NEIGHBOURHOOD-SCALE WATER QUALITY RISKS IN RURAL EAST AFRICA

A METHODOLOGY TO INFORM NEIGHBOURHOOD-SCALE WATER QUALITY INTERVENTIONS IN RURAL SUB-SAHARAN AFRICA

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Title: A Methodology to Inform Neighbourhood-Scale Water Quality Interventions in Rural Sub-Saharan Africa

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Abstract

Diarrhoea due to the consumption of unsafe drinking water is a major cause of death worldwide, despite many small and large-scale water, sanitation and hygiene (WASH) intervention programs and policy processes. Many Sub-Saharan African communities have relied on WASH interventions by governmental and non-governmental organizations to reduce the burden of diarrhoeal diseases, however they often fail to be sustainable.

Safe drinking water is achieved by protecting/treating water at all points along the drinking water supply chain (DWSC), from the source to the point-of-use. Gathering data on the sanitary environment and microbiological quality of water along the DWSC can support the design of water quality interventions. In addition, an examination of the knowledge, attitudes and practices (KAP) of local people on WASH topics could support the design of more socioculturally relevant interventions. The purpose of this research was to develop and pilot a simple yet economical and robust method to inform more socioculturally relevant water quality interventions in rural Sub-Saharan Africa, and to test whether variation in the risks existed at the neighbourhood-scale within three neighbourhoods of a single community in rural Kenya.

The results of this study demonstrated that practices, which affect water quality in the DWSC, varied at the neighbourhood-scale. For example, source water quality was poor in the three study neighbourhoods, however the hazards and contaminating practices that posed a risk to water quality varied (i.e., bathing, toileting, laundry). Household water quality was also poor and at risk in all three neighbourhoods, however the practices that represented a risk to household water quality varied (e.g. storage conditions, sanitation practices). Female water collectors were knowledgeable on the causes of diarrhoea, however their preferred approaches toward WASH intervention approaches varied by neighbourhood. The collection and analysis of neighbourhood-scale social and environmental WASH data is therefore recommended for the prioritization and design of appropriate interventions to improve water quality.

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Preface

This thesis has been prepared according to the McMaster University regulations for theses consisting of previously published/prepared material. Chapters 2 and 3 consist of material prepared for publication as two individual journal articles. As such, the material in Chapters 2 and 3 was co-authored. The original contributions made by the thesis author to the material in each of these chapters are outlined below:

Chapter 2

Title: A comprehensive method for assessing neighbourhood-scale water quality risks

Authors: Hilary M. Barber, Sarah E. Dickson, Susan Elliott, and Corinne Schuster-Wallace

Submitted to: *African Geographical Review*

The field program, including water sampling program, household survey, clinic/dispensary outpatient review, was conceived, designed, and conducted by H.M. Barber in consultation with S.E. Dickson and S. Elliott. S.E. Dickson, S. Elliott and C. Schuster-Wallace provided field support and expert advice. The theoretical model of the drinking water supply chain and the associated water quality risk assessment was conceived, designed and conducted by H.M. Barber in consultation with S.E. Dickson. H.M. Barber conducted the interpretation of the results in consultation with S.E. Dickson and S.J. Elliott. The text was written by H.M. Barber and edited by S.E. Dickson.

Chapter 3

Title: A water, sanitation and hygiene status of three neighbourhoods to support local water quality interventions

Authors: Hilary M. Barber, Sarah E. Dickson, Susan Elliott, and Corinne Schuster-Wallace

Submitted to: *Tropical Medicine and International Health*

The field program, including water the sampling program, household survey, and clinic/dispensary outpatient review, was conceived, designed, and conducted by H.M. Barber in consultation of S.E. Dickson and S. Elliott. S.E. Dickson, S. Elliott and C. Schuster-Wallace provided field support and expert advice. The theoretical model of the drinking water supply chain and the associated water quality risk assessment was conceived, designed and conducted by H.M. Barber in consultation with S.E. Dickson. H.M. Barber conducted the interpretation of the results in consultation with S.E. Dickson and S.J. Elliott. The text was written by H.M. Barber and edited by S.E. Dickson.

The material in Chapter 2 will be submitted to *African Geographical Review.* Copyright has therefore not yet been assigned. The material in Chapter 3 will be submitted to *Tropical Medicine and International Health,* therefore copyright has not yet been assigned.

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Chapter 1 Introduction

1.1. Background

1.1.1. Problem scope

Approximately 2.2 million deaths each year are attributed to diseases such as diarrhoea, largely due to a lack of access to safe drinking water, improved sanitation facilities and hygienic practices (Davison et al. 2005; Thompson et al. 2003). As of 2010, the World Health Organization (WHO) estimated that 330 million people in Sub-Saharan Africa lacked access to improved drinking water (e.g. protected springs, boreholes, tube wells, piped-water), while 565 million lacked access to improved sanitation facilities (e.g. protected pit latrines, sewer systems) (World Health Organization/United Nations Children's Fund 2010; Fewtrell et al. 2005). Access to improved drinking water and sanitation facilities in Sub-Saharan Africa remains a challenge, particularly in rural and remote communities, despite many small- and large-scale water, sanitation and hygiene (WASH) intervention programs (e.g., efforts by non-governmental organizations (NGOs)) and policy processes (e.g., the Millennium Development Goals and the WHO's Sanitation and Water for All).

The widespread lack of access to safe drinking water and improved sanitation facilities, together with insufficient hygienic practices, render waterborne and water-washed faecal-oral diseases a significant risk to public health in many communities where these conditions are present (Rosen and Vincent 1999; White et al. 1972). Waterborne diseases are those that are transmitted through the consumption of contaminated water, such as typhoid fever and cholera, while water-washed diseases are those that arise as a result of insufficient water quantity for personal or domestic hygiene (White et al. 1972; Rosen and Vincent 1999). For the purpose of this thesis, waterborne and water-washed diseases will be herein collectively referred to as "water-related diseases". Many communities have historically relied on WASH intervention projects supported by external governmental and NGOs to reduce the health impact of these diseases (Harvey and Reed 2006).

There are two overarching factors to consider when approaching a community WASH intervention. The first is the attributes of the community in which change is being pursued, and the second is the technical feasibility and sustainability of potential interventions. For the purpose of this thesis, community is defined as a population living in a single social organizational structure (Minkler and Wallerstein 2011), and the term 'neighbourhood' will be used to describe the geographically distinct units within the community. Carter et al. (1999) stipulate that community involvement alone in a WASH intervention does not ensure sustainability, while technological interventions without community support often fail to produce the intended health benefits and behavioural changes (Carter et al., 1999). Therefore, if a WASH intervention is to be both effective and sustainable, these two aspects must be pursued together.

1.1.2. Technical water, sanitation and hygiene interventions

WASH interventions can be grouped into five technical categories: water supply, water quality, sanitation or 'hardware', hygiene, and multiple interventions (i.e., water, sanitation, hygiene and/or health education) (Fewtrell et al. 2005). A wide variety of technical intervention approaches exist within these categories, however there is still uncertainty regarding the type of intervention that will ultimately be the most effective at reducing water-related diseases and sustainable in a particular community (Fewtrell et al. 2005; Clasen et al. 2007; Waddington and Snilstveit 2009; Cairncross et al. 2010; Kariuki et al. 2012).

It can be argued that for any WASH intervention to maximize in its potential health benefit, the effort ought to be well informed and based on the community's unique needs and attributes (Carter et al. 1999). For example, water sources such as piped-water and wells can be installed to improve the quality of drinking water sources. However, water quality can deteriorate between the source and point-of-use (i.e. along the drinking water supply chain (DWSC)) by becoming contaminated during collection, transportation and/or storage, depending on how hygienically how it is handled (Trevett et al. 2004; Wright et al. 2004). If unhygienic water handling practices are employed at any point along the DWSC, a source water quality intervention alone will not be sufficient to improve health for all.

The WHO's Water Safety Plans (2005) indicate that safe drinking water is achieved by protecting or treating water at all points along the DWSC, including the water source and the post-supply phases of transportation, distribution, storage, and handling (Davison et al. 2005). Gathering a set of reference data on the sanitary environment and hygienic handling of water along the DWSC to the point-of-use can be key to developing an effective and sustainable water quality intervention. Furthermore, examining the water-related local sociocultural factors like the knowledge, attitudes and practices (KAP) can support the design of locally relevant interventions (Banda et al. 2007).

These social and environmental factors can vary greatly between communities, and even within a community's various geographic neighbourhoods.

1.1.3. Models for community intervention

Along with the technological aspects of any WASH intervention, the appropriateness of models of community participation and behaviour change must also be considered. Two of Rothman's (1995) community development models, 'social planning' and 'locality development', will be discussed with respect to their impact on the participatory and behavioural aspects of WASH interventions.

A 'social planning' intervention model uses an institutionally-driven framework, relying on external experts to plan and implement a defined strategy to change the conditions, typically within a given timeline (Rothman 1995; Boutilier et al. 1999). Community participation is not central to the project, however it may occur to varying degrees depending on the circumstances (Rothman 1995). In contrast, a 'locality development' approach to a WASH intervention would use a community-driven, consensus-building approach for gradual problem resolution. The community itself would scope the issues while strengthening group identity, internal capacity and external relationships throughout the intervention process (Fraser 2005; Minkler and Wallerstein 2011; Boutilier et al. 1999). Technical experts are usually employed as consultants in locality development rather than for program development and implementation.

WASH development initiatives have often followed a social planning model of community intervention, with prescribed funding for technically-focused programming. For example, NGOs have historically employed a project-based approach to construct new community water facilities. The NGO typically departs within a few months or years after 'ownership' of the project had been 'transferred' or shifted to the community (Harvey and Reed 2006). The intervention may be successful at implementing the technology and initially creating enthusiasm for it within the community, however its longer-term sustainability can be more uncertain (Montgomery et al. 2009; Carter et al. 1999; Mehta and Movik 2011; Waddington and Snilstveit 2009).

Social planning-style interventions can fail to support true behaviour change for many reasons, including the advancement of projects that are not socio-culturally relevant, and a lack of sustained funding (internal and external), motivation, capacity development and proficient program surveillance (Esrey et al. 1991; Thompson et al. 2003; Mehta and Movik 2011; Carter et al. 1999; Howard 2002; Harvey and Reed 2006). The unique practices, beliefs, values, norms, experiences and geographies of specific communities are often not integrated into the project approach, and may contribute to its breakdown (Waddington and Snilstveit 2009). These social and environmental factors can vary, even by neighbourhood within a community, and should to be integrated into the intervention to secure the odds of success.

A locality development approach to a WASH intervention may be more effective than social planning at cultivating locally relevant change, due to the inclusive, integrated and empowered nature of the community in which it is being enacted (Harvey and Reed 2006). Locality development is not a guarantee for intervention success, as consensus-building is gradual, the most highly marginalized portions of the community can still be overlooked, and there is an inherent reliance on the service of external partners for support (Bongartz et al. 2010; Rothman 1995). Furthermore, the community at large has to want the change and believe in its value (Carter et al. 1999). The health and wellness benefits of WASH interventions can be slow to materialize, as there are typically numerous, incremental behavioural changes to be made (Carter et al. 1999). Nevertheless, if the community is motivated and willing to act, informed on its options along with their potential benefits and limitations, and has a support network of external governmental and technical partners, it is the belief of this author it is best equipped to translate its conditions into a relevant intervention.

1.2. Research objectives

The purpose of this study was to develop and pilot a robust yet simple and economical baseline data collection methodology to support a community-driven, locality development-based approach to a water quality intervention. The methodology was developed in conjunction with a rural community to collect technical and social WASH data, unique to three different neighbourhoods in a single community. A key objective was to pilot-test the developed methodology in all three neighbourhoods to elucidate the effectiveness of the methodology at this scale. The following research questions were developed to meet this goal:

- What points in the DWSC are at risk of microbiological contamination, and what is the actual microbiological water quality? This question was addressed by conducting source and point-of-use/household sanitary risk inspections, and microbiological water quality analyses in the study community. The risk assessment methodology is presented and evaluated through the theoretical framework of the DWSC for a single neighbourhood in Chapter 2, and compared for three neighbourhoods in Chapter 3.

- What KAP do water collectors and their family members have that may pose a risk to microbiological water quality within the DWSC? This question was addressed through the development and implementation of a questionnaire of household water collectors in the study community. The KAP questionnaire methodology is developed and evaluated through the theoretical framework of a single neighbourhood's DWSC in Chapter 2, and the results are compared for three neighbourhoods in Chapter 3.
- What are the potential and actual effects of the local drinking water quality on community health? This question was addressed through a self-evaluation exercise in the questionnaire that inquired about diarrhoea frequency and general health rating within the family, and through a review of the available local clinic and dispensary outpatient records. The health data were analyzed in reflection of the results of the DWSC water quality risk assessment, and its potential impact on community health. The methodology and the results are presented for a single neighbourhood in Chapter 2, and t compared for the three neighbourhoods in Chapter 3.
- What types of water source and household WASH interventions may be most useful in pursuing in order to secure local water quality? This question was evaluated through the execution of three problem and preference ranking exercises with female water collectors in the study neighbourhoods. The methodology and the results are presented for a single neighbourhood in Chapter 2, and the results compared for the three neighbourhoods in Chapter 3.

The methodology presented in this thesis was developed for use in rural sub-Saharan African communities who identify with the above-described conditions and seek to improve existing or develop novel WASH programming to improve drinking water quality. The results are to be assimilated and returned to the community and its neighbourhoods as a resource to support their WASH initiatives. To the best of the authors' knowledge, this is the first research effort to develop a methodology at the request of a community to systematically review their WASH status and its impact on health prior to their pursuit of a water quality intervention.

1.3. Thesis overview

The thesis herein was prepared according to McMaster University's regulations for theses containing previously prepared material. Chapters 2 and 3 consist of papers prepared for submission in academic journals. Each paper contains its own introduction and methodology sections, however some material may be repeated as the articles are presented as they were prepared for submission. It should be noted, however, that formatting of the headings, text, tables, figures and equations have been edited to reflect the style of this thesis.

Chapter 2 presents the baseline WASH data collection methodology developed to support a community-led water quality intervention by presenting the method, its theoretical basis, and results for a single neighbourhood within the study community. Chapter 3 presents the results of the WASH data collection methodology for three neighbourhoods, highlighting the similarities and differences that can exist even within one community. Chapter 4 presents the overall conclusions and recommendations for this work.

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Chapter 2 A comprehensive method for assessing neighbourhood-scale microbial water quality risks

2.1. Introduction

Approximately 2.2 million deaths each year are attributed to diarrhoeal diseases, largely due to a lack of access to safe drinking water, improved sanitation facilities and hygienic practices (Davison et al. 2005; Thompson et al. 2003). As of 2010, the World Health Organization (WHO) estimated that 330 million people in Sub-Saharan Africa lack access to improved drinking water (e.g. protected springs, boreholes, tube wells, piped-water), while 565 million lacked access to improved sanitation facilities (e.g. protected pit latrines, sewer systems) (World Health Organization/United Nations Children's Fund 2010; Fewtrell et al. 2005). Access to improved facilities in Sub-Saharan Africa remains a challenge, particularly in rural communities, despite many small and large-scale water, sanitation and hygiene (WASH) intervention programs (e.g. efforts by non-governmental organizations) and policy goals (e.g., establishment of the Millennium Development Goals and the WHO's Sanitation and Water for All).

The widespread lack of access to safe drinking water and improved sanitation facilities, along with insufficient hygiene practices, leaves many people at risk of waterborne and water-washed faecal-oral diseases (Rosen and Vincent 1999; White et al., 1972). Waterborne diseases are those that are transmitted through the consumption of contaminated water (e.g. typhoid fever, cholera, gastroenteritis, amoebic dysentery), while water-washed diseases are those that arise due to an insufficient quantity of water for personal or domestic hygiene (e.g. trachoma, skin sepsis, conjunctivitis, yaws are strictly water-washed) (White et al. 1972; Rosen and Vincent 1999). Waterborne diseases can be due to an insufficient water quantity for domestic hygiene, therefore for the purpose of this thesis, waterborne and water-washed diseases will be herein collectively referred to as "water-related diseases" (Rosen and Vincent 1999). Many communities have historically relied on WASH intervention projects supported by external governmental agencies and NGOs to reduce the health impact of these diseases (Harvey and Reed 2006).

There are two overarching factors to consider when approaching a community WASH intervention. The first is the attributes of the community in which change is being pursued, and the second is the technical approach to be harnessed for improving local WASH conditions. For the purpose of this paper, a 'community' is defined as a population living within a single social organizational structure (Minkler and Wallerstein 2011), and the term 'neighbourhood' will be used to describe the geographically distinct units within the community. Carter et al. (1999) stipulate that community involvement alone in a WASH intervention does not ensure sustainability, while technological interventions without community support often fail to produce the intended health benefits and desired behavioural change. For WASH interventions to be sustainable, these two aspects should be considered in tandem.

WASH interventions can be grouped into five technical categories: water supply, water quality, sanitation or 'hardware', hygiene, and multiple interventions (i.e., water, sanitation, hygiene and/or health education) (Fewtrell et al. 2005). A wide variety of technical intervention approaches exist given the five categories, however there is uncertainty regarding the type of intervention that is ultimately most effective at having a long term effect on reducing water-related diseases in a particular community (Fewtrell et al. 2005; Clasen et al. 2007; Waddington and Snilstveit 2009; Cairncross et al. 2010; Kariuki et al. 2012).

It can be argued that to maximize the potential health benefit for any type of WASH intervention, the effort ought to be well informed and based on the community's unique needs and attributes (Carter et al. 1999). For example, water source interventions, such as piped-water networks or wells, can be installed to improve drinking water quality. Water quality can deteriorate between the source and point-of-use, however, by becoming contaminated during collection, transportation and/or storage, depending on how hygienically it is handled (Trevett et al. 2004; Wright et al. 2004). If unhygienic water use practices are employed between the source and the point of consumption in the drinking water supply chain (DWSC), this source water quality intervention alone may not be sufficient to improve overall health.

The WHO's Water Safety Plans (2005) indicate that safe drinking water is achieved by protecting or treating water at all points along the DWSC, including the water source and the post-supply phases of transportation, distribution, storage, and handling (Davison et al. 2005). Gathering data on the sanitary environment and hygienic handling of water along the DWSC (i.e. from the source to the point-of-use) is therefore key to developing a sustainable water quality intervention. Furthermore, examining water-related sociocultural factors, such as the WASH knowledge, attitudes and practices (KAP) of the local community, can further support the design of relevant interventions (Banda et al. 2007). These social and environmental factors can vary greatly between communities, and the authors of this paper hypothesize that this variation can also exist at the neighbourhood-scale within a single community.

Along with the technological aspects of any WASH intervention, the appropriateness of models of community participation and behaviour change must be also considered. Two of Rothman's (1995) community development models will be discussed in reflection of their impact on WASH interventions: 'social planning' and 'locality development'.

A 'social planning' intervention model uses an institutionally-driven framework, relying on external experts to plan and implement a defined strategy to change the conditions in a community, typically within a given timeline (Rothman 1995; Boutilier et al. 1999). Community participation is not central to the project, however it may occur to varying degrees depending on the circumstances (Rothman 1995). In contrast, a 'locality development' approach to a WASH intervention would use a community-driven, consensus-building approach for gradual problem resolution. The community itself would scope the issues, and through this process would also benefit from strengthening group identity, internal capacity and external relationships (Fraser 2005; Minkler and Wallerstein 2011; Boutilier, Cleverly, and Labonte 1999). Technical experts are usually employed as consultants in locality development rather than for program development and implementation.

WASH development initiatives have often followed a social planning model of community intervention, with prescribed funding for technically-focused programming. For example, NGOs have historically employed a project-based approach to construct new community water facilities. The NGO typically departs within a few months or years after 'ownership' of the project had been 'transferred' or shifted to the community (Harvey and Reed 2006). The intervention may be successful at implementing the technology and initially creating enthusiasm for it within the community, however its longer-term sustainability can be more uncertain (Montgomery et al. 2009; Carter et al. 1999; Mehta and Movik 2011; Waddington and Snilstveit 2009).

Social planning-style interventions can fail to support true behaviour change for many reasons, including the advancement of projects that are not socio-culturally relevant, and a lack of sustained funding (internal and external), motivation, capacity development and proficient program surveillance (Esrey et al. 1991; Thompson et al. 2003; Mehta and Movik 2011; Carter et al. 1999; Howard 2002; Harvey and Reed 2006). The unique practices, beliefs, values, norms, experiences and geographies of individual communities are often not integrated into the project approach, and may contribute to its breakdown (Waddington and Snilstveit 2009). These social and environmental factors can vary, even at the neighbourhood-scale within a single community, and therefore need to be integrated into the intervention to increase the probability of success.

A locality development approach to WASH interventions may be a more effective means of cultivating locally relevant change than a social planning approach due to the more inclusive, integrated and empowered nature of the community in which it is being implemented (Harvey and Reed 2006). Locality development is not a guarantee for intervention success, however, as consensus-building is gradual, the most highly marginalized portions of the community can still be overlooked, and there is an inherent reliance on the service of external partners for support (Bongartz et al. 2010; Rothman 1995). Furthermore, the community at large must want the change and believe in its value, because the health and wellness benefits of WASH interventions can be slow to materialize as there are typically numerous, incremental behavioural changes to be made (Carter et al. 1999). Nevertheless, if the community is motivated and willing to act, informed regarding its options together with the potential benefits and limitations, and has a support network of external governmental organizations and technical partners, it is the belief of these authors that the community itself is best equipped to translate its own conditions into a relevant WASH intervention.

The purpose of this study was to develop and pilot a robust yet simple and economical methodology to collect the baseline data required for a community-driven, locality development-based approach to a water quality intervention. The methodology was developed at the request of a rural Kenyan Maasai community with the goal of collecting a set of social and technical data to support their community-driven water quality intervention. The following research questions were developed to meet this goal:

- What points in the DWSC are at risk of microbiological contamination, and what is the actual microbiological water quality?
- What KAP do water collectors and their family members have that may pose a risk to microbiological water quality within the DWSC?

- What are the potential and actual effects of the local drinking water quality on community health?
- What types of water source and household WASH interventions might the community want to pursue in order to improve water quality?

The methodology presented in this paper was developed for use in rural or remote sub-Saharan African communities who identify with the above-described conditions and seek to improve existing, or develop novel, water-quality focused WASH programming. To the best of these authors' knowledge, this is the first research effort to develop a methodology at the request of a community to systematically review their WASH status and its impact on health to inform a community-driven water quality intervention program.

2.2. Theoretical model

The methodology in this study investigates potential and actual pathways of faecal contamination within a local DWSC. Figure 2.1 shows a theoretical model of a DWSC in a rural Sub-Saharan African community. This model was developed based on the theory of the multi-barrier approach to drinking water protection (Davison et al. 2005; World Health Organization 2011), faecal-oral pathogen transmission (e.g., Fawzi and Jones 2010; Fewtrell et al. 2005; Dufour and Bartram 2012), and post-supply drinking water contamination research (e.g., Garrett et al. 2008; Trevett et al. 2005; Trevett et al. 2004).

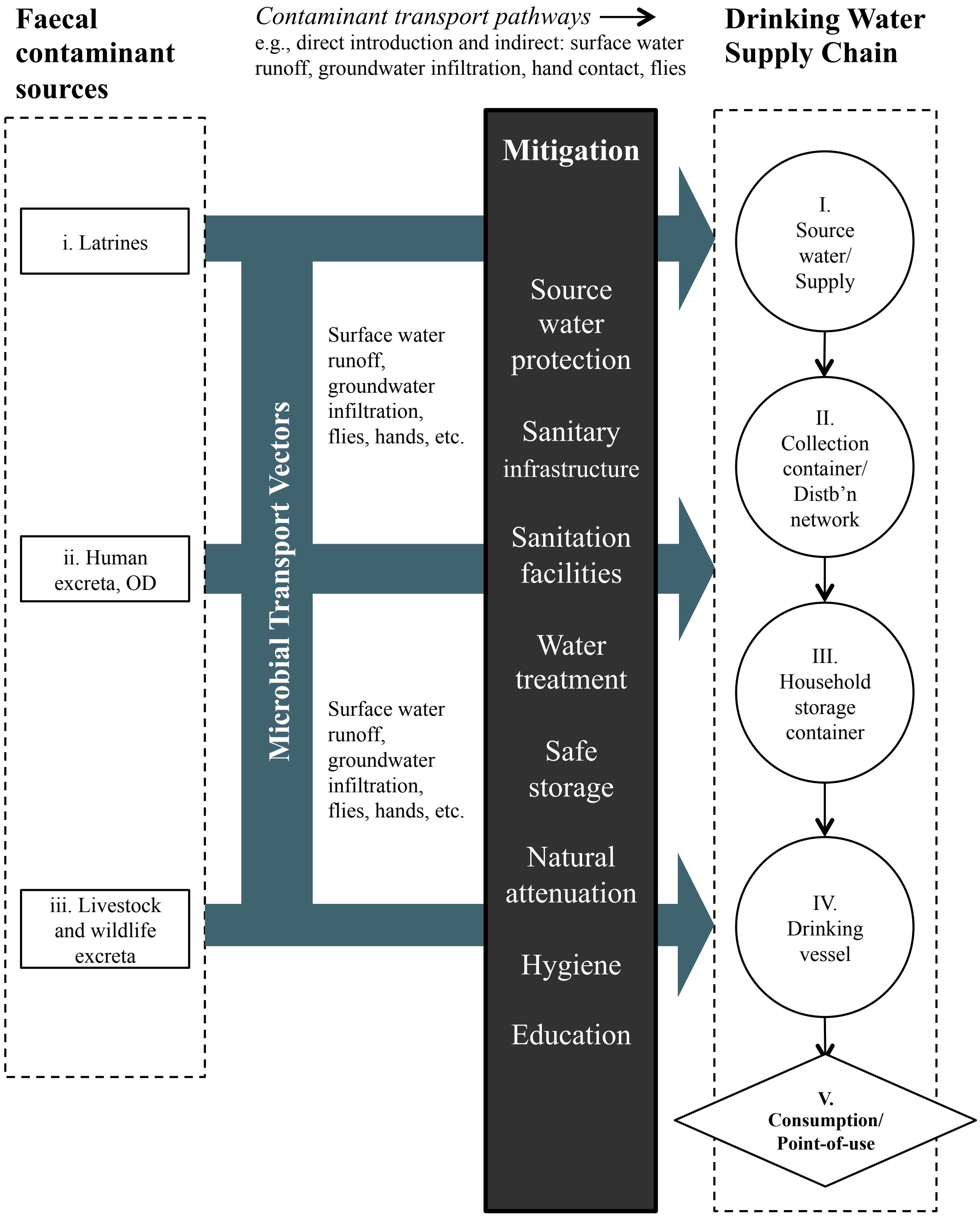

Figure 2.1 Theoretical model of the drinking water supply chain (DWSC), sources of microbiological contamination, and potential water, sanitation and hygienic interventions.

As outlined in Figure 2.1, household water in rural sub-Saharan African communities is often gathered from a source or supply (point I), such as a spring or well, and then transferred into a collection container (point II) for transport home. Once at home, the drinking water may be separated into a storage container (point III), and then transferred to a drinking vessel (point IV) for consumption by the user at the point-of-use (point V).

At any point in DWSC, the water can become contaminated through various faecal sources or vectors (e.g., livestock, human excreta, flies) via potential hydrologic (e.g. surface runoff, groundwater infiltration) or behavioural (e.g., unclean hands) pathways. If faecally contaminated drinking water is consumed (Figure 2.1Figure 2.1, point V), depending on the contamination load and the consumer's immunity, it can lead to a water-related disease with or without symptoms such as diarrhoea (Carr and Strauss 2001; VanDerSlice and Briscoe 1993).

2.3. Methods

2.3.1. Sanitary risk inspections and assessments

Sanitary risk inspections are a rapid drinking water quality assessment tool used to evaluate the likelihood of drinking water contamination based on local sanitary and/or hygienic conditions (United Nations Children's Fund 2008; Howard 2002). The inspections can be conducted at many points within the DWSC to inform where sanitary and hygienic interventions could be employed to improve water quality (Howard 2002). The inspections are completed through a visual assessment and/or asking simple interview questions to complete a checklist, which varies depending on the point in the DWSC point being evaluated (United Nations Children's Fund 2008; Howard et al. 2003). The checklists employed in the current study, presented in Table 2.1, were adapted from Howard (2003).

Table 2.1 Source water and household sanitary risk inspection checklists.

Inspection type		**Question/hazard**		**Magnitude, M_i**
CHECKLIST A: WATER SOURCE INSPECTION	A) General	1	Is the source unprotected?	3
		2	Does spilt (or other) water flood the collection area?	2
		3	Is the fence absent or faulty?	2
		4	Can animals have access within 10 m of the source?	3
		5	Are there any animal faeces uphill of or near the source (within 15 m)?	3
		6	Is there any other waste uphill of or near the source (within 15 m)?	1
	B) Spring, borehole or well	1	Is the masonry protecting the source faulty?	3
		2	Is the backfill area behind the retaining wall eroded?	2
		3	Is there a latrine uphill of the spring/borehole/well?	2
		4	Is there a latrine within 30 m of the spring/borehole/well?	2
		5	Does surface water collect uphill of the spring/borehole/well?	3
		6	Is the diversion ditch above the spring absent or faulty?	3
		7	Is the cover of the well insanitary or absent?	3
	C) Pipes and taps	1	Do any taps leak?	1
		2	Are pipes exposed anywhere?	1
		3	Is the main pipe exposed anywhere?	1
		4	Are human excreta on the ground within 10 m of any tap?	2
		5	Has there been a discontinuity of service within the last 10 days?	2
		6	Are there signs of leaks in the main piped of the neighborhood?	2
		7	Does the community report any pipe breaks within the last week?	2
	D) Gravity-fed systems	1	Does the pipe leak between the source and the storage tank?	2
		2	Is the storage tank cracked, damaged or leaking?	3
		3	Are the vents and covers on the tank damaged or open?	2
	E) Hand pump	1	Would ponding occur within 2 m of the borehole (i.e., bad drainage)?	2
		2	Is the drainage channel cracked, broken or in need of cleaning?	2
		3	Is the concrete pad less than 1 m in radius?	2
		4	Is the concrete pad cracked or damaged?	2
		5	Is the hand pump loose at the point of attachment to the apron?	3
	F) Rainwater harvesting	1	Is rainwater collected in an open container (as opposed to a closed tank)?	3
		2	Are there visible signs of contamination on the roof of the tank, if applicable?	3
		3	Are the collection gutters dirty or blocked?	3
		4	Are the tops or walls of the tank cracked or damaged?	2
		5	Is the water collected directly from the tank (i.e., no tap)?	2
		6	Is there a bucket in use for retrieval and is it in a place where it could become dirty?	3
		7	Is the tap leaking or damaged?	1
		8	Is the concrete floor under the tap defective, dirty or absent?	1
		9	Is there any garbage/dung/other pollution near the tank/collection area?	2
		10	Is the inside of the tank clean?	2
CHECKLIST B: HOUSEHOLD/POST-SUPPLY INSPECTION		F1	Water collection container type	1
		F2	Drinking water separation from other domestic water	4
		F3	Storage location and presence or absence of lids on drinking water storage containers	3
		F4	Frequency and method of drinking water treatment	10
		F5	Hand washing method and water retrieval method (i.e., with utensil, tap, pour)	8
		F6	Storage container cleaning frequency and method	7
		F7	Use of plastic bag between container and lid for leakage prevention during transportation	3
		F8	Interior and exterior container cleanliness appearance	4

Geographic coordinates were collected using handheld global positioning system (GPS) units for all water sources and households at which a sanitary risk inspection was conducted. The household sanitary risk inspections were conducted in tandem with the household questionnaire (Section 2.2.3).

Sanitary risk assessments were conducted with the inspection data to evaluate the microbiological water quality risk at each inspection site. Each question in the risk assessment represents a hazard with an assigned a magnitude, M_i, which was determined based on the relative severity of its potential impact on water quality rated on a scale of one to three for the source water inspections, and a scale of one to 10 for the household inspections (Table 2.1). The site risk score, s_j, was calculated using Equation 2.1:

$$s_j = \sum_{i=1}^{n} p_{ij} M_i \tag{2.1}$$

where s is the risk assessment score for a particular source or household (i.e., "site"), j is the site in question, n is the number of risk factors assessed at that site, p is the probability of hazard i being observed at that site, and M is the relative magnitude assigned to a given risk factor. Normalized risk scores, S_j, were calculated using Equation 2.2:

$$S_j = \frac{s_j}{s_{max}} \tag{2.2}$$

where s_{max} is the maximum risk score for the given site, j. The site assessment scores were standardized and grouped into low (s=0.00-0.33), moderate (s=0.34-0.66), and high (s=0.67-1.00) risk brackets.

The probability that each hazard will cause the deterioration of water quality at the water source level (i.e., Point I of the DWSC) was determined using binary categorical data, with the assigned values being the minimum (hazard not observed) and maximum (hazard observed) probability that the hazard could cause the deterioration of water quality. These probabilities were assigned based on the relationship between each observed hazard and microbiological contamination as reported by Howard et al. (2003).

The probability of water quality deterioration posed by each hazard at the household level (i.e., Point III in the DWSC) was assigned based on the frequency of the practice, where the probability is linearly related to the frequency indicated by the response, as shown in Equation 2.3:

$$p = mv + b \tag{2.3}$$

where m is the slope of the linear relationship, v is the reported frequency of the practice, and b is the intercept or the assigned maximum probability.

For example, as shown in Figure 2.2 and Table 2.2, a question with five response options (never, rarely, sometimes, often and always), Equation 2.3 would assign probabilities of having deteriorated water quality at the point-of-use is illustrated in Figure 2.2 and Table 2.2.

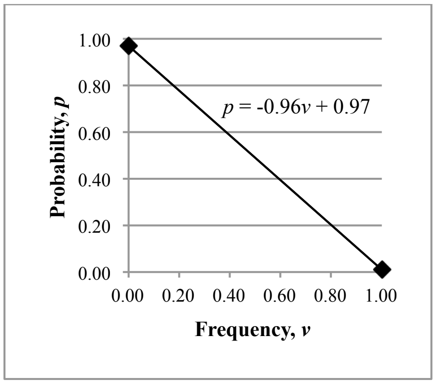

Figure 2.2 Linear relationship between the water treatment frequency and the probability of microbiologically contaminated water at the point-of-use associated with the treatment practice of boiling water.

Table 2.2 Sample sanitary risk inspection scoring table demonstrating the frequency distributions and the associated water quality risk probabilities for water treatment by boiling. The italicized probability values were determined with the using the linear relationship illustrated in Figure 2.2.

Inspection response	Frequency, v	Probability, p	Assigned parameters
Never	0.00	0.97	*v, p*
Rarely	0.20	*0.78*	*v*
Sometimes	0.50	*0.49*	*v*
Often	0.80	*0.20*	*v*
Always	1.00	0.01	*v, p*

The magnitudes of the household assessment hazard questions were weighted using a magnitude scale of 1 to 10 (Table 2.1), and site risk scores calculated using Equation 2.1 and Equation 2.2.

2.3.2. Water quality analyses

The purpose of the water quality analyses was to elucidate the persistence of faecal contamination at DWSC points I and III (Figure 2.1). Two techniques were used to evaluate microbiological water quality: Micrology Laboratory's ECA Check Plus® Easygel® (Easygel®) rapid water quality assessment technology was employed to enumerate four kinds of bacteria, and hydrogen sulphide gas (H_2S) paper test strips were employed to determine the presence or absence of sulphur-reducing bacteria.

Easygel® was employed to quantify total coliforms, *E. coli*, *Salmonella spp*. and *Aeromonas spp*. The water sampling procedure is described in Micrology Laboratories (2011). At the time of water sampling, a 1 mL to 5 mL water sample was injected with a single-use sterile syringe into an Easygel® bottle containing the growth medium (nutrients and a chromogenic substrate), sealed, swirled, and stored for 2 to 8 hours at or below 4°C until the time of plating. The sample was then poured into a pre-prepared petri dish prior to incubation at 35°C for 24 hours for the counting of *E. coli* colonies under ultraviolet light, and 48 hours for counting of *E. coli*, total coliforms, *Salmonella spp*. and *Aeromonas spp.* under ambient light. Two thirds of the water samples were collected and quantified in duplicate, and the remaining third of the water samples were collected and quantified in triplicate. Fields blanks and sample blanks were employed and analysed according to the American Water Works Association's (AWWA) Quality Assurance/Quality Control Method 9020 of 2011.

Water samples were also analysed for the presence or absence of sulphur-reducing bacteria, which are predominantly associated with the intestinal tracts of warm-blooded animals (Sobsey and Pfaender 2002) and are therefore indicators of faecal contamination. The test is a simple, inexpensive means for detecting the presence of H_2S gas-producing faecal bacteria such as *Salmonella spp*., *Staphylococcus spp*. and *Clostridium perfringens* at very low concentrations (Huang et al. 2011; United Nations Children's Fund 2008; Pillai, Mathew, and Ho 2009). It should be noted that this test cannot differentiate between the sulphur-reducing bacteria, nor can it quantify them; it is simply a presence/absence test. The test is conducted by combining a water sample with a strip of treated paper in a sealed test tube for one to three days (Manja et al. 1982). If sulphur-reducing bacteria are present, an insoluble, black iron sulphate precipitate forms in the tube due to the reaction of the sulphide with the iron impregnated in the strip (Allen and Geldreich 1975; Sobsey and Pfaender 2002).

H_2S strip analysis was conducted by injecting a 20 to 25 mL water sample into a tube containing a test strip. The tube was sealed, shaken, and allowed to incubate at room temperature for 72 hours. The samples were evaluated for the presence or absence of a black precipitate. Two thirds of the water samples were collected and quantified in duplicate, and the remaining third of the water samples were collected and quantified in triplicate. Fields blanks and sample blanks were employed and analysed according to the AWWA Quality Assurance Method 9020 of 2011.

Both the Easygel® and H_2S strip methods were chosen due to their low cost, ease of field use, and the fact that the methodologies do not require electricity. Chuang et al. (2011) indicated the Easygel® test in conjunction with the H_2S test-strip method with a 20 mL sample volume was the most accurate method of detecting faecal contamination in water samples, among the various rapid assessment microbiological water quality field tests available. It should be noted here, however, that the field of rapid, low-cost microbiological water quality analysis is developing rapidly, and therefore future researchers employing the water security assessment methodology presented in this paper are advised to perform a literature search to determine if any new, more effective water quality analysis techniques are appropriate.

The Easygel® and H_2S strip test results should be compared to the relevant regulatory standards. It is recommended that the World Health Organization's (2011) *Guidelines for Drinking Water Quality, 4th Edition* be employed in the absence of appropriate regulatory standards. For the test community in this paper, the Kenya Water Services Regulatory Board's (KWRSB) *Drinking Water Quality and Effluent Monitoring Guideline Schedule 5: Microbial limits for drinking water and containerized drinking water* of 2009 *(Guideline)* (Kenya Water Services Regulatory Board 2009) (Table 2.3).

Given that there is no established limit for *Aeromonas spp.* in the KWSRB's 2009 *Guideline* of 2009, the results are not presented in this paper.

The Easygel® and H_2S strip test results are scored using binary categories, with '1' representing a guideline exceedence and '0' representing a non-exceedence for each of the evaluated microbiological criteria. The maximum potential score was four exceedences per sample.

Table 2.3 The Kenya Water Services Regulatory Board's (KWSRB's) *Drinking Water Quality and Effluent Monitoring Guideline, Schedule 5: Microbiological limits for drinking water* of 2009.

Type of microorganism in water	**Drinking water quality**
Coliforms in 250 mL	Shall be absent
E. coli in 250 mL	Shall be absent
Salmonella spp. in 250 mL	Shall be absent
Sulphate-reducing anaerobes in 50 mL (H_2S-producing bacteria)	Shall be absent

2.3.3. Household questionnaire

A household questionnaire was used to collect measurements of water collector KAP on matters of WASH and personal health. Topics of interest included water collection practices, household water handling, family hygiene and sanitation, family diarrhoea frequency and health status, knowledge of the causes of diarrhoea, and attitudes toward various WASH intervention strategies (Levison et al. 2011) The questionnaire was reviewed by key informants to ensure that the questions prevented the participants from providing socially desirable responses to sensitive questions, such as hand washing practices.

Questionnaire interviewers were fluent in English, Swahili and Maasai. The questionnaire was developed in English, and then translated to Swahili by a key informant. It was reported that some questionnaire participants might only be fluent in Maasai, which is an oral language with no written form. During a two-day training session, interviewers reviewed the questionnaire to ensure the Swahili and English versions of the questionnaire were consistent, and reviewed Maasai translations for consistency. The interviewers were also trained on techniques and were provided with information on the topics covered in the questionnaire.

Interviewers randomly selected 75 households within the neighbourhood to voluntarily participate in the questionnaire while ensuring broad geographic coverage, and they arrived without preannouncement. Approximately 10% of adult females in the study neighbourhood were surveyed. The coded questionnaire results were double entered into a database for quality assurance/quality control purposes.

Questionnaire participants also completed a family health self-evaluation by reporting the frequency of diarrhoea and the general health status of all family members. The self-evaluation was completed using a five-level Likert scale arranged by age cohort, including young children (0 to 5 years of age), children (6 to 12 years), young adult females (13 to 17 years), young adult males (13 to 17 years), adult females (over 18 years), adult males (over 18 years), and elders.

Problem- and preference-ranking exercises were also conducted in conjunction with the questionnaire to evaluate explicit knowledge on causes of diarrhoea (Exercise A), attitudes toward implementing various WASH interventions to potentially reduce diarrhoea (Exercise B), and water source development preferences (Exercise C). The methodology for the ranking exercise was adapted from (Keller 2012), and was conducted to support a later visioning process for neighbourhood WASH initiatives. The exercises allowed participants to rank priorities or potential solutions to the hypothetical WASH situations using pairwise ranking.

The method employed to conduct the problem- and preference-ranking exercises can be illustrated using an example from Exercise A. In Exercise A, participants were asked why people become ill with ‘watery stomach’, or diarrhoea. Responses to the question were printed and illustrated individually on eight cue cards. The interviewer then showed the participant pairings of the cards, asking the participant to indicate which of the two ‘responses’, in their opinion, was more likely to cause diarrhoea. The interviewer would systematically show pairs of cards until all possible pairings were presented to the participant. The preferred response from each pairing was recorded. The interviewers applied the same systematic pairwise cue card technique used in Exercise A to conduct Exercises B and C. The exercises were tallied by counting the number of times a participant chose each response; larger counts of a given response indicates that the participant believes it is more likely to be true. Based on the results of the counts, the responses were ranked 1st to 8th, representing the participant’s hierarchical set of beliefs regarding the question. The questionnaire participant results for Exercises A, B and C were subsequently integrated into neighbourhood-wide ranks, and the response frequencies, f_i, for each question were calculated using Equation 2.4:

$$f_i = \frac{q_i}{\sum_{i=1}^{n} q_i} \tag{2.4}$$

where q_i is the number of times question i was preferred, and n is the number of total responses to all questions in the given Exercise.

A complete copy of the questionnaire is presented in Appendix A.

2.3.4. Dispensary outpatient records

Monthly outpatient reports were obtained from the local dispensary for review as a proxy for the reported burden of actual diarrhoeal disease in the study neighbourhood. The reports provided the count and description of outpatient curative visits by ailment type, including a category for water-related diseases and diarrhoea. Monthly records were available from November 2011 to December 2011 and March 2012 to October 2012. The dispensary was closed between January and February 2012. Water-related disease rates, w were calculated using the expression in Equation 2.5:

$$w = \frac{\sum_{i=1}^{n} a_i}{\sum_{i=1}^{n} A_i} \times 100\% \tag{2.5}$$

where n is the number of cases reported at the dispensary, and a_i is the number of reported water-related disease cases, A_i is the number of all outpatient cases of at the dispensary, i, during the same time period.

2.3.5. Study community and neighbourhood

The Il Ngwesi Group Ranch (IGR) is an 8,675 hectare area of land in the eastern portion of the Laikipia District in Rift Valley Province, Kenya, communally owned by the Il Ngwesi Maasai (Ngwesi Group Ranch 2010). IGR land is dedicated to tourism and conservation, with the communal landowners living in eight neighbourhoods on or surrounding the ranch land. The area is classified as semi-arid grassland with soils of volcanic origin (Jaetzold and Schmidt 1983), and the annual temperature range is 20°C to 28°C (Huho et al. 2012).

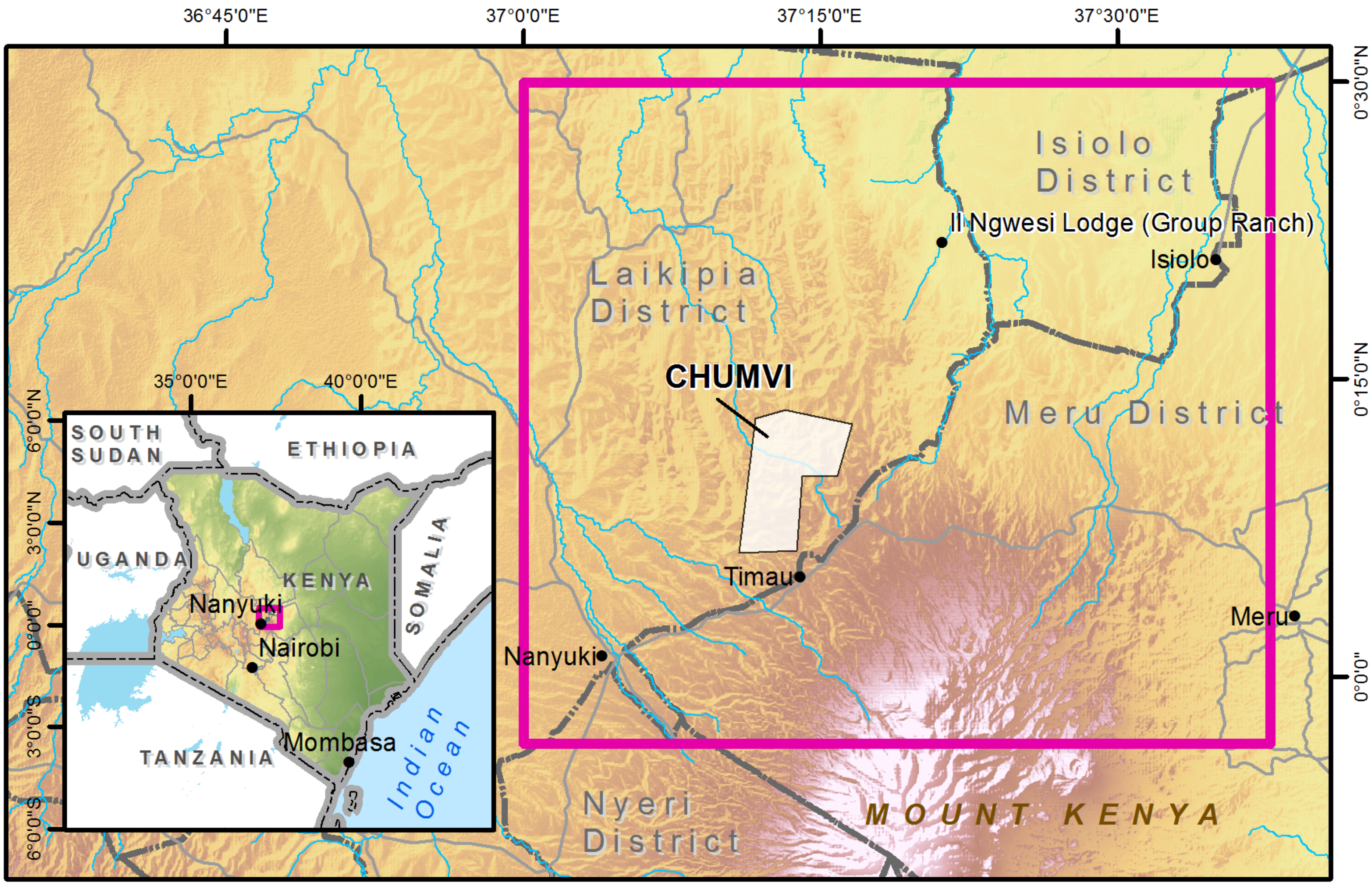

Figure 2.3 Inset: Map of study area within Kenya, East Africa. Main: Study neighbourhood of Chumvi within the Laikipia District.

The Maasai population is traditionally semi-nomadic, practicing a pastoralist, polygamous family lifestyle. The male head of household customarily works as a herdsman, raising and grazing livestock including goats, sheep and cattle as a livelihood, while his wife or wives are responsible for child rearing and household duties including water collection. Although Maasai people remain dependent on this pastoralist existence, they have settled geographically while undergoing diversification away from natural resource-based livelihoods (Homewood et al. 2009). The data collection methodology presented in this study was adapted so that it can be used within the eight neighbourhoods of the IGR.

The data collection methodology presented in this paper was piloted in the IGR neighbourhood of Chumvi during the dry seasons of September 2011 to early November 2011, and February 2012. Chumvi is located approximately 20 kilometers southwest of the IGR, and covers about 7,600 hectares of land. The topography in the study neighbourhood is diverse, ranging from gradual slopes in the south to relatively hilly in the north. The study area receives an average of 580 mm of rain annually, with distinct dry and wet seasons. The longer wet season typically occurs from March to May annually, while the shorter wet season begins in mid-November and lasts for approximately one month (Lolmarik Ranch 2005).

Chumvi has a population of approximately 2,000 people, with an average of 7.7 people per household. The community is not serviced by electricity, and its access roads are not paved. The Chumvi Cottage Hospital, a subsidiary of the Nanyuki Cottage Hospital, is a private dispensary that provides medical care. The neighbourhood has one publicly funded primary school, and at the time of fieldwork, one privately funded girl’s secondary school was under construction.

Women and girls are responsible for the provisioning of domestic drinking water in the study community. The neighbourhood is partially serviced by a pipe network that conveys water directly from two springs, located 20 km to the southwest, to some homes and at least two public taps. It should be noted that the source water springs for the piped-water network will be herein referred to as ‘Headwater Spring I’ and ‘Headwater Spring II’, and the accessible downgradient piped-water network locations will be referred to as ‘piped-water network points’. Headwater Spring I is located approximately 130 metres (m) to the west of Headwater Spring II, and they are hydraulically connected by a buried pipe. Neighbourhood members who are not serviced by the piped-water network collect their water from open springs and a single drilled well equipped with a hand pump. Some households also harvest rainwater for domestic use during the wet seasons.

2.4. Results

The results and discussion of this study are first presented using the framework of the DWSC (Figure 2.1), presenting risks from the source to the point-of-use. The risk assessment is then followed by an evaluation of the effect(s) of water quality on family health and a presentation of the results of the three Problem and Preference Ranking exercises.

2.4.1. Source water use and practices

The three main water source types used by questionnaire participants were open springs (57%), the piped-water network (42%), and a single well with a hand pump (4%). Forty-four percent of participants supplemented their water supply with rainwater during the wet seasons.

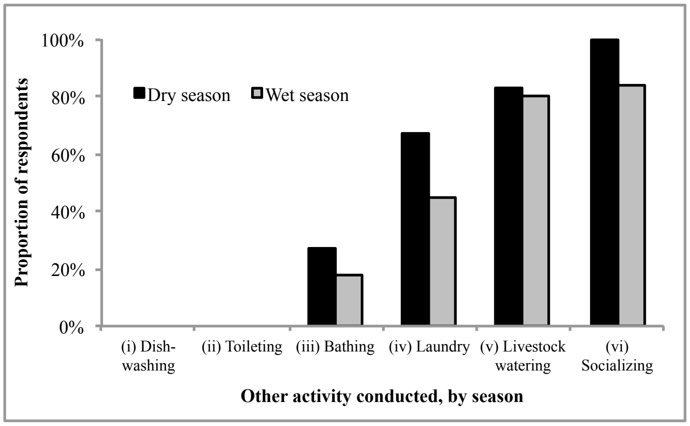

Figure 2.4 Proportion of questionnaire participants who reported practicing other activities at the source water during the dry and wet seasons. Other activities included: (i) dishwashing; (ii) toileting; (iii) bathing; (iv) laundry; (v) livestock watering; and, (vi) socializing.

Questionnaire participants indicated that all of these other practices are conducted more frequently during the dry season than during the wet season (Figure 2.4). Dishwashing and toileting at the water sources were not reported during either season in the study neighbourhood. The practices of bathing, laundry, and livestock watering at a water source pose a potential risk of microbiological contamination at point I of the DWSC (Figure 2.1). Livestock watering poses a greater risk of contamination than either bathing or laundry due to the high reported frequency of the practice and the potential for direct introduction of faecal matter into unprotected water sources, such as open springs.

2.4.2. Source water sanitary risk inspections and assessments

Twenty-one source water sanitary risk inspections were completed in the study neighbourhood during the dry season of September 2011 through early November 2011. Fourteen percent of the sources inspected were assessed to be at low risk of water quality deterioration due to poor sanitary conditions, 33% at moderate risk, and 52% at high risk. In general, 71% of the sites inspected had faeces near or within 15 m upgradient of the source, including open springs, piped-water network's public access points (e.g. tanks, taps) and the hand pump. The results of the source water risk assessments by source type are presented in Figure 2.5.

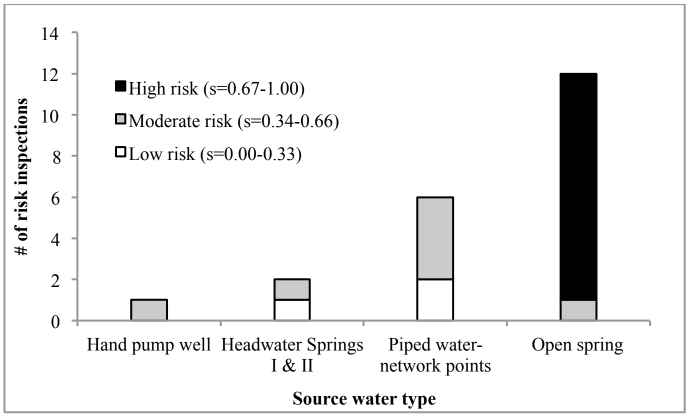

Figure 2.5 Source water sanitary risk assessment scores by source type in the study neighbourhood.

Open springs in the study neighbourhood were the source type with the highest risk of contamination due to their lacking sanitary conditions (Figure 2.5). One of the 12 open springs inspected was assessed to be at moderate risk (s = 0.64), while the remaining 11 were assessed at high risk (s = 0.69-0.86). Open springs were typically void of protective infrastructure such as masonry and diversion ditches, and 91% were observed to have faecal matter present adjacent to the source. It should be noted that efforts had been made at many of the open spring sites to build protective fences using plant matter to inhibit livestock use, however they were observed to be broken and/or ineffective.

The hand-pump well inspected was assessed to be at moderate risk of contamination (s = 0.52). Headwater Springs I and II were assessed to be at low risk (s = 0.26) and moderate risk (s = 0.34), respectively. Both of the Headwater Springs were observed to have been excavated approximately 15 m below grade, were inaccessible to livestock, and had protective netting strung above the surface to prevent infilling with detritus. Two of the six piped-water network public access points inspected (i.e., one gravity-fed holding tank and one distribution tank with tap) were assessed to be at low risk (s = 0.00-0.33), while the other four inspection points within the system (i.e., two gravity-fed holding tanks and two distribution tanks with tap) were assessed to be at moderate risk (s = 0.34-0.62). The inherently protective infrastructure associated with the hand-pumped well and the piped water network points (e.g., facilities housed within concrete infrastructure, metal taps and pouring spouts) resulted in the improved (i.e., low and moderate) risk scores compared to the open springs.

2.4.3. Source water microbiological quality analysis

Twenty-four water samples were collected for microbiological water quality analysis using Easygel® and H_2S test strips from 19 water sources. All of the source water samples were analysed for exceedences of total coliforms, *E. coli, Salmonella spp.,* and H_2S-producing bacteria, and compared to the KWSRB's *Guideline* of 2009 (Table 2.3).

The hand-pump well and eight open springs were sampled and analysed. Headwater Springs I and II of the piped-water network, and eight other accessible points within its distribution system, were also sampled and analysed, including one sample that had reportedly undergone chemical treatment by the user. The hand-pump well was sampled twice during one sampling event. Two open springs and were sampled twice over two sampling events, and Headwater Spring II was sampled three times during two sampling events.

The results of the water quality analyses are presented in Figure 2.6, and demonstrate that every source water sample analyzed exceeded at least one of the four microbiological criteria evaluated.

At the hand-pump well, one sample was collected using a funnel present at the source for communal use, and a second sample was collected without the funnel. Both samples from the hand-pump well exceeded for one microbiological criterion (total coliforms). The first sampling event at Headwater Spring I exceeded for three microbiological criteria (total coliforms, *E. coli,* H_2S-producing bacteria), while Headwater Spring II exceeded for all four microbiological criteria. Four weeks later, Headwater Spring II was sampled twice more, with one sample exceeding for three microbiological criteria (total coliforms, *Salmonella spp.*, and H_2S-producing bacteria), and the other exceeding for all four microbiological criteria. The chemically treated water sample from the piped-water network exceeded for both total coliforms and *Salmonella spp.* Of the seven other samples collected from public access points within the piped-water network, five exceeded for *E. coli,* while all seven exceeded for total coliforms, *Salmonella spp.*, and H_2S-producing bacteria.

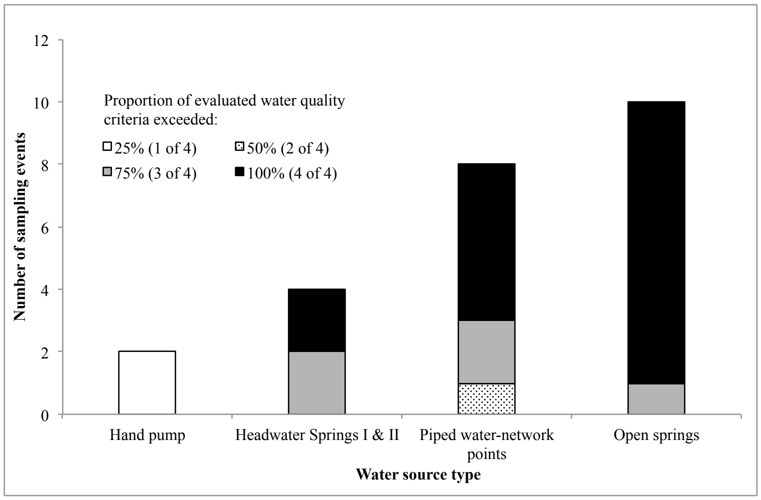

Figure 2.6 Proportion of water quality indicator exceedences for each sampling event, displayed by water source type.

Two open spring water sources were sampled on two separate occasions four weeks apart, and the other nine open springs were sampled once. One of the open springs sampled twice exceeded three microbiological criteria on the first sampling event (total coliforms, *Salmonella spp.,* H_2S-producing bacteria), and exceeded all four microbiological criteria on the second sampling event. All other open spring samples collected exceeded all four microbiological contaminants.

2.4.4. Household sanitation and hygiene

Toileting practices of the families and their young children, as reported by the questionnaire participants, are presented in Figure 2.7.

Respondents reported various toileting practices, with these practices varying by age group. While 38% of households surveyed reported the use of covered pit latrines for family excreta management (Figure 2.7a), the remaining participants reported practicing open defecation in various locations including vegetation (27%), open pits (28%), and/or water sources (7%). Collectively, 38% of the respondents in the study neighbourhood reported toileting using an improved sanitation facility, while 62% reported open defecation.

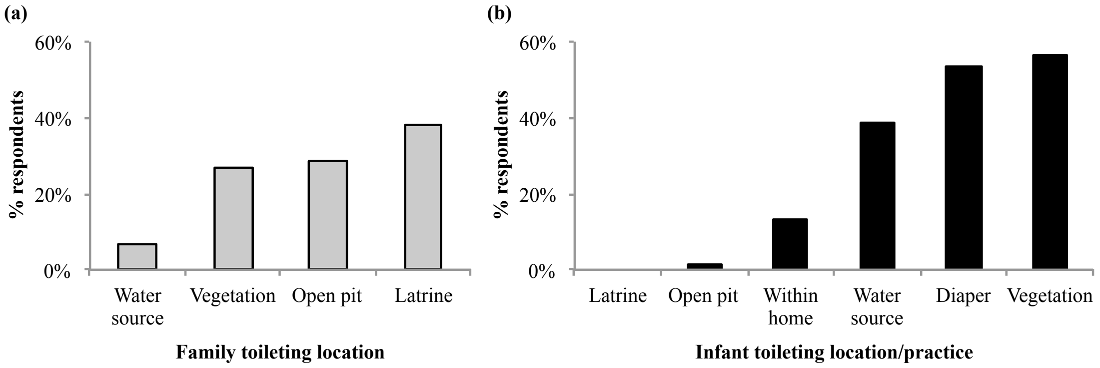

Figure 2.7 Toileting locations of (a), the family and (b), young children as reported questionnaire respondents.

It should be noted that 49% of respondents provided multiple responses on the topic of toileting practices of young children. Young children, three years of age and under, practiced open defecation (67%) in locations such as vegetation (57%), water sources (39%), in the household compound (13%), and in open pits (1%) (Figure 2.7b). Additionally, 54% of participants reported using diapers for their young children's' toileting, and 21%, 13%, and 10% reported their young children toileted exclusively in vegetation, water sources and diapers, respectively.

Latrines were not observed at or within 30 m of any of the water sources, therefore they are not anticipated to represent a likely cause of microbiological source water quality deterioration. Open defecation at water sources, in contrast, represents a direct pathway for faecal contamination and water quality deterioration of source water, or point I of the DWSC (Figure 2.1). The risk of open defecation at the water sources causing faecal contamination is particularly high at the open spring sources in the neighbourhood.

The presence of faecal matter from open defecation (i.e., open pits, vegetation), in conjunction with surface water runoff and/or infiltration, also represents a potential pathway of source water contamination. As a result, open defecation represents a high risk of water quality deterioration at point I of the DWSC (Figure 2.1), particularly at the open spring water sources, and to a lesser extent, the hand pump.

Furthermore, the presence of faecal matter within the household from toileting by young children increases the risk of family exposure to excreta. Hand contact with faecal matter represents an indirect risk to household water quality (Figure 2.1, DWSC points II to V), particularly in households where hand washing with soap is not practiced regularly.

The majority of questionnaire participants indicated that family members most often washed their hands using soap and water (81%), with the remaining participants reporting hand washing by rinsing with water (15%) or wiping with a cloth (4%). Eleven percent of participants reported washing hands using multiple methods. Participants who reported hand washing by rinsing or wiping are at increased risk water quality deterioration at DWSC points II, III, and IV (Figure 2.1).

2.4.5. Household sanitary risk inspections and assessments

Seventy-two household sanitary risk inspections were completed in the study neighbourhood using the questions outlined in Table 2.1. The results of the assessments indicated that 10% of the inspected household water supplies were at low risk, 70% were at moderate risk, and 21% were at high risk of water quality deterioration due to the sanitary and hygienic conditions. Elevated risk scores were typically attributed to infrequent water container cleaning and/or the use of ineffective container cleaning methods (e.g. sand and water, water only), the use of a utensil for water retrieval in conjunction with unhygienic hand washing practices (e.g. rinsing with water), and a lack of water treatment prior to consumption.

Given that the majority of household supplies inspected were assessed to be at moderate or high risk of water quality deterioration, the handling, treatment and storage of drinking water at home represents a water quality risk. The results of the household sanitary inspections demonstrate a risk of water quality deterioration between DWSC points II and V (Figure 2.1).

2.4.6. Household microbiological water quality analyses

Fourteen household water samples were collected and analysed for microbiological water quality analysis using Easygel® and H_2S-strip tests. Eleven of the samples were analysed for *Salmonella spp.* and total coliforms (two microbiological criteria), one sample was analysed for *E. coli*, *Salmonella spp.,* and total coliforms (three microbiological criteria), and three samples were analysed for *E. coli*, *Salmonella spp.*, H_2S-producing bacteria, and total coliforms (four microbiological criteria). The varying numbers of analyses were conducted due to the limited availability of laboratory services at the time of sampling. Odds ratio analysis indicated that results were comparable to the source water samples despite the varying number of microbiological criteria analysed (OR = 1.05, lower bound = 0.82 and upper bound = 1.23).

The water quality analysis indicated that two samples exceeded for 50% of evaluated microbiological criteria, one sample exceeded for 75% of the evaluated microbiological criteria, and 12 samples exceeded for 100% of evaluated microbiological criteria when compared to the KWSRB's 2009 *Guideline* (Table 2.3).

The results of the analysis demonstrate that water quality remains poor at the household level to the point of consumption (i.e. points II and V of the DWSC, in Figure 2.1Figure 2.1), given that all samples exceeded for at least one evaluated criterion in comparison with the KWSRB's 2009 *Guideline*. Should it not be effectively treated prior to consumption, the poor water quality at the point of use represents a potential health concern to the inhabitants of the study neighbourhood.

2.4.7. Household drinking water treatment

Water treatment represents the final means of water quality improvement prior to consumption at the point-of-use, or point V in the DWSC (Figure 2.1). Questionnaire participants indicated that drinking water treatment is an infrequent practice in the study neighbourhood, with 80% reporting that they 'never' treated their water prior to consumption. Of those who 'sometimes' (11%), 'often' (3%), or 'always' (7%) treated their drinking water, 80% reported treatment by boiling water, 13% reported treatment by decanting, and 3% reported treatment by chemical product.

2.4.8. Family health self-evaluation

The results of the family diarrhoea frequency and health evaluation are presented in Figure 2.8.

The results of the diarrhoea evaluation indicated that diarrhoea frequency generally decreased with increasing age within the study neighbourhood, with the exception of the elders cohort, who experience a relatively high incidence of diarrhoea. According to the questionnaire participants, adult females and adult males were the least frequently afflicted with diarrhoea of all of the evaluated cohorts. Young children (0 to 5 years) were reportedly afflicted with diarrhoea the most frequently, with 84% of this cohort reportedly 'sometimes' and 'often' suffering from diarrhoea. Based on the frequency distributions in Figure 2.8a, at least 20% of all young children, children, and elders were 'often' living with diarrhoea. Young adult females also experienced diarrhoea more often than their male peers.

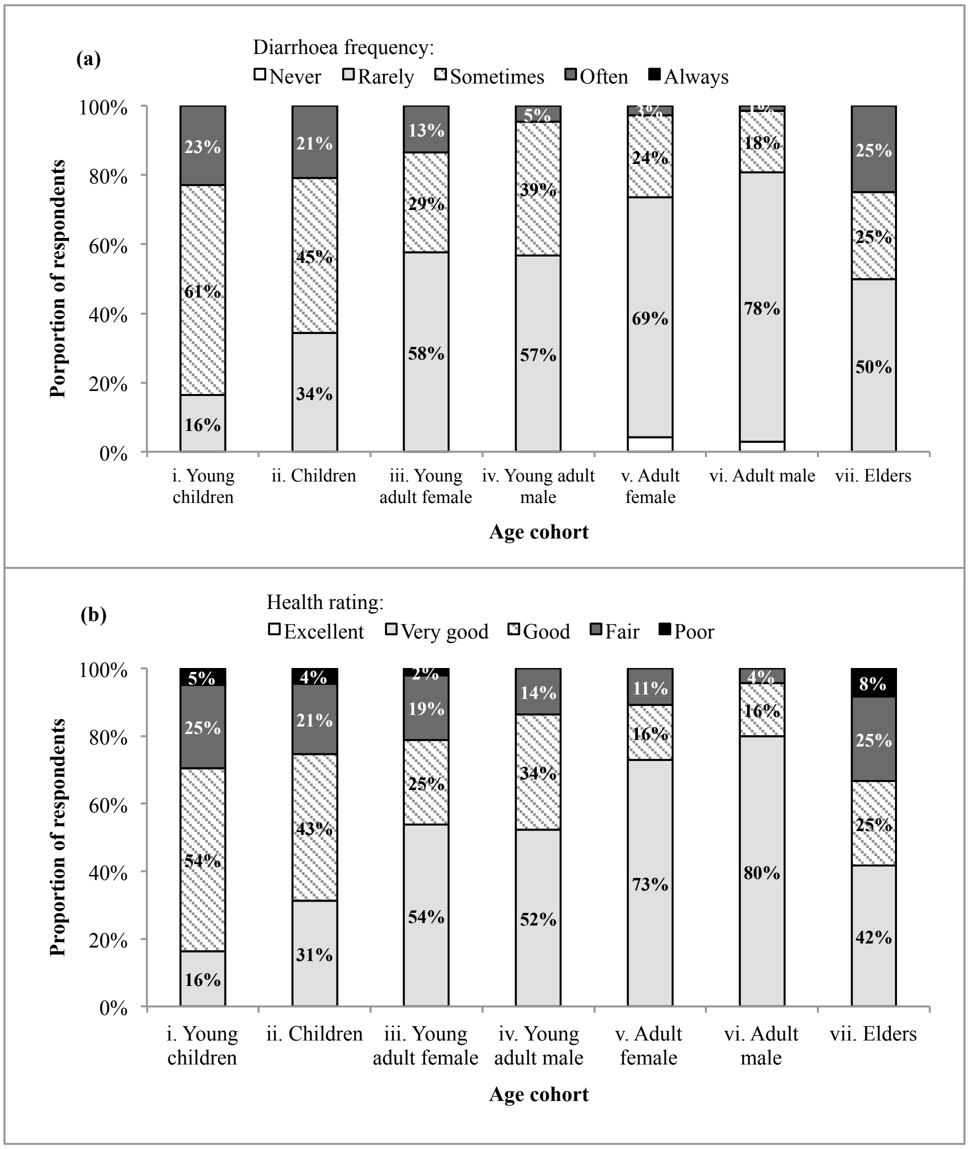

Figure 2.8 Results of the self-reported health evaluation for questions on (a) diarrhoea frequency, and (b) general health rating of family members, arranged by age cohort.

The results of the general health rating exercise indicated that health status also generally improved with increasing age in the study neighbourhood, with the exception of the ‘elders’ cohort (Figure 2.8b).

According to the questionnaire participants, adult females and males were reported to have the most improved health within the study neighbourhood, with 73% and 80% living in ‘very good’ health, respectively. At least 25% of young children, children, and elders were reported by questionnaire participants to be living in ‘fair’ and ‘poor’ health. Young adult females were reportedly living in poorer general health than their male peers.

2.4.9. Outpatient dispensary records

The results of the curative outpatient records review from the dispensary in the study neighbourhood are presented in Figure 2.9.

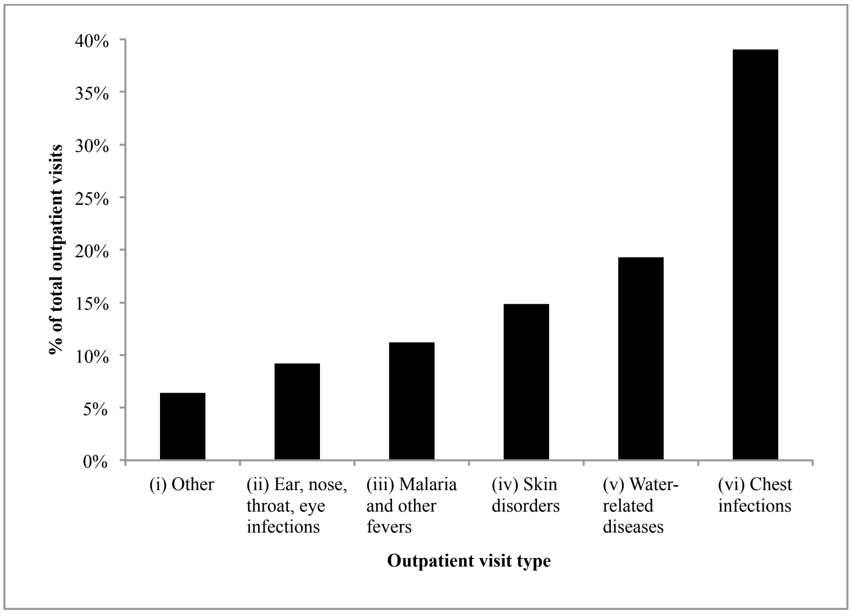

Figure 2.9 Rate of outpatient visits at the study neighbourhood's dispensary, where: (i) other visits included the sum of visits (in order of decreasing frequency) for sexually transmitted infections, arthritis, falls and injuries, "other" visits, urinary tract infections, ascites and gastric ulcers; (iv) "skin disorders" included visits for general skin disorders, varicella and ringworm; and, (v) water-related diseases.

The outpatient record review indicated that water-related diseases, including diarrhoea and vomiting, amoebiasis, intestinal worms, typhoid fever and lower abdominal pain, were the second most common visit type at the dispensary after chest infections. Water-related diseases accounted for 19% of all outpatient visits during the reviewed period. These outpatient record results indicate that water-related diseases are relatively frequently in the study neighbourhood, potentially providing evidence of the effect of poor water quality in the study neighbourhood.

2.4.10. Problem and preference ranking exercises

The results of problem and preference ranking Exercises A, B and C are presented in Table 2.4.

Table 2.4 Results of problem and preference ranking exercises A, B and C.

Response Rank	**Response**	**Response frequency, *f***
Exercise A: Why do people get watery stomach?		
1st	Bad or dirty water	0.20
2nd	Dirty hands	0.19
3rd	Germs and parasites	0.18
4th	Bad or dirty food	0.16
5th	Bad air	0.11
6th	Dirty house	0.09
7th	It happens to everyone	0.07
8th	Spiritual reasons	0.01
Exercise B: The following activities can reduce watery stomach. What would be easier to do in your family to prevent watery stomach?		
1st	ALWAYS preparing your drinking water	0.186
2nd	Going to a MEETING about water and health	0.134
3rd	ALWAYS using SOAP for dishwashing	0.133
3rd	NEVER letting your livestock near your water sources	0.133
5th	Washing WATER CONTAINERS with SOAP OFTEN	0.117
6th	ALL family members ALWAYS wash hands with SOAP	0.113
7th	Collecting water that is CLEANER but FURTHER FROM HOME	0.093
8th	Joining a women's group that MAKES and SELLS SOAP	0.090
Exercise C: What would you prefer should a new water source be developed?		
1st	Gives CLEAN WATER	0.27
2nd	LITTLE or NO PREPARATION needed before drinking	0.19
2nd	Is CLOSE TO HOME	0.19
4th	LOW COST to DEVELOP water source	0.17
5th	Gives LOTS OF WATER	0.12
6th	LOW COST to BUY WATER	0.07

The results of Exercise A indicated that female water collectors in the study neighbourhood are relatively knowledgeable regarding the causes of diarrhoea (Table 2.4). Participants chose 'bad or dirty water' ($f = 0.20$), 'dirty hands' ($f = 0.19$), and 'germs and parasites' ($f = 0.18$) as the top three causes of diarrhoea from the eight possible responses. Questionnaire participants chose 'dirty house', 'it happens to everyone' and 'spiritual reasons' as the three least likely causes of diarrhoea. It should be noted, however, that the variation in response rate between the options ranked 1st to 3rd is relatively small (i.e., 2%), indicating that the participants felt the two responses are almost equally responsible for causing diarrhoea.

Exercise B indicated that the participants in the study neighbourhood had felt that 'always preparing drinking water' (i.e., drinking water treatment) was the most feasible practice to implement in their households to reduce the diarrhoea, followed by 'going to a meeting about water and health' (Table 2.4). The high frequency variation (5.2%) between the 1st and 2nd ranks indicates that the participants felt strongly about their 1st ranked response of drinking water treatment over the other responses. The participants had the attitude that 'collecting water that is cleaner but further from home' ($f = 0.093$) and 'joining a women's group that makes and sells soap' ($f = 0.090$) were the least feasible practices to reduce diarrhoea at home.

Questionnaire participants indicated in Exercise C that water source development within the neighbourhood should prioritize the provisioning of 'clean water' ($f = 0.27$) (Table 2.4). Questionnaire participants also indicated that it was important to develop a source that provides water requiring 'little to no preparation before drinking' ($f = 0.19$) and 'is close to home' ($f = 0.19$). Sources that 'give lots of water' ($f = 0.12$) and had a 'low water cost to purchase water' ($f = 0.07$) were the least important aspects of future water source development.

2.5. Discussion and conclusions

This research method was developed to provide data to support future water quality interventions in the study neighbourhood. To the best of the authors' knowledge, this is the first paper to develop a methodology to systematically review a neighbourhood's WASH status and its impact on health to support the design of more culturally relevant water quality intervention. While the results of this research are meant to support technical and social aspects of future water quality intervention efforts, the community itself has the ability to decide the most appropriate measures to promote the behaviour change needed to improve water quality, and how to foster the necessary behaviour necessary, based on these results.

The field component of this multidisciplinary method incorporated sanitary risk inspections, water quality sampling, a review of the local dispensary outpatient records, and a questionnaire with female water collectors on their KAP of WASH topics. These field data informed a water quality risk assessment using the theoretical model of the DWSC, and were used to assess the potential impact of water quality on public health. Together, this information can be synthesized to vision potential pathways to pursue an integrated WASH intervention to improve water quality, and ultimately, community health.

The results of this study indicated that the lack of excreta management throughout the neighbourhood (i.e. at the water sources, in the general environment, and at home), the relatively low availability and use of soap and water for personal and domestic hygiene, and nearly ubiquitous consumption raw water represent the main challenges to water quality in the study neighbourhood.

Questionnaire participants indicated that certain other activities, including bathing, laundry, livestock watering, toileting and socializing, are conducted at the source water more frequently during the dry season than the wet season. This is likely because those who practice rainwater harvesting (44%) for domestic water provisioning have water at home for hygienic purposes during the wet season, and the weather conditions are not conducive to being outdoors for extended periods of time. The source water practices of bathing, laundry, toileting and livestock watering represented risks to source water quality (i.e., Figure 2.1, DWSC point I), particularly at the open spring sources in the study neighbourhood. Wastewater from laundry has a relatively low faecal load, with the exception of the washing of faecally soiled clothing (i.e. diapers) (Ottoson and Stenstrom 2003), and therefore it is not anticipated to represent a significant contamination risk relative to some of the other activities conducted at the water sources. Bathing can be of concern because it represents a direct means of exposure to microbially contaminated water to the bather (Zwane 2006). It should be noted, however, that there is a relationship between water service level, water availability, and the location where hygienic practices occur (i.e., at the source or at home). Users with low or basic water service levels (5 to 20 litres of water per person per day) typically cannot conduct hygienic practices such as laundry and bathing unless they are done at the water source, posing a health risk for water-washed diseases (Howard and Bartram 2003; White et al. 1972). Should household water service levels improve in future, the water collectors may practices these activities less frequently at the source during the dry season as well.

Seventy-one percent of water sources, including 91% of open springs, were observed during the sanitary risk inspections to have faecal matter near or within 15 m upgradient. It should be noted that the questionnaire participants did not report using water sources for personal toileting purposes (Figure 2.4), yet 7% indicated that source water was used as a family toileting location (Figure 2.7Figure 2.7). This apparent discrepancy may be because: i) the participants did not feel comfortable indicating that they themselves defecate in their water sources; or, ii) family members other than the questionnaire participant are using the water sources for toileting. Nevertheless, the use of source water as a human toileting location represents a risk to the source water quality (Figure 2.1, point I in the DWSC).

It was also reported by the questionnaire respondents that 7% of families and 24% of young children most often use water sources for toileting (Figure 2.7), representing a significant risk to source water quality (Figure 2.1, point I in the DWSC). In addition to the high frequency of source use for livestock watering reported in the questionnaire (), the authors frequently observed herdsmen taking their livestock to domestic sources for watering during their fieldwork. These practices significantly increase the risk of faecal contamination at point I in the DWSC (Dufour and Bartram 2012; Tate et al. 2003). In order to improve water quality at the source, the use of source waters for human defecation and livestock watering must be eliminated within the study neighbourhood.

In general, the results of the water source sanitary risk inspections indicated that all sources in the study neighbourhood were vulnerable to water quality deterioration due to their sanitary conditions, with exception to the Headwater Spring I and some downgradient points within the piped-water network that were determined to be at ‘low risk’. Sources that had more infrastructure (i.e., hand-pump well, piped-water network public access points) inherently had more physical protection from microbiological contamination than the open springs, resulting in scores that were in the ‘low’ to ‘moderate’ ranges.

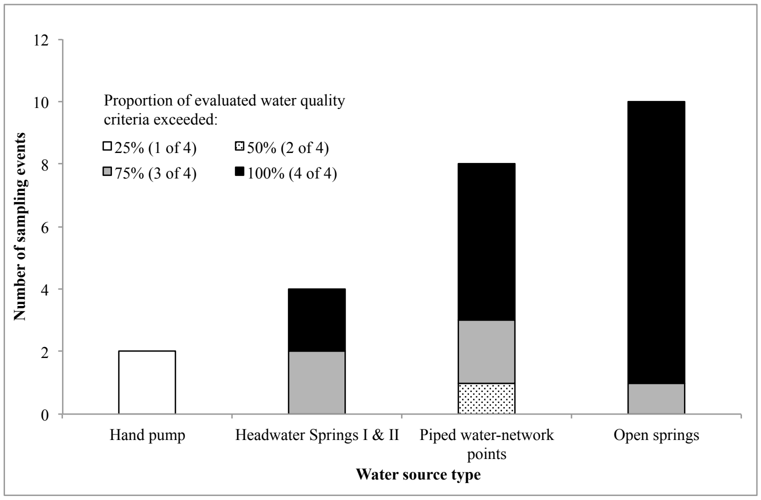

Figure 2.6Although the hand-pump well provides the most improved water quality, only 4% of the questionnaire participants indicated using it throughout the year, likely due to its relatively remote location. Questionnaire participants also indicated little interest in travelling greater distances to collect water that is cleaner (Table 2.4, Exercise B), therefore it may be most worthwhile to encourage its use only among its most localized residents.

Despite the relatively robust infrastructure observed in association with the piped-water network’s public access points in the study neighbourhood, the water quality remained poor. Of the water samples analysed from the publicly accessible points in the piped-water network, 67% tested positive for the presence of *E. coli,* 92% for *Salmonella spp.* and H_2S-producing bacteria, and 100% for total coliforms. This is likely because Headwater Springs I and II were of poor microbiological quality, and microbiological contamination is not attenuated within the network.

It is important to note that moderate-scale farming using manure for fertilizer is conducted approximately 20 m upgradient of both Headwater Springs I and II, which is just beyond the 15 m observation distance for faecal matter used in the sanitary risk inspections (Table 2.1Table 2.1). In addition, small-scale farming with manure is also practiced within what appeared to be a gated, upgradient headwater protection zone adjacent to Headwater Spring II. The upgradient use of manure is likely to increase the faecal microbiological load at Headwater Springs I and II (Dufour and Bartram 2012), resulting in downstream contamination of the entire piped-water network. The source water sanitary risk score methodology could be improved by incorporating hazard observation categories for upgradient farming and the use of manure.

Open springs were typically void of protective infrastructure such as masonry, and were consistently observed to have adjacent faecal matter. These two factors increased their vulnerability to water quality deterioration, and as a result, 92% of the inspected open springs were assessed to have ‘high risk’ scores (Figure 2.6). Accordingly, 90% of the analysed samples exceeded for concentrations of *E. coli,* and 100% of the samples exceeded for concentrations of total coliforms, *Salmonella spp.*, and H_2S-producing bacteria (Figure 2.6).

Given that the water collectors reported a heavy reliance the open spring and piped-water network sources, the poor microbiological quality of these sources represents a risk to community health (Thompson et al. 2003; Sobsey 2002). It should be noted that questionnaire participants indicated they know that ‘dirty water’ and ‘germs and parasites’ cause diarrheoa (Table 2.4, Exercise A), however it remains unclear whether they know that germs and parasites are present in human and animal excreta and are transferred to, and survive in, water, ultimately causing disease.

Future source water quality initiatives ought to focus on evaluating the viability of the existing sources, reducing their contamination with excreta, and improving sanitary completion (Howard et al. 2003; Thompson et al. 2003). For example, Headwater Springs I and II are lacking protective masonry, and the proximate farming with manure is a concern. The water from the Headwater Springs is diverted to various other water users including ranches and communities other than just the study neighbourhood, therefore any interventions to improve their quality would require collaboration with these other stakeholders.

Open spring sources in the study neighbourhood require more protective infrastructure, and human and livestock drinking water sources need to be sanitarily separated. Questionnaire participants indicated that they would be relatively willing to ‘never let their livestock near [their] water sources' (Table 2.4Table 2.4, Exercise C). Their willingness does not gauge the attitude of the herdsmen toward doing the same, however, so the immediate feasibility of separating human and livestock water sources requires further investigation. Given the local reliance on livestock as a means of subsistence, this water quality intervention approach requires a much more extensive understanding of the local pastoralist lifestyle, and integration of all stakeholders for effective implementation.

The WHO's Water Safety Plans suggest corrective actions for existing water sources based on the results of sanitary inspections (Davison et al. 2005). Consideration should also be given to developing novel water sources while bearing in mind source water development preferences outlined in Exercise C (Table 2.4). Ideally, questionnaire participants in the study neighbourhood would like water that is 'clean' from the source, requiring little treatment prior to consumption, and is close to home.

In order to improve and maintain water quality throughout the DWSC, and ultimately protect community health, future interventions ought to focus on promoting a multi-barrier approach to protection to the point-of-consumption by incorporating elements of sanitation and hygiene (Table 2.1) (Health Canada 2009; Davison et al. 2005). Post-supply water quality protection measures ought to involve improving household excreta management within the study neighbourhood by ensuring faecal waste is safely separated from human contact (Carr and Strauss 2001; Bongartz et al. 2010; Esrey et al. 1991). Furthermore, the household sanitary risk inspections indicated that 10% of water supplies were at 'low risk', 70% at 'moderate risk', and 21% at 'high risk' of microbiological quality deterioration due to their sanitary and hygienic conditions. The primary hazards resulting in elevated risk scores were infrequent and/or ineffective water container cleaning, the use of utensils for water retrieval in conjunction with unhygienic hand washing, and a lack of drinking water treatment prior to consumption. In order to maintain drinking water quality to the point of use, these risks need to be addressed.

Questionnaire participants indicated that 63% of families and 67% of young children reported practicing open defecation. It is suggested that the minimum technology for safe family excreta disposal is the consistent use of diapers for young children (followed by safe disposal of excreta within the diaper) and ventilated pit latrines for other family members (Carter et al., 1999; Kamat and Malkani 2003). The ventilation of latrines prevents nuisance animals such as flies from contacting excreta and transmitting disease (Carr and Strauss 2001), thereby protecting water quality within the home environment. Nevertheless, further work must be done to not only promote and install these technologies, but also ensure the behavioural change occurs with the study neighbourhood to ensure their use.

Water collectors were knowledgeable that unclean hands can lead to diarrhoea (Table 2.4, Exercise A), and soap use for family hand washing was reported by 81% of questionnaire participants. Nevertheless, soap was rarely observed during fieldwork, and was not easily accessible for purchase. Questionnaire participants also ranked ensuring 'all family members always wash their hands with soap' as a hygienic intervention with little feasibility, and they ranked 'joining a women's group that makes and sell soap' as the least welcome interventions strategy (Table 2.4, Exercise B). Based on these observations, the low household incomes of the questionnaire participants, and anecdotal evidence from conversations with community members, it strongly suspected that the usage of soap for hand washing was exaggerated due to its social desirability (van de Mortel 2008). This matter requires further investigation in the study neighbourhood, and refinement methodological within the questionnaire.

Regular hand washing with soap, particularly after defecation, will be important for water quality protection at the post-supply phases of the DWSC, and the lessening faecal-oral disease transmission in the study neighbourhood (Carter et al. 1999; Carr and Strauss 2001; Cairncross et al. 2010). Seventy-six percent of questionnaire participants indicated that water is retrieved from drinking water storage containers using a utensil. Increasing the use of water containers for collection and dispensing with narrow openings and/or with taps/spigots would reduce hand contact with drinking water and protect water quality prior to consumption (World Health Organization 2012; Thompson et al. 2003).

Issues of soap accessibility and affordability may be inhibiting soap use container cleaning in the study neighbourhood. Furthermore, *Lippia javanica*, or "osinoni" in Maasai, is a medicinal herb that grows locally. The essential oil of *Lippia javanica* has strong antimicrobial properties (Viljoen et al. 2005; Mujovo et al. 2008), and some water collectors in other neighbourhoods within the community of Il Ngwesi reported using it to clean their water storage containers. The presence of this herb in the study neighbourhood as an alternative to soap for cleaning requires further investigation.

The actual microbiological water quality at the household levels of the DWSC (Figure 2.6, points II to V) was poor. Eighty-seven percent of household water samples (*s*=15) tested positive for the presence of *Salmonella spp.*, 93% tested positive for total coliforms (*s*=15), and 100% tested positive for *E. coli* (*s*=4) and H_2S-producing bacteria (*s*=3). The lack of water treatment and often-poor sanitary water conditions, along with the poor microbiological quality of available source and household water samples, represent a health risk to the consumers.

Eighty percent of participants in the current study also indicated that they 'never' treat water prior to consumption. Of the 20% of participants who reported treating their water, the reported methods of water treatment were boiling (*n*=12), decanting/settling (*n*=2) and chemical disinfection (*n*=1). There is little evidence that the treatment practice of decanting/settling has beneficial effect on microbiological water quality (Wright and Gundry 2009). The low frequency of treatment poses a risk to water quality prior to the point of consumption in the DWSC (Figure 2.1, point V in the DWSC).

The causes of the low water treatment frequency in the study neighbourhood require further investigation. The community nurse indicated that water treatment is advocated and chemical treatment products are available. Since boiling was the most frequently reported treatment practice, it should be noted that charcoal and wood for stove use is limited in terms of availability and affordability in the study neighbourhood. Chest infections were also the most commonly reported ailment at the local dispensary in the study neighbourhood (Figure 2.9), and their prevalence may be partially attributable to poor air quality from indoor charcoal stove use (Clasen et al. 2008; K. R. Smith 2002). Increasing the use of the charcoal and wood burning for water boiling may further deteriorate indoor air quality. A number of low-cost point-of-use treatment methods, such as ceramic filtration, heating by boiling or ultraviolet radiation, and chemical flocculants or disinfectants, can interrupt water-related disease transmission (World Health Organization 2012; Thompson et al. 2003).

The current study focused on bacterial contamination using faecal indicators of total coliforms, *E. coli*, *Salmonella spp.,* and H_2S-producing bacteria in water. The presence or absence of enteric viruses and protozoan parasites in water has not been analyzed in the study neighbourhood. For example, the waterborne illness amoebiasis, which was noted in the dispensary outpatient records, is caused by a protozoan parasite (Dugdale and Vyas 2010). Moreover, the protozoan genus *Cryptosporidium* is also globally widespread, and known to be excreted by animals while causing diarrhoea in humans (Dufour and Bartram 2012). *Cryptosporidium* is resistant to chlorination, however it is efficiently removed using ceramic filtration (World Health Organization 2012;

Dufour and Bartram 2012). Enteric viruses and protozoan parasites ought to be considered during interventions that involve water treatment, as methodological effectiveness varies by organism type (Dufour and Bartram 2012; United Nations Children's Fund 2008).

Nevertheless, water collectors indicated that they are highly willing to treat their drinking water prior to consumption should it reduce diarrhoea in their family (Table 2.4, Exercise B). It should be considered that the residents of the study neighbourhood regularly consume a sweetened tea beverage that requires heating over a charcoal stove prior to consumption, which likely reduces the viability of some water-related pathogens (Sobsey 2002).

The results of the health assessment in the questionnaire indicated that diarrhoea frequency generally decreased and health status generally improved with increasing age, (Figure 2.8). Young adult males, and adult males and adult females generally suffer from ill health the least frequently. The poorer health reported for the young child, child, young adult female and elder cohorts by the questionnaire participants may be due to the nearly ubiquitous consumption of water of low microbiological quality, as presented in the DWSC risk assessment. Individuals such as infants, children and the elderly, as well as immunosuppressed individuals are at greater risk than healthy adults of suffering from severe diarrhoea and other symptoms from the consumption of contaminated water (Davison et al. 2005; British Columbia Ministry of Water, Land and Air Protection 2002; Dufour and Bartram 2012). Young adult females in the study neighbourhood are also reportedly experiencing diarrhoea more frequently and poorer general health than their male counterparts. This discrepancy in health by gender within the young adult age cohort requires further investigation.

Additionally, the pathogens that cause water-related diseases may be contributing to ailments other than the diarrhoea reported in the study neighbourhood. For example, health effects other than diarrhoea range from general symptoms such as malaise and fatigue, headache, anorexia, rash and jaundice, and respiratory disease, to more specific diseases such as conjunctivitis, arthritis and pharyngitis (Macler and Merkle 2000; Howard et al. 2006; Arizona Department of Health Services 2012). The effects of poor water quality in the study neighbourhood may therefore be impacting health beyond just gastroenterological ailments.

Water-related diseases and diarrhoea were the second most frequently reported ailment at the local dispensary after chest infection, with a rate of 19% of outpatient visits (Figure 2.9). Moreover, the dispensary in the study neighbourhood is privately funded, and the average cost for visit due to diarrhoeal illness was between 4 to 10 times greater than at a publicly funded dispensary. Furthermore, one visit to the local dispensary costs approximately 8% of a questionnaire participant's median annual income. Due to this expense, water-related diseases are likely underreported in the dispensary outpatient records. In future, public communication and education on the financial burden of water-related diseases due to the lack of sanitation and hygiene, in addition to their potential to cause for absenteeism from work and school, may help to drive the WASH improvements necessary to improve water quality in the study neighbourhood (World Health Organization/UN-Water 2012).

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Chapter 3 A water, sanitation and hygiene assessment of three rural neighbourhoods to support localized water quality interventions

3.1. Introduction

Every year approximately 2.2 million deaths are attributed to diarrhoea globally, largely due to a lack of access to safe drinking water, improved sanitation facilities and hygienic practices (Davison et al. 2005; Thompson et al. 2003). As of 2010, the World Health Organization (WHO) estimated that 330 million people in Sub-Saharan Africa lacked access to improved drinking water (e.g. protected springs, boreholes, tube wells, piped-water), while 565 million lacked access to improved sanitation facilities (e.g. protected pit latrines, sewer systems) (World Health Organization/United Nations Children's Fund 2010; Fewtrell et al. 2005). Access to improved drinking water and sanitation facilities in Sub-Saharan Africa remains a challenge, particularly in rural communities, despite many small- and large-scale water, sanitation and hygiene (WASH) intervention programs (e.g. efforts by non-governmental organizations (NGO)) and policy goals (e.g., establishment of the Millennium Development Goals and the WHO's Sanitation and Water for All).

Safe drinking water and improved sanitation facilities, in conjunction with good hygienic practices, can provide a significant measure of protection from waterborne and water-washed faecal-oral diseases (Rosen and Vincent 1999; White et al. 1972). Waterborne diseases are those that are transmitted through the consumption of contaminated water, including typhoid fever and cholera, while water-washed diseases are those that arise as a result of insufficient water quantity for personal or domestic hygiene (White et al. 1972; Rosen and Vincent 1999). For the purpose of this paper, waterborne and water-washed diseases will be collectively referred to as "water-related diseases". Many communities have historically relied on WASH intervention projects supported by external governmental and NGOs to reduce the health impact of such water-related diseases (Harvey and Reed 2006).

Barber et al. (2013) indicated that there are two fundamental factors to consider when pursuing a community WASH intervention. The first is the attributes of the community in which change is being pursued, and the second is the technical feasibility and sustainability of potential interventions. For the purpose of this article, 'community' is defined as a population living in within a single social organizational structure (Minkler and Wallerstein 2011), and the term 'neighbourhood' is used to describe the geographically distinct units within the community. Carter et al. (1999) propose that community social participation alone in a WASH intervention does not ensure sustainability, while technological interventions without community support often fail to secure the behavioural change required for improved health (Carter et al. 1999). These two aspects of community WASH interventions work interdependently to contribute to program success and sustainability.

Gathering a set of technical and social reference data on the sanitary and hygienic environment of the water within the drinking water supply chain (DWSC) can be key to developing a well informed, evidence-based water quality intervention (Carter et al. 1999). For example, infrastructure developments such as piped-water networks and wells can be installed to improve community drinking water quality. If community members have handling practices that contaminate the water at later stages in their DWSC, however, this source water quality intervention alone may not be sufficient to improve overall health. As such, social conditions, such as the practices, beliefs, values, norms, experiences and geographies of a community can also affect its WASH conditions (Waddington and Snilstveit 2009). Examining the sociocultural factors like the knowledge, attitudes and practices (KAP) of community members regarding water use can support the design of locally relevant interventions (Banda et al. 2007).

The WHO's Water Safety Plans (2005) specify that safe drinking water is achieved by protecting or treating water at all points along the DWSC, including the water source and the post-supply phases of transportation, distribution, storage, and handling (Davison et al. 2005). In rural Sub-Saharan African communities, protecting water quality at all points in the DWSC requires knowledge of local water infrastructure, and an understanding of how water is handled by the community up to the point-of-use. The authors of this study hypothesize that the social and environmental factors that affect water quality can vary at the neighbourhood-scale within a community, and therefore data must be collected at this scale in order to design a locally relevant intervention.

The purpose of this study is to investigate the baseline WASH conditions of three neighbourhoods within a single rural Kenyan community. The specific objectives include the determination of: 1) the points within the DWSC at which the water quality at risk of microbiological contamination; 2) the KAP of water collectors on WASH topics that may affect microbiological water quality within the DWSC; 3) the potential and actual effects of drinking water quality on health, both within and between neighbourhoods; and 4) an assessment of WASH interventions that water collectors in each neighbourhood consider feasible to pursue. The results of this study will be used to support the design of neighbourhood-scale water quality interventions.

The results of this research are to be returned to the study community to support their planning of single or multiple WASH intervention strategies for each of the three neighbourhoods. This research was conducted at the request of the Il Ngwesi Group Ranch, which self-identified inadequate water and sanitation services as a priority issue, and requested external support to initiate data collection to inform a WASH program.

3.2. Methods

3.2.1. Study community and neighbourhoods

The Il Ngwesi Group Ranch (IGR) is an 8,675 hectare area of land in the eastern portion of the Laikipia District in Rift Valley Province, Kenya, communally owned by the Il Ngwesi Maasai (Ngwesi Group Ranch 2010) (Figure 3.1). IGR land is dedicated to tourism and conservation, with the communal landowners living in eight neighbourhoods. The local area is classified as semi-arid grassland with soils of volcanic origin (Jaetzold and Schmidt 1983), with the annual temperature ranging between 20°C and 28°C (Huho et al. 2012). The study area receives an average of 580 mm of rain annually, with distinct dry and wet seasons. The longer wet season typically occurs between March and May annually, while the shorter wet season begins in mid-November and lasts for approximately one month.

The Maasai population is traditionally semi-nomadic, practicing a pastoralist, polygamous family lifestyle. The male head of household customarily raises and grazes livestock including goats, sheep and cattle as a source of family livelihood, while his wife or wives are responsible for child rearing and household duties including water collection. Although Maasai people remain dependent on this pastoralist existence, they are simultaneously undergoing livelihood diversification away from animal husbandry (Homewood et al. 2009).

The water quality risk assessment methodology developed by Barber et al. (2013) was chosen as the principle methodology to collect and analyse both the technical and social WASH data sets at the neighbourhood-scale. The WASH baseline data collection methodology presented by Barber et al. (2013) was adapted so that it could be used within each of the eight neighbourhoods of the Il Ngwesi Group Ranch, and was piloted in neighbourhoods of Chumvi, Ethi and Nadungoro between September 2011 and February 2012. The location and attributes of the three neighbourhoods are presented in Figure 3.1 and Table 3.1.

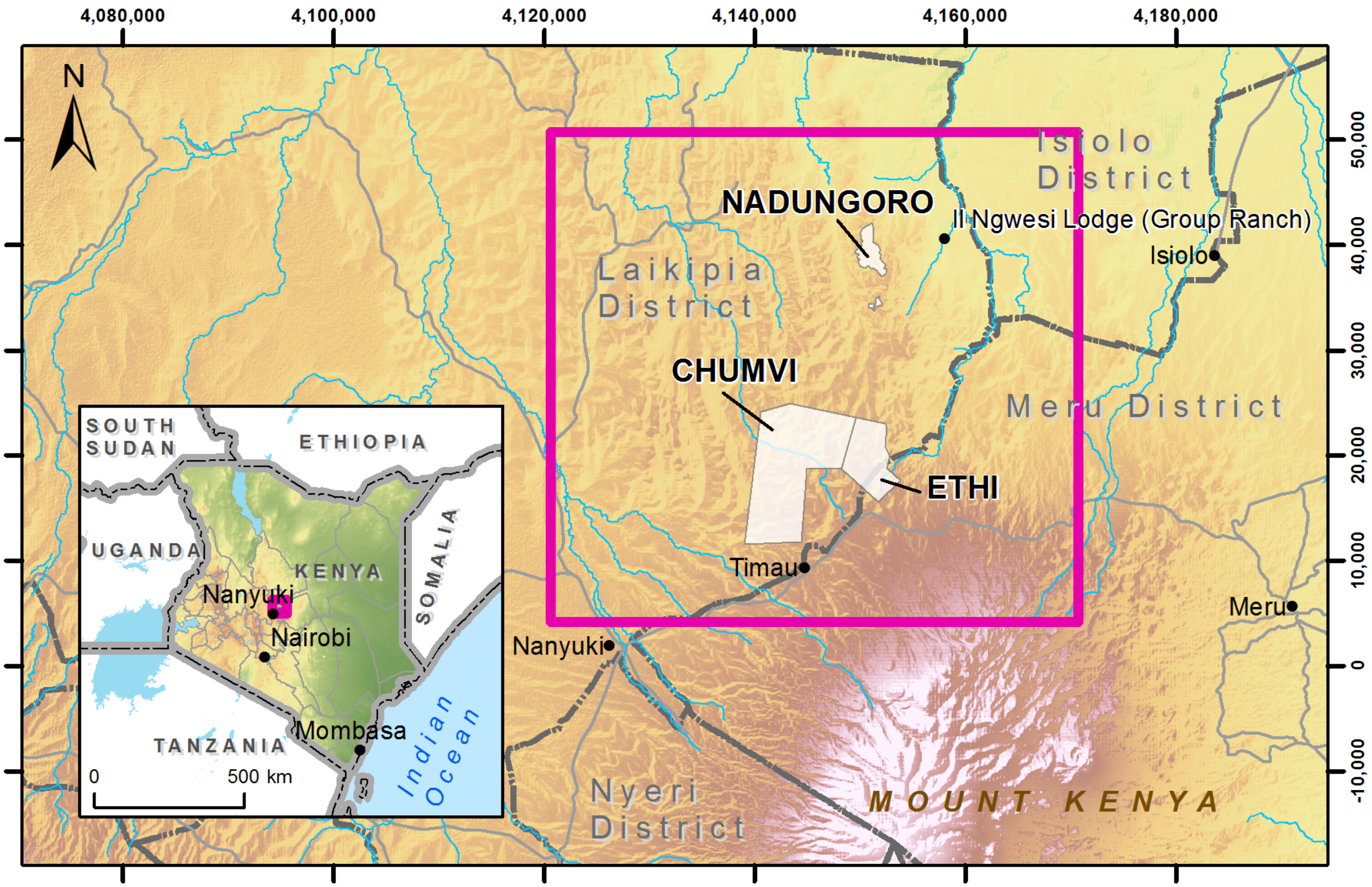


Figure 3.1 Inset: Map of study area within Kenya. Main: Study neighbourhoods of Chumvi, Ethi and Nadungoro within Kenya.

Table 3.1 Geographic and social attributes of Chumvi, Ethi and Nadungoro.

Neighbourhood attribute	***Neighbourhood***		
	Chumvi	***Ethi***	***Nadungoro***
Land area (approx. km^2)	*75*	*23*	*8*
General topography	Hilly in north, planar in south	Hilly	Open plain within foothills, gradual southward slope
Population (est. 2010)	2,000	750	375
Population density (approx.. persons/km^2)	27	37	49
Water sources	Approx. 13 open springs, piped-water network, one hand-pump well, seasonal rainwater harvesting	Approx. 11 open springs, one solar-powered well and one diesel-powered well (abandoned), seasonal rainwater harvesting	Approx. 15 open springs, two hand-pump wells (one broken), one diesel-powered well, one wind-powered well (broken), seasonal rainwater harvesting at schools and clinic
*Clinic or dispensary funding; approx. visit cost in Kenyan Shillings (KES)**	Private dispensary; 200 KES	Private dispensary; 100-200 KES	Public clinic; 20 KES under 6 years, 50 KES 6 years and elder

*1 Canadian Dollar = 90 Kenyan Shilling (approximate, November 2011).

Women and girls are responsible for the provisioning of domestic drinking water in the three study neighbourhoods. Approximately 45% of households in Chumvi are serviced by piped-water obtained from two springs located approximately 20 km to the southwest of the neighbourhood. The springs supplying the piped-water network will herein be referred to as ‘Headwater Spring I’ and ‘Headwater Spring II’, or collectively referred to as ‘the Headwater Springs’. The accessible downgradient piped-water network locations will be herein referred to as ‘piped-water network points’. Headwater Spring I is located approximately 130 metres (m) upgradient to the west of Headwater Spring II, and they are hydraulically connected by a buried pipe. Community members who are not serviced by the piped-water network collect their water from open springs and wells. Some households in the study neighbourhoods also harvest rainwater for domestic use during the wet seasons.

3.2.2. Drinking water supply chain and study design

The theoretical water quality risk model of the DWSC presented by Barber et al. (2013) was applied in the current study (Figure 3.2).

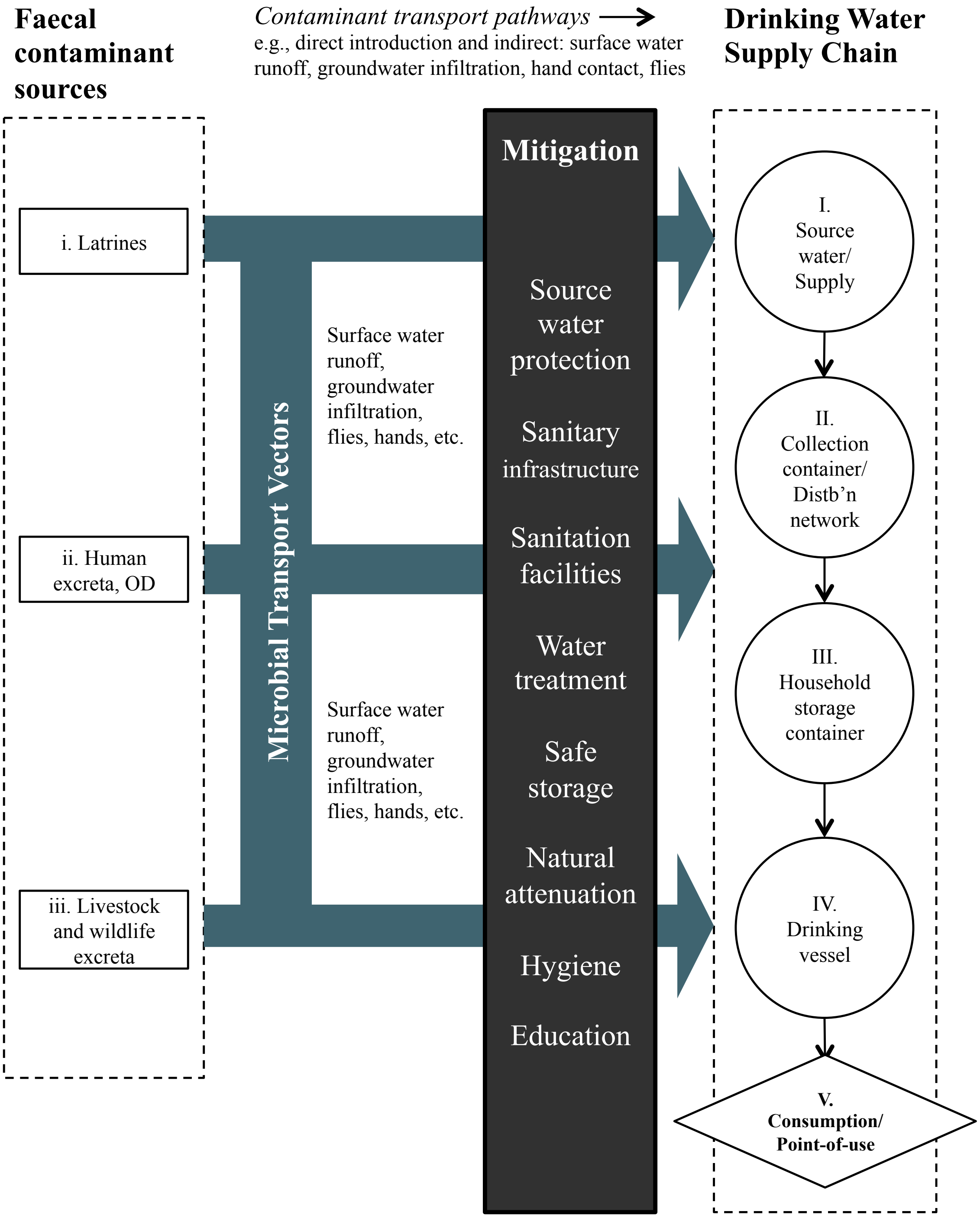


Figure 3.2 Theoretical model of faecal contaminant sources, contaminant pathways and the drinking water supply chain.

The model describes the sources of faecal matter within the environment, their potential relationship to the DWSC, and some associated measures to mitigate drinking water contamination (Figure 3.2). The model assumes that household water is collected in a container at a source, carried home, and potentially transferred to a drinking water storage container prior to consumption. Water may become microbially contaminated at any point in the DWSC, through any number of different faecal sources (i.e., livestock or wildlife faeces, human excreta, excreta from latrines) in tandem with environmental (e.g., surface water runoff, groundwater infiltration, flies) or human transfer pathways (e.g. hand contact, foot transfer). Microbiological contamination can also be mitigated prior to point V in the DWSC, for example by eliminating transfer pathways through source water protection or reducing contamination by water treatment (Figure 3.2). This model was developed to collect information on the presence of these different sources and pathways of contamination within a community's DWSC, and the presence or absence of mitigating measures.

This paper presents the results of this research using the DWSC risk model as a framework by highlighting points of actual and/or potential sources of microbiological contamination between points I (source water) and V (consumption) in the DWSC, and the KAPs of water collectors that may be affecting water quality (Figure 3.2). The DWSC risk results are followed by an assessment water quality on family health. Lastly, the preferences of water collectors are presented regarding household hygiene initiatives and future water source development.

Fieldwork for this research was conducted in four parts: (i) local method adaptation; (ii) source water risk inspections and water quality analyses; (iii) household WASH KAP questionnaire, household sanitary risk inspections, and water quality analysis; and, (iv) a community clinic/dispensary logbook review. Geographic coordinates were also collected using handheld global positioning system (GPS) units for all field sites visited, including water sources and households, to enable their mapping and spatial analysis using a Geographic Information System (GIS). Details regarding the field methodology are presented in Barber et al. (2013), however brief descriptions are provided below.

3.2.3. Sanitary risk inspections and assessments

Sanitary risk inspections are a rapid drinking water quality assessment tool used to evaluate the risk of water contamination based on local sanitary and hygienic conditions (United Nations Children's Fund 2008; Howard 2002). The inspections are completed at various points in the DWSC by evaluating the presence or absence of various risk factors and/or asking simple interview questions presented in checklists tailored to the type of water site (United Nations Children's Fund 2008; Howard et al. 2003). Upon completion of the inspection, the risk assessment is conducted by summing and standardizing the inspection scores for the observed risk factors.

The sanitary risk inspection checklists for the current study assess the risk of microbiological contamination at water sources and household/point-of-use in the DWSC respectively, and were developed by adapting those developed by Howard (2011) in consultation with key community informants. The checklists are presented in Barber et al. (2013).

Sanitary risk assessments were conducted with the inspection data to evaluate the microbiological water quality risk at each inspection site. Each question in the risk assessment represents a hazard with an assigned a magnitude, M_i, which was determined based on the relative severity of its potential impact on water quality rated on a scale of one to three for the source water inspections, and a scale of one to 10 for the household inspections (Table 2.1). The site risk score, s_j, was calculated using Equation 3.1:

$$s_j = \sum_{i=1}^{n} p_{ij} M_i \tag{3.1}$$

where s is the risk assessment score for a particular source or household (i.e., "site"), j is the site in question, n is the number of risk factors assessed at that site, p is the probability of hazard i being observed at that site, and M is the relative magnitude assigned to a given risk factor. Normalized risk scores, S_j, were calculated using Equation 3.2:

$$S_j = \frac{s_j}{s_{max}} \tag{3.2}$$

where s_{max} is the maximum risk score for the given site, j. The site assessment scores were standardized and grouped into low (s=0.00-0.33), moderate (s=0.34-0.66), and high (s=0.67-1.00) risk brackets.

where s is the risk score for a particular source, n is the number of risk factors assessed at that source, p_i is the probability of risk factor i being present at that water source or household (0 to 1), and M_i is the magnitude of risk factor i. Following the risk score calculation, the scores were standardized into categories of low (s=0.00-0.33), moderate (s=0.34-0.66) and high (s=0.67-1.00).

The assigned magnitudes are available in Barber et al. (2013), and the risk factor descriptions are presented in Table 3.2.

Table 3.2 Risk factors assessed in the household sanitary water quality risk assessment.

Risk factor	*Description*
F1	Water collection container type
F2	Drinking water separation from other domestic water
F3	Storage location and presence or absence of lids on drinking water storage containers
F4	Frequency and method of drinking water treatment
F5	Hand washing method and water retrieval method (i.e., with utensil, tap or pour)
F6	Storage container cleaning frequency and method
F7	Use of plastic bag between container and lid during transportation (leakage prevention)
F8	Interior and exterior container cleanliness

3.2.4. Source and household water quality analysis

The purpose of the source and household water quality analysis was to evaluate the presence or absence of faecal microbiological contamination at points I (source water) and III (household storage container) within the DWSC (Figure 3.2). All water sources that were visited during fieldwork and reportedly used for household drinking water were sampled and analyzed.

The samples were quantitatively analysed for total coliforms, *Escherichia coli (E. coli), Salmonella spp.* and *Aeromonas spp.* using Micrology Laboratory's ECA Check Plus® Easygel® (Easygel®). Easygel® is a clear gel medium containing nutrients and a chromogenic substrate for bacterial growth (Micrology Laboratories, LLC 2011). Water samples were also analysed for the presence or absence of sulphur-reducing bacteria, which are predominantly associated with the intestinal tracts of warm-blooded animals (Sobsey and Pfaender 2002), and are therefore indicators of faecal contamination. This test is a simple, inexpensive means for detecting sulphur-reducing faecal bacteria such as *Salmonella spp., Staphylococcus spp.* and *Clostridium perfringens* at very low concentrations (Huang et al. 2011; United Nations Children's Fund 2008; Pillai et al. 2009).

The Easygel® analytical results were converted to sample volumes of colony forming units (cfu) per 250 milliliters (mL). The Easygel® and H_2S analytical results were compared to the Kenya Water Services Regulatory Board's (KWSRB) 2009 *Drinking Water Quality and Effluent Monitoring Guideline Schedule 5: Microbiological limits for drinking water and containerized drinking water (Guideline)* (Kenya Water Services Regulatory Board 2009). Since the KWSRB has not set a drinking water guideline for *Aeromonas spp.*, these results have been omitted from the present study. The water quality results were scored with '1' representing a *Guideline* exceedence and '0' representing non-exceedence, with a maximum of four microbiological indicator exceedences per water sample.

3.2.5. Household questionnaire

The household questionnaire, provided as supplemental material in Barber et al. (2013) (Appendix A), was executed in all three neighbourhoods. The questionnaire supports an understanding of water collector KAP related to WASH. The goal of the questionnaire was to learn how neighbourhood members use the water sources and handle water once it is collected, and determine the potential risk of post-supply water quality deterioration prior to consumption at home. Post supply risk was assessed in part by evaluating household sanitation and hygiene, including family toileting and hand washings habits.

Toileting practices that were considered to represent a lower risk to post-supply water quality deterioration included the use of improved sanitation facilities, such as a latrine or diapers/cloths for infants (provided that excreta from the diaper is safely disposed of within a latrine). Less sanitary toileting practices, considered to be a greater risk to post-supply water quality deterioration, included the use of unimproved sanitation facilities such as open pits and open defecation within water sources, vegetation or the household. For the purpose of this study, latrines were not considered to represent a risk of source water contamination via groundwater infiltration, as they were not in close enough proximity to any source waters to represent a significant risk (i.e., within 100 metres) (Greaves and Simmons 2011).

Hand washing with soap was also considered to represent a lower risk of post supply water quality deterioration in comparison to hand washing without soap (i.e. wiping with a cloth or rinsing with water), which was considered to pose a greater risk to post-supply water quality deterioration.

The questionnaire also served as a means to gather self-reported data on family health and diarrhoea frequency to assess the potential impact of water quality on health. Questionnaire participants reported the frequency of diarrhoea and general health status of all family members using a five-level Likert scale arranged by age cohort.

Ten percent of adult females were surveyed in Chumvi and Ethi, and 15% in Nadungoro; these numbers of participants were sufficient to achieve data saturation in the questionnaire responses. Interviewers randomly selected households while ensuring broad geographic coverage.

3.2.6. Clinic and dispensary outpatient records

Water-related disease attributed to WASH status includes, but are not limited to, diarrhoea, typhoid fever, cholera, salmonellosis, amoebiasis, giardiasis, campylobacteriosis, cryptosporidiosis and other viral, bacterial and protozoan gastrointestinal infections (Pruss-Ustun et al. 2002; Howard et al. 2006; Pruss-Ustun et al. 2004). Outpatient records were gathered from the dispensaries in Chumvi and Ethi, and the clinic in Nadungoro, to assess the actual rate of reported water-related disease in the three study neighbourhoods. Monthly outpatient record summaries that provided the count and description of outpatient curative visits, including water-related diseases, were assessed from the Chumvi and Ethi dispensaries. Monthly records were available from November 2010 through December 2010, and March 2011 trough October 2011 from the Chumvi dispensary, and January 2011 through June 2011 from the Ethi dispensary. Monthly summary records were not available for the clinic that serves the population of Nadungoro (i.e., Lokusero Dispensary), and therefore daily clinic outpatient records were reviewed and synthesised for this neighbourhood from November 2010 through October 2011. Records of water-related disease were recorded in conjunction with the total number of outpatient visits per month.

The terminology used for reporting water-related diseases was varied in the records from the three local medical facilities, therefore the water-related disease rate calculations were based on different reported terms. The terminologies used for the diagnoses of water-related disease are presented in Table 3.3.

Table 3.3 Water-related illness terminologies reported in the clinic and dispensary outpatient records.

Clinic	*Chumvi*	*Ethi*	*Nadungoro*
Water-related disease criteria	diarrhoea dysentery typhoid fever intestinal worms amoebiasis gastroenteritis vomiting lower abdominal pain constipation	diarrhoea dysentery typhoid fever intestinal worms	diarrhoea dysentery typhoid fever intestinal worms amoebiasis gastroenteritis dehydration giardiasis

The reported rate of water-related disease for each neighbourhood's clinic or dispensary was calculated using Equation 3.3:

$$w = \frac{\sum_{i=1}^{n} a_i}{\sum_{i=1}^{n} A_i} \times 100\% \tag{3.3}$$

where *w* rate of water-related disease outpatient visits at a particular clinic/dispensary, n is the number of cases assessed at the clinic/dispensary, and a_i is the number of reported water-related disease cases, A_i is the number of all outpatient cases of at clinic/dispensary, i.

3.2.7. Problem and preference ranking exercises

Problem and preference ranking (PPR) exercises were conducted in conjunction with the questionnaire to determine knowledge on causes of diarrhoea (Exercise A), and attitudes toward implementing hygienic habits at home (Exercise B). The PPR method was adapted from (Keller 2012), and allowed participants to rank priorities or solutions to hypothetical WASH situations presented to them using a pairwise ranking of responses. Further details on the methodology are included in Barber et al. (2013).

The results of the exercise were tallied by counting the number of times a participant selected each response. Larger counts of a given response indicated that the participant believed it was either preferable or more likely to be true. Based on the tallies, a response rank I was calculated, with 1st to n^{th} representing the participant's a hierarchical set of beliefs regarding the original question. Individual questionnaire participant response ranks for Exercises A and B were summed to produced neighbourhood-wide ranks.

3.3. Results and Discussion

3.3.1. Source water use and practices

Seasonal water source usage as reported by questionnaire participants in the three study neighbourhoods is presented in Table 3.4. The results indicate that source type use varied both by season and among the neighbourhoods.

Table 3.4 Source water type use by neighbourhood and season as reported by *n* questionnaire participants.

Season	***Dry***			***Wet***		
Neighbourhood (*n* respondents)	***Chumvi*** (*n*=69)	***Ethi*** *(n=40)*	***Nadungoro*** (*n*=23)	***Chumvi*** (*n*=69)	***Ethi*** (*n*=38)	***Nadungoro*** (*n*=22)
Open spring	51%	78%	91%	23%	61%	73%
Piped-water network	45%	-	-	35%	-	-
Well tap	0%	45%	17%	0%	32%	23%
Dam	4%	0%	0%	1%	3%	9%
Hand-pump well	6%	0%	0%	1%	0%	0%
Water vendor	6%	5%	4%	6%	0%	0%
Rainwater harvesting	0%	0%	0%	45%	21%	0%

In the dry season, 91% of questionnaire participants in Nadungoro (*n*=23) indicated that they collected water from open spring water sources, followed by 78% in Ethi (*n*=40) and 51% in Chumvi (*n*=69). During the dry season in Chumvi, 45% of the participants indicated that they use the piped-water network, while in Ethi and Nadungoro, 45% and 17% of respondents, respectively, indicated that they relied on a well tap for water collection. Other water sources that had low reported usage in the dry season included dams, hand-pump wells and water vendors.

During the wet season, rainwater harvesting increased from 0% to 45% in Chumvi (*n*=69) and to 21% in Ethi (*n*=38). Rainwater harvesting was not reported during either season in Nadungoro (*n*=22). Usage of open spring water sources in the wet season decreased in Chumvi, Ethi and Nadungoro to 23%, 61% and 73%, respectively compared to the higher percentages reported in the dry season. The use of the piped water network also decreased by 10% in the wet season, compared to the dry season. Also in the wet season, the well tap use decreased in Ethi to 32% while it increased in Nadungoro to 23%. Other sources that had low reported usage in the wet season included dams, hand-pump wells and water collectors.

Questionnaire participants in the three study neighbourhoods indicated that they conduct various activities while they are at the water source other than collecting water. Results demonstrate that practices at the water sources varied seasonally and by neighbourhood (Figure 3.3).

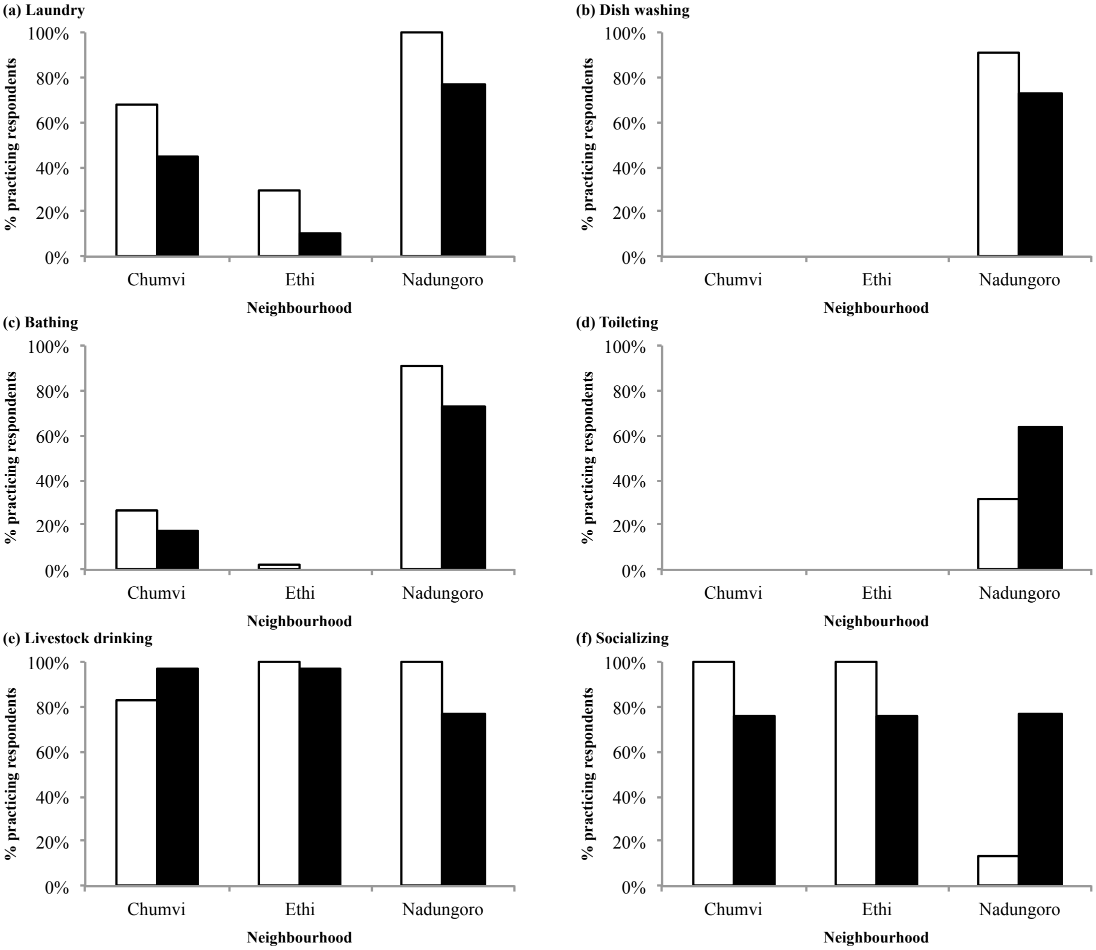


Figure 3.3 Proportion of questionnaire respondents by neighbourhood who conducted various other activities while at the water source in both the dry (white bars) and the wet (black bars) seasons, including: (a) laundry; (b) dish washing; (c) bathing; (d) toileting; (e) livestock drinking; and, (f) socializing.

Respondents in Nadungoro (n_{dry}=21; n_{wet}=22) reportedly conducted laundry at the water source in both the dry and the wet season most frequently, followed by respondents Chumvi (n_{dry}=52; n_{wet}=51) and Ethi (n_{dry}=37; n_{wet}=37). The proportion of respondents who practiced laundry at the water source decreased by approximately 20% in the wet season compared to the dry season in all three neighbourhoods (Figure 3.3a). The relative importance of this risk factor is generally low compared to other practices presented in Figure 3.3 with the exception of users laundering diapers or other clothing soiled with faecal matter adjacent to open spring sources (Ottoson and Stenstrom 2003).

Dishwashing at the source water was not reported by respondents in Chumvi (n_{dry}=52; n_{wet}=52) or

Ethi (n_{dry}=37; n_{wet}=37) during either season, however it was reported in Nadungoro during both the dry (91%; n_{dry}=22) and the wet seasons (73%; n_{wet}=22) (Figure 3.3b). Again, dishwashing represents a relatively low risk of source water quality deterioration in comparison to other practices conducted at the sources.

Bathing at the water source was rarely practiced by participants in Ethi (n_{dry}=37; n_{wet}=37), with 3% of participants reporting this activity during the dry season and 0% in the wet season (Figure 3.3c). In Chumvi (n_{dry}=52; n_{wet}=51), 27% and 18% of participants reported bathing at the water source during the dry and wet seasons, respectively. In contrast, 91% of participants in Nadungoro (n_{dry}=22; n_{wet}=22) reported bathing during the dry season, while 73% reported bathing during the wet season.

It should be noted that there is a relationship between water service level and the location where domestic hygienic is practiced (i.e., laundry, bathing, dishwashing). Users with low or basic water service levels (5 to 20 litres of water per person per day) typically cannot conduct domestic hygiene unless it is done at the water source, posing a health risk for water-washed diseases in the family (Howard and Bartram 2003; White et al. 1972). Should household water service levels improve in future, the various domestic hygiene practices that are currently conducted at the source may be conducted more frequently at home, thereby reducing source water quality risk.

Questionnaire participants did not report toileting at the water source during either season in either Chumvi (n_{dry}=51; n_{wet}=51) or Ethi (n_{dry}=37; n_{wet}=37). In contrast, the reported frequency of toileting at the source water increased in Nadungoro (n_{dry}=22; n_{wet}=22) from 32% to 64% in the dry and wet seasons, respectively (Figure 3.3d). Toileting at the water source, in particular open spring sources, introduces human faecal matter directly into DWSC, representing a significant risk to microbiological water quality. In order to improve the microbiological quality of Nadungoro's DWSC, the use of water sources as a place of defecation must be eliminated.

Livestock drinking at the source water was common practice during both seasons in Chumvi (n_{dry}=52; n_{wet}=51), Ethi (n_{dry}=37; n_{wet}=37) and Nadungoro (n_{dry}=22; n_{wet}=22) (Figure 3.3e). Given that there is a positive correlation between livestock faecal pathogen loading and drinking water sites in the rangeland landscape (Tate et al. 2003), the high usage rate of neighbourhood drinking water sources by livestock significantly increases the risk of water quality deterioration at point I in the DWSC in Chumvi, Ethi and Nadungoro (Figure 3.2) (Dufour and Bartram 2012; Tate et al. 2003). This is particularly true at open spring water sources, as the presence of livestock near these sources implies the presence of faeces. In order to improve source water quality, the shared use of human and livestock drinking water sources must be eliminated.

Socializing is also a relatively common practice at the water source, particularly in Chumvi (n_{dry}=52; n_{wet}=51) and Ethi (n_{dry}=37; n_{wet}=37) in both seasons (Figure 3.3f). The proportion of participants who reported socializing in Nadungoro (n_{dry}=22; n_{wet}=22), increased markedly from the dry season (14%) to the wet season (77%). While socializing does not represent a microbiological contamination concern to the source water, it demonstrates a social routine that may be an integral part of local water collection in the three study neighbourhoods, and should therefor be considered in any water intervention. The marked increase in socializing at the water source during the wet season in Nadungoro requires further investigation.

The results indicate that practices at the source water can vary by neighbourhood and by season; therefore there is some variation in their water quality risks at Point I (source water) in the DWSC (Figure 3.2). In Chumvi, the main water collector practice that represents a water quality risk is the use of the sources for livestock drinking. Laundry and bathing are practiced to a lesser extent than livestock drinking in Chumvi, and also represent a much lesser risk to water quality. Questionnaire participants in Ethi reported conducting the fewest domestic activities at the water source, however livestock watering represents a significant risk to source water microbiological water quality. In Nadungoro, questionnaire participants reported using source water for many domestic practices, including laundry, bathing, dishwashing, and toileting, and these practices varied by season. Livestock drinking was also practiced frequently by participants in Nadungoro. Toileting and livestock drinking both represent significant microbiological source water quality risks in Nadungoro. The water quality impact of the various domestic activities conducted at each source must be considered once the major risks are controlled (i.e. toileting and live stock drinking), particularly at the open spring sources. The implications of the seasonally varying source water practices on the source water quality require further inquiry prior to the design of local water quality interventions.

3.3.2. Source water sanitary risk inspections and assessments

Source water sanitary risk inspections were conducted at 21 sites in Chumvi, 11 sites in Ethi and 21 sites in Nadungoro. The results of the risk assessments indicated that the majority of the water sources in all three neighbourhoods were at moderate to high risk of water quality deterioration due their sanitary conditions (Figure 3.2). In general, the spring water sources in the three study neighbourhoods were at a greater risk of water quality deterioration due to their sanitary conditions compared to the rainwater and groundwater sources.

In Chumvi (*n*=14), one of the inspected spring water sources was assessed to be at low risk water quality deterioration (i.e., Headwater Spring I), while none of the spring water sources in Ethi (*n*=7) or Nadungoro (*n*=13) were assessed to be at low risk (Figure 3.4). Fourteen percent, 43% and 15% of spring water sources were assessed to be at moderate risk in Chumvi (including Headwater Spring II), Ethi, and Nadungoro, respectively, while 79%, 57% and 85% were assessed to be at high risk, respectively. It should be noted that 80% of the spring water sources in Chumvi, and 100% in both Ethi and Nadungoro, were observed at the time of the inspection to be "unprotected". Furthermore, 86% of the spring water sources in Chumvi, and 100% in both Ethi and Nadungoro, were observed to have excreta upgradient or within 15 m of the source.

In Chumvi (*n*=7), Ethi (*n*=4), and Nadungoro (*n*=8), 29% (two sites from the piped-water network), 75% (one rainwater harvesting tank, the solar-powered well and its associated tap stand) and 50% (one rainwater harvesting tank and the diesel-powered well, its associated holding tank and clinic tap stand), respectively, of the "other water sources" were determined to be at low risk of water quality deterioration (Figure 3.4b). Seventy-one percent of the other water sources in Chumvi were determined to be at moderate risk of water quality deterioration (one hand pump and four piped-water network sites), in comparison to 25% in both Ethi (one rainwater harvesting tank) and Nadungoro (one rainwater harvesting tank and the communal tap stand associated with the diesel-powered borehole). In contrast to the spring water sources, 13%, 20% and 29% of the "other water sources in Chumvi, Ethi and Nadungoro, respectively, were determined to be unprotected. Fifty-six percent, 80% and 100% of the other sources in Chumvi, Ethi and Nadungoro, respectively, were observed to have excreta within 15 m upgradient or near the source at the time of the inspection.

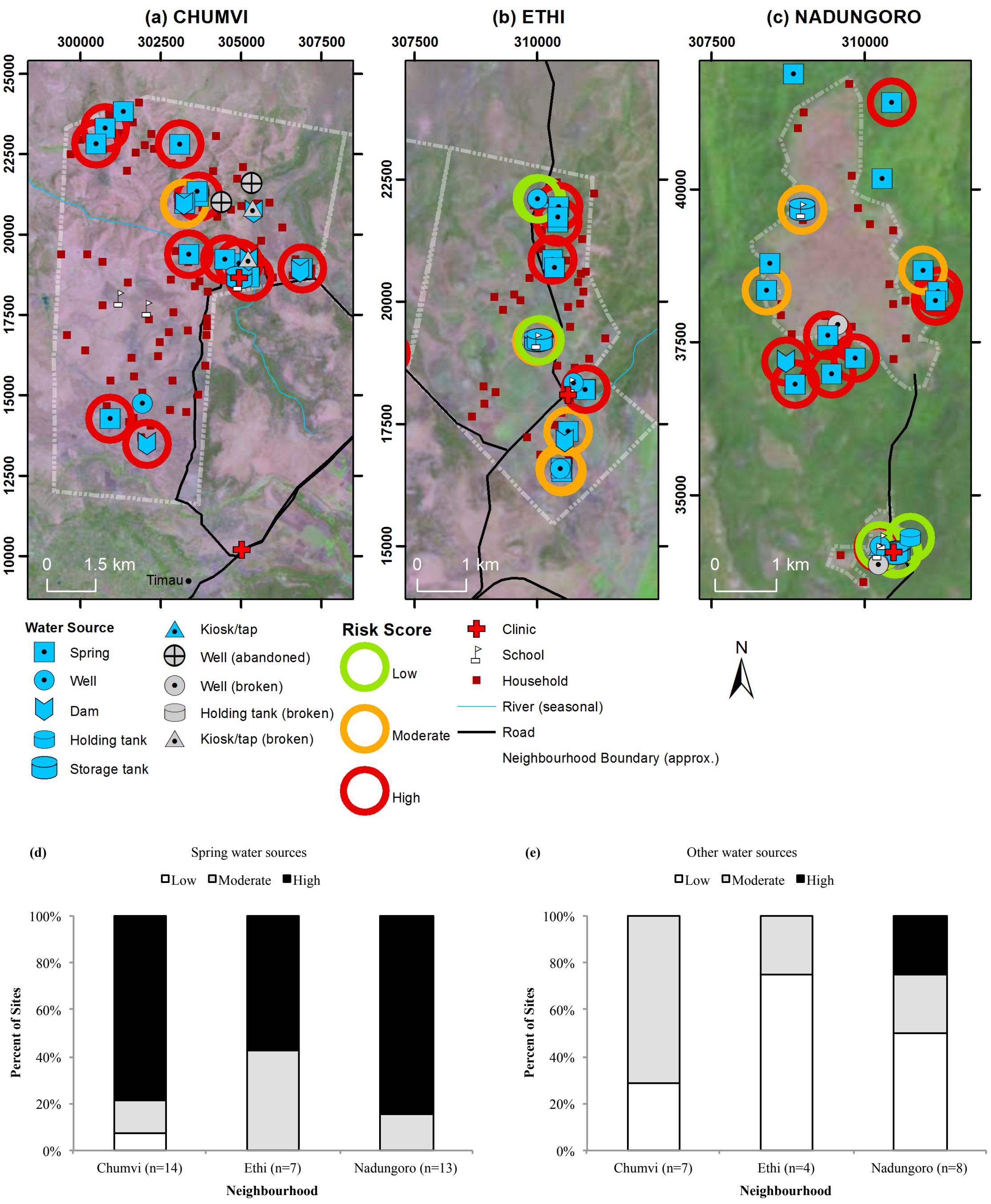


Figure 3.4 Sanitary risk scores for water sources in (a) Chumvi, (b) Ethi, and (c) Nadungoro, and the percentage of assessed, (d) spring water sources, and (e) other water sources, with low, moderate and high risk scores.

The results of the source water risk assessments indicate that the sanitary conditions at the spring water sources, including Headwater Spring II of Chumvi's piped-water network, were generally at higher risk of water quality deterioration due to their sanitary conditions than the other water sources inspected (Figure 3.4). The majority of the spring water sources were observed to be unprotected and have faecal matter adjacent to the source in the three study communities. The poor sanitary conditions represent a microbiological water quality risk at DWSC point I (Figure 3.4). Furthermore, given that a significant proportion of questionnaire participants in the three neighbourhoods indicated that they rely on open springs and the piped-water network (Table 3.4Table 3.4), the poor sanitary completion of the open springs represents a risk to community health. The other water sources were generally assessed to be at low or moderate risk of water quality deterioration due to their sanitary condition in comparison to the spring water sources. While many of the other water sources were observed to have excreta near or adjacent to the source, the increased prevalence of sanitary hardware and infrastructure would likely assist in protecting water quality from faecal contamination, contributing to their lower overall risk scores.

3.3.3. Source water quality

Fifty water samples were collected and analysed from 60 sites in the three study neighbourhoods between September 2011 and early November 2011. One rainwater tank that was reportedly only used for laundry at the dispensary in Chumvi was discarded from the results. Figure 3.5 and Figure 3.6 demonstrate the distribution of microbiological water quality criteria exceedences in comparison to the KWSRB 2009 *Guideline* in each study neighbourhood.

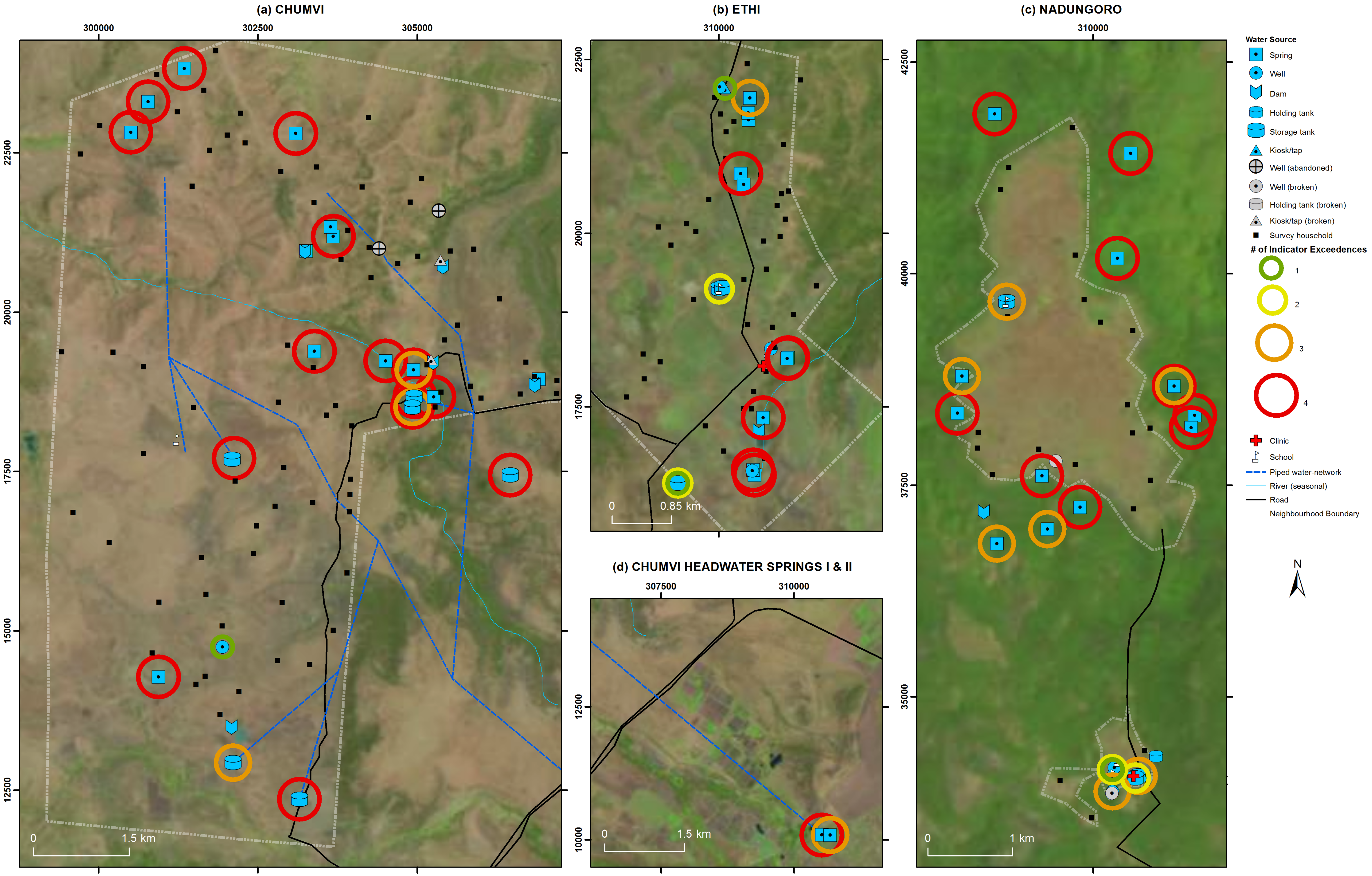
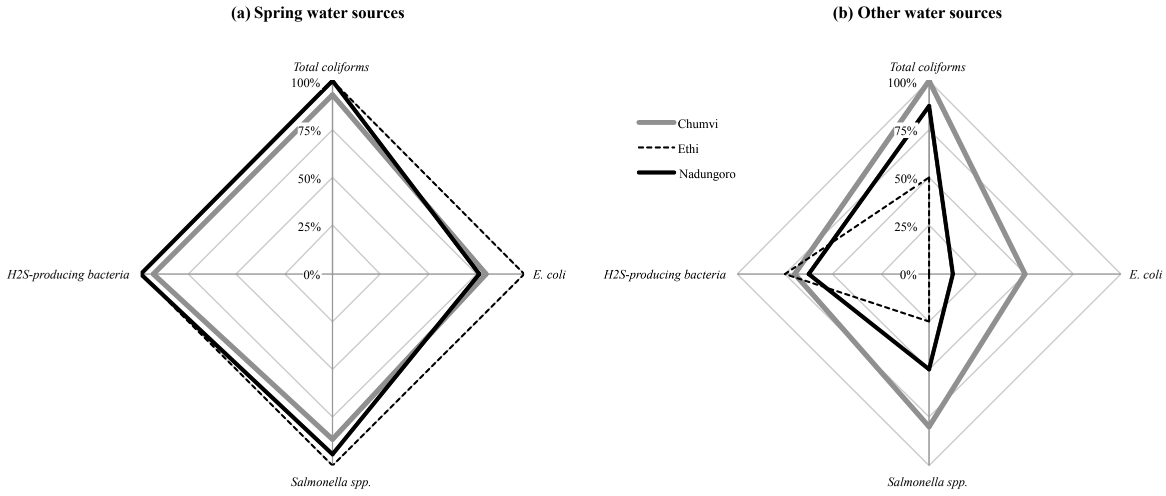


Figure 3.5 Map of the source water quality analytical results presented the by number of microbiological indicator exceedences in comparison to the KWSRB's 2009 *Guideline* in each neighbourhood: (a) Chumvi, (b) Ethi, (c), Nadungoro, and (d) Headwater Springs of Chumvi's piped-water network.


(a) Spring water sources

(b) Other water sources

Figure 3.6 Proportion of water samples from (a) spring water sources, and (b), other water sources, that exceeded the KWSRB's 2009 *Guideline* for the analysed microbiological indicators.

The results of the analysis indicate that all water samples collected and analysed from "spring water sources" and "other sources types" in the three study neighbourhoods exceeded for at least one of the four microbiological criteria analysed (Figure 3.6). Results were categorized in this fashion because the sanitary risk scores demonstrated that open springs are more vulnerable to microbiological contamination than the other types of water sources. The following subsections analyse the microbiological water quality trends by neighbourhood and by water source grouping.

3.3.3.1. Chumvi source water quality sampling and analytical results

In Chumvi, 25 samples were collected and analysed from 19 water sources. Eight open springs and the semi-protected Headwater Springs I and II were included in the "spring water sources" analysis group (Figure 3.6a). The single hand-pump well and eight down-gradient piped water network samples comprised the "other source types" group (Figure 3.6b).

Of the 10 open spring water samples collected and analysed in Chumvi, 100% exceeded for the presence of total coliforms, *Salmonella spp.* and H_2S-producing bacteria, and 90% exceeded for the presence of *E. coli.* Eighty percent of the Headwater Spring I and II samples (*n*=5) exceeded total coliforms and H_2S-producing bacteria, while 60% of the samples exceeded for *E. coli* and *Salmonella spp.*

Eight samples were collected and analysed from the downgradient piped-water network points, with 100% of the samples exceeding for total coliforms and *Salmonella spp.*, and 63% and 88%

exceeding for *E. coli* and H_2S-producing bacteria, respectively. Two samples were collected from the single hand-pump well in Chumvi. One sample was collected by passing the well water through a communal funnel present at the source to aid in filling drinking water containers, while the second sample was taken without the funnel. Both samples from the single hand-pump well exceeded only for the presence of total coliforms.

3.3.3.2. Ethi source water quality sampling and analytical results

Ten water samples were collected from eight accessible water sources in Ethi, including five open springs (*n=6)*, one rainwater tank (*n*=1), and two wells (*n*=3) (one solar-powered and one abandoned diesel-powered well). Open spring water samples were included in the "spring water sources" analysis group (Figure 3.6a), while the well water and the rainwater harvesting tank samples were included in the "other source types" group (Figure 3.6b).

In Ethi, all of the open spring water samples analysed exceeded the four microbiological criteria. The single rainwater tank sample analysed exceeded for two of four microbiological criteria (total coliforms, *Salmonella spp.*). One water sample from the diesel-powered well exceeded for total coliforms, while both samples exceeded for H_2S-producing bacteria. The single sample from the solar-powered well exceeded for H_2S-producing bacteria.

3.3.3.3. Nadungoro source water sampling and analytical results

Twenty-five water samples were collected for analysis from 22 water sources in Nadungoro. Seventeen water samples were collected from 15 open spring sources, and were included in the "spring water sources" analysis group (Figure 3.6a). One hand-pump well, two rainwater-harvesting tanks and one diesel-powered well with two tap stands were also sampled in Nadungoro, and were included in the "other source types" group (Figure 3.6b). The diesel-powered well was sampled once from the clinic tap and four times from the communal tap during two sampling events.

All 17 samples analysed from open spring sources exceeded for total coliforms and H_2S-producing bacteria, 94% exceeded for *Salmonella spp.*, and 72% exceeded for *E. coli*.

The single hand-pump well sample analysed exceeded for three of four microbiological criteria (total coliforms, *E. coli*, and H_2S-producing bacteria). It should be noted that the hand pump had reportedly sustained damage by elephants shortly prior to sampling, which may have compromised the sanitary infrastructure, leading to microbiological groundwater contamination.

The two rainwater harvesting tanks sampled also exceeded for three of four microbiological criteria (total coliforms, *Salmonella spp.* and H_2S-producing bacteria). Eighty percent of the five samples analysed from the two diesel-powered well taps exceeded for total coliforms, while 40% exceeded for *Salmonella spp*. and H_2S-producing bacteria.

3.3.3.4. Neighbourhood water quality comparison

The microbiological water quality analysis provided evidence of actual source water contamination in all three study neighbourhoods, given that all samples analysed exceeded at least one of the four microbiological criteria compared to the KWSRB *Guideline* (Figure 3.6; Figure 3.2, DWSC point I). The analytical results contrast to the sanitary risk assessment results, which were designed to evaluate the "potential" risk of contamination at a water source. One would thus expect that a water source's sanitary risk score would be proportional to its level of actual microbiological contamination. The spring water sources, which scored higher sanitary risk scores compared to other sources (Figure 3.4), also scored higher microbiological contamination scores (Figure 3.7). This trend was apparent in all three neighbourhoods.

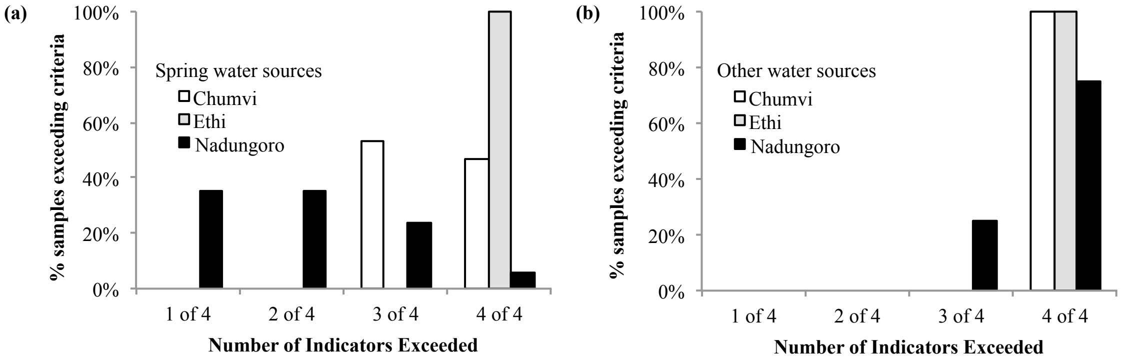


Figure 3.7. Proportion of source water samples collected from (a) "spring water sources", and (b) "other water sources", in each neighbourhood that exceeded for the analysed microbiological indicators in comparison to the KWSRB's 2009 *Guideline*.

There was more variability in the number of indicator exceedences in the "other water sources" group (Figure 3.7b) in comparison to the "spring water sources" group (Figure 3.7a). This difference between the spring water and other water sources groups can be attributed to the fact that while in theory the other water source types were all better protected than the open springs, in actuality protective infrastructure was either damaged or ineffective because of poor upstream water quality (e.g. Headwater Springs I and II of the piped-water network). Among the different classes within the "other water sources" category, the wells with associated tanks or taps (n=10) exceeded for one or two microbiological indicators. In these cases, the sanitary risks may have been rated as high due the presence of contamination hazards at the ground surface, however the protected nature of the groundwater provided some mitigation against such surficial contamination. The one chemically treated piped water network sample and the rainwater harvesting tank sample, which were grouped within the "other sources" category also exceeded for two indicators.

The consumers typically perceive the piped water to be of better quality than water from open springs, partly because of its lack of turbidity and odour. The results demonstrate however, that in many cases, the water quality at the endpoints within the piped-water network had more water quality exceedences than the source water springs (Figure 3.8), with the exception of the one chemically treated water sample.

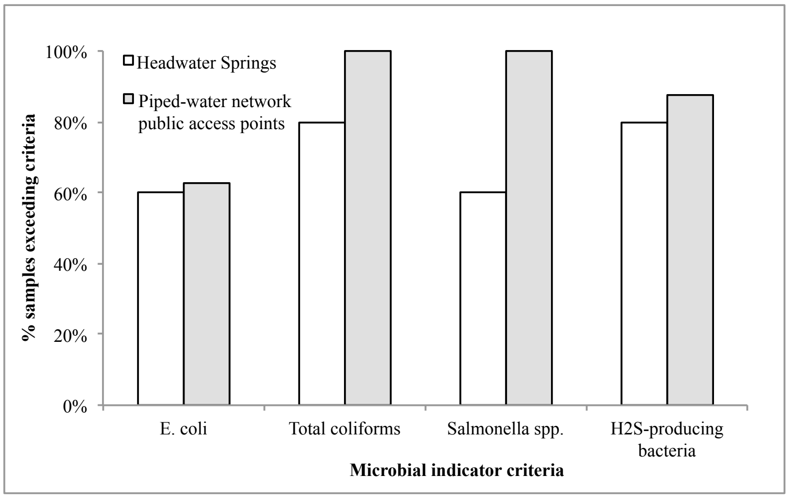


Figure 3.8 Proportion of samples collected from the Headwater Springs and the piped-water network points in Chumvi that exceeded for the analysed KWSRB 2009 *Guideline* indicators.

The results of this analysis indicate the presence of actual contamination originating from point I in the DWSC in all three neighbourhoods. The majority of samples from each neighbourhood exceeded for four of four evaluated microbiological parameters in comparison to the KWSRB's *Guideline* of 2009, which indicated that there is a high risk of the consumption of faecally contaminated drinking water within each neighbourhood if the water is not treated prior to consumption (i.e., point V in the DWSC, Figure 3.2).

3.3.4. Household sanitation and hygiene

This section presents toileting and hand washing practices in the study neighbourhoods and discusses their potential risk on household drinking water quality (DWSC points III to V, Figure 3.2).

3.3.4.1. Toileting at home

Toileting practices of the questionnaire participants' families and their young children (i.e., under four years of age) are presented in Figure 3.9. It should be noted that improved sanitation for the current study includes toileting in a latrine and the use of diapers by young children (provided excreta from the diapers is safely disposed of within a latrine), while unimproved sanitation includes open defecation in vegetation, water sources, and open pits. The results indicate that toileting locations varied both by neighbourhood and age cohort.

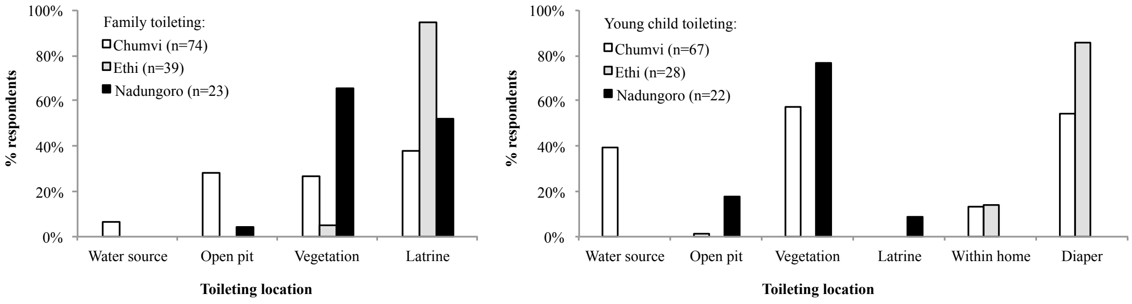


Figure 3.9 Toileting location of (a) the family, and (b) young children (3 years of age and under), in the three study neighbourhoods, where *n* is the number of question respondents.

3.3.4.1.1. *Family toileting practices*

Questionnaire participants in the three study neighbourhoods reported varying family toileting practices (Figure 3.9a). In Chumvi (*n*=74), 38% of respondents indicated that their families toileted in latrines, while 28% reported toileting open pits, 27% in vegetation, and 7% in water sources. Collectively, 38% of the respondents in Chumvi reported toileting using an improved sanitation facility, while 62% reported open defecation.

In Ethi (*n*=39), 95% of respondents reported the use a latrine (improved sanitation facility) for family toileting, and 5% reported toileting in vegetation (open defecation). Respondents in Ethi did not report any other places for family toileting.

In Nadungoro (*n*=23), 52% of respondents reported family latrine use, while 65% and 4% reported toileting in vegetation and open pits, respectively. Collectively, 52% of respondents in Nadungoro reported using an improved sanitation facility, and 70% reported practicing open defecation. Twenty-two percent of the respondents in Nadungoro reported multiple family toileting practices.

3.3.4.1.2. *Infant toileting practices*

Figure 3.9b presents the toileting location of young children (i.e., 3 years and under), as reported by questionnaire participants raising infants at the time of the questionnaire. It should be noted that 49% of the respondents in Chumvi (*n*=67) and 4% of the respondents in Nadungoro (*n*=22) provided multiple responses on this topic.

In Chumvi, 54% of respondents indicated that their young children toileted in diapers, and 57% reported toileting in vegetation, 39% in water sources, 13% in the household, and 1% in open pits. Twenty-one percent, 13% and 10% of the respondents in Chumvi reported that their young children toileted exclusively in vegetation, water sources, and diapers, respectively. Collectively, 54% of the questionnaire respondents' young children at least sometimes toileted in diapers, while 92% at least sometimes practiced open defecation.

In Ethi (*n*=28), 86% of the respondents reported that their young children defecated using diapers, and 14% reported defecation in the household. Questionnaire respondents in Ethi did not report any other infant toileting locations.

Seventy-seven percent of respondents in Nadungoro (*n*=22) indicated that their young children practiced open defecation in vegetation, and 18% reported the use of open pits. Respondents in Nadungoro did not report diaper use; rather, 9% reported the use of latrines. Only one participant indicated that her young child toileted in multiple locations (open pit and vegetation).

3.3.4.1.3. *Neighbourhood toileting comparison*

Minimum safe technologies for safe excreta exposal include the use of ventilated improved pit latrines (VIPs) and the consistent use of diapers with young children (provided that excreta in the diaper is safely disposed of within a latrine) (Carter et al. 1999; Kamat and Malkani 2003). VIPs were not observed in the study neighbourhoods, except at the Nadungoro clinic, however latrines were routinely observed.

Toileting practices were the most varied in Chumvi and the least varied in Ethi. Ethi reported the most sanitary toileting practices, with most respondents indicating that their families mostly used latrines and diapers. These improved practices are in stark contrast to those reported in Chumvi and Nadungoro, where open defecation was the most common toileting practice.

Respondents in Chumvi reported that family members and young children at least sometimes used water sources, open pits and vegetation for toileting. Many questionnaire respondents from Nadungoro also reported toileting in open pits and vegetation. Some questionnaire respondents from Nadungoro indicated that they toileted at water sources during water collection (Figure 3.3d), however they did not report that their families or young children did the same (Figure 3.9). This discrepancy requires further investigation. Nevertheless, the high reported rate of open defecation by the families and infants in Chumvi and Nadungoro represent both a direct (source water toileting) and an indirect (open pit, open defecation) pathway for the faecal contamination of source water (DWSC point I, Figure 3.2). Only 5% of respondents in Ethi reported open defecation, therefore this practice presents a lesser yet still important risk to source water quality in that neighbourhood.

Should excreta not safely disposed of, there is a risk of human hand contact with faecal matter present in the environment/household and domestic drinking water supplies during water collection and transportation (i.e., between DWSC points II and III) and during transfer from the storage container for consumption (i.e., between DWSC points III and V). For example, the presence of excreta in the household compound due to infant defecation represents an indirect risk to household drinking water quality (DWSC points II to V, Figure 3.2) due to the potential for family member exposure to the excreta by hand contact. Young children reportedly defecated within the household in Chumvi and Ethi. Although toileting in the household was not reported in Nadungoro, it is likely because it was not presented as a question response on the questionnaire. Additionally, Nadungoro was the only neighbourhood that reported the use of latrines by young children, however this toileting method seems unlikely for young children. One participant in Chumvi noted that children are not allowed to use latrines because they use them incorrectly and it is dangerous. Other community members made similar remarks at the time of fieldwork.

3.3.4.2. Family hand washing

Family hand washing practices are presented in Figure 3.10. It should be noted that 15% of respondents in Chumvi (*n*=73) and 9% of respondents in Nadungoro (*n*=23) provided multiple responses on this topic.

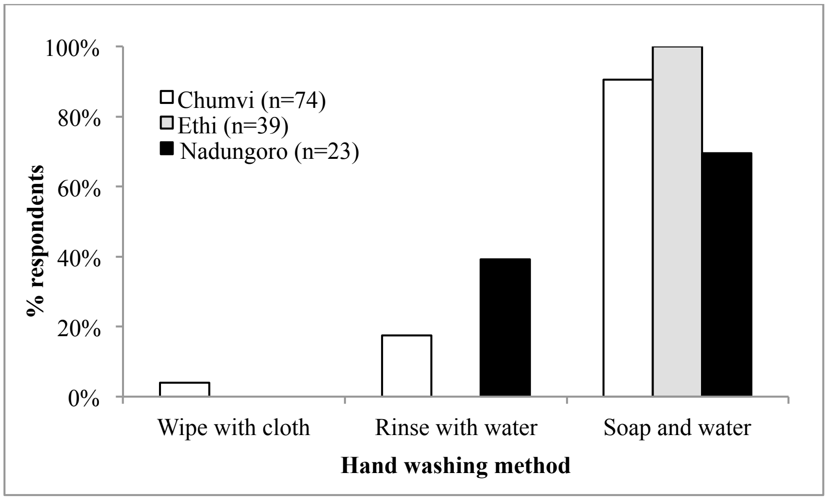


Figure 3.10 Hand washing methods practiced by the questionnaire respondents in the three study neighbourhoods, where *n* represents the number respondents to the question.

Twenty-three percent of respondents in Chumvi and 39% of respondents in Nadungoro reported less hygienic family hand washing methods, including wiping the hands or rinsing them with water. Respondents in Ethi did not report either of the two less-hygienic hand washing methods.

All questionnaire respondents in Ethi (*n*=39) reported hand washing using soap and water. Ninety-two percent of participants in Chumvi and 70% of participants in Nadungoro also reported hand washing using soap and water. It should be noted that soap was not observed in any of the study neighbourhoods during fieldwork, and one questionnaire respondent from Chumvi noted that soap is quite costly for her to purchase. Based on these observations and anecdotal evidence from conversations with community members, it suspected that the soap usage rate was over-reported due to is socially desirability over the other responses (van de Mortel 2008). The method used for elucidating soap usage requires refinement. Regardless of whether or not the soap usage rates were exaggerated in the current study, the results imply that the questionnaire participants recognize the value of hand washing with soap. Furthermore, the family hand washing method results are consistent with other findings in this study that indicate participants in the neighbourhood of Ethi are reporting the most sanitary and hygienic practices.

3.3.5. Household water quality

3.3.5.1. Household sanitary risk inspections and assessments

Seventy-two household inspections were completed in Chumvi, 39 were completed in Ethi and 18 were completed in Nadungoro. The results of the sanitary risk assessments are presented in Figure

3.11.

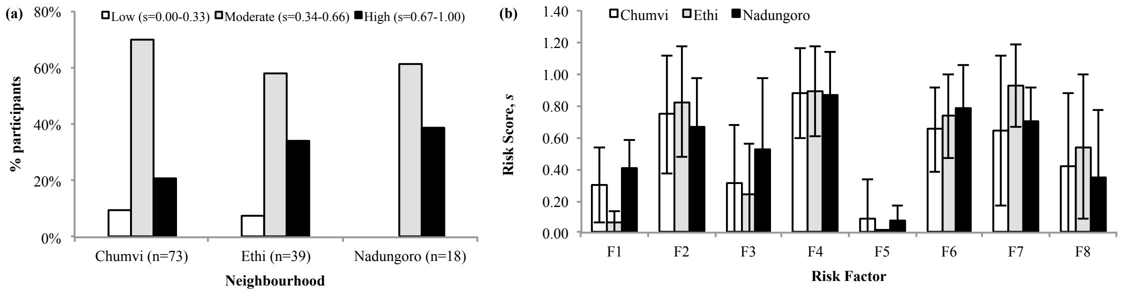


Figure 3.11 Household sanitary risk assessment scores, *s*, for *n* participants, presented (a) by proportion of participants assessed to be in the low, moderate and high risk score brackets, and (b) average risk score by risk factor in each neighbourhood.

In Chumvi, Ethi, and Nadungoro, the mean household risk scores were moderate, with scores of *s* = 0.55, *s* = 0.59 and *s* = 0.63, respectively (Figure 3.11a). In Chumvi, 10% of the assessed household water sources were determined to be at low risk, 70% at moderate risk, and 20% at high risk. In Ethi, 8% of the assessed household water sources were determined to be at low risk, 58% at moderate risk, and 34% at high risk. In Nadungoro, 0% of the household water sources were determined to be at low risk, 61% at moderate risk, and 39% at high risk.

Figure 3.11b indicated that the top two observed factors that contributed to elevated risk scores were drinking water treatment frequency/method (F4) and drinking water separation (F2) (see Table 3.2 for further risk factor descriptions). The two least frequently observed risk factors were hand washing and water retrieval (F5) and container type (F1). The greatest variations in risk factor score between neighbourhoods were container type (F1), storage location and lids (F3), plastic bag use (F7), indicating variation in the practices between the neighbourhoods.

The results of the household sanitary risk assessments in the three study neighbourhoods indicated that most household water supplies were generally at moderate or high risk of contamination due to their hygienic and sanitary conditions. The high proportion of household water supplies assessed to be in relatively poor sanitary and hygienic conditions represents a risk to water quality between DWSC points II and V (Figure 3.2).

All of the inspected households in Nadungoro were determined to be at moderate or high risk, and none at low risk. The elevated risk scores are may be due to relatively small sample size in the questionnaire.

Participants with low risk scores generally their kept their drinking water separate from the rest of their domestic water, kept lids on their drinking water storage containers, washed their hands and did not use utensils to retrieve water, and treated their drinking water using an effective methodology (e.g. boiling, chemical treatment) prior to consumption.

3.3.5.2. Household microbiological water quality

Twenty-five household water samples were collected and analysed from the three study neighbourhoods, including 15 samples from Chumvi, and 5 samples each from Ethi and Nadungoro. The analytical results were divided into two groups for odds ratio analysis: those that were analysed for four microbiological criteria, and those that were analysed for less than four microbiological criteria. Some samples were analysed for only three microbiological indicators because of inconsistencies in analysis of the *E. coli* plates by one of the analysts. The odds ratio analysis indicated that the 95% confidence interval spans 1.0, therefore the slightly increased odds of exposure (i.e. positive test result) in the 'less than four microbiological criteria' analysis group does not reach statistical significance (OR 1.3, 95% CI: 0.73-2.45). As a result, despite of the varying quantity of microbiological parameters that were evaluated within the household samples (i.e., three versus four), the sample results are comparable. The results of the microbiological water quality analysis were compared to the KWSRB's *Guidelines* of 2009, and are presented in Figure 3.12.

All water samples analysed from the three study neighbourhoods exceeded for at least one evaluated microbiological indicator. In Chumvi, 93%, 87%, 27% and 20% exceeded for the presence of total coliforms, *Salmonella spp.*, *E. coli* and H_2S-producing bacteria, respectively. In Ethi, all samples exceeded for the presence of total coliforms, and 80% and 20% exceeded for the presence of *Salmonella spp.* and H_2S-producing bacteria, respectively. In Nadungoro, 60% of the samples analysed for the presence of *Salmonella spp.* and H_2S-producing bacteria, while 40% exceeded for the presence of total coliforms. No household water samples from Ethi or Nadungoro were analysed for *E. coli.*

The results of the microbiological analyses demonstrate the presence of drinking water contamination between points III and IV in the DWSC in all three neighbourhoods (Figure 3.2). There are differences in the magnitude of the analysed indicators within the study neighbourhood samples, however due to the low number of samples in Ethi and Nadungoro, it is not possible to establish patterns or causes for the variation. It is possible that there are differences in the microbiological quality of household water in the three neighbourhoods, however more sampling and analyses would be required to elucidate the contributing factors definitively. In addition, the source water quality analysis indicated that there might be some differences in microbiological contamination risk among the three neighbourhoods. Due to the low number of household water samples, the potential relationship between household and source water quality cannot be reliably established.

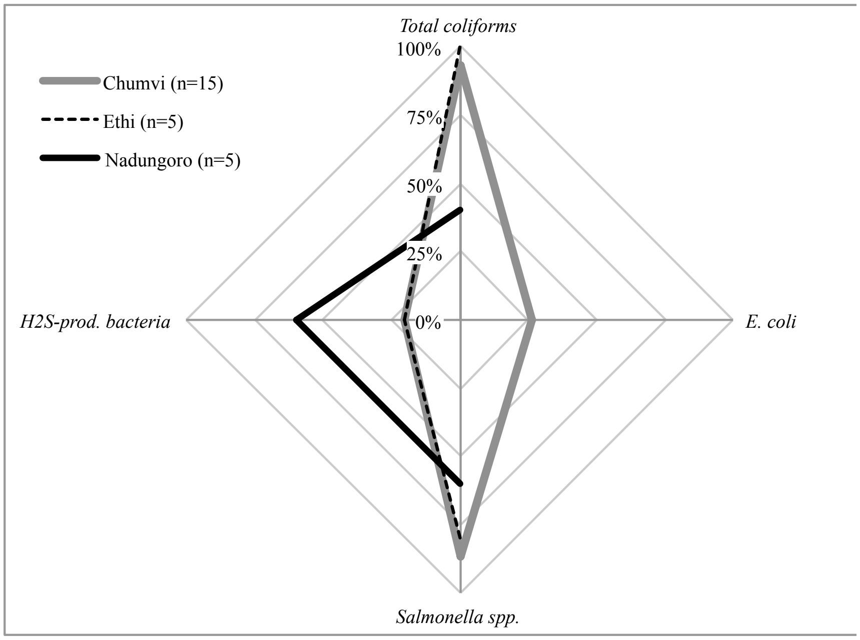


Figure 3.12 Proportion of household water samples from the three study neighbourhoods that exceeded the KWSRB’s 2009 *Guideline* for the analysed microbiological indicators.

Based on the household sanitary risk assessment results, the primary factors that are likely contributing to poor water quality, and water quality deterioration include the lack of drinking water treatment prior to consumption (discussed in Section 3.3.5.3), and the lack of safe drinking water storage (Figure 3.11b). Despite the other improved household practices reported in Ethi, such as toileting in latrines, the use of diapers, and hand washing with soap, water quality at home remained poor. The fact that these practices have not resulted in improved household water quality (Carter et al. 1999; Kamat and Malkani 2003; Carr and Strauss 2001; Cairncross et al. 2010) supports the fact that they are secondary to improving source water quality. Nevertheless, improved sanitation and household hygiene are important factors in maintaining household health and reducing the burden of water-related diseases (Kariuki et al. 2012).

3.3.5.3. Household drinking water treatment

Figure 3.13 demonstrates the frequency of household water treatment prior to consumption as reported questionnaire participants by the in the three study neighbourhoods.

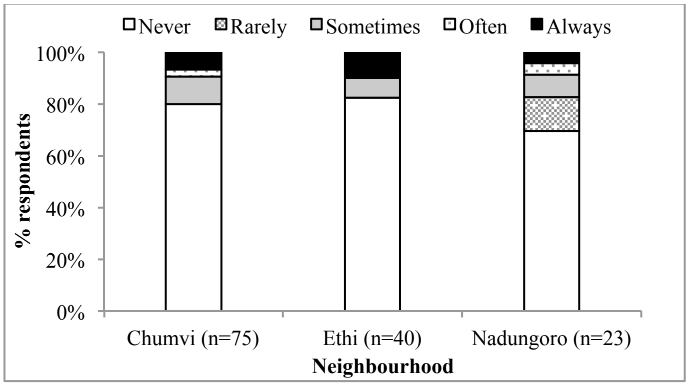


Figure 3.13 Household water treatment frequency as reported by questionnaire participants in the three study neighbourhoods, where *n* represents the number of respondents to the question.

The results of the analysis indicated that the majority of questionnaire participants in the three study neighbourhoods 'never' treated their household water prior to consumption, including 80% of respondents in Chumvi (*n*=75), 83% of respondents in Ethi (*n*=40) and 70% of respondents in Nadungoro (*n*=23). Of the respondents who reported water treatment (i.e., responses of 'rarely' to 'always') in Chumvi (*n*=15), 80% reported treatment by boiling water, 13% reported treatment by decanting, and 7% reported treatment using a chemical product. Of those who reported water treatment in Ethi (*n*=7), 86% reported treatment by boiling and 29% reported treatment using a chemical product. All respondents who reported water treatment in Nadungoro (*n*=7) reported treatment by boiling, while 14% also reported treatment by both sunlight and decanting.

The results of the water quality analysis indicated that drinking water is generally microbially contaminated at the point of consumption (Figure 3.2), regardless of source water quality (Figure 3.7 and Figure 3.12). Furthermore, the results of the sanitary risk assessments at the source water and the household points of the DWSC indicate that the majority of supplies are stored in relatively poor sanitary and/or hygienic conditions (Figure 3.4 and Figure 3.11), therefore natural attenuation prior to consumption is unlikely. Given the known water quality in the three study neighbourhoods, the general lack of water treatment prior to consumption represents a significant health concern to consumers of this water. It is interesting to note that the clinic nurse Nadungoro reported that she had been consistently promoting water treatment within the neighbourhood. This educational effort by the nurse may be reflected in the results, given that Nadungoro reported a slightly higher water treatment rate.

3.3.6. Family health self-evaluation

Figure 3.14 demonstrates the self-reported diarrhoea frequency and general health rating of the questionnaire respondents' families in the three study neighbourhoods.

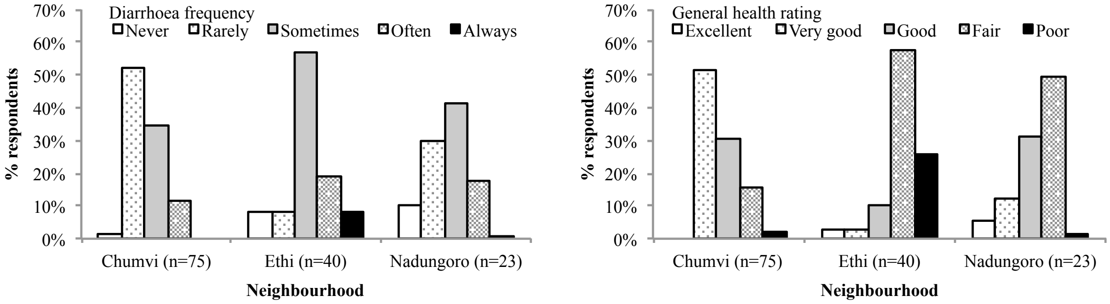


Figure 3.14 Neighbourhood family health self-evaluation as reported by questionnaire participants in the study neighbourhoods, including (a) reported diarrhoea frequency, and (b) general health.

Figure 3.14a indicates that the neighbourhood of Ethi is reporting the most frequent incidence of diarrhoea, with 27% of participants indicating that family members are 'often' or 'always' having diarrhoea. In contrast, 18% of respondents in Nadungoro and 11% of participants in Chumvi reported 'often' or 'always' having diarrhoea.

Figure 3.13b illustrates that reported health of families in the three study neighbourhoods was weighted toward the 'fair' and 'poor' end of the scale. Respondents in Ethi reported the least favourable health status, with 84% indicating that their family health was 'fair' or 'poor'. Fifty-one percent of respondents in Nadungoro and 18% of respondents in Chumvi also reported 'fair' or 'poor' family health.

The elevated diarrhoea frequency and poorer health status reported in Ethi are consistent with the findings of poor water drinking quality throughout the neighbourhood's DWSC (Figure 3.2). Nevertheless, Ethi reported the most improved household toileting and hand washing habits of the three study neighbourhoods, however it does not appear to be having a positive impact on reducing water-related diseases. This is likely due to the fact that these habits affect water quality towards the end of the DWSC; if the water is contaminated before reaching this point in the DWSC (i.e. poor source water quality), the only intervention that can improve quality is appropriate treatment.

Given that water-related diseases can cause health effects other than diarrhoea, ranging from general symptoms such as malaise and fatigue, headache, anorexia, rash and jaundice, respiratory illness and nausea, to more specific diseases such as conjunctivitis, arthritis and pharyngitis (Macler and Merkle 2000; Howard et al. 2006; Arizona Department of Health Services 2012), the nearly ubiquitous consumption of water of poor quality in the study neighbourhoods is likely contributing to the poor health reported by many of the questionnaire respondents.

It should be noted that the consumption of raw milk is reportedly common within the study community, and malaria is also a relatively common local disease. The health hazards of raw milk and malaria both represent potential confounders for water-related disease, as they cause similar symptoms such as diarrhoea, vomiting and abdominal pain, along with other symptoms of illness (United States Food and Drug Administration 2012; Mayo Foundation 2010; National Institute of Health 2009).

3.3.7. Clinic and dispensary outpatient records

The outpatient record review indicated that the dispensary in Ethi had the greatest frequency of visits due to water-related diseases in comparison to the Chumvi dispensary and the Nadungoro clinic. Twenty-nine percent of the outpatient visits at the Ethi dispensary (*n*=217) were due to water-related disease, in contrast to 18% of visits at both the Chumvi dispensary (*n*=607) and Nadungoro clinic (*n*=1231). The results of the outpatient record review were consistent with the findings of the self-reported health exercise (Figure 3.7a), given that questionnaire respondents in Ethi also reported the most frequent diarrhoea.

It must be noted that only six months of outpatient records were available for review from the dispensary in Ethi, in contrast to the 11 and 12 months available from the Chumvi dispensary and the Nadungoro clinic, respectively. Given the inconsistent timespans available for analysis, it is possible that the elevated water-related illness rate calculated for the dispensary in Ethi overlooks some seasonal variability in water-related disease. Furthermore, at the time of the fieldwork, it was reported that the Ethi dispensary had been sporadically closed due to funding inconsistencies, and was set to increase a visit cost from 100 to 200 KES. These factors may affect the data sample from the Ethi dispensary as they may have affected patient attendance.

The clinic in Nadungoro is publicly funded, therefore outpatient visit fees are subsidized and are therefore one quarter to one tenth of the cost of a visit to the dispensaries in Chumvi and Ethi

(Table 3.1). Thus, water-related illnesses in Chumvi and Ethi may be underreported due to the financial burden of a visit.

3.3.8. Water collector knowledge and attitudes

The results of problem and preference ranking Exercises A and B are presented in Table 3.5.

Table 3.5 Results of problem ranking Exercises A and B, where *R* represents the response rank, and *f* represents the response frequency for the questionnaire respondents, *n*, in the study neighbourhoods.

Responses	**Chumvi (*n*=75) *R, f***	**Ethi (*n*=40) *R, f***	**Nadungoro (*n*=23) *R, f***
Exercise A: Why do you think people get watery stomach?			
Bad or dirty water	1st, 0.20	2nd, 0.21	3rd, 0.18
Dirty hands	2nd, 0.19	1st, 0.23	4th, 0.14
Germs and parasites	3rd, 0.18	3rd, 0.16	1st, 0.21
Bad or dirty food	4th, 0.16	4th, 0.14	2nd, 0.20
Bad air	5th, 0.11	5th, 0.11	6th, 0.08
Dirty home	6th, 0.09	6th, 0.09	5th, 0.12
It happens to everyone	7th, 0.07	7th, 0.06	7th, 0.05
Spiritual reasons	8th, 0.01	8th, 0.01	8th, 0.03
Exercise B: All of these actions can help to reduce watery stomach. What would be easier to do in your family?			
Always preparing your drinking water	1st, 0.19	4th, 0.13	1st, 0.17
Going to a meeting about water and health	2nd, 0.134	3rd, 0.14	2nd, 0.16
Always using soap for dishwashing	3rd, 0.133	2nd, 0.14	8th, 0.08
Never letting your livestock near your water sources	3rd, 0.133	8th, 0.05	3rd, 0.15
Washing water containers with soap often	5th, 0.12	5th, 0.13	6th, 0.10
All family members always wash hands with soap	6th, 0.11	6th, 0.11	7th, 0.09
Collecting water that is cleaner but further from home	7th, 0.093	7th, 0.09	5th, 0.11
Joining a women's group to make/sell soap	8th, 0.090	1st, 0.21	3rd, 0.15

The results of Exercise A indicated that the questionnaire respondents in the study neighbourhoods had a relatively good understanding of the causes of the 'watery stomach', or diarrhoea. Respondents in Chumvi (*n*=75) and Ethi (*n*=60) most frequently chose 'bad or dirty water' and 'dirty hands' as the most likely causes of diarrhoea, while respondents in Nadungoro (*n*=23) chose 'germs and parasites' and 'bad or dirty food'. In the three neighbourhoods, participants chose 'it happens to everyone' and 'spiritual reasons' as the least likely causes of diarrhoea.

The results of Exercise A indicate that the questionnaire participants from Chumvi and Ethi have a thorough understanding of the relationships between waterborne and hygiene-related causes of diarrhoea, and also understand the importance of the microbiological and foodborne origins of diarrhoea. Participants from Nadungoro demonstrated a thorough understanding of the microbiological and foodborne origins of diarrhoea, and knowledge on the waterborne and hygiene-related causes of diarrhoea. During future WASH intervention efforts, an emphasis needs to be placed on applying this knowledge into improved hygienic and sanitary practices, and strategizing how the participants can encourage others in their families to improve their habits.

The results of Exercise B in Table 3.5 indicated that the three communities responded differently regarding feasible actions their households could take to reduce diarrhoea. Both Chumvi and Nadungoro found that ‘always preparing drinking water’ and ‘going to a meeting about water and health’ were the top two actions that they could take to reduce the burden of diarrhoea, while participants in Ethi responded that ‘joining a women’s group to make/sells soap’ and ‘always using soap for dishwashing’ as the most feasible actions.

In contrast, participants in Chumvi indicated that ‘collecting water that was cleaner but further from home’ and ‘joining a women’s group that makes and sells soap as the least feasible actions they could take within their households to reduce diarrhoea. Participants in Ethi also indicated that ‘collecting water that is cleaner but further from home’ was of low feasibility, along with ‘never letting their livestock near their water sources’. In Nadungoro, participants indicated that the least feasible actions to implement were to have ‘all family members always washing hands with soap’ and ‘always using soap for dishwashing’.

The results of Exercise B indicate how different neighbourhoods would prefer to approach the same issue, reducing watery stomach, by taking different actions (Table 3.5Table 3.5). For example, participants in Ethi felt strongly about ‘joining a women’s group to make/sell soap’ as their first choice among the responses given the high frequency of the response rate, however participants in Chumvi placed this as their least preferred course of action, while participants in Nadungoro responded more moderately about it.

Furthermore, given that the participants in Chumvi and Nadungoro felt willing to undertake water treatment prior to consumption to reduce diarrhoea, this option should be pursued as it can reduce drinking water contamination just prior to consumption. Nevertheless, safe water treatment practices need to be explored as boiling water inside the household using a charcoal stove can cause poor indoor air quality and related health issues.

With the exception of ‘joining a women’s group to make and sell soap’, participants in Nadungoro ranked the activities involving soap in 6th to 8th. Given its relatively remote location, accessibility to soap may be especially low in Nadungoro in comparison to the other two study communities. Accessibility to soap requires further investigation during future WASH work.

3.4. Conclusions

Based the results of the sanitary risk assessments and the microbiological water quality analyses, source water protection and improvement are needed in the three study neighbourhoods. It also became evident from the WASH KAP questionnaire that water sources were used for various purposes (i.e., bathing, toileting, livestock drinking) beyond drinking water, and the purposes varied by neighbourhood. Information on neighbourhood-scale WASH KAPs is therefore valuable in prioritizing the technical and social components in the design of source water interventions.

The results of the household sanitary risk inspections and water quality analyses indicated that the point-of-use drinking water was poor in microbiological quality for all three neighbourhoods. Effective water treatment prior to consumption was also seldom conducted. The results of the WASH KAP questionnaire indicated, however, that factors that affect water quality at home such as handling practices, hygiene, and sanitation, varied by neighbourhood, as did water collector attitudes toward household intervention approaches. Designing an intervention that increases household water treatment frequency could potentially reduce the frequency of water-related illnesses due to the consumption of the water of poor microbiological quality. The results of this study demonstrate, however, that the design of water treatment interventions could be improved by considering neighbourhood-specific handling, hygiene and sanitation practices that affect point-of-use water quality.

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Chapter 4 Conclusions and Recommendations

4.1. Overall Conclusions

The goal of this research was to develop a methodology to elucidate water quality risks at the neighbourhood-scale. This was accomplished by evaluating the varying environmental conditions in which drinking water is located and the social conditions in which it is handled. The following conclusions can be drawn based on the results of this research.

1. With the exception of livestock watering, the practices that water collectors conduct at the source water sites vary by neighbourhood. The varying practices included laundry, dishwashing, bathing, toileting, each of which pose unique water quality risks. It is important to consider these risks in the design of any source water quality intervention (i.e., at Point I of the DWSC).
2. The sanitary risk assessments indicated that water sources (i.e., point I of the DWSC) in the study neighbourhoods were generally at moderate to high risk of water quality deterioration, with the vast majority of sources observed to have faecal matter within 15 metres of the source. Water sources that had lower risk scores (i.e., wells and the piped-water network's public access points) typically had more protective infrastructure to mitigate environmental contamination to protect water quality, such as diversion ditches and concrete masonry.
3. Source water quality (i.e., point I of the DWSC) in the study neighbourhoods was generally poor, with samples analysed exceeding the KWSRB's *Guideline* for at least one of the evaluated microbiological indicators (i.e., total coliforms, *E. coli*, *Salmonella spp.* and H_2S-producing bacteria). Spring water sources, including water within the piped-water network, were consistently of poor water quality, likely because they were shared by livestock, and/or due to the lack of protective infrastructure to prevent faecal contamination. The number of water quality exceedences comparison to the KWSRB's *Guideline* in samples analysed from "other water sources" (e.g., wells and rainwater harvesting tanks) tended to be more variable. Nevertheless, well water generally had fewer indicator exceedences than all other water sources.
4. Based on the above findings, source water protection and improvement are needed in the

three study neighbourhoods, however the various other uses of the water sources, which the WASH KAP questionnaire indicated varied by neighbourhood, ought to be considered during the design of the interventions in order to secure local water quality.

5. Household sanitation practices varied by neighbourhood. Respondents in Ethi reported nearly universal family use of latrines and diapers with young children. Toileting practices were more varied in Chumvi and Nadungoro, with open defecation in open pits, water sources and vegetation being relatively common, and the use of diapers with young children less frequent. The presence of human excreta due to open defecation in the local environments of Chumvi and Nadungoro present direct (water sources) and indirect (runoff associated with open defecation) risks to source water quality (i.e., point I of the DWSC), thereby elevating the risk of human exposure to faecal matter.
6. Hand washing using soap was reportedly unanimously practiced in Ethi, and regularly practiced in both Chumvi and Nadungoro. There is some concern that the reported soap usage rate was elevated due to its social desirability. Soap was not observed or accessible for purchase during fieldwork, and some community members reported it was too costly to own.
7. The results of the household sanitary risk inspections and water quality analyses indicated that the point-of-use drinking water was poor in microbiological quality in all three neighbourhoods, and effective water treatment prior to consumption is rare. The results of the WASH KAP questionnaire indicated, however, that factors that affect water quality at home such as handling practices, hygiene, and sanitation, varied by neighbourhood, as did water collector attitudes toward household intervention approaches. Designing an intervention that increases point-of-use water treatment frequency could potentially reduce the frequency of water-related illnesses due to the consumption of the water of poor microbiological quality. The results of this study demonstrate, however, that the design of water treatment interventions could be improved by considering neighbourhood-specific handling, hygiene and sanitation practices that affect household water quality.
8. The neighbourhood of Ethi reported the most frequent incidence of diarrhoea, the poorest family health, and the highest rate of patient visits at the local dispensary for water-related diseases. This was the case despite Ethi reporting the most improved household sanitation and hygiene practices. The reasons for this discrepancy are unclear, however

the result indicates that improved hygiene and sanitation alone do not ensure improved household water quality or improved health.

9. Female water collectors in the study neighbourhoods were knowledgeable on the causes of diarrhoea, reporting the consumption of contaminated food and water, along with dirty hands and microbial contamination as the main causes of diarrhoea. This result suggests that WASH interventions to improve water quality will not be as simple as educating female water collectors on the causes of diarrhoea and water-related illnesses, but supporting the translation of this knowledge into improved sanitary and hygienic practices. Nevertheless, water collectors in the three neighbourhoods preferred different intervention approaches for mitigating diarrhoea in their households. These attitudinal differences will be important to consider in the design of sustainable intervention efforts.

4.2. Contributions

This research has produced a novel multidisciplinary methodology to assess neighbourhood-scale water quality risks throughout the DWSC, rather than at a single point within it. The use of this method supports the development of a baseline understanding of the relationship between the water in the local environment and the people who use it in order to inform more socio-culturally relevant and sustainable multi-barrier water quality interventions. The field pilot of this method indicated that the water quality risks did in fact vary at the neighbourhood-scale in the study community of Il Ngwesi based on their different knowledge, attitudes and practices regarding water, sanitation, hygiene and health. As a result, the different neighbourhoods necessitate adapted intervention approaches in order to improve local intervention sustainability. The following section presents the specific contributions made to science and engineering made by this research.

1. This research applied community development theory and Rothman's models of community intervention to the concept of how to best protect drinking water supply chain and improve water quality interventions (Chapter 2). To the best of the authors' knowledge, community development theory and water quality intervention approaches have not been integrated.
2. The methodology developed for this research integrated social and technical research methods from multiple disciplines to develop a rich picture of risks to local water quality (Chapter 2), including microbiological water quality analysis, and environmental risk

assessments, and social research including a water collector questionnaire, problem and preference ranking exercises, and a review of medical records to establish disease rates associated with local water.

3. This research provides a useful tool for elucidating in the microbiological water quality risks within the drinking water supply chain at various scales, including a single neighbourhood or community (Chapter 2), or various neighbourhoods within a single community (Chapter 3). Developing an understanding of the unique water quality risks, which vary even at the neighbourhood-scale, will inform the development evidence-based yet socio-culturally relevant WASH interventions to improve local water quality.
4. The pairwise ranking exercise used in this research presents a useful means of elucidating community member preferences regarding various potential intervention approaches (Chapters 2 and 3). The results of this exercise demonstrated that intervention approach preferences varied at the neighbourhood-scale, thereby supporting the development of informed and appropriate intervention approaches. This method could be adapted to gather information regarding various other community WASH problems in future research.

4.3. Recommendations for future work

Several recommendations for future work are made in the following section.

1. Increased community consultation, particularly with female water collectors, prior to the initiation of fieldwork and the questionnaire. Female water collectors are the most knowledgeable about where water is located in the neighbourhoods, and how it is handled. More community consultation is recommended to increase local involvement in the work, and ultimately improve the quality of the data that is collected.
2. Improve the family hand washing assessment in questionnaire in order to ensure that socially desirable responses are not being provided. Perhaps survey staff could request to see the hand washing station at the home to assess for the presence or absence of hand soap.
3. Conduct further household water quality sampling and analysis in order to elucidate whether there is variability in neighbourhood-scale point-of-use water quality.
4. Conduct focus groups with neighbourhood members in order to develop an improved understanding of local knowledge, attitudes and practices surrounding water collection

and use. For example, it would be worthwhile to investigate the varying toileting practices in the three neighbourhoods, the feasibility of separating human and livestock water sources, and the feasibility of various water treatment practices at the home. Focus groups could also be used to investigate the feasibility of water quality various intervention approaches.

Appendix A Household questionnaire

The questionnaire developed for female household water collectors is presented in Appendix A. The questionnaire is presented in the following sections:

- Preamble (Consent, Household UTM Coordinates, Drinking Water Sample Information),
- Part A (Introductory Questions);
- Part B: B1 (Households with Piped-Water), B2 (Households without Piped-Water) and B (Household Water Sources);
- Part C (Water at Home);
- Part D (Family Sanitation and Hygiene);
- Part E (Family Health);
- Part F (Household Information);
- Problem and Preference Ranking A (Community Water Source Development);
- Problem and Preference Ranking Exercise B (Causes of Diarrhoea); and,
- Problem and Preference Ranking C (Household Diarrhoea Prevention).

Il Ngwesi Baseline Water, Sanitation and Health Questionnaire for Women
Questionnaire Information

Village & Neighbourhood: ______________________________ **Date:** _____________
Team Member 1: ____________________________________ **Survey #** _____ **of today**
Team Member 2: _________________________________

Information and Consent Script

We are working with students who are here to learn about water and health in the community. They are from McMaster University and the United Nations University in Canada. We are working with the community to help develop sustainable water resources and improve community health.

We would like to ask you questions about your family's water and health. What you have to say will be used to help the community to develop safe water sources and ultimately reduce the prevalence of diarrhea. Some of the questions are personal. You do not have to answer any questions that you do not want to.

You may also be asked if we can take a water sample from your home. This water is being collected to learn about the quality of water in your community. Everything you say, and the results of the water sample will be kept private.

We know you are very busy. Participation is your choice, and it is okay to say no. We do not have money to give you. **Would you like to participate in the survey?**

Was the participant informed? ☐ Yes ☐ No
Is she willing to participate? ☐ Yes ☐ No
Signature (Team Member 1): ____
Signature (Team Member 2): ____

Boma code: - - -
Village - team initials - day of month - survey # of day; e.g.: ***C - HJ - 25 - 1***

Boma GPS coordinates: 37 N _______________ E **Elevation:** ______________ m
_______________ N

Drinking water sample	☐ Yes	☐ No
SAMPLE LABEL: Boma code - - -	Time of sampling:	
Sampled from: ☐ Container (Photo letter: _____) ☐ Tap (Piped water) ☐ Tap (Rainwater barrel)		
Sample taken from family's normal drinking water container? Notes about container/type of water sampled:	☐ Yes	☐ No
Water sampled was collected from the family's usual drinking water source? Notes about source of water sampled:	☐ Yes	☐ No

Notes and comments:

McMaster University, UN University - Water, Env., Health; Hamilton, CANADA
Waandishi /Authors: Ms. H. Barber, Mr. J. Newton

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 *If yes, continue to Part B1 (page 2)*
   b. no *If no, continue to Part B2 (page 3)*

Part B1 ~ Households With Piped Water

1 **During the dry season, how often do you receive piped water to your boma?** *(Answer in hours per day OR days per week)* Comments:	**DRY SEASON** Hours per day: ________________ OR Days per week: ____________	**…and in the WET SEASON?** 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?** Comments:	(See photos, circle all that apply.) a. b. c. d. e. f. g. h. i. j. k. l. m.

3 **During the dry season, approximately how many trips per week do you need to collect drinking water outside of your boma?** Comments:	**DRY SEASON** a. 1 b. 2 c. 3 d. 4 e. 5 or more f. other:	**…and in the WET SEASON?** a. 1 b. 2 c. 3 d. 4 e. 5 or more f. other:

Question 4 on next page…

5 **Answer YES or NO to whether the following make water collection difficult for you during the dry season?**	**DRY SEASON**			**…and in the WET SEASON?**		
Comments:		Yes	No		Yes	No
	a. finding water	☐	☐	a. finding water	☐	☐
	b. long walking distance	☐	☐	b. long walking distance	☐	☐
	c. long wait time at source	☐	☐	c. long wait time at source	☐	☐
	d. money	☐	☐	d. money	☐	☐
	e. disputes with others	☐	☐	e. disputes with others	☐	☐
	f. injury or sickness	☐	☐	f. injury or sickness	☐	☐
	g. looking after children	☐	☐	g. looking after children	☐	☐
	h. dangerous location	☐	☐	h. dangerous location	☐	☐
	i. other:___________			i. other:___________		

Part B2 ~ Homes Without Piped Water

1 **During the dry season, how often do you receive piped water to your boma?** *(Answer in hours per day OR days per week)*	**DRY SEASON**	**…and in the WET SEASON?**
	Hours per day: ________________	Hours per day: ________________
Comments:	OR Days per week: ____________	OR Days per week: ____________

2 **About how many trips per week do you make to collect drinking water for your boma in the dry season?**	**DRY SEASON**	**…and in the WET SEASON?**
Comments:		

3 **Based on the photos, what type of container(s) do you use to collect drinking water?**	(See photos, circle all that apply.) a. b. c. d. e. f. g. h. i. j. k. l. m.
Comments:	

4 **In the dry season, how many water containers do you typically fill per visit at your most often visited source?**	**DRY SEASON**	**…and in the WET SEASON?**
	a. 1	a. 1
	b. 2	b. 2
Comments:	c. 3	c. 3
	d. 4	d. 4
	e. 5	e. 5
	f. More than 5 (#________)	f. More than 5 (#________)

5 **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:**	**DRY SEASON**			**...and in the WET SEASON?**		
		Do	*Do not*		*Do*	*Do not*
	a. laundry	☐	☐	a. laundry	☐	☐
Comments:	b. dish washing	☐	☐	b. dish washing	☐	☐
	c. bathing	☐	☐	c. bathing	☐	☐
	d. washroom	☐	☐	d. washroom	☐	☐
	e. livestock grazing and drinking	☐	☐	e. livestock grazing and drinking	☐	☐
	f. socializing	☐	☐	f. socializing	☐	☐
	g. do not know			g. do not know		
	h. other:			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
Comments:	b. sometimes
	c. always
	d. do not know

7 **i. In the dry season, how often, if ever, do you use an animal to carry the water you collect home?**	**DRY SEASON**		…and in the **WET SEASON?**	
Comments:	a. never		a. never	
	b. sometimes		b. sometimes	
	c. always		c. always	
If answered thenb or c, answer 7ii.	d. do not know		d. do not know	
ii. Which type(s) of animal do you use? (Indicate all that apply)	a. donkey b. cow	c. other __________	a. donkey b. cow	c. other __________

8 **Answer YES or NO if the following activities make water collection hard for you in the dry season.**	**DRY SEASON**			…and in the **WET SEASON?**		
		Yes	**No**		**Yes**	**No**
	a. finding water	☐	☐	a. finding water	☐	☐
Comments:	b. long walking distance	☐	☐	b. long walking distance	☐	☐
	c. long wait time at source	☐	☐	c. long wait time at source	☐	☐
	d. money	☐	☐	d. money	☐	☐
	e. disputes with others	☐	☐	e. disputes with others	☐	☐
	f. injury or sickness	☐	☐	f. injury or sickness	☐	☐
	g. looking after children	☐	☐	g. looking after children	☐	☐
	h. dangerous location	☐	☐	h. dangerous location	☐	☐
	i. other:____________			i. other:____________		

Il Ngwesi Baseline Water, Sanitation and Health Questionnaire for Women
Part B1 and B2 - Water Sources

Part B ~ Question 1 and 4

Name ALL of the sources you use to collect <u>drinking water</u> in the <u>dry and wet seasons</u>?
(Check all that apply)

ETHI	*Dry*	*Wet*
1 Enchoro Olenkusero	☐	☐
2 Enchoro Moyno 1	☐	☐
3 Olenkusero Dam	☐	☐
4 Enchoro Moyno 2	☐	☐
5 Enaikishomi Kiosk 1	☐	☐
6 Encho eLekurruki	☐	☐
7 Enchoro Ekashara	☐	☐
8 Endemo Ekiama	☐	☐
9 Olekuruki	☐	☐
10 Enchoro Sharat	☐	☐
11 Ethi Centre Kiosk	☐	☐
12 Kiyaa Water Kiosk	☐	☐
13 Enchoro Olekiyaa	☐	☐
14 Enchoro Olobunga Kinoi	☐	☐
15 Kaunga Tank	☐	☐
16 Water vendor	☐	☐
17 Other: _______________	☐	☐
18 Other: _______________	☐	☐

CHUMVI	*Dry*	*Wet*
1 Enchoro Leshapa	☐	☐
2 Endemu Leshapa	☐	☐
3 Lariak lenkampi	☐	☐
4 Chumvi Enchoro 1	☐	☐
5 Chumvi Enchoro 2	☐	☐
6 Chumvi Endemu 1	☐	☐
7 Chumvi Endumu 2	☐	☐
8 Olemugur 1	☐	☐
9 Olemugur 2	☐	☐
10 Olemugur 3/Main	☐	☐
11 Endemu Entailunya	☐	☐
12 Oloipushi	☐	☐
13 Enchoro Olaitole	☐	☐
14 Olotasha Secondary	☐	☐
15 Enchoro Orantilei	☐	☐
16 Chumvi Enchoro Oolera	☐	☐
17 Endemu Engam	☐	☐
18 Enchoro Engam	☐	☐
19 Water vendor	☐	☐
20 Other: _____________	☐	☐
21 Other: _____________	☐	☐

NADUNGORO	*Dry*	*Wet*
1 Mashini	☐	☐
2 Nadungoro Nchoroi 1	☐	☐
3 Nadungoro Nchoro 2 (Teresea)	☐	☐
4 Nadungoro Enchoro Makilisia	☐	☐
5 Olendemu	☐	☐
6 Enchoro Ololopero	☐	☐
7 Nangama Little Waterfall	☐	☐
8 Enchoro Eterienkui	☐	☐
9 Enchoro Ololera	☐	☐
10 Enchoro Oloontana	☐	☐
11 Enchoro Olosikiria	☐	☐
12 Water vendor	☐	☐
13 Other: _______________	☐	☐
14 Other: _______________	☐	☐

LOKUSERO	*Dry*	*Wet*
1 Lokusero Borehole	☐	☐
2 Enchoro Lokusero	☐	☐
3 Enchoro Oledopoi	☐	☐
4 Lukuseru Borehole Tank	☐	☐
5 Clinic Borehole	☐	☐
6 Lokusero Pry Tap	☐	☐
7 Water vendor	☐	☐
8 Other: _____________	☐	☐
9 Other: _____________	☐	☐

Which souce do you visit MOST OFTEN in both the <u>dry and the wet seasons</u>?

DRY: ______________________________

WET: ______________________________

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Waandishi /Authors: Ms. H. Barber, Mr. J. Newton

Part C ~ Water at Home

1	Ask mama: ***"Would you please show me the container(s) that you store your drinking water in?"***	
i.	Using the photo album, observe: *Based on the photos, what type of container(s) is drinking* Comments:	See photos. Circle all letters that apply. a. b. c. d. e. f. g. h. i. j. k. l. m.
ii.	**How often, if ever, do you keep your drinking water in a separate container from the rest of your water?** Comments:	a. never b. rarely c. sometimes d. often e. always f. do not know
iii.	Observe: *Is a lid on all of the drinking water container(s)?*	☐ Yes ☐ No ☐ Not applicable
iv.	Observe: *Where are most of the drinking water containers located?*	☐ On ground ☐ Above ground ☐ Both

2i.	**How often, if ever, do you prepare your water before drinking it?** Comments: ** *If answered 'b' or 'c' above, then proceed to 2 ii. Otherwise proceed to 3.*	a. never b. rarely c. sometimes d. often e. always f. do not know
ii.	**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 to the right. Comments:	☐ 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, iodine) ☐ g. None of the above ☐ h. Other:
iii.	**Which way do you prepare your water MOST OFTEN?** *(Choose letter from above.)*	__________
3	Observe: *How is drinking water retrieved from storage container?* *Circle method in question 3i. below, OR ask the following question:*	a. By pouring b. By utensil (e.g., cup, ladle, pot) c. By tap d. Other: ______________________ e. do not know
i.	**How does your family most often get drinking water from the containers?**	
ii.	**Which way does your family get water from the container most often?** (Fill in corresponding letter from 3 i. above)	__________________
iii.	Observe: ***If answered b. to 3i. above,*** *is the utensil stored hygienically when not in use? (e.g., off of ground, away from animals & children)* Comments:	☐ Yes ☐ No ☐ Not applicable

4i.	**How often, if ever, do you clean the water storage container between uses?** *If answered **b** OR **c**, answer 4ii.*	a. never b. sometimes c. always d. do not know
ii.	**Tell me how you clean the water storage container.** *WAIT for the mama to TELL YOU what she does, if anything.*	
iii.	Observe: *Does the inside of the container appear to be clean?*	☐ Yes ☐ No
iv.	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 <u>most often</u> cleans their hands.** *<u>WAIT</u> for the mama to respond, do not tell her the choices* Comments:	☐ rinse with water ☐ use towel or cloth ☐ soap and water ☐ unsure ☐ does not wash hands ☐ other: ________________

2	**If you have soap in your house, what does your family use it for?** *<u>WAIT</u> for the mama to respond, do not tell her the choices* Comments:	☐ dish washing ☐ house keeping ☐ laundry ☐ bathing ☐ hand washing ☐ other: ________________ ☐ do not know

3i.	**Tell me all of the places where your family goes to the toilet when they are at home.** *<u>WAIT</u> for the mama to respond, do not tell her the choices* Comments:	☐ a. covered pit latrine ☐ b. open pit ☐ c. bush or tree ☐ d. nchoro, river, pond ☐ e. flush latrine ☐ f. do not know ☐ g. other: _____________
ii.	**Where does your family <u>most often</u> go to the toilet?** (a.-g.)	___________

4	**Where do your children under 3 years <u>most often</u> go to the toilet?** *<u>WAIT</u> for the mama to respond, do not tell her the choices* Comments:	☐ covered pit latrine ☐ open pit ☐ bush or tree ☐ nchoro, river, pond ☐ flush latrine ☐ diaper or cloth ☐ do not know ☐ other: _____________

Any other comments to add about sanitation and hygiene at home?

Part E ~ Family health

1	**How often do the following family members in your boma suffer from watery stomach?**	*Never*	*Rarely*	*Sometimes*	*Often*	*Always*	Do not know	No family member this age
	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							

Never = no diarrhea ever, ***Rarely*** = very seldom has diarrhea, ***Sometimes*** = diarrhea once and a while, ***Often*** = regularly has diarrhea, ***Always*** = person lives with diarrhea every day

2	**How would you rate the health of the following family members?**	*Excellent*	*Very good*	*Good*	*Fair*	*Poor*	Do not know	No family member this age
	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							

Excellent = person of optimal health, very rarely ill and recovers quickly; ***Very good*** = generally quite healthly and rarely ill,
Good = Health generally good, but ill regularly; ***Fair*** = Ill fairly often, recovers slowly; ***Poor*** = Usually ill, slow recovery, rarely healthy

Comments about family health:

Part F ~ Household information

1 Including yourself, what is the age and sex each person living in your boma right now?

Person	***Age***	***Sex***
Oldest		
2nd oldest		
3rd oldest		
4th oldest		
5th oldest		
6th oldest		
…		
…		
…		
Youngest		

Comments:

2 What is the highest level of school you have completed, if any?

Comments:

a. no formal schooling
b. primary school, class: ______________
c. secondary school, class: ____________
d. college/university
e. other ____________________________

3 How much money, if any, do you PERSONALLY make in a month during the dry season?

Comments:

	DRY SEASON:	**…in the WET SEASON?**
	_______	_______

4 Please answer 'Yes' or 'No' to the following statements.	**YES**	**NO**
a. I know someone I can confide in.	☐	☐
b. I know someone who listens to what I have to say.	☐	☐
c. I know someone who would help me with chores.	☐	☐
d. I know someone who would lend me money.	☐	☐
e. I know someone who would help me if I was sick.	☐	☐

5 Please answer 'Yes' or 'No' if you think any of the following are barriers for developing sustainable water resources.

	YES	**NO**
a. Money	☐	☐
b. Disagreements	☐	☐
c. Lack of rain	☐	☐
d. Community politics	☐	☐
e. Local government	☐	☐
f. National government	☐	☐
g. Water quality	☐	☐
h. Upkeep and care of new sources	☐	☐

Comments:

Il Ngwesi Baseline Water, Sanitation and Health Questionnaire for Women
Ranking Exercise A

RANKING EXERCISE A

Instructions:
For this question I will give you many choices.
Each time, tell me which choice you prefer.

Which situation would you like more if your community developed a new water source?			**B**					
			1 Gives LOTS OF WATER	**2** Is CLOSE TO HOME	**3** LITTLE or NO PREPARATION needed before drinking	**4** LOW COST to DEVELOP water source	**5** LOW COST to BUY WATER	**6** Gives CLEAN WATER
A	**1**	Gives LOTS OF WATER		1 / 2	1 / 3	1 / 4	1 / 5	1 / 6
	2	Is CLOSE TO HOME			2 / 3	2 / 4	2 / 5	2 / 6
	3	LITTLE or NO PREPARATION needed before drinking				3 / 4	3 / 5	3 / 6
	4	LOW COST to DEVELOP water source					4 / 5	4 / 6
	5	LOW COST to BUY WATER						5 / 6
	6	Gives CLEAN WATER						

Il Ngwesi Baseline Water, Sanitation and Health Questionnaire for Women
Ranking Exercise B

RANKING EXERCISE B

Instructions:
For this question I will give you many choices.
Each time, tell me which you think is more true.

Why do you think people get watery stomach?			**B**							
			1 Dirty boma	**2** Spiritual reasons (e.g. magic, curse, God, spirits)	**3** Bad or dirty food	**4** Bad or dirty water	**5** It happens to everyone	**6** Germs and parasites (bacteria, viruses, amoebas, worms)	**7** Bad air	**8** Dirty hands
A	**1**	Dirty boma		1 / 2	1 / 3	1 / 4	1 / 5	1 / 6	1 / 7	1 / 8
	2	Spiritual reasons (e.g. magic, curse, God, spirits)			2 / 3	2 / 4	2 / 5	2 / 6	2 / 7	2 / 8
	3	Bad or dirty food				3 / 4	3 / 5	3 / 6	3 / 7	3 / 8
	4	Bad or dirty water					4 / 5	4 / 6	4 / 7	4 / 8
	5	It happens to everyone						5 / 6	5 / 7	5 / 8
	6	Germs and parasites (bacteria, viruses, amoebas, worms)							6 / 7	6 / 8
	7	Bad air								7 / 8
	8	Dirty hands								

Il Ngwesi Baseline Water, Sanitation and Health Questionnaire for Women
Ranking Exercise C

RANKING EXERCISE C

Instructions:
For this question I will give you many choices.
Each time, tell me which choice is easiest for you to do with your family.

All of these actions can help to REDUCE WATERY STOMACH. **What would be EASIER TO DO IN YOUR FAMILY?**			**B**							
			1 ALL family members ALWAYS wash hands with SOAP	**2** ALWAYS using SOAP for dishwashing	**3** ALWAYS preparing your drinking water	**4** Washing WATER CONTAINERS with SOAP OFTEN	**5** Collecting water that is CLEANER but FURTHER FROM HOME	**6** NEVER letting your livestock near your water sources	**7** Going to a MEETING about water and health	**8** Joining a women's group that MAKES and SELLS SOAP
A	**1**	ALL family members ALWAYS wash hands with SOAP		1 / 2	1 / 3	1 / 4	1 / 5	1 / 6	1 / 7	1 / 8
	2	ALWAYS using SOAP for dishwashing			2 / 3	2 / 4	2 / 5	2 / 6	2 / 7	2 / 8
	3	ALWAYS preparing your drinking water				3 / 4	3 / 5	3 / 6	3 / 7	3 / 8
	4	Washing WATER CONTAINERS with SOAP OFTEN					4 / 5	4 / 6	4 / 7	4 / 8
	5	Collecting water that is CLEANER but FURTHER FROM HOME						5 / 6	5 / 7	5 / 8
	6	NEVER letting your livestock near your water sources							6 / 7	6 / 8
	7	Going to a MEETING about water and health								7 / 8
	8	Joining a women's group that MAKES and SELLS SOAP								

Appendix B Source water microbiological water quality

Source water quality analytical results are presented and compared to the Kenya Water Services Regulatory Board's (KWSRB's) *Drinking Water Quality and Effluent Monitoring Guideline Schedule 5*: *Microbiological limits for drinking water and containerized drinking water* (Source: Adopted from KS 05-459, Part 1:1996). The results are also mapped by neighbourhood, based on the number of water quality microbial indicator exceedences at each water source. It should be noted that the results for the water quality analysis and *Aeromonas spp.* are presented in the source water analytical results, however they were not discussed in Chapters 2 and 3 because the KWSRB has not set a drinking water quality limit for this microbiological contaminant.

Furthermore, it should also be noted that geographic locality of Lokusero (page 123) is a hamlet of the neighbourhood of Nadungoro.

Data table notes:

*	Microbiological drinking water limit as stated in the 2009 Kenyan Water Services Regulatory Board's *Drinking Water Quality and Effluent Monitoring Guideline Schedule 5*: *Microbiological limits for drinking water and containerized drinking water* (Source: Adopted from KS 05-459, Part 1:1996)
BOLD	Exceeds the Kenyan drinking water limit
--	No Kenyan Drinking Water Limit has been set by the Kenyan Water Services Board
H_2S	Hydrogen sulphide
a	H_2S-producing bacteria per 20 mL water sample, as recommended by Chuang et al. (2011). The Kenyan Water Services Board's *Microbiological limit for drinking water* (KS 05-459-01, Part 1:1996) for H_2S-producing bacteria is evaluated per 50 mL water sample
b	H_2S-producing bacteria per 25 mL water sample. The Kenyan Water Services Board's *Microbiological limit for drinking water* (KS 05-459-01, Part 1:1996) for H_2S-producing bacteria is evaluated per 50 mL water sample
cfu	Colony forming unit
Enchoro	Swahili word meaning "spring"
Endemu	Swahili word meaning "dam"
NA	Not analyzed
NS	Not sampled

Chumvi North and South water sources and water quality

Water sources

Source type

- ▣ Spring
- ◉ Well
- ◉ Well (broken)
- ◉ Well (abandoned)
- ⛉ Dam
- ▲ Kiosk/tap
- ▲ Kiosk/tap (broken)
- ⛁ Storage tank
- ⛁ Holding tank
- ⛁ Holding tank (broken)

Water quality

 # criteria exceeded

- ● 1
- ● 2
- ● 3
- ● 4

N

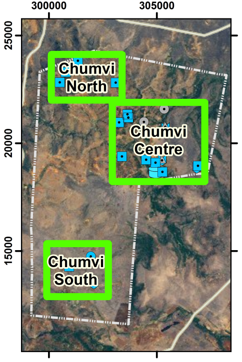
Surveyed boma (2011)

- ●
- ● Boma (2008 Census)

Community Land Area

- ☐ Community Land Area

Inset basemap



Parameter (cfu/250 mL unless otherwise indicated)	**Enchoro Olemugur I A; 11-09-26**	**Enchoro Olemugur I B; 11-09-26**
E. coli (UV)	***1,750***	***1,750***
E. coli	***1,500***	***1,750***
Total coliforms	***25,000***	***6,500***
Aeromonas spp.	17,500	16,000
Salmonella spp.	***5,500***	***3,750***
H_2S-producing bacteria[a]	***Present***	***Present***

Parameter (cfu/250 mL unless otherwise indicated)	**Enchoro Olemugur II A; 11-09-26**	**Enchoro Olemugur II B; 11-09-26**	**Enchoro Olemugur II C; 11-09-26**
E. coli (UV)	***250***	0	***500***
E. coli	***250***	0	***500***
Total coliforms	***>25,000***	***>25,000***	***>25,000***
Aeromonas spp.	>25,000	>25,000	>25,000
Salmonella spp.	***2,250***	***2,000***	***1,500***
H_2S-producing bacteria[a]	***Present***	***Present***	***Present***

Parameter (cfu/250 mL unless otherwise indicated)	**Enchoro Olemugur Main A; 11-09-26**	**Enchoro Olemugur Main B; 11-09-26**	**BLANK Enchoro Olemugur Main; 11-09-26**
E. coli (UV)	***250***	***500***	0
E. coli	***250***	***>25,000***	0
Total coliforms	***>25,000***	***>25,000***	0
Aeromonas spp.	>25,000	>25,000	0
Salmonella spp.	0	***3,500***	0
H_2S-producing bacteria[a]	***Present***	***Present***	Absent

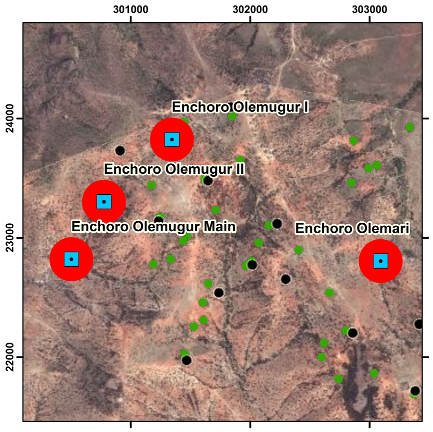
Parameter (cfu/250 mL unless otherwise indicated)	**Enchoro Olemari A; 11-09-23**	**Enchoro Olemari B; 11-09-23**	**BLANK Enchoro Olemari; 11-09-23**
E. coli (UV)	***250***	***250***	*0*
E. coli	***250***	***250***	*0*
Total coliforms	***>25,000***	***>25,000***	***500***
Aeromonas spp.	>25,000	>25,000	0
Salmonella spp.	***20,250***	***21,250***	0
H_2S-producing bacteria[a]	***Present***	***Present***	Absent

Parameter (cfu/250 mL unless otherwise indicated)	**Oloipushi Handpump A; 11-09-27**	**Oloipushi Handpump B; 11-09-27**	**BLANK Oloipushi Handpump; 11-09-27**
E. coli (UV)	0	0	0
E. coli	0	0	0
Total coliforms	0	***100***	0
Aeromonas spp.	0	0	0
Salmonella spp.	0	0	0
H_2S-producing bacteria[a]	Absent	Absent	Absent

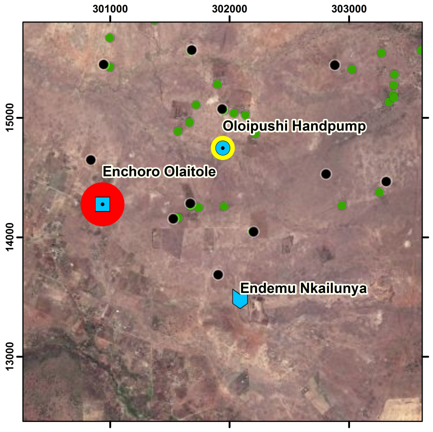
Parameter (cfu/250 mL unless otherwise indicated)	**Enchoro Olaitole A; 11-09-27**	**Enchoro Olaitole B; 11-09-27**	**Enchoro Olaitole C; 11-09-27**
E. coli (UV)	***1,500***	***1,750***	***1,250***
E. coli	***1,750***	***2,000***	***500***
Total coliforms	***10,000***	***25,000***	***15,750***
Aeromonas spp.	>25,000	>25,000	>25,000
Salmonella spp.	***10,250***	***16,500***	***14,750***
H_2S-producing bacteria[a]	***Present***	***Present***	***Present***

Parameter (cfu/250 mL unless otherwise indicated)	**Sample ID; Date sampled (yy-mm-dd)**
	Kenyan drinking water limit*
E. coli	Shall be absent
Total coliforms	Shall be absent
Aeromonas spp.	--
Salmonella spp.	Shall be absent
H_2S-producing bacteria[a,b]	Shall be absent

Chumvi North



Chumvi South



Chumvi Centre water sources and water quality

Water sources

- ▣ Spring
- ▭ Storage tank
- ▬ Holding tank
- ▲ Kiosk/tap
- ▼ Dam
- ⊙ Well
- ⊙ Well (abandoned)
- ⊙ Well (broken)
- ▲ Kiosk/tap (broken)
- ▬ Holding tank (broken)

Water quality

 # criteria exceeded

- ● 1
- ● 2
- ● 3
- ● 4

N

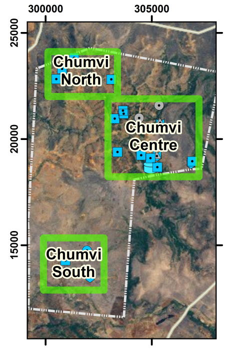
Surveyed boma (2012)

- ●
- ● Boma (2008 Census)

Clinic

- ✚
- ⚐ School
- ☐ Community Land Area

Inset basemap

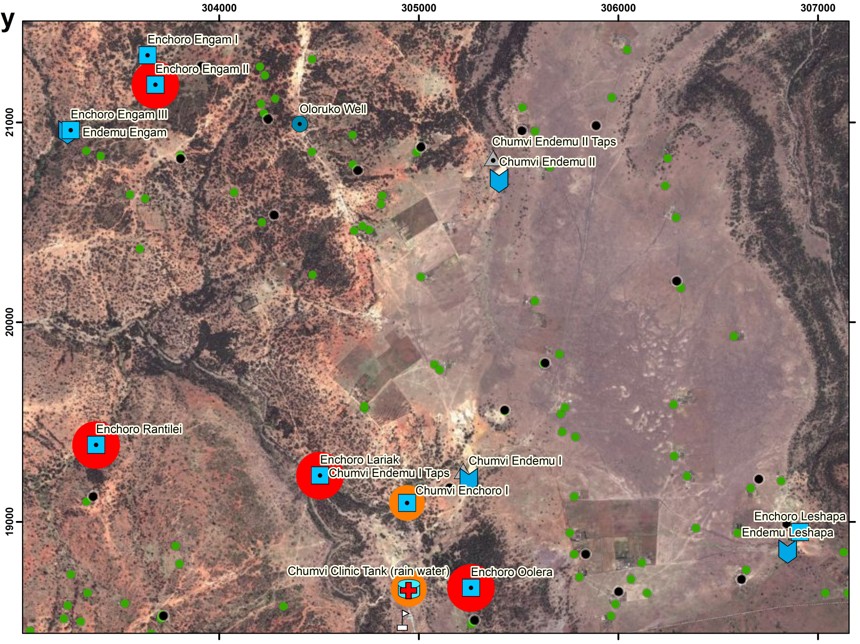


Parameter (cfu/250 mL unless otherwise indicated)	**Sample ID; Date sampled (yy-mm-dd)** **Kenyan drinking water limit***
E. coli	Shall be absent
Total coliforms	Shall be absent
Aeromonas spp.	--
Salmonella spp.	Shall be absent
H_2S-producing bacteria[a,b]	Shall be absent

Parameter (cfu/250 mL unless otherwise indicated)	**Enchoro Engam II A; 11-09-29**	**Enchoro Engam II B; 11-09-29**
E. coli (UV)	***2,250***	***2,000***
E. coli	***1,500***	***1,750***
Total coliforms	***9,250***	***6,750***
Aeromonas spp.	>25,000	>25,000
Salmonella spp.	***1,000***	***750***
H_2S-producing bacteria[a]	***Present***	***Present***

Parameter (cfu/250 mL unless otherwise indicated)	**Enchoro Rantilei A; 11-09-27**	**Enchoro Rantilei B; 11-09-27**
E. coli (UV)	***3,250***	***2,000***
E. coli	***3,250***	***3,250***
Total coliforms	***>25,000***	***>25,000***
Aeromonas spp.	>25,000	>25,000
Salmonella spp.	***9,250***	***3,000***
H_2S-producing bacteria[a]	***Present***	***Present***

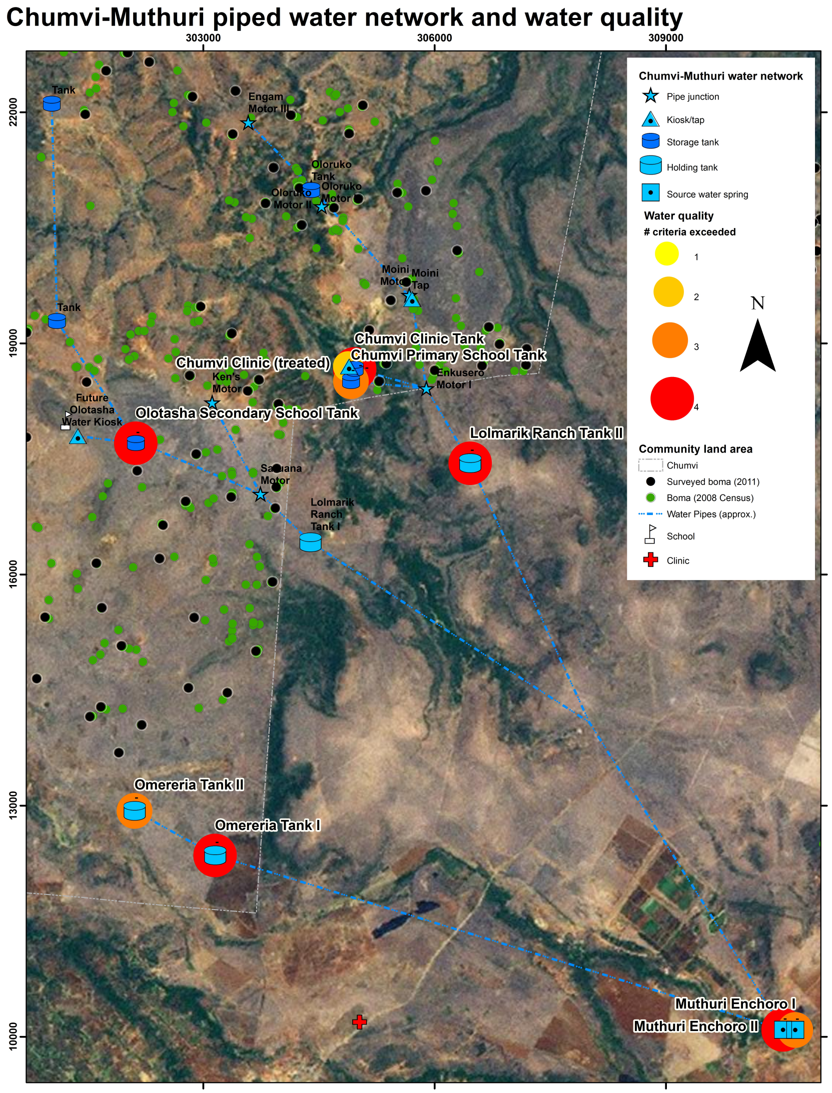
Parameter (cfu/250 mL unless otherwise indicated)	**Enchoro Lariak A; 11-10-31**	**Enchoro Lariak B; 11-10-31**
E. coli (UV)	***250***	***333***
E. coli	0	***167***
Total coliforms	***>8,333***	***>8,333***
Aeromonas spp.	>8,333	>8,333
Salmonella spp.	***6,417***	***7,167***
H_2S-producing bacteria[a]	***Present***	***Present***



Parameter (cfu/250 mL unless otherwise indicated)	**Chumvi Enchoro I A; 11-10-31**	**Chumvi Enchoro I B; 11-10-31**
E. coli (UV)	***2,750***	***2,583***
E. coli	0	0
Total coliforms	***>8,333***	***>8,333***
Aeromonas spp.	>8,333	>8,333
Salmonella spp.	***>8,333***	***>8,333***
H_2S-producing bacteria[a]	***Present***	***Present***

Parameter (cfu/250 mL unless otherwise indicated)	**Chumvi Enchoro I A; 11-09-28**	**Chumvi Enchoro I B; 11-09-28**
E. coli (UV)	***250***	***250***
E. coli	***250***	***250***
Total coliforms	***7,500***	***6,750***
Aeromonas spp.	14,500	18,250
Salmonella spp.	***1,000***	0
H_2S-producing bacteria[a]	***Present***	***Present***

Parameter (cfu/250 mL unless otherwise indicated)	**Oloolera A; 11-10-05**	**Oloolera B; 11-10-05**
E. coli (UV)	***750***	***500***
E. coli	***750***	***250***
Total coliforms	***26,500***	***27,750***
Aeromonas spp.	7,750	8,250
Salmonella spp.	***1,250***	***1,750***
H_2S-producing bacteria[a]	***Present***	***Present***



Chumvi-Muthuri piped water network and water quality

Parameter (cfu/250 mL unless otherwise indicated)	Sample ID; Date sampled (yy-mm-dd) / Kenyan drinking water limit*
E. coli	Shall be absent
Total coliforms	Shall be absent
Aeromonas spp.	--
Salmonella spp.	Shall be absent
H$_2$S-producing bacteria^{a,b}	Shall be absent

Parameter (cfu/250 mL unless otherwise indicated)	Chumvi Primary School Tank A; 11-09-28	Chumvi Primary School Tank B; 11-09-28	Chumvi Primary School Tank C; 11-09-28
E. coli (UV)	0	***100***	0
E. coli	0	***100***	0
Total coliforms	***4,650***	***>5,000***	***5,250***
Aeromonas spp.	450	450	450
Salmonella spp.	***250***	***50***	***350***
H$_2$S-producing bacteria^{a}	***Present***	***Present***	***Present***

Parameter (cfu/250 mL unless otherwise indicated)	Chumvi Clinic Tank A; 11-09-26	Chumvi Clinic Tank B; 11-09-26
E. coli (UV)	***150***	0
E. coli	***150***	0
Total coliforms	***>25,000***	***>25,000***
Aeromonas spp.	>25,000	>25,000
Salmonella spp.	***300***	***300***
H$_2$S0producing bacteria^{a}	***Present***	***Present***

Parameter (cfu/250 mL unless otherwise indicated)	Chumvi Clinic Treated A; 11-10-31	Chumvi Clinic Treated B; 11-10-31	Chumvi Clinic Treated C; 11-10-31
E. coli (UV)	0	0	0
E. coli	0	0	0
Total coliforms	0	***50***	***50***
Aeromonas spp.	50	0	0
Salmonella spp.	***50***	***50***	0
H$_2$S-producing bacteria^{a}	Absent	Absent	Absent

Parameter (cfu/250 mL unless otherwise indicated)	Olotasha Secondary School Tank A; 11-09-27	Olotasha Secondary School Tank B; 11-09-27
E. coli (UV)	0	0
E. coli	0	***250***
Total coliforms	***3,750***	***3,400***
Aeromonas spp.	>5,000	>5,000
Salmonella spp.	***350***	***250***
H$_2$S-producing bacteria^{a}	***Present***	***Present***

Parameter (cfu/250 mL unless otherwise indicated)	Lolmarik Storage Tank II A; 11-10-27	Lolmarik Storage Tank II B; 11-10-27	Lolmarik Storage Tank II C; 11-10-27	BLANK Lolmarik Storage Tank II; 11-10-27
E. coli (UV)	***300***	***250***	***100***	0
E. coli	***100***	***150***	***50***	0
Total coliforms	***>5,000***	***>5,000***	***>5,000***	0
Aeromonas spp.	>5,000	>5,000	>5,000	0
Salmonella spp.	***1,850***	***1,900***	***1,000***	0
H$_2$S-producing bacteria^{a}	***Present***	***Present***	***Present***	Absent

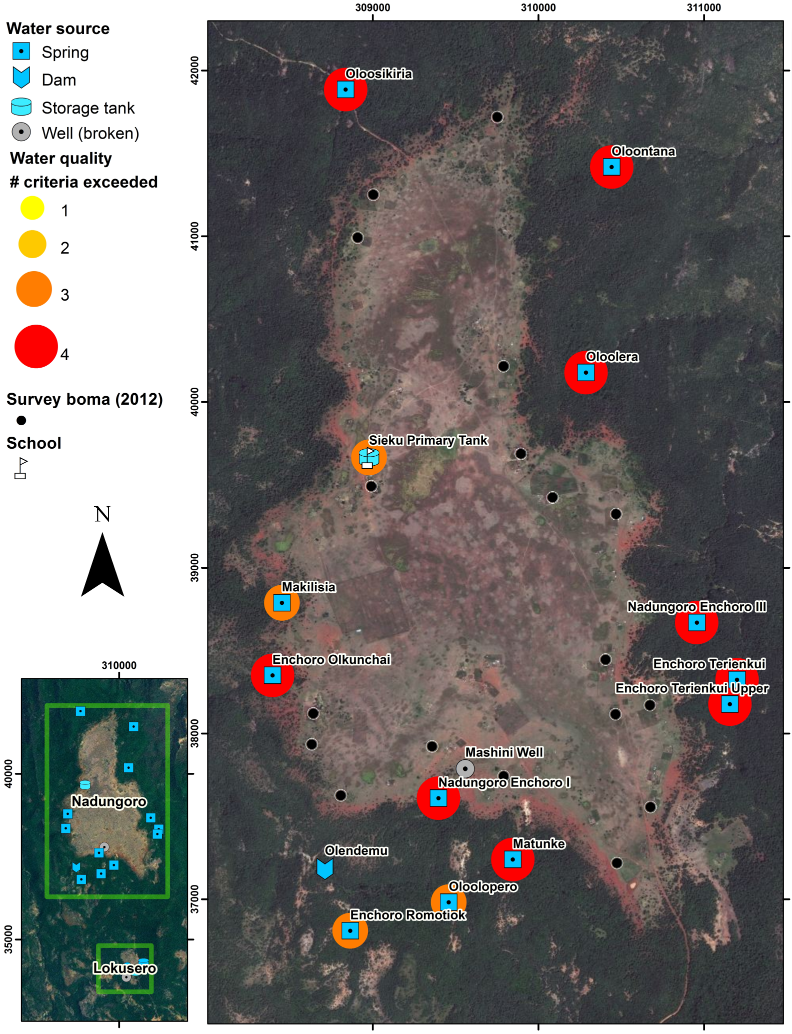
Parameter (cfu/250 mL unless otherwise indicated)	Omereria Tank I A; 11-09-23	Omereria Tank I B; 11-09-23
E. coli (UV)	***50***	***100***
E. coli	***50***	***100***
Total coliforms	***>5,000***	***>5,000***
Aeromonas spp.	>5,000	>5,000
Salmonella spp.	***3,350***	***4,250***
H$_2$S-producing bacteria^{a}	***Present***	***Present***

Parameter (cfu/250 mL unless otherwise indicated)	Omereria Tank II A; 11-09-27	Omereria Tank II B; 11-09-27
E. coli (UV)	0	0
E. coli	0	0
Total coliforms	***>5,000***	***>5,000***
Aeromonas spp.	3,550	>5,000
Salmonella spp.	***>5,000***	***>5,000***
H$_2$S-producing bacteria^{a}	***Present***	***Present***

Parameter (cfu/250 mL unless otherwise indicated)	Muthuri Enchoro I A; 11-09-29	Muthuri Enchoro I B; 11-09-29	Muthuri Enchoro I C; 11-09-29	BLANK Muthuri Enchoro I; 11-09-29
E. coli (UV)	0	0	0	0
E. coli	0	0	0	0
Total coliforms	***14,000***	***>12,000***	***>12,000***	0
Aeromonas spp.	7,875	7,000	8,875	0
Salmonella spp.	0	***625***	0	0
H$_2$S-producing bacteria^{a}	***Present***	***Present***	***Present***	Absent

Parameter (cfu/250 mL unless otherwise indicated)	Muthuri Enchoro II A; 11-10-27	Muthuri Enchoro II B; 11-10-27	Muthuri Enchoro II C; 11-10-27	BLANK Muthuri Enchoro II; 11-10-27
E. coli (UV)	***50***	***100***	0	0
E. coli	***150***	***50***	0	0
Total coliforms	***>5,000***	***>5,000***	***>5,000***	0
Aeromonas spp.	>5,000	>5,000	>5,000	0
Salmonella spp.	***>5,000***	***>5,000***	***>5,000***	0
H$_2$S-producing bacteria^{a}	***Present***	***Present***	***Present***	Absent

Nadungoro water sources and water quality



Parameter (cfu/250 mL unless otherwise indicated)	**Sample ID; Date sampled (yy-mm-dd)**
	Kenyan drinking water limit*
E. coli	Shall be absent
Total coliforms	Shall be absent
Aeromonas spp.	--
Salmonella spp.	Shall be absent
H_2S-producing bacteria[a,b]	Shall be absent

Parameter (cfu/250 mL unless otherwise indicated)	**Oloosikiria A; 11-10-05**	**Oloosikiria B; 11-10-05**
E. coli (UV)	***750***	***1,750***
E. coli	***500***	***1,250***
Total coliforms	***>25,000***	***>25,000***
Aeromonas spp.	>25,000	>25,000
Salmonella spp.	***4,250***	***7,000***
H_2S-producing bacteria[a]	***Present***	***Present***

Parameter (cfu/250 mL unless otherwise indicated)	**Oloontana A; 11-10-05**	**Oloontana B; 11-10-05**	**BLANK Oloontana; 11-10-05**
E. coli (UV)	***4,500***	***3,750***	0
E. coli	***500***	0	0
Total coliforms	***>25,000***	***>25,000***	0
Aeromonas spp.	>25,000	>25,000	0
Salmonella spp.	***>25,000***	***>25,000***	0
H_2S-producing bacteria[a]	***Present***	***Present***	Absent

Parameter (cfu/250 mL unless otherwise indicated)	**Enchoro Oolera A; 11-09-28**	**Enchoro Oolera B; 11-09-28**	**Enchoro Oolera C; 11-09-28**
E. coli (UV)	***7,750***	***6,000***	***9,000***
E. coli	***8,500***	***6,000***	***5,000***
Total coliforms	***>25,000***	***>25,000***	***>25,000***
Aeromonas spp.	>25,000	18,000	>25,000
Salmonella spp.	***12,750***	***14,250***	***14,250***
H_2S-producing bacteria[a]	***Present***	***Present***	***Present***

Parameter (cfu/250 mL unless otherwise indicated)	**Sieku Primary Tank A; 11-10-06**	**Sieku Primary Tank B; 11-10-06**	**Sieku Primary Tank C; 11-10-06**
E. coli (UV)	0	0	0
E. coli	0	0	0
Total coliforms	***1,500***	***1,188***	***1,500***
Aeromonas spp.	188	375	250
Salmonella spp.	***813***	***1,313***	***625***
H_2S-producing bacteria[a]	***Present***	***Present***	***Present***

Parameter (cfu/250 mL unless otherwise indicated)	**Makilisia A; 11-10-05**	**Makilisia B; 11-10-05**	**Makilisia C; 11-10-05**
E. coli (UV)	***1,250***	***250***	***750***
E. coli	***250***	0	0
Total coliforms	***>25,000***	***>25,000***	***>25,000***
Aeromonas spp.	>25,000	>25,000	>25,000
Salmonella spp.	***>25,000***	***>25,000***	***>25,000***
H_2S-producing bacteria[a]	***Present***	***Present***	***Present***

Parameter (cfu/250 mL unless otherwise indicated)	**Nadungoro Enchoro III A; 11-09-30**	**Nadungoro Enchoro III B; 11-09-30**
E. coli (UV)	***750***	***500***
E. coli	***1,250***	***250***
Total coliforms	***>25,000***	***>25,000***
Aeromonas spp.	>25,000	>25,000
Salmonella spp.	***8,500***	***11,250***
H_2S-producing bacteria[a]	***Present***	***Present***

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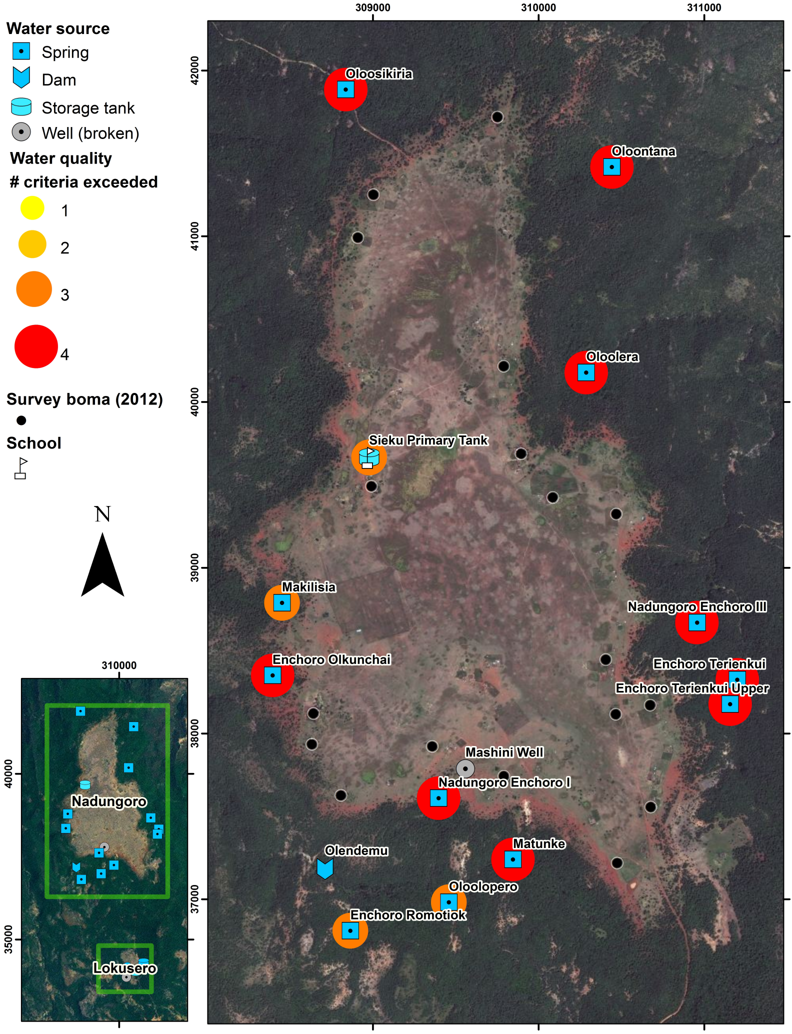
Nadungoro water sources and water quality



Parameter (cfu/250 mL unless otherwise indicated)	**Sample ID;** **Date sampled (yy-mm-dd)** **Kenyan drinking water limit***
E. coli	Shall be absent
Total coliforms	Shall be absent
Aeromonas spp.	--
Salmonella spp.	Shall be absent
H_2S-producing bacteria[a,b]	Shall be absent

Parameter (cfu/250 mL unless otherwise indicated)	**Enchoro Olkunchai A; 11-09-30**	**Enchoro Olkunchai B; 11-09-30**
E. coli (UV)	***250***	0
E. coli	***250***	0
Total coliforms	***4,750***	***2,750***
Aeromonas spp.	11,500	10,500
Salmonella spp.	***500***	***250***
H_2S-producing bacteria[a]	***Present***	***Present***

Parameter (cfu/250 mL unless otherwise indicated)	**Enchoro Terienkui A; 11-10-05**	**Enchoro Terienkui B; 11-10-05**	**Enchoro Terienkui C; 11-10-05**
E. coli (UV)	***2,000***	***3,500***	***3,000***
E. coli	***2,000***	***2,750***	***3,500***
Total coliforms	***>25,000***	***>25,000***	***20,250***
Aeromonas spp.	>25,000	20,250	21,000
Salmonella spp.	***4,750***	***1,750***	***4,750***
H_2S-producing bacteria[a]	***Present***	***Present***	***Present***

Parameter (cfu/250 mL unless otherwise indicated)	**Enchoro Terienkui Upper A; 11-10-05**	**Enchoro Terienkui Upper B; 11-10-05**	**BLANK Enchoro Terienkui Upper; 11-10-05**
E. coli (UV)	***1,000***	***1,000***	0
E. coli	***1,000***	***750***	0
Total coliforms	***>25,000***	***>25,000***	0
Aeromonas spp.	14,000	13,250	0
Salmonella spp.	***3,750***	***5,250***	0
H_2S-producing bacteria[a]	***Present***	***Present***	Absent

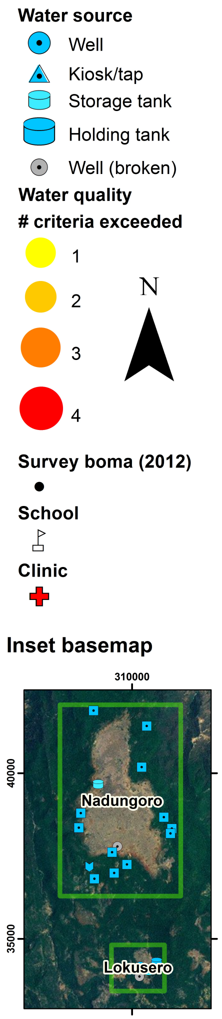
Parameter (cfu/250 mL unless otherwise indicated)	**Nadungoro Enchoro I A; 11-09-30**	**Nadungoro Enchoro I B; 11-09-30**
E. coli (UV)	0	0
E. coli	0	0
Total coliforms	***19,750***	***>25,000***
Aeromonas spp.	10,500	7,500
Salmonella spp.	***1,000***	***1,500***
H_2S-producing bacteria[a]	***Present***	***Present***

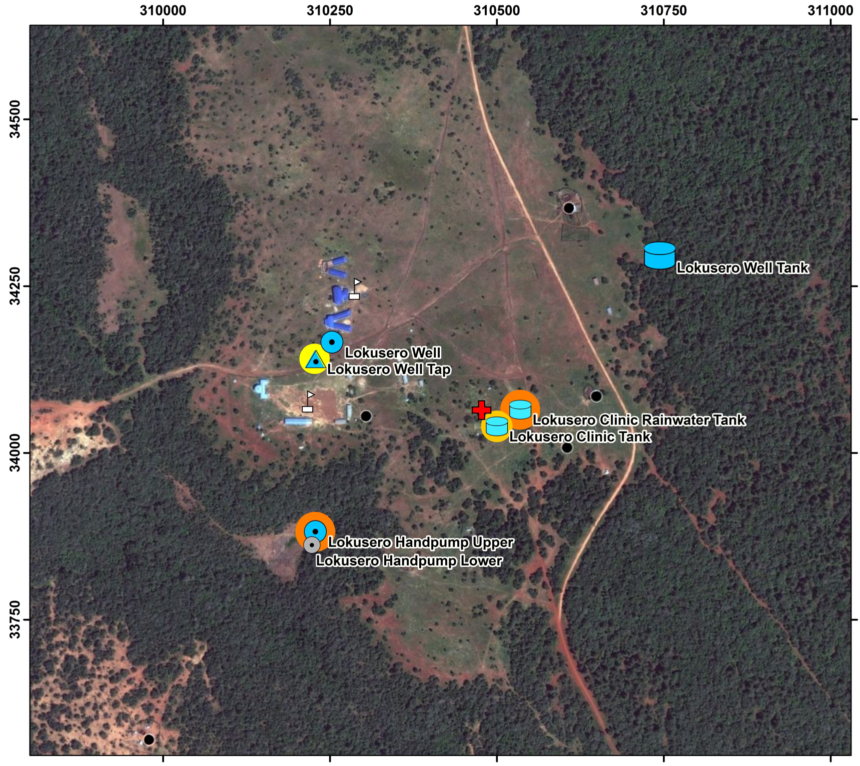
Parameter (cfu/250 mL unless otherwise indicated)	**Matunke A; 11-10-05**	**Matunke B; 11-10-05**	**BLANK Matunke; 11-10-05**
E. coli (UV)	***3,000***	***4,000***	0
E. coli	***250***	***500***	0
Total coliforms	***>25,000***	***>25,000***	0
Aeromonas spp.	>25,000	>25,000	0
Salmonella spp.	***23,250***	***>25,000***	0
H_2S-producing bacteria[a]	***Present***	***Present***	Absent

Parameter (cfu/250 mL unless otherwise indicated)	**Oloolopero A; 11-10-06**	**Oloolopero B; 11-10-06**
E. coli (UV)	***500***	NA
E. coli	***500***	NA
Total coliforms	***19,750***	NA
Aeromonas spp.	7,500	NA
Salmonella spp.	0	NA
H_2S-producing bacteria[a]	***Present***	***Present***

Parameter (cfu/250 mL unless otherwise indicated)	**Enchoro Romotiok A; 11-10-06**	**Enchoro Romotiok B; 11-10-06**
E. coli (UV)	0	0
E. coli	0	0
Total coliforms	***6,250***	***12,750***
Aeromonas spp.	4,500	6,000
Salmonella spp.	0	***250***
H_2S-producing bacteria[a]	***Present***	***Present***

Lokusero water sources and water quality





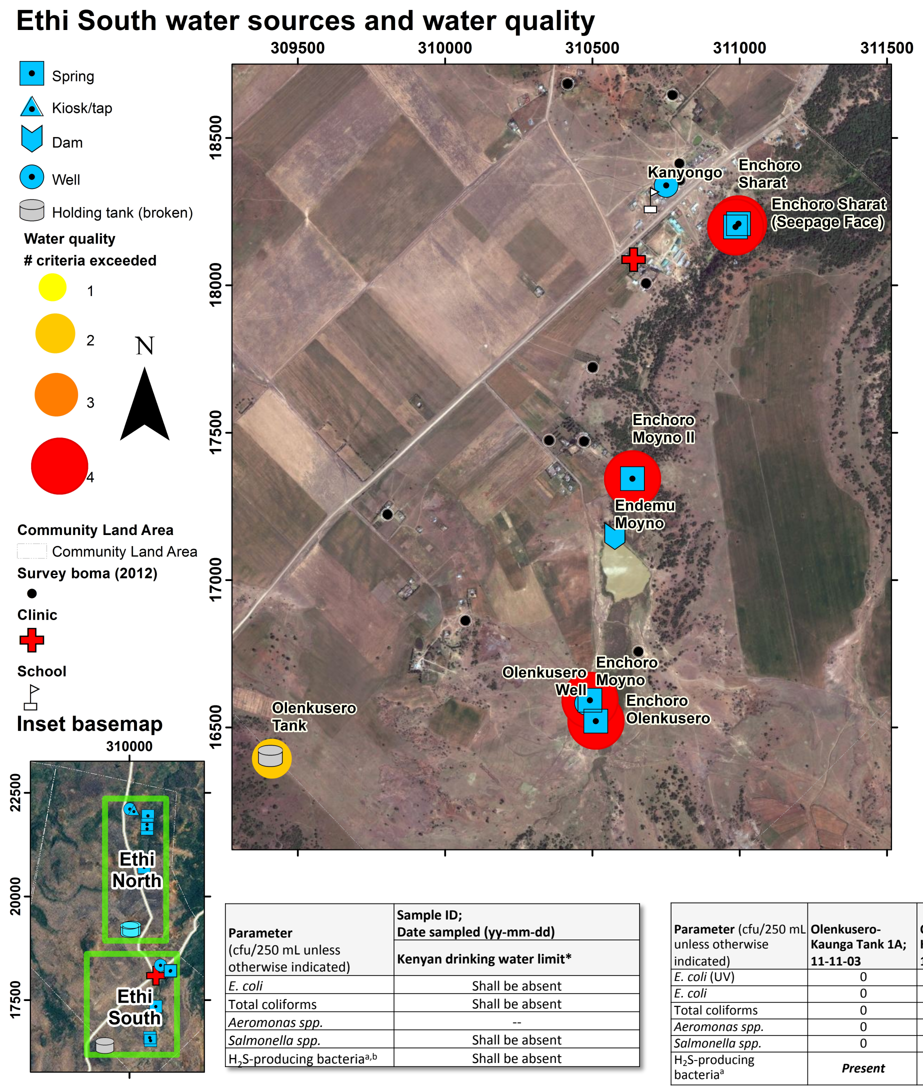
Parameter (cfu/250 mL unless otherwise indicated)	**Lokusero Clinic Rainwater Tank A; 11-09-30**	**Lokusero Clinic Rainwater Tank B; 11-09-30**	**BLANK Lokusero Clinic Rainwater Tank; 11-09-30**
E. coli (UV)	0	0	0
E. coli	0	0	0
Total coliforms	***>8,333***	***>8,333***	0
Aeromonas spp.	7,833	7,833	0
Salmonella spp.	***833***	***667***	0
H_2S-producing bacteria[a]	***Present***	***Present***	Absent

Parameter (cfu/250 mL unless otherwise indicated)	**Lokusero Clinic Tank A; 11-09-30**	**Lokusero Clinic Tank B; 11-09-30**	**BLANK Lokusero Clinic Tank; 11-09-30**
E. coli (UV)	0	0	0
E. coli	0	0	0
Total coliforms	***2,650***	***2,750***	0
Aeromonas spp.	0	0	0
Salmonella spp.	0	0	0
H_2S-producing bacteria[a]	***Present***	***Present***	Absent

Parameter (cfu/250 mL unless otherwise indicated)	**Lokusero Handpump Upper A; 11-09-30**	**Lokusero Handpump Upper B; 11-09-30**	**BLANK Lokusero Handpump Upper; 11-09-30**
E. coli (UV)	***400***	***500***	0
E. coli	***400***	***550***	0
Total coliforms	***2,450***	***1,950***	0
Aeromonas spp.	450	500	0
Salmonella spp.	0	0	0
H_2S-producing bacteria[a]	***Present***	***Present***	Absent

Parameter (cfu/250 mL unless otherwise indicated)	**Sample ID; Date sampled (yy-mm-dd)** **Kenyan drinking water limit***
E. coli	Shall be absent
Total coliforms	Shall be absent
Aeromonas spp.	--
Salmonella spp.	Shall be absent
H_2S-producing bacteria[a,b]	Shall be absent

Parameter (cfu/250 mL unless otherwise indicated)	**Lokusero Well Tap A; 11-09-30**	**Lokusero Well Tap B; 11-09-30**	**Lokusero Well Tap A1; 11-10-28**	**Lokusero Well Tap B1; 11-10-28**	**Lokusero Well Tap A2; 11-10-28**	**Lokusero Well Tap B2; 11-10-28**	**Lokusero Well Tap C2; 11-10-28**
E. coli (UV)	0	0	0	0	0	0	0
E. coli	0	0	0	0	0	0	0
Total coliforms	***3,050***	***1,400***	***50***	***150***	0	***700***	0
Aeromonas spp.	0	0	0	0	350	0	0
Salmonella spp.	0	0	0	0	***300***	***>5,000***	0
H_2S-producing bacteria[a]	Absent	Absent	Absent	Absent	Absent	***Present***	Absent


Ethi South water sources and water quality

Parameter (cfu/250 mL unless otherwise indicated)	**Enchoro Sharat A; 11-09-21**	**Enchoro Sharat B; 11-09-21**	**BLANK Enchoro Sharat; 11-09-21**	**Enchoro Sharat Seepage A; 11-09-21**	**Enchoro Sharat Seepage B; 11-09-21**	**Enchoro Sharat Seepage C; 11-09-21**
E. coli (UV)	***250***	***250***	0	0	0	***500***
E. coli	***250***	***750***	0	***250***	***250***	***500***
Total coliforms	***4,500***	***4,000***	0	***12,000***	***7,500***	***7,500***
Aeromonas spp.	4,250	6,250	0	>25,000	26,000	30,000
Salmonella spp.	***2,500***	***1,500***	0	***6,500***	***9,750***	***13,750***
H_2S-producing bacteria[b]	***Present***	***Present***	Absent	***Present***	***Present***	***Present***

Parameter (cfu/250 mL unless otherwise indicated)	**Enchoro Moyno II A; 11-09-20**	**Enchoro Moyno II B; 11-09-20**	**BLANK Enchoro Moyno II; 11-09-20**
E. coli (UV)	***250***	***500***	0
E. coli	***250***	***2,750***	0
Total coliforms	***7,000***	***4,500***	0
Aeromonas spp.	16,000	13,750	0
Salmonella spp.	***14,750***	***34,250***	0
H_2S-producing bacteria[b]	***Present***	***Present***	Absent

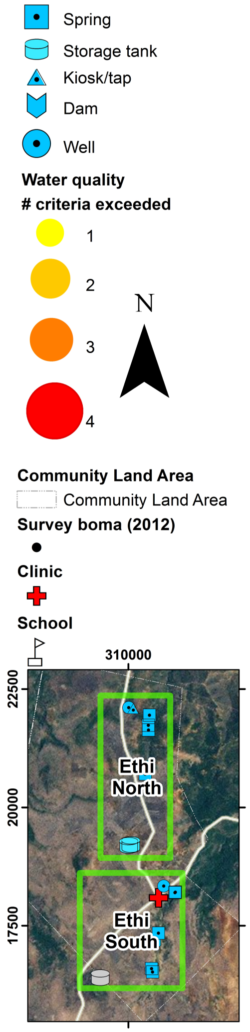
Parameter (cfu/250 mL unless otherwise indicated)	**Enchoro Moyno A; 11-09-20**	**Enchoro Moyno B; 11-09-20**
E. coli (UV)	0	0
E. coli	0	***750***
Total coliforms	***1,000***	0
Aeromonas spp.	4,000	3,500
Salmonella spp.	0	0
H_2S-producing bacteria[b]	***Present***	***Present***

Parameter (cfu/250 mL unless otherwise indicated)	**Enchoro Olenkusero A; 11-09-20**	**Enchoro Olenkusero B; 11-09-20**
E. coli (UV)	***1,000***	***250***
E. coli	***500***	***1,000***
Total coliforms	***6,500***	***7,250***
Aeromonas spp.	16,500	13,750
Salmonella spp.	***250***	***250***
H_2S-producing bacteria[b]	***Present***	***Present***

Parameter (cfu/250 mL unless otherwise indicated)	**Sample ID; Date sampled (yy-mm-dd)**
	Kenyan drinking water limit*
E. coli	Shall be absent
Total coliforms	Shall be absent
Aeromonas spp.	--
Salmonella spp.	Shall be absent
H_2S-producing bacteria[a,b]	Shall be absent

Parameter (cfu/250 mL unless otherwise indicated)	**Olenkusero-Kaunga Tank 1A; 11-11-03**	**Olenkusero-Kaunga Tank 1B; 11-11-03**	**Olenkusero-Kaunga Tank 1C; 11-11-03**	**BLANK Olenkusero-Kaunga Tank 1; 11-11-03**	**Olenkusero-Kaunga Tank 2A; 11-11-03**	**Olenkusero-Kaunga Tank 2B; 11-11-03**
E. coli (UV)	0	0	***83***	0	0	NA
E. coli	0	0	***83***	0	0	NA
Total coliforms	0	***83***	***167***	0	0	NA
Aeromonas spp.	0	83	167	0	0	NA
Salmonella spp.	0	0	0	0	0	NA
H_2S-producing bacteria[a]	***Present***	***Present***	***Present***	Absent	***Present***	***Present***

Ethi North water sources and water quality



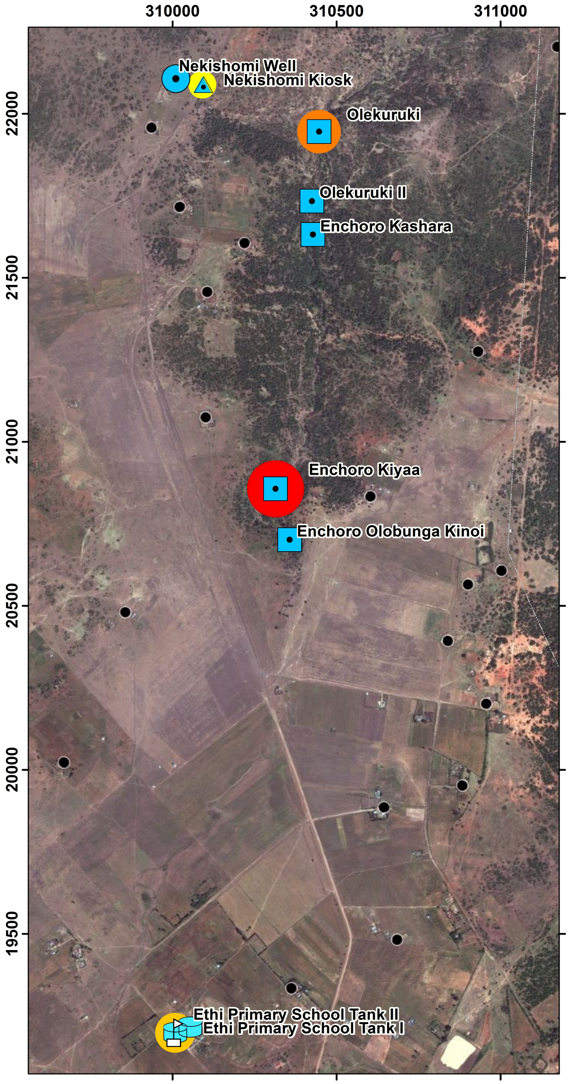
Parameter (cfu/250 mL unless otherwise indicated)	**Sample ID;** **Date sampled (yy-mm-dd)**
	Kenyan drinking water limit*
E. coli	Shall be absent
Total coliforms	Shall be absent
Aeromonas spp.	--
Salmonella spp.	Shall be absent
H_2S-producing bacteria[a,b]	Shall be absent

Parameter (cfu/250 mL unless otherwise indicated)	**Nekishomi Kiosk A; 11-09-20**	**Nekishomi Kiosk B; 11-09-20**	**Nekishomi Kiosk C; 11-09-20**
E. coli (UV)	0	0	0
E. coli	0	0	0
Total coliforms	0	0	0
Aeromonas spp.	100	0	63
Salmonella spp.	0	0	0
H_2S-producing bacteria[b]	***Present***	***Present***	Absent

Parameter (cfu/250 mL unless otherwise indicated)	**Olekurruki A; 11-09-20**	**Olekurruki B; 11-09-20**
E. coli (UV)	***250***	0
E. coli	***2,000***	***500***
Total coliforms	***17,750***	***16,500***
Aeromonas spp.	>25,000	>25,000
Salmonella spp.	***500***	0
H_2S-producing bacteria[b]	***Present***	***Present***

Parameter (cfu/250 mL unless otherwise indicated)	**Enchoro Kiyaa A; 11-09-21**	**Enchoro Kiyaa B; 11-09-21**	**BLANK Enchoro Kiyaa; 11-09-21**
E. coli (UV)	***500***	***1,000***	0
E. coli	***500***	***1,000***	0
Total coliforms	***>25,000***	***>25,000***	0
Aeromonas spp.	>25,000	>25,000	0
Salmonella spp.	***6,500***	***7,750***	0
H_2S-producing bacteria[a]	***Present***	***Present***	Absent

Parameter (cfu/250 mL unless otherwise indicated)	**Ethi Primary School Tank I A; 11-09-22**	**Ethi Primary School Tank I B; 11-09-22**
E. coli (UV)	0	0
E. coli	0	0
Total coliforms	***2,300***	***5,650***
Aeromonas spp.	950	550
Salmonella spp.	***50***	***150***
H_2S-producing bacteria[a]	Absent	Absent



Appendix C Household microbiological water quality

Household drinking water quality analytical results are presented and compared to the Kenya Water Services Regulatory Board's (KWSRB's) *Drinking Water Quality and Effluent Monitoring Guideline Schedule 5*: *Microbiological limits for drinking water and containerized drinking water* (Source: Adopted from KS 05-459, Part 1:1996). The drinking water quality results are presented by neighbourhood. It should be noted that the results for the water quality analysis and *Aeromonas spp.* are presented in the source water analytical results, however they were not discussed in Chapters 2 and 3 because the KWSRB has not set a drinking water quality limit for this microbiological contaminant.

Chumvi household microbial water quality

Parameter (cfu/250 mL unless otherwise indicated)	**Sample ID; Date sampled (yy-mm-dd)**
	Kenyan drinking water limit*
E. coli	Shall be absent
Total coliforms	Shall be absent
Aeromonas spp.	--
Salmonella spp.	Shall be absent
H_2S-producing bacteria[a,b]	Shall be absent

Parameter (cfu/250 mL unless otherwise indicated)	**C-PR-10-1 A; 12-02-10**	**C-PR-10-1 B; 12-02-10**	**BLANK C-PR-10-1; 12-02-10**
E. coli (UV)	NA	NA	NA
E. coli	0	0	NA
Total coliforms	***3,650***	***2,750***	0
Aeromonas spp.	0	0	2,100
Salmonella spp.	***2,100***	***200***	0
H2S-producing bacteria	NA	NA	NA

Parameter (cfu/250 mL unless otherwise indicated)	**C-PR-10-2 Aå; 12-02-10**	**C-PR-10-2 B; 12-02-10**
E. coli (UV)	NA	NA
E. coli	0	0
Total coliforms	***250***	***1,500***
Aeromonas spp.	0	0
Salmonella spp.	0	***50***
H_2S-producing bacteria	NA	NA

Parameter (cfu/250 mL unless otherwise indicated)	**C-PR-10-3 A; 12-02-10**	**C-PR-10-3 B; 12-02-10**
E. coli (UV)	NA	NA
E. coli	0	0
Total coliforms	***3,000***	***4,000***
Aeromonas spp.	0	0
Salmonella spp.	***2,100***	***3,600***
H_2S-producing bacteria	NA	NA

Parameter (cfu/250 mL unless otherwise indicated)	**C-PR-12-1 A; 12-02-12**	**C-PR-12-1 B; 12-02-12**
E. coli (UV)	NA	NA
E. coli	0	0
Total coliforms	***10,000***	***4,450***
Aeromonas spp.	0	0
Salmonella spp.	***6,750***	***6,750***
H_2S-producing bacteria	NA	NA

Parameter (cfu/250 mL unless otherwise indicated)	**C-PR-12-2 A; 12-02-12**	**C-PR-12-2 B; 12-02-12**
E. coli (UV)	NA	NA
E. coli	0	0
Total coliforms	***800***	***700***
Aeromonas spp.	0	0
Salmonella spp.	***600***	***550***
H_2S-producing bacteria	NA	NA

Data table notes:

*	Microbiological drinking water limit as stated in the 2009 Kenyan Water Services Regulatory Board's *Drinking Water Quality and Effluent Monitoring Guideline Schedule 5*: *Microbiological limits for drinking water and containerized drinking water* (Source: Adopted from KS 05-459, Part 1:1996)
BOLD	Exceeds the Kenyan drinking water limit
--	No Kenyan Drinking Water Limit has been set by the Kenyan Water Services Board
H_2S	Hydrogen sulphide
a	H_2S-producing bacteria per 20 mL water sample, as recommended by Chuang et al. (2011). The Kenyan Water Services Board's *Microbiological limit for drinking water* (KS 05-459-01, Part 1:1996) for H_2S-producing bacteria is evaluated per 50 mL water sample
b	H_2S-producing bacteria per 25 mL water sample. The Kenyan Water Services Board's *Microbiological limit for drinking water* (KS 05-459-01, Part 1:1996) for H_2S-producing bacteria is evaluated per 50 mL water sample
cfu	Colony forming unit
NA	Not analyzed
NS	Not sampled

Chumvi household microbial water quality (continued)

Parameter (cfu/250 mL unless otherwise indicated)	**Sample ID; Date sampled (yy-mm-dd)**
	Kenyan drinking water limit*
E. coli	Shall be absent
Total coliforms	Shall be absent
Aeromonas spp.	--
Salmonella spp.	Shall be absent
H_2S-producing bacteria[a,b]	Shall be absent

Parameter (cfu/250 mL unless otherwise indicated)	**C-PR-12-3 A; 12-02-12**	**C-PR-12-3 B; 12-02-12**
E. coli (UV)	NA	NA
E. coli	0	0
Total coliforms	0	0
Aeromonas spp.	0	0
Salmonella spp.	***1,100***	***400***
H_2S-producing bacteria	NA	NA

Parameter (cfu/250 mL unless otherwise indicated)	**C-PR-14-1 A; 12-02-14**	**C-PR-14-1 B; 12-02-14**
E. coli (UV)	NA	NA
E. coli	0	0
Total coliforms	***4,900***	***4,800***
Aeromonas spp.	0	0
Salmonella spp.	***4,500***	***4,400***
H_2S-producing bacteria	NA	NA

Parameter (cfu/250 mL unless otherwise indicated)	**C-PR-14-2 A; 12-02-14**	**C-PR-14-2 B; 12-02-14**
E. coli (UV)	NA	NA
E. coli	0	0
Total coliforms	***100***	***250***
Aeromonas spp.	0	0
Salmonella spp.	0	0
H_2S-producing bacteria	NA	NA

Parameter (cfu/250 mL unless otherwise indicated)	**C-PR-14-3 A; 12-02-14**	**C-PR-14-3 B; 12-02-14**
E. coli (UV)	NA	NA
E. coli	0	**0**
Total coliforms	***3,500***	***5,000***
Aeromonas spp.	0	0
Salmonella spp.	***250***	***4,800***
H_2S-producing bacteria	NA	NA

Parameter (cfu/250 mL unless otherwise indicated)	**C-PR-15-2 A; 12-02-17**	**C-PR-15-2 B; 12-02-17**
E. coli (UV)	NA	NA
E. coli	0	0
Total coliforms	***2,600***	***5,000***
Aeromonas spp.	0	100
Salmonella spp.	***450***	***3,600***
H_2S-producing bacteria	NA	NA

Parameter (cfu/250 mL unless otherwise indicated)	**C-PR-15-1 A; 12-02-17**	**C-PR-15-1 B; 12-02-17**
E. coli (UV)	NA	NA
E. coli	0	0
Total coliforms	***1,000***	***3,450***
Aeromonas spp.	150	850
Salmonella spp.	***3,350***	***1,650***
H_2S-producing bacteria	NA	NA

Parameter (cfu/250 mL unless otherwise indicated)	**C-PR-15-3 A; 12-02-17**	**C-PR-15-3 B; 12-02-17**	**BLANK C-PR-15-3; 12-02-17**
E. coli (UV)	NA	NA	NA
E. coli	***550***	0	0
Total coliforms	***2,600***	***3,200***	0
Aeromonas spp.	650	0	0
Salmonella spp.	***4,650***	***2,550***	0
H_2S-producing bacteria	NA	NA	NA

Parameter (cfu/250 mL unless otherwise indicated)	**L's Boma Yellow Jug A; 11-09-22**	**L's Boma Yellow Jug B; 11-09-22**	**L's Boma Yellow Jug C; 11-09-22**	**L's Boma Yellow Jug BLANK; 11-09-22**
E. coli (UV)	***50***	0	***50***	0
E. coli	***50***	0	***125***	0
Total coliforms	***>5,000***	***5,050***	***>5,000***	***>5,000***
Aeromonas spp.	>5,000	3,300	2,700	0
Salmonella spp.	***150***	0	***250***	0
H_2S-producing bacteria[a]	***Present***	***Present***	***Present***	Absent

Parameter (cfu/250 mL unless otherwise indicated)	**L's Boma Black Jug A; 11-09-22**	**L's Boma Black Jug B; 11-09-22**
E. coli (UV)	***1,050***	***1,200***
E. coli	***1,400***	***1,350***
Total coliforms	***4,650***	***5,350***
Aeromonas spp.	2,600	2,250
Salmonella spp.	0	0
H_2S-producing bacteria[a]	***Present***	***Present***

Ethi household microbial water quality

Parameter (cfu/250 mL unless otherwise indicated)	**Sample ID; Date sampled (yy-mm-dd)**
	Kenyan drinking water limit*
E. coli	Shall be absent
Total coliforms	Shall be absent
Aeromonas spp.	--
Salmonella spp.	Shall be absent
H_2S-producing bacteria[a,b]	Shall be absent

Parameter (cfu/250 mL unless otherwise indicated)	**E-JJ-3-25 A; 12-02-03**	**E-JJ-3-25 B; 12-02-03**
E. coli (UV)	NA	NA
E. coli	0	0
Total coliforms	***2,800***	***900***
Aeromonas spp.	100	100
Salmonella spp.	***50***	***100***
H_2S-producing bacteria[a]	Absent	Absent

Parameter (cfu/250 mL unless otherwise indicated)	**E-JJ-3-26 A; 12-02-03**	**E-JJ-3-26 B; 12-02-03**
E. coli (UV)	NA	NA
E. coli	0	0
Total coliforms	0	***5,000***
Aeromonas spp.	0	0
Salmonella spp.	***1,800***	0
H_2S-producing bacteria[a]	Absent	Absent

Parameter (cfu/250 mL unless otherwise indicated)	**E-JJ-3-27 A; 12-02-03**	**E-JJ-3-27 B; 12-02-03**
E. coli (UV)	NA	NA
E. coli	0	0
Total coliforms	***5,000***	***5,000***
Aeromonas spp.	0	0
Salmonella spp.	***350***	NA
H_2S-producing bacteria[a]	***Present***	***Present***

Parameter (cfu/250 mL unless otherwise indicated)	**E-JJ-9-40 A; 12-02-09**	**E-JJ-9-40 B; 12-02-09**	**BLANK E-JJ-9-40; 12-02-09**
E. coli (UV)	NA	NA	NA
E. coli	0	0	NA
Total coliforms	***900***	***650***	0
Aeromonas spp.	500	0	0
Salmonella spp.	***850***	***1,450***	0
H_2S-producing bacteria	Absent	Absent	NA

Parameter (cfu/250 mL unless otherwise indicated)	**E's Boma (rainwater) A; 11-09-21**	**E's Boma (rainwater) B; 11-09-21**
E. coli (UV)	NA	NA
E. coli	0	0
Total coliforms	***>8,333***	***7,667***
Aeromonas spp.	1,917	2,167
Salmonella spp.	0	0
H_2S-producing bacteria[a]	Absent	Absent

Nadungoro household microbial water quality

Parameter (cfu/250 mL unless otherwise indicated)	**Sample ID; Date sampled (yy-mm-dd)**
	Kenyan drinking water limit*
E. coli	Shall be absent
Total coliforms	Shall be absent
Aeromonas spp.	--
Salmonella spp.	Shall be absent
H_2S-producing bacteria[a,b]	Shall be absent

Parameter (cfu/250 mL unless otherwise indicated)	**N-PM-30-1 A; 12-01-30**	**N-PM-30-1 B; 12-01-30**
E. coli (UV)	NA	NA
E. coli	0	0
Total coliforms	0	0
Aeromonas spp.	0	0
Salmonella spp.	***3,400***	***2,800***
H_2S-producing bacteria[a]	***Present***	***Present***

Parameter (cfu/250 mL unless otherwise indicated)	**N-PM-30-2 A; 12-01-30**	**N-PM-30-2 B; 12-01-30**
E. coli (UV)	NA	NA
E. coli	0	0
Total coliforms	0	0
Aeromonas spp.	0	0
Salmonella spp.	***1,600***	***2,250***
H_2S-producing bacteria[a]	***Present***	***Present***

Parameter (cfu/250 mL unless otherwise indicated)	**N-PM-30-3 A; 12-01-30**	**N-PM-30-3 B; 12-01-30**	**N-PM-30-3 C; 12-01-30**
E. coli (UV)	NA	NA	NA
E. coli	0	0	0
Total coliforms	***600***	0	0
Aeromonas spp.	100	350	450
Salmonella spp.	***2,100***	***600***	***500***
H_2S-producing bacteria	***Present***	***Present***	Absent

Parameter (cfu/250 mL unless otherwise indicated)	**N-PM-31-1 A; 12-02-13**	**N-PM-31-1 A; 12-02-13**
E. coli (UV)	NA	NA
E. coli	0	0
Total coliforms	***350***	***1,500***
Aeromonas spp.	0	5,000
Salmonella spp.	0	0
H_2S-producing bacteria[a]	NA	NA

Parameter (cfu/250 mL unless otherwise indicated)	**N-PM-31-3 A; 12-02-13**	**N-PM-31-3 A; 12-02-13**
E. coli (UV)	NA	NA
E. coli	0	0
Total coliforms	***1,250***	***1,000***
Aeromonas spp.	1,750	0
Salmonella spp.	0	0
H_2S-producing bacteria[a]	NA	NA

Parameter (cfu/250 mL unless otherwise indicated)	**M's boma/Ndg Enchoro III A; 11-09-30**	**M's boma/Ndg Enchoro III A; 11-09-30**
E. coli (UV)	***1,000***	***750***
E. coli	***750***	0
Total coliforms	***>25,000***	***>25,000***
Aeromonas spp.	>25,000	>25,000
Salmonella spp.	***>25,000***	***20,500***
H_2S-producing bacteria[a]	***Present***	***Present***