, possession and/or property damage	1 - Minimal: Daily life more difficult	0 - None	-
		In the past 30-50 years, have any extreme events affected the community's access to water? (Extreme events typically occur no more than once every 10 years.) Extreme flooding impact	Qualitative	4 - Devastating: Also caused human deaths	3 - Significant: Also caused families to relocate	2 - Moderate: Animal deaths, possession and/or property damage	1 - Minimal: Daily life more difficult	0 - None	-

Component	Sub-component	Question	Formula	Opt 1 (0.00)	Opt 2 (O.25)	Opt 3 (0.50)	Opt 4 (0.75)	Opt 5 (1.00)	Reference
		In the past 30-50 years, have any extreme events affected the community's access to water? (Extreme events typically occur no more than once every 10 years.) Extreme other impact	Qualitative	4 - Devastating: Also caused human deaths	3 - Significant: Also caused families to relocate	2 - Moderate: Animal deaths, possession and/or property damage	1 - Minimal: Daily life more difficult	0 - None	-
Quality	Pollution sources	For rivers and streams: how many development or industrial sites (mines, landfills, industries) are upstream?	Qualitative	More than 10	6 - 10	2 - 5	1	0	Alessa et al., 2008
		How often do farmers use recycled wastewater on their crops?	Qualitative	Always	Often	Sometimes	Rarely	Never	-
		How often do farmers use pesticides and herbicides on their crops?	Qualitative	Always	Often	Sometimes	Rarely	Never	-
		How frequently do farmers apply fertilizers to their crops?	Qualitative	Always	Often	Sometimes	Rarely	Never	-

Component	**Sub-component**	**Question**	**Formula**	**Opt 1 (0.00)**	**Opt 2 (0.25)**	**Opt 3 (0.50)**	**Opt 4 (0.75)**	**Opt 5 (1.00)**	**Reference**
		Does the community have any domestic animals that are either confined or that graze openly near water sources?	Qualitative	Open animal grazing with access to water sources	Open animal grazing with limited access to water sources	No domestic animal grazing, but animal confinement within 100 m of water sources	No domestic animal grazing, but animal confinement within 250 m of water sources	No domestic animal grazing or confinement	-
		How often do people use proper sanitation facilities as opposed to defecating outside or openly?	Qualitative	Never	Rarely	Sometimes	Often	Always	-
Dimension 2: Environment									
Water	Quality	What is the average Biochemical Oxygen Demand (BOD_5) of your surface water (mg O_2/L)?	x	10.001	5	3	1	0	Chaves and Alipaz, 2007
		Approximately how many native fish species have populations that are: increasing, stable, decreasing	$(x_{inc} + 0.75x_{stable}) / x_{total}$						cf. PRI, 2007

Component	Sub-component	Question	Formula	Opt 1 (0.00)	Opt 2 (O.25)	Opt 3 (0.50)	Opt 4 (0.75)	Opt 5 (1.00)	Reference
		For rivers, streams, and shorelines: What is the total length (km)? How much is good for fishing (km)?	% good for fishing	0	0.05	0.2	0.3	0.5	Alessa et al., 2008
Land	Land	What percent of the land is under protected status or has Best Management Practices in place?	%						Pérez-Foguet and Giné, 2011; Alessa et al., 2008
		How much of a problem is soil erosion in the community?	Qualitative	Very high	High	Moderate	Low	Very low	Sullivan et al., 2003
		How much of a problem are crop losses in the community?	Qualitative	Very high	High	Moderate	Low	Very low	Sullivan et al., 2003
		Approximately what percent of the community is at high risk of being impacted by drought?	1 - %						Sullivan et al., 2003

Component	Sub-component	Question	Formula	Opt 1 (0.00)	Opt 2 (O.25)	Opt 3 (0.50)	Opt 4 (0.75)	Opt 5 (1.00)	Reference
		Approximately what percent of the community is at high risk of being impacted by flooding or waterlogging?	1 - %						Sullivan et al., 2003
Dimension 3: Developed Sources*									
Quantity*	Wet periods*	Quantity collected (L/person/day) for households < 100 m	Qualitative	0	7.5	20	50	100	Howard and Bartram, 2003
		Quantity collected (L/person/day) for households between 100 and 1000 m	Qualitative	0	7.5	20	50	100	Howard and Bartram, 2003
		Quantity collected (L/person/day) for households > 1000 m	Qualitative	0	7.5	20	50	100	Howard and Bartram, 2003
		Water needs met for households with water on property	Qualitative	None or almost none	Drinking and basic cooking	Drinking, cooking, basic hygiene	All domestic needs	All domestic and other productive needs	Howard and Bartram, 2003
	Dry periods*	Quantity collected (L/person/day) for households < 100 m	Qualitative	0	7.5	20	50	100	Howard and Bartram, 2003

Component	Sub-component	Question	Formula	Opt 1 (0.00)	Opt 2 (O.25)	Opt 3 (0.50)	Opt 4 (0.75)	Opt 5 (1.00)	Reference
		Quantity collected (L/person/day) for households between 100 and 1000 m	Qualitative	0	7.5	20	50	100	Howard and Bartram, 2003
		Quantity collected (L/person/day) for households > 1000 m	Qualitative	0	7.5	20	50	100	Howard and Bartram, 2003
		Water needs met for households with water on property	Qualitative	None or almost none	Drinking and basic cooking	Drinking, cooking, basic hygiene	All domestic needs	All domestic and other productive needs	Howard and Bartram, 2003
Reliability*	Weekly*	How often is the water available from this water point compromised or interrupted on a daily or weekly basis?	Qualitative	Always	Often	Sometimes	Rarely	Never	WHO, 2011
	Seasonal*	How often is the water available from this water point compromised or interrupted on a seasonal basis?	Qualitative	Always	Often	Sometimes	Rarely	Never	WHO, 2011

Component	Sub-component	Question	Formula	Opt 1 (0.00)	Opt 2 (O.25)	Opt 3 (0.50)	Opt 4 (0.75)	Opt 5 (1.00)	Reference
Quality*	Sanitary conditions*	Has a sanitary inspection been completed for this water point? If yes, answer True or False to the following 10 questions	1 - (# of FALSE's)/10	The questions depend on the type of source. See Table 10 below.					WHO and UNICEF, 2012b
	Treatment*	Is the water treated before it is provided to users?	Qualitative	Not treated	-	Filtered	Chemically or UV treated	Filtered and chemically or UV treated	cf. Alessa et al., 2008
	Contaminants*	What is the percent of samples testing positive for E. coli (Answer this only if more than 10 records are available)	Qualitative	More than 30%	Between 21 and 30%	Between 11 and 20%	Between 1 and 10%	None (0%)	WHO, 2011
		What is the average concentration of E. coli (Answer this if there are less than 10 records available)	Qualitative	More than 100 cfu/100 mL	Between 11 and 100 cfu/100 mL	Between 1 and 10 cfu/100 mL	Less than 1 cfu/100 mL	0 cfu/100 mL	WHO, 2011
	Acceptability*	Does the water have a bad taste?	Qualitative	Repulsive	Strong	Moderate	Slight	No	WHO, 2011
		Does the water have a bad odour?	Qualitative	Repulsive	Strong	Moderate	Slight	No	WHO, 2011
		How clear is the water?	Qualitative	Dirty and/or opaque	Cloudy	Slightly cloudy	Clear but coloured	Clear	WHO, 2011

Component	Sub-component	Question	Formula	Opt 1 (0.00)	Opt 2 (O.25)	Opt 3 (0.50)	Opt 4 (0.75)	Opt 5 (1.00)	Reference
Dimension 4: Access*									
Distance*	Wet periods*		Qualitative	Households that live > 1000 m (> 30 min round trip)	-	Households that live within 100-1000 m (5-30 min round trip)	Households that live < 100 m (< 5 min round trip)	Households that have on-property access to water	Howard and Bartram, 2003
	Dry periods*		Qualitative	Households that live > 1000 m (> 30 min round trip)	-	Households that live within 100-1000 m (5-30 min round trip)	Households that live < 100 m (< 5 min round trip)	Households that have on-property access to water	Howard and Bartram, 2003
Affordability*	Affordability*	Do users report cost as a burden?*	Qualitative	This parameter is evaluated on a seven-point scale, rather than a five-point scale, with the following options: All (more than 95% of users), Vast majority (81 to 95% of users), Many (61 to 80% of users), About half (41 to 60% of users), Some (21 to 40% of users), Few (5 to 20% of users), None (less than 5% of users).					-
Ease of use*	Queue*	How long does it take to withdraw water from this source? Include time spent in line-ups.	Qualitative	More than 25 minutes	More than 15 minutes	Between 10 and 15 minutes	Between 5 and 10 minutes	Less than 5 minutes	cf. SCHR, 2004
	Effort*	How much effort is required to withdraw water from this source?	Qualitative	Difficult - some cannot use it	Lots of effort	Some effort	Little effort	Almost no effort	cf. Hoko and Hertle, 2006

Component	**Sub-component**	**Question**	**Formula**	**Opt 1 (0.00)**	**Opt 2 (O.25)**	**Opt 3 (0.50)**	**Opt 4 (0.75)**	**Opt 5 (1.00)**	**Reference**
	Safety*	What level of danger does using this source pose to people using it (e.g. wildlife, cliffs, floods)?	Qualitative	Very dangerous	Usually dangerous	Sometimes dangerous	A little dangerous	No danger	cf. Sullivan et al., 2003
Competition*	Disputes*	How often do community members dispute over use of this source?	Qualitative	Always	Often	Sometimes	Rarely	Never	cf. Sullivan et al., 2003
	Domestic needs prioritized*	How often are domestic water needs out-competed by other water needs (e.g. by upstream industry, local business, neighbours)	Qualitative	Always	Often	Sometimes	Rarely	Never	cf. Gine and Perez-Foguet, 2010
Dimension 5: Water Management									
Administration	Planning	Is there a Water Committee, and how often do they meet to discuss water plans or problems?	Qualitative	There is no Water Committee	Only during emergencies	Less than monthly	Monthly	Bi-weekly or weekly	cf. Hoko and Hertle, 2006
		How often does the Water Committee consult the broader community?	Qualitative	Never	Only during emergencies	Less than once per year	Once per year	Twice per year or more	cf. Davis et al., 2008

Component	Sub-component	Question	Formula	Opt 1 (0.00)	Opt 2 (O.25)	Opt 3 (0.50)	Opt 4 (0.75)	Opt 5 (1.00)	Reference
		Do you have a water action plan for your community and how would you describe its status?	Qualitative	No plan exists	-	Draft plan	Approved plan	Implemented plan	Alessa et al., 2008
	Documentation: How often, if ever, does the Water Committee keep the following records:	Administrative records	Qualitative	Seldom or never		Sometimes		Almost always	cf. Hoko and Hertle, 2006
		Financial records	Qualitative	Seldom or never		Sometimes		Almost always	cf. Hoko and Hertle, 2006
		Water quality records	Qualitative	Seldom or never		Sometimes		Almost always	cf. Hoko and Hertle, 2006
		Water quantity records	Qualitative	Seldom or never		Sometimes		Almost always	cf. Hoko and Hertle, 2006
		Maintenance	Qualitative	Seldom or never		Sometimes		Almost always	cf. Hoko and Hertle, 2006

Component	Sub-component	Question	Formula	Opt 1 (0.00)	Opt 2 (O.25)	Opt 3 (0.50)	Opt 4 (0.75)	Opt 5 (1.00)	Reference
Finances	Finances	What type of fee structure is in place for the majority of users?	Qualitative	None	Fixed monthly fee	Fixed bi-monthly fee	Fixed block rate (pay by volume)	Increasing block rate (pay by volume)	Henriques and Louis, 2011; Davis et al., 2008
		What would best describe the Water Committee's accounting system?	Qualitative	None	Basic accounting	Tracked annually	Tracked annually with external audit	Tracked quarterly with external audit	Henriques and Louis, 2011
		Are funds sufficient for operation and maintenance costs?	Qualitative	Insufficient funds, has not operated in over 6 months	Funds are irregular and so is operation	Near-sufficient operating funds (more than 90%)	Sufficient operating funds	Sufficient operating funds with savings for repairs	cf. Davis et al., 2008
Representation	Equity	How well are social groups (gender, class, cliques, castes) represented on the Water Committee?	Qualitative	Very low	Low	Moderate	High	Very high	cf. Vishnudas et al., 2008
	Satisfaction	What is the community's overall satisfaction level with operation and maintenance of water infrastructure?	Qualitative	Very low	Low	Moderate	High	Very high	cf. Davis et al., 2008

Component	Sub-component	Question	Formula	Opt 1 (0.00)	Opt 2 (O.25)	Opt 3 (0.50)	Opt 4 (0.75)	Opt 5 (1.00)	Reference
	Service	Is there an avenue for community members to present their needs and concerns to the Water Committee?	Qualitative	No	The committee only listens to certain community members	The committee is willing to listen but rarely asks for feedback	The committee sometimes asks for community feedback	The committee frequently consults with community members	-
Water point operation*	Inspection frequency*	How often is the infrastructure associated with this water point inspected for problems?	Qualitative	No one is responsible for inspecting this source	Irregularly or only when requested	Once every month	Once every two weeks	Once per week or more	-
	Water conservation*	To what degree is water wasted from use of this source? (e.g. inefficient technology, poor design causing spilling)	Qualitative	Very high	High	Moderate	Low	Very low	-
	Fund sufficiency*	Do sufficient funds exist for operation and maintenance costs?	Qualitative	Insufficient funds, has not operated in over 6 months	Funds are irregular and so is operation	Near-sufficient operating funds (more than 90%)	Sufficient operating funds	Sufficient operating funds with savings for repairs	cf. Davis et al., 2008

Component	Sub-component	Question	Formula	Opt 1 (0.00)	Opt 2 (O.25)	Opt 3 (0.50)	Opt 4 (0.75)	Opt 5 (1.00)	Reference
Dimension 6: Community Capacity									
Knowledge capital	Schooling	Approximately what percent of households have at least one member with at least five years of education?	%						Alkire and Santos, 2010
		Approximately what percent of households with school-aged children have at least one school-aged child (grades 1-8) who is not regularly attending school?	1 - %						Alkire and Santos, 2010
	Special training	Have any community members have been trained in any of the following capacities? Mechanic Laboratory technician, Water systems operator, Administrative assistant, IT technician	x/5						Henriques and Louis, 2011

Component	Sub-component	Question	Formula	Opt 1 (0.00)	Opt 2 (O.25)	Opt 3 (0.50)	Opt 4 (0.75)	Opt 5 (1.00)	Reference
		Have any community members been trained in any of the following professional job positions? Administrative supervisor, Health scientist (nurse or doctor), Engineer, Lawyer, Accountant	x/5						Henriques and Louis, 2011
	Indigenous knowledge	How many people live in this community that are 50 years of age or older AND were born here?	(x / villagePop)* 1000	0	10	50	100	200	Alessa et al., 2008
		How many people have lived in this community for more than 30 years?	(x / villagePop)* 1000	0	50	100	250	500	Alessa et al., 2008
Financial capital	Household	Approximately what percent of households have reliable incomes throughout the year?	%						Sullivan et al., 2003

Component	Sub-component	Question	Formula	Opt 1 (0.00)	Opt 2 (O.25)	Opt 3 (0.50)	Opt 4 (0.75)	Opt 5 (1.00)	Reference
		a. How often, if ever, do community members come together to form a Rotating Savings and Credit Associations (ROSCA) or equivalent? b. Are microfinance services available in your area? If so, are they used?	Qualitative	Combination … make special note					-
		Approximately what percent of households have at least two of the following: radio, TV, phone, bike, motorbike, automobile, improved sanitation facilities, electricity in home	%						Alkire and Santos, 2010
		Approximately what percent of households own livestock or other domestic animals that could be sold in the market?	%						-

Component	Sub-component	Question	Formula	Opt 1 (0.00)	Opt 2 (O.25)	Opt 3 (0.50)	Opt 4 (0.75)	Opt 5 (1.00)	Reference
	Community	What would best describe the community's accounting system?	Qualitative	None	Basic accounting	Tracked annually	Tracked annually with external audit	Tracked quarterly with external audit	Henriques and Louis, 2011
		Which, if any, of the following assets does the community own collectively? Land / real estate, Equipment, Cash, Other investments (stocks, bonds, etc.)	x/4						Henriques and Louis, 2011
Social capital	Women	How engaged are women in community meetings?	Qualitative	Women do not attend	Women attend but do not participate	Women attend, listen and ask questions	Women attend, listen, ask questions, and answer questions	Women attend, ask and answer questions, and give presentations	-
		Approximately what percent of community-based organizations or committees have at least one women on the board?	%						-

Component	Sub-component	Question	Formula	Opt 1 (0.00)	Opt 2 (O.25)	Opt 3 (0.50)	Opt 4 (0.75)	Opt 5 (1.00)	Reference
	Solidarity	In general, how willing are neighbours to help each other?	Qualitative	Generally unwilling to help each other	Generally hesitant to help each other	Neither willing nor unwilling, neighbours prefer to keep to themselves	Willing to help each other	Willing to help each other and ask for help	-
		In general, what level of trust do members have with each other and the community leadership?	Qualitative	Strong sense of distrust	Small sense of distrust	Mixed sense of trust and distrust	Small sense trust	Strong sense of trust	-
		To what extent do social classes cause division or unfairness in the community?	Qualitative	Very high	High	Moderate	Low	Very low	Henriques and Louis, 2011
		Approximately what percent of households have at least one person regularly attending community meetings?	%						-

Component	Sub-component	Question	Formula	Opt 1 (0.00)	Opt 2 (O.25)	Opt 3 (0.50)	Opt 4 (0.75)	Opt 5 (1.00)	Reference
	Institutions	Does your community have any community-based organizations focused on health, education, or other aspects of community development?	Qualitative	None	One or more, but poorly organized	One or more, well organized	One or more, well organized with positive impact	One or more, well organized with positive impact and external funding	-
		In the last 5 years, has the community submitted application for or received any funding?	Qualitative	None	One submitted	Two or more submitted	One granted	Two or more granted	-
		Which, if any, of the following institutional resources does the community have? Documented policies, Documented future plans or goals, Office space, Elected community council, Paid staff dedicated to community affairs	x/5						Henriques and Louis, 2011

Component	Sub-component	Question	Formula	Opt 1 (0.00)	Opt 2 (O.25)	Opt 3 (0.50)	Opt 4 (0.75)	Opt 5 (1.00)	Reference
Dimension 7: Health and Hygiene									
Knowledge and health	Knowledge	In your opinion, what percent of the community understands the link between poor quality drinking water and negative health effects?	%						-
		What percent, if any, of the community has received training in water, sanitation, and hygiene issues?	%						Garfi and Ferrer-Marti, 2011
	Health	How often do community members suffer from water-related illness? (e.g. Diarrhoea)	Qualitative	Always	Often	Sometimes	Rarely	Never	-
		What level best describes the mortality rate for children under 5 years of age?	Qualitative	Very high	High	Moderate	Low	Very low	cf. Alkire and Santos, 2010; Sullivan et al., 2003

Component	**Sub-component**	**Question**	**Formula**	**Opt 1 (0.00)**	**Opt 2 (O.25)**	**Opt 3 (0.50)**	**Opt 4 (0.75)**	**Opt 5 (1.00)**	**Reference**
Water practices	Storage	Approximately what percent of households store drinking water separately from water used for other purposes?	%						WHO and UNICEF, 2012b
		If applicable: approximately what percent of households cover drinking water containers?	%						WHO and UNICEF, 2012b
		If applicable: approximately what percent of households store drinking water containers off the ground?	%						WHO and UNICEF, 2012b
	Preparation	a. Approximately what percent of households treat their drinking water before consumption? (include those using water from a pre-treated source)	%						WHO and UNICEF, 2006

Component	Sub-component	Question	Formula	Opt 1 (0.00)	Opt 2 (O.25)	Opt 3 (0.50)	Opt 4 (0.75)	Opt 5 (1.00)	Reference
		or b. What disinfection methods do people use? - Percent that boil, use sand filter, bleach or chlorine, and/or solar disinfection - Percent that decant	(% using improved means) + 0.5*(% decanting)						WHO and UNICEF, 2006
Hygiene	Practices	Approximately what percent of households wash their hands with soap or other "scrubbing agent"?	%						Howard and Bartram, 2003
		Approximately what percent of households hygienically dispose of their children's faeces?	%						WHO and UNICEF, 2006
	Facilities	Approximately what percent of households own improved sanitation facilities?	%						Gine and Perez-Foguet, 2010

Component	Sub-component	Question	Formula	Opt 1 (0.00)	Opt 2 (O.25)	Opt 3 (0.50)	Opt 4 (0.75)	Opt 5 (1.00)	Reference
		Approximately what percent of schools have improved sanitation (a Ventilated Improved Pit latrine or better toilet)?	%						-
Access	Clinics	What is the average travel time to a health clinic for the majority of community members?	Qualitative	Travel to a clinic is difficult for most of the community	Most households must travel more than 90 minutes to clinic	Some households can travel to clinic within 90 minutes	Most households can travel to clinic within 90 minutes	Most households can travel to clinic within 45 minutes	-
		How affordable are clinic visitation and treatment costs?	Qualitative	Unaffordable to most of the community		Affordable for about half the community	Costs are based on a "pay what you can" policy	Free for the community	-
		How often are nurses and other clinic staff available?	Qualitative	Never	Rarely	Sometimes	Often	Always	-
	Resources	What is the availability of health and hygiene workshops in your community?	Qualitative	Never	Rarely	Sometimes	Often	Always	-
		What is the proportion of schools with health clubs in your community?	Qualitative	None		Available in at least one community school	Available in all community schools	Available in all community schools and students are active	-

Component	**Sub-component**	**Question**	**Formula**	**Opt 1 (0.00)**	**Opt 2 (O.25)**	**Opt 3 (0.50)**	**Opt 4 (0.75)**	**Opt 5 (1.00)**	**Reference**
Dimension 8: External Support									
Government	Water policy	Does your national constitution and/or bill of rights recognize the Human Right to Water?	Qualitative	No		Unsure		Yes	Adapted from Backman et al., 2008
		Does your national government have a water policy?	Qualitative	No		Yes, last updated more than 30 years ago		Yes, and updated within last 30 years	Adapted from Backman et al., 2008
	Water plans	Has any level of government undertaken a comprehensive analysis of water resource issues?	Qualitative	No analysis done	Yes, for the country	Yes, for the country and our province	Yes, for the country, our province, and our watershed	Yes, for the country, our province, and our watershed within last 10 years	Adapted from Backman et al., 2008
		Does any level of government have a water management plan for your watershed?	Qualitative	No plan exists	A plan is being drafted	Plan exists	Plan exists, with steps for managing water quantity and quality	Plan exists, with steps for managing water quantity and quality, and is enforced	Adapted from Backman et al., 2008

Component	Sub-component	Question	Formula	Opt 1 (0.00)	Opt 2 (O.25)	Opt 3 (0.50)	Opt 4 (0.75)	Opt 5 (1.00)	Reference
Linkages	Accessibility	How many relationships does your community have with external individuals, organizations or other communities? *(This is used to gauge your community's access to information and support, as well as opportunities for resource sharing and collaboration)*	x/LOG10(Population) **Note: Actual ranges are calculated and presented in a dropdown list*	0	5	7.5	10	20	Alessa et al., 2008
		On average, how long does it take to drive to the nearest city? (hours)	1 - x/4						cf. Davis et al., 2008

Component	Sub-component	Question	Formula	Opt 1 (0.00)	Opt 2 (O.25)	Opt 3 (0.50)	Opt 4 (0.75)	Opt 5 (1.00)	Reference
	Support	How often do representatives from external organizations (including the government) visit the community to help with the following water resource-related needs: 1) technical support (e.g. inspections, repairs, upgrades) 2) administrative support (e.g. documentation, organization, accounting, recruitment, proposal-writing) 3) training workshops for operators	Qualitative	Never	Less than once every two years	About once every two years	About once per year	About once per year and visits have been to help with 2 or more of these needs	cf. Davis et al., 2008

Component	Sub-component	Question	Formula	Opt 1 (0.00)	Opt 2 (O.25)	Opt 3 (0.50)	Opt 4 (0.75)	Opt 5 (1.00)	Reference
		How accessible "expert" information to you? This information may be related to water availability, technology assistance, understanding government policy, health and hygiene, etc.	Qualitative	Very low	Low	Moderate	High	Very high	

APPENDIX 5

Sanitary inspection questions used in Part 2: Water Points Assessment

In Community-SWAT, these questions are in a True or False format. Answering "True" or leaving the question blank result in a lower score.

Table 10 Sanitary inspection questions (after WHO and UNICEF, 2012).

#	Question
Surface water (lake, river, dam)	
	Not applicable; assigned a score of 0.
Unprotected spring	
	Not applicable; assigned a score of 0.
Other water vendor	
	Not applicable; assigned a score of 0.
Protected spring	
1	Collection or spring box is absent or faulty
2	Masonry or backfill area protecting spring is faulty or eroded
3	Inspection cover or air vent is absent or insanitary
4	Spilt water can pool in collection area
5	Fence is absent or faulty
6	Animals can access within 10 m
7	A latrine is uphill or within 30 m
8	Surface water can collect uphill within 30 m
9	Diversion ditch above the spring is absent or faulty
10	Other sources of pollution are uphill
Borehole with mechanized pumping	
1	A latrine or sewer is within 100 m of the pump
2	A latrine is within 10 m
3	Other source of pollution are within 50 m
4	An uncapped well is within 100 m
5	Drainage is absent, cracked, broken or needs cleaning
6	Animals can come within 50 m due to missing or faulty fence
7	Cement apron/platform is missing or has cracks
8	There is stagnant water within 2 m
9	The well seal is insanitary or has pollution sources near it
10	The borehole cap is cracked
Borehole with handpump	
1	A latrine is within 10 m
2	A latrine or other source of faecal pollution is uphill
3	Other pollution sources are within 10 m
4	Drainage is absent or faulty allowing ponding within 2 m

#	Question
5	Drainage channel absent, cracked, broken or needs cleaning
6	Animals can come within 10 m due to missing or faulty fence
7	Cement apron/platform is less than 2 m in diameter
8	Spilt water can collect in the apron area
9	Apron or pump cover is cracked or damaged
10	Handpump loose at attachment point (for rope-washer pumps, pump cover is missing)
Dug well with handpump	
1	A latrine is within 10 m
2	Nearest latrine is uphill of well
3	Other pollution sources are within 10 m
4	Drainage channel is absent or faulty, allowing ponding within 3 m
5	Drainage channel is absent, cracked, broken or needs cleaning
6	Cement or slab is less than 2 m in diameter around top of well
7	Spilt water can collect in the apron area
8	Cement floor or slab has cracks
10	Well cover is absent or insanitary
9	Handpump loose at attachment point (for rope-washer pumps, pump cover is missing)
Rainwater harvesting tank	
1	First flush system is broken or absent
2	Rainwater is collected in an open container
3	Visible signs of contamination are on roof (e.g. faeces, dirt)
4	Gutters that collect water are dirty or blocked
5	Tank wall or top is cracked or damaged
6	Water is collected directly from tank
7	Tap is leaking or damaged
8	Concrete floor under tap is missing, broken or dirty
9	Pollution sources are near the tank or collection area
10	Inside of tank is dirty
Household piped water	
1	Tap is located outside of the house (e.g. in the yard)
2	Water is drawn and then stored in a container
3	Storage tank or any taps are leaking or damaged
4	Taps are shared with other households
5	Area around the tank or tap is insanitary
6	Household pipes leak
7	Animals can access area around the pipe
8	Users report pipe breaks in the last week
9	A discontinuity in water supply has occurred in the last 10 days
10	Household obtains water from more than one source

WHO and UNICEF. (2012). Rapid Assessment of Drinking-water Quality: A Handbook for Implementation. Available at http://www.wssinfo.org/fileadmin/user_upload/resources/RADWQ_Jordan.pdf.

APPENDIX 6

Certificate of Ethics Clearance to Involve Human Participants in Research

McMaster University
Inspiring Innovation and Discovery

McMaster University Research Ethics Board (MREB)

c/o Office of Research Services, MREB Secretariat, GH-305/H, e-mail: ethicsoffice@mcmaster.ca

CERTIFICATE OF ETHICS CLEARANCE TO INVOLVE HUMAN PARTICIPANTS IN RESEARCH

Application Status: ☐ **New** ☑ **Addendum | Project Number:** 2011 148

TITLE OF RESEARCH PROJECT:

Baseline data collection to support a water intervention in Il Ngwesi, Kenya

Faculty Investigator(s)/ Supervisor(s)	Dept./Address	Phone	E-Mail
S. Dickson	Engineering	24914	sdickso@mcmaster.ca

Co-Investigator(s): S. Elliott, C. Wallace

Student Investigator(s)	Dept./Address	Phone	E-Mail
J. Newton	Engineering	905-667-5488	newtojj@mcmaster.ca

Co-Investigator(s): H. Barber

The application in support of the above research project has been reviewed by the MREB to ensure compliance with the Tri-Council Policy Statement and the McMaster University Policies and Guidelines for Research Involving Human Participants. The following ethics certification is provided by the MREB:

☐ The application protocol is cleared as presented without questions or requests for modification.

☐ The application protocol is cleared as revised without questions or requests for modification.

☐ The application protocol is cleared subject to clarification and/or modification as appended or identified below:

COMMENTS AND CONDITIONS: Ongoing clearance is contingent on completing the annual completed/status report. A "Change Request" or amendment must be made and cleared before any alterations are made to the research.

Reporting Frequency: **Annual:** Sep-08-2012 **Other:**

Date: Sep-08-2011 **Chair, Dr. B. Detlor:**

APPENDIX 7

Instrument for Key Informant Questionnaire

Table 11 Instrument for Key Informant Questionnaire

ID	Question
BACKGROUND	
1a	What do you do for work?
1b	What are your responsibilities?
1c	For how long have you had this job?
2a	Which of the group ranches do you come from?
2b	Where do you currently live? How long?
3	What is your connection to Il Ngwesi?
4a	Do you have any responsibilities within Il Ngwesi?
4b	If YES, what are they?
4c	If NO, do you have any responsibilities within another Group Ranch?
WATER SECURITY	
Questions 1a-e were each asked with respect to the following water security dimensions: quantity, quality, access, drought and dry season, rain and wet season, cost.	
1a	Are there any issues?
1b	What is the goal? What would you like?
1c	How will this be achieved? By when?
1d	What has been done to date?
1e	What obstacles have you encountered or do you expect to encounter?
2	In your opinion, please rank the importance of each of the water security dimensions above (1 = Highest, 6 = Lowest)
3	Are any of these goals or achievements written in any documents, plans, reports? If so, may we have a copy?
SEASONS, AGRICULTURE, LIVESTOCK	
1a	What are the rainy months?
1b	What are the dry months?
1c	How do the seasons vary from year to year?
1d	What are the signs that the dry season is coming?

ID	Question
1e	What are the signs that the wet season is coming?
1f	Do your responsibilities change with the seasons? How?
2a	Do you have any vegetable crops? If yes, please answer the following: i. Crop ii. When do you plant? iii. When are they watered? iv. How much water (or rain) do they require? v. When are they harvested? vi. What do you do with the harvest?
2b	Have you noticed any soil degradation in recent years? Where? For how long?
3a	Do you own any sheep, goats, cows, or other livestock? If yes, please answer the following questions for each: i. When do they mate? ii. When do they give birth? iii. When do you sell them? (Age of animal, AND time of year) iv. What's the price in the DRY season? v. What's the price in the WET season?
3b	When do the livestock migrate?
3c	To where?
3d	When do the livestock return?
4	Has there been noticeable livestock GAIN in recent years? When? Why?
5	Has there been noticeable livestock LOSS in recent years? When? Why?
6a 6b 6c	What are all the different water needs for the community? Which uses require the most water? Which use is most important?
OTHER	
1a	In your experience, what are the features communities successful in water and sanitation development?
1b	In your experience, what hinders community water resource development?
2a	What is challenging about hygiene and sanitation improvement in the community?
2b	Are there plans for hygiene and sanitation improvement? Yes No
2c	*If yes…* What are they?
2d	*If no…* Why not?
3a	Are you familiar with the **Water Act 2002**? Yes No

ID	Question
3b	Are you familiar with the **National Water Services Strategy** plans? Yes No
3c	Are you familiar with the **National Water Resource Management Strategy** plans? Yes No
3d	*If yes...* What has been difficult to implement?
4a	Are you familiar with the new **Constitution of Kenya, 2010**? Yes No
4b	*If yes...* What are the implications for rural water supply and development?
	[Allow person to speak first; then use the following prompts below]
4c	The 2010 Constitution introduced new land laws. What will it mean for rural water supply and development?
4d	The 2010 Constitution declares "Every person has the right to clean and safe water in adequate quantities" (Article 43.1.d.). What effect do you think this will have for rural water supply and development?

APPENDIX 8

Instrument for Household Questionnaire

The following questionnaire was jointly used for two graduate student's research. It was developed by Hilary Barber with Jesse Newton. An overview of the sections and the quality assurance, quality control procedures used to enter the data is given in Appendix 7.

Table 12 Instrument for Household Questionnaire

ID	Question	Response options
Part A: Introductory Questions		
1	Which statement is most correct about water collection at your boma?	a. I am NOT responsible (if answered a., DO NOT PROCEED)
		b. I share the responsibility
		c. I AM responsible
		d. other
2	Do you currently have functioning piped water at your boma?	a. Yes
		b. No
Part B1: Households With Piped Water		
1a	During the dry season, how often do you receive piped water to your boma? (Answer in hours per day OR days per week)	
1b	During the wet season, how often do you receive piped water to your boma? (Answer in hours per day OR days per week)	
2	Based on the photos, what type of container(s) do you use to collect drinking water from your pipe?	*(Photos not included as this question was irrelevant for this research)*
3a	During the dry season, approximately how many trips per week do you need to collect drinking water outside of your boma?	a. 1
		b. 2
		c. 3
		d. 4
		e. 5 or more
		f. other:
3b	During the wet season, approximately how many trips per week do you need to collect drinking water outside of your boma?	a. 1
		b. 2
		c. 3
		d. 4
		e. 5 or more
		f. other:

ID	Question	Response options
4a	Name ALL of the sources you use to collect drinking water in the dry season?	
	Which source do you visit MOST OFTEN?	
4b	Name ALL of the sources you use to collect drinking water in the wet season?	
	Which source do you visit MOST OFTEN?	
5a	Answer YES or NO to whether the following make water collection difficult for you during the dry season?	a. finding water
		b. long walking distance
		c. long wait time at source
		d. money
		e. disputes with others
		f. injury or sickness
		g. looking after children
		h. dangerous location
		i. other
5b	Answer YES or NO to whether the following make water collection difficult for you during the wet season?	a. finding water
		b. long walking distance
		c. long wait time at source
		d. money
		e. disputes with others
		f. injury or sickness
		g. looking after children
		h. dangerous location
		i. other
Part B2: Homes Without Piped Water		
1a	During the dry season, how often do you receive piped water to your boma? (Answer in hours per day OR days per week)	
1b	During the wet season, how often do you receive piped water to your boma? (Answer in hours per day OR days per week)	
2a	About how many trips per week do you make to collect drinking water for your boma in the dry season?	
2b	About how many trips per week do you make to collect drinking water for your boma in the wet season?	
3	Based on the photos, what type of container(s) do you use to collect drinking water from your pipe?	*(Photos not included as this question was irrelevant for this research)*

ID	Question	Response options
4a	During the dry season, approximately how many trips per week do you need to collect drinking water outside of your boma?	a. 1
		b. 2
		c. 3
		d. 4
		e. 5 or more
		f. more than 5 (#________)
4b	During the wet season, approximately how many trips per week do you need to collect drinking water outside of your boma?	a. 1
		b. 2
		c. 3
		d. 4
		e. 5 or more
		f. more than 5 (#________)
5a	Answer if you do or do not do any of the following activities while you are at your main water source in the dry season:	a. laundry
		b. dish washing
		c. bathing
		d. washroom
		e. livestock grazing and drinking
		f. socializing
		g. do not know
		h. other:
5b	Answer if you do or do not do any of the following activities while you are at your main water source in the wet season:	a. laundry
		b. dish washing
		c. bathing
		d. washroom
		e. livestock grazing and drinking
		f. socializing
		g. do not know
		h. other:
6	How often, if ever, do you use a plastic bag in between your water jug and the lid to prevent leakage when carrying water home?	a. never
		b. sometimes
		c. always
		d. do not know

ID	Question	Response options
7a	In the dry season, how often, if ever, do you use an animal to carry the water you collect home?	a. never
		b. sometimes
		c. always
		d. do not know
	If answered b. or c., then ask: Which type(s) of animal do you use? (indicate all that apply)	a. donkey
		b. cow
		c. other
7b	In the wet season, how often, if ever, do you use an animal to carry the water you collect home?	a. never
		b. sometimes
		c. always
		d. do not know
	If answered b. or c., then ask: Which type(s) of animal do you use? (indicate all that apply)	a. donkey
		b. cow
		c. other
8a	Answer YES or NO to whether the following make water collection difficult for you during the dry season:	a. finding water
		b. long walking distance
		c. long wait time at source
		d. money
		e. disputes with others
		f. injury or sickness
		g. looking after children
		h. dangerous location
		i. other
8b	Answer YES or NO to whether the following make water collection difficult for you during the wet season:	a. finding water
		b. long walking distance
		c. long wait time at source
		d. money
		e. disputes with others
		f. injury or sickness
		g. looking after children
		h. dangerous location
		i. other
9a	Name ALL of the sources you use to collect drinking water in the dry season:	
	Which source do you visit MOST OFTEN?	
9b	Name ALL of the sources you use to collect drinking water in the wet season:	
	Which source do you visit MOST OFTEN?	

ID	Question	Response options
Part C: Water at Home		
1i	*Ask mama:* "Would you please show me the container(s) that you store your drinking water in?" *(Using the photo album, observe: Based on the photos, what type of container(s) is drinking water stored in?)*	-
1ii	How often, if ever, do you keep your drinking water in a separate container from the rest of your water?	a. never
		b. rarely
		c. sometimes
		d. often
		e. always
		f. do not know
1iii	*Observe:* Is a lid on all of the drinking water container(s)?	Yes
		No
		Not applicable
1iv	*Observe:* Where are most of the drinking water containers located?	a. on ground
		b. above ground
		c. both
2i	How often, if ever, do you prepare your water before drinking it?	a. never
		b. rarely
		c. sometimes
		d. often
		e. always
		f. do not know
2ii	*If answered 'b' or 'c' above, proceed to ask 2 ii. Otherwise skip to 3.* Tell me all of the ways that you prepare your drinking water. *(WAIT for the mama to TELL YOU what she does; do not tell her the options.)*	a. boil water
		b. decant (let dirt settle, use clear water on top)
		c. keep it in sunlight
		d. cloth filter
		e. sand filter
		f. chemical treatment (e.g. Waterguard, Aquatabs, io-dine)
		g. none of the above
		h. other:
2iii	Which way do you prepare your water MOST OFTEN?	*(Choose letter from 2ii above.)*

ID	Question	Response options
3i	How does your family most often get drinking water from the containers?	a. by pouring
		b. by utensil (e.g., cup, ladle, pot)
		c. by tap
		d. other
		e. do not know
3ii	Which way does your family get water from the container most often?	*(Choose letter from 3i. above)*
3iii	*Observe: If answered b. to 3i. above, is the utensil stored hygienically when not in use? (e.g., off of ground, away from animals and children)*	Yes
		No
		Not applicable
4i	How often, if ever, do you clean the water storage container between uses?	a. never
		b. sometimes
		c. always
		d. do not know
4ii	*If answered b OR c, answer 4ii.* Tell me how you clean the water storage container. *(WAIT for the mama to TELL YOU what she does, if anything.)*	
4iii	*Observe: Does the inside of the container appear to be clean?*	Yes / No
4iv	*Observe: Does the outside of the container appear to be clean?*	Yes / No
Part D: Family Sanitation and Hygiene		
1	Tell me how your family most often cleans their hands. *(Check all that apply.)*	a. rinse with water
		b. use towel or cloth
		c. soap and water
		d. unsure
		e. does not wash hands
		f. other
2	If you have soap in your house, what does your family use it for? *(Check all that apply.)*	a dish washing
		b. house keeping
		c. laundry
		d. bathing
		e. hand washing
		f. other
		g. do not know

ID	Question	Response options
3i	Tell me all of the places where your family goes to the toilet when they are at home.	a. covered pit latrine
		b. open pit
		c. bush or tree
		d. enchoro, river, pond
		e. flush latrine
		f. do not know
		g. other:
3ii	Where does your family most often go to the toilet?	*(Choose letter from 3i.)*
4	Where do your children under 3 years most often go to the toilet? *(Choose all that apply.)*	a. covered pit latrine
		b. open pit
		c. bush or tree
		d. enchoro, river, pond
		e. flush latrine
		f. diaper or cloth
		g. do not know
		h. other
5	Any other comments to add about sanitation and hygiene at home?	
Part E: Family Health		
For questions 1a - 1g, the options are: Never, Rarely, Sometimes, Often, Always, Do not know, No family member this age		
1	How often do the following family members in your boma suffer from watery stomach?	
	a. children under 5 years	
	b. children 5 - 12 years	
	c. young adult female (13 to 17 years)	
	d. young adult male (13 to 17 years)	
	e. adult female (18 years and over)	
	f. adult male (18 years and over)	
	g. grandparents	
For questions 2a - 2g, the options are: Excellent, Very good, Good, Fair, Poor, Do not know, No family member this age		
2	How would you rate the health of the following family members?	
	a. children under 5 years	
	b. children 5 - 12 years	
	c. young adult female (13 to 17 years)	
	d. young adult male (13 to 17 years)	
	e. adult female (18 years and over)	
	f. adult male (18 years and over)	
	g. grandparents	

ID	Question	Response options
Part F: Household Information		
1	Including yourself, what is the age and sex each person living in your boma right now?	
	a. Oldest	
	b. 2nd oldest	
	c. 3rd oldest	
	d. 4th oldest	
	e. 5th oldest	
	f. 6th oldest	
	g. 7th oldest	
	h. 8th oldest	
	i. 9th oldest	
	j. Youngest	
2	What is the highest level of school you have completed, if any?	a. no formal schooling
		b. primary school, class:
		c. secondary school, class:
		d. college/university
		e. other:
3a	How much money, if any, do you PERSONALLY make in a month during the dry season?	
3b	How much money, if any, do you PERSONALLY make in a month during the wet season?	
4a	I know someone I can confide in.	Yes / No
4b	I know someone who listens to what I have to say.	Yes / No
4c	I know someone who would help me with chores.	Yes / No
4d	I know someone who would lend me money.	Yes / No
4e	I know someone who would help me if I was sick.	Yes / No
5	Please answer 'Yes' or 'No' if you think any of the following are barriers for developing sustainable water resources.	
	a. Money	Yes / No
	b. Disagreements	Yes / No
	c. Lack of rain	Yes / No
	d. Community politics	Yes / No
	e. Local government	Yes / No
	f. National government	Yes / No
	g. Water quality	Yes / No
	h. Upkeep and care of new sources	Yes / No

ID	Question	Response options
Pairwise Preference Ranking Exercises A, B, C		
(For each question, the respondent is shown every possible pair of the options. They choose the option that best answers the question for them.)		
A	Which situation would you like more if your community developed a new water source?	a. Gives LOTS OF WATER
		b. Is CLOSE TO HOME
		c. LITTLE or NO PREPARATION needed before drinking
		d. LOW COST to DEVELOP water source
		e. LOW COST to BUY WATER
		f. Gives CLEAN WATER
B	Why do you think people get watery stomach?	a. Dirty boma
		b. Spiritual reasons (e.g. magic, curse, God, spirits)
		c. Bad or dirty food
		d. Bad or dirty water
		e. It happens to everyone
		f. Germs and parasites (bacteria, viruses, amoebas, worms)
		g. Bad air
		h. Dirty hands
C	All of these actions can help to REDUCE WATERY STOMACH. What would be EASIER TO DO IN YOUR FAMILY?	a. ALL family members ALWAYS wash hands with SOAP
		b. ALWAYS using SOAP for dishwashing
		c. ALWAYS preparing your drinking water
		d. Washing WATER CONTAINERS with SOAP OFTEN
		e. Collecting water that is CLEANER but FURTHER FROM HOME
		f. NEVER letting your livestock near your water sources
		g. Going to a MEETING about water and health
		h. Joining a women's group that MAKES and SELLS SOAP

“boma” means household; “enchoro” means spring

APPENDIX 9

Household Questionnaire Quality Assurance and Quality Control Methods

The household questionnaire designed by Hilary Barber with Jesse Newton (Appendix 6) in order to survey women who were either partially or fully responsible for providing water in their home. The overall goal was to understand water practices, hygiene, and health in the community. Household locations were geocached and assigned a unique code for mapping and spatial analysis. Drinking water samples were collected from approximately 20 households. An overview of the questionnaire instrument is in the following table.

Table 13 Sectional overview of the household questionnaire

Section	Focus	Details	# questions (sub-questions)
A	Introduction	Screening question; Does home have piped water	2 (2)
B1	Collection practices for households with piped water	For wet and dry seasons: Frequency of piped water service; type of collection container; additional trips to collect water outside home; difficulties; additional water sources used	5 (27)
B2	Collection practices for households without piped water	For wet and dry seasons: Water collection trip details; activities done while at water source; use of animal to help carry; difficulties; water sources used	9 (42)
C	Storage and use of drinking water	Storage container type; separation of drinking water from other water; use of lid; storage location; frequency and type of treatment used; retrieval practices; container cleaning means	4 (14)
D	Family hygiene and sanitation	Family hand-cleaning practices; soap use; family facilities for defecation; disposal practices of children's faeces	4 (5)
E	Family health	Frequency of diarrhoea and perceived health of family members grouped by age and sex	2 (14)
F	Household information	Age and sex of household members; education level of respondent; respondent's personal income in dry and wet seasons; trust and availability of help; perceived barriers to new water developments	5 (26)
PR-A	Preferences for a new water source	Pairwise preference ranking between quantity, proximity, quality, development cost, purchase cost	6 (15)
PR-B	Perceptions of diarrhoea causes	Pairwise preference ranking between actual and supposed causes	8 (28)
PR-C	Easiest diarrhoea-reducing actions to implement	Pairwise preference ranking between eight realistic measures that have proven effective for improving health	8 (28)

The questionnaire was developed based on Levison et al. (2011), the authors' experience, and reviewing other literature on water- and health-related knowledge, attitudes, and practices in RRM communities. The questionnaire was also translated from English to Swahili; there was no translation into Maa as it is an oral and not a written language.

Six community members were hired and trained to administer the survey in three co-located communities in rural Kenya. Training was led by the two student researchers, H. Barber and J. Newton, and assisted by their local field assistant John Legei. The sessions took place in October 2011, spanned three days, and were held in the home of the head of Community 1's water committee. Sessions consisted of teaching, were often interactive, and much time was devoted to using the survey and becoming familiar with its questions. Several topics were covered, including an overview of water, sanitation and health; ethical conduct, consent, and confidentiality; approaching a potential participant; troubleshooting; and the importance of obtaining a representative sample of households in the community. The surveyors also received training in how to use a handheld GPS system and collecting water samples.

Although the McMaster Research Ethics Board granted ethics approval in September 2011, in-country ethics approval was not granted until January 2012. This caused a three month delay between the original training sessions and the questionnaire's administration. Therefore, a one-day review session was held for the surveyors on 19 January 2012. The questionnaire was administered between 25 January and 15 February 2012. The surveyors worked in pairs, with each of the three teams being devoted to a village. The one exception is that team from Community 2 helped survey Community 1, as it was larger. In total 139 surveys were completed (Community 1, n=75; Community 2, n=40; Community 3, n=24).

Data entry and analysis was split between H. Barber and J. Newton. Data was entered into Microsoft® Excel, in database tabular format. An example is found in Table 14. Planning involved coding missing responses as "-99"; assigning a unique question identification number for each possible response; and coding response entries.

Table 14 Database section headings for entering the household questionnaire data

Part	Question	Sub-question	Unique question ID	Response	Survey code	Note
B	4	d	112d	1	E-JJ-25-1	
B	4	w	112w	1	E-JJ-25-1	

Originally 10% of the entries were manually checked against the hardcopy questionnaire. Some discrepancies were found and it was then decided to enter the data in its entirety a second time by a third person. The two sets of entries then underwent an electronic line-by-line comparison in Microsoft® Excel; all discrepancies were resolved by consulting the original questionnaire. In total, for the 139 surveys there were 28,382 unique entries; the first and second sets of data had error ratios of 0.80% and 0.33%, respectively, which is about one error for every 126 and 299 entries, respectively. The resulting data set was then used in this research.

REFERENCE

Levison, M. M., Elliott, S. J., Karanja, D. M., Schuster-Wallace, C. J., and Harrington, D. W. (2011). You cannot prevent a disease; You can only treat diseases when they occur: Knowledge, attitudes and practices to water-health in a rural Kenyan community. *East African Journal of Public Healh*, *8*(2), 103–111.