Monitoring and Evaluation of Household Water Treatment and Safe Storage Technologies: The Sustained Use of the KOSIM Ceramic Water Filter in Northern Region Ghana

by

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Submitted to the Engineering Systems Division
in Partial Fulfillment of the Requirements for the Degree of

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ABSTRACT

Today, approximately 884 million people lack access to an improved drinking water (WHO and UNICEF, 2008). According to the World Health Organization (WHO), contaminated water and poor sanitation cause 30,000 deaths worldwide each day (WHO and UNICEF, 2008). Household drinking water and safe storage (HWTS), is a new health intervention that enables people to treat water in their own homes. Today, hundreds of non-profit organizations, for-profit business, social enterprises, academic institutions, faith-based organizations and governments are working around the world to promote HWTS technologies, especially to those people most in need.

This thesis uses Pure Home Water (PHW), a small non-profit in Northern Region Ghana, as a case study to evaluate the use of a widespread HWTS technology, the ceramic pot filter. During the months of January, June and July 2008, I surveyed 309 of Pure Home Water's rural customers who had purchased a KOSIM filter between 2005 and 2008 to determine both the sustained use of the KOSIM ceramic pot filter and the factors that contribute to sustained use or disuse. I also conducted water quality analysis using the Colilert® and the 3M™ Petrifilm™ tests to evaluate the performance of the KOSIM filter in the field.

Forty-six percent of PHW's rural customers were still using the KOSIM ceramic pot filter at the time of the interview. The survey results indicated that household income, reported water source, and the price paid for the filter are each associated with sustained use or disuse of the KOSIM filter. The average total coliform (TC) and *E.coli* counts for KOSIM-filtered water using the lower test detection limit of the 3M™Petrifilm™/Colilert® test combination were 323 CFU/100 mL and 7 CFU/100 mL respectively, which corresponds to a "low" risk level (WHO, 1997). The average TC and *E.coli* counts for KOSIM-filtered water using the upper test detection limits increased to 1,097 CFU/100 mL and 37 CFU/mL respectively. These results correspond to an "intermediate" risk level (WHO, 1997). On average, the KOSIM water filter removes 96.2% of TC (1.42 log reduction) and 89.2% (0.99 log reduction) of *E.coli* using the lower test detection limit. The average TC and *E.coli* reductions using the upper test detection limits are 88.8% (0.95 log reduction) and 82% (0.75 log reduction) respectively.

Key Words: monitoring and evaluation, household water treatment and safe storage, household surveys, ceramic filter, sustained use, Millennium Development Goals, Ghana, Pure Home Water

Thesis Supervisor: Susan Murcott
Title: Senior Lecturer of Civil and Environmental Engineering

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While in Ghana, I was very grateful for the support of everyone at Pure Home Water. Especially, Peter and Bernice who's insights during the pretest survey were invaluable and helped lay the foundation of this project; Shak, who, during a very busy time of year, found the time to help me dig through PHW's sales receipts and identify village liaisons. His incredible work ethic and wonderful sense of humor inspired me throughout my time in Ghana and made it very enjoyable; Davy, who allowed our team of students to invade his office at the PHW house; Nurideen was always ready to lend a helping hand and could always make me laugh; And finally, Amin, who spent countless hours helping me conduct the surveys. Despite the many challenges that we faced (rain, mud, rivers, heat etc), his positive attitude and amazing moto-driving skills helped bring this project to completion.

A special thanks to the rest of the 2008 MIT Ghana team members, Vanessa, Matt, Andy, Tamar, Cash, and Izumi, the summer team, Ming, Derek, Jenny and Jake, and both G-lab teams, Shavani, Udit, Eswar, Geeta, Avani, Gabe, Gaetan, and Matt, for making my time in Ghana both productive and fun.

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List of Abbreviations

CFU: Colony Forming Unit
E.coli: Escherichia Coli
JMP: The World Health Organization and United Nation Children's Fund's Joint Monitoring Program for Water Supply and Sanitation
M&E: Monitoring and Evaluation
MDGs: Millennium Development Goals
MIT: Massachusetts Institute of Technology
PHW: Pure Home Water
TC: Total Coliform
TU: Turbidity Units
UN: the United Nations
UNICEF: The United Nation Children's Fund
WHO: World Health Organization

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Chapter 1 Introduction to the Global Water Problem and Household Water Treatment

Today, approximately 884 million people lack access to an improved drinking water (WHO and UNICEF, 2008). According to the World Health Organization (WHO), contaminated water and poor sanitation cause 30,000 deaths worldwide each day (WHO and UNICEF,). While clean water supply remains a significant global challenge, major advances have been made in the field of household drinking water and safe storage (HWTS).

HWTS is a new health intervention that enables people to treat water in their own homes. Household chlorination and safe storage, solar disinfection in PET plastic bottles, biosand filters, and the Potters for Peace ceramic pot filters are all examples of core, proven HWTS technologies that have been developed in the past ten to fifteen years. Today, hundreds of non-profit organizations, for-profit business, social enterprises, academic institutions, faith-based organization, and governments are working around the world to promote HWTS technologies, especially to those people most in need. In 2003, the World Health Organization together with industry, academic, non-profit, and government partners started the International Network to Promote HWTS ("The Network"), a public-private partnership that brings together leading proponents of HWTS from governments, private and non-profit sectors and academia. Over the past six years the Network has grown to include over 120 different organizations from both the public and private sectors around the world.

Although HWTS technologies have increased the access to safe drinking water for millions of people over the past ten years, the use of these technologies has yet to be recognized as an official indicator for the Millennium Development Goal drinking water target[1]. This is partly due to the lack of systematic monitoring and evaluation (M&E) of these interventions, resulting in inadequate knowledge about the use of many of these technologies in the field. One step towards potential, official UN recognition of HWTS as a means to achieve increased "access to improved water supply" would be for the Network needs to develop common M&E methods that can provide more data on the actual use of these technologies in households[2].

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[1] The Millennium Development Goal drinking water target is to halve the number of people who lack access to safe drinking water by 2015. This target is discussed in detail in Chapter 2.

[2] Recently, the Network has increased their efforts to develop common M&E methods. This effort began after the start of this thesis and is discussed in Section 3.3 of this report.

This thesis uses Pure Home Water (PHW), a small non-profit in Northern Region Ghana, as a case study to evaluate the use of a commonly used HWTS technology, the ceramic pot filter (also know as the ceramic water purifier or CWP). Over the past year I surveyed over 300 of PHW's customers in rural Tamale to determine:

1. The sustained use of the KOSIM ceramic pot filter in Northern Region Ghana;
2. The factors that are associated with filter use or disuse; and
3. The filter's performance in the field.

I defined "sustained use" based on the following observations at the time of the interview:

1. The KOSIM filter is correctly installed in storage unit.
2. Water is currently in KOSIM pot filter.
3. Clear water (<5 TU) is currently in KOSIM storage unit.

1.1 Pure Home Water

Pure Home water is a social enterprise and legally registered non-profit located in Northern Region Ghana. It was founded in 2005 by Susan Murcott, Senior Lecturer in MIT's Department of Civil and Environmental Engineering, with Ghanaian partners to provide safe drinking water to people in Northern Ghana through the dissemination of HWTS products. This social enterprise was originally funded for its first two years by the C.N. Hilton Foundation and has gone on to work with major international non-profit organizations such as UNICEF and PATH (Murcott, 2008).

Figure 1: KOSIM ceramic water filter and safe storage unit (photo: author)

Over the past four years, PHW has focused on the sale of the KOSIM water filter. The KOSIM filter (see Figure 1) is manufactured in Accra, Ghana by Ceramica Tamakloe Ltd. and is based on the Potters for Peace ceramic water filter design. To date, Pure Home Water has sold 10,793 KOSIM filters in both rural and urban villages in Northern Region Ghana.

1.2 The Potters For Peace Ceramic Water Filter

The Potters for Peace ceramic pot filter (see Figure 2) was designed by Dr. Fernando Mazariego in 1981 to filter turbid water and make bacterially contaminated water safe while keeping the cost low enough so that the filter could be reproduced in communities around the world (Potters for Peace, 2008). It consists of a colloidal-silver impregnated ceramic pot that, in Ghana, holds 8.2 liters of water and sits in a 20-30 liter plastic receptacle with a spigot (the KOSIM receptacle is 30 liters, sizes can vary across different countries and manufacturers). Typical flow rates range from 1-2.5 liters per hour and, if manufactured properly, the CWP can effectively eliminate 97%-100% of *E.Coli*, Coliform and Streptococcus organisms (Brown, 2007; Johnson, 2007; Lantagne, 2001; Oyanedel-Craver & Smith, 2008; Westphal, Wall, Guo, & Schwab, 2008). Since 1998, Potters for Peace and Ron Rivera[3] inspired and actively collaborated in the training and implementation of filter factories in Guatemala, Honduras, Mexico, Cambodia, Bangladesh, Ghana, El Salvador, the Darfur region of Sudan, Myanmar, (Burma), Nicaragua, Columbia, Tanzania, the Dominican Republic, Yemen, Kenya, Benin, Indonesia, Sri Lanka, Bali, Mozambique, Peru, Canada, Nigeria, Haiti, and Cuba.

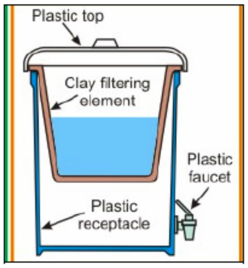

Figure 2: The Potters for Peace Ceramic Water Purifier (Potters for Peace, 2008)

1.3 Water Problems in Northern Region Ghana

Northern Region Ghana (see Figure 3) is comprised of 20 districts, and is the largest region in Ghana in terms of land area, occupying about 70,383 square kilometers (Ghana Districts, 2009). Pure Home Water is located in Tamale, which is the region's capital city. Like

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[3] Ron Rivera passed away on September 8, 2008 at the age of 60 of malaria that he contracted while working on his 30th filter enterprise, in Nigeria. The factories he helped establish have to date made more than 300,000 filters, used by 1.5 million people.

many regions of West Africa, Northern Region Ghana remains unable to provide improved water access to the majority of its 1.8 million people. Recent statistics state that approximately 900,000 people in this region lack access to safe drinking water (Ghana Statistical Service (GSS), 2005). Figure 4 illustrates the percentage of improved vs. unimproved water supplies in the different districts of Northern Region Ghana[4].

Figure 3: The nine regions of Ghana (Ghana Expeditions, 2009)

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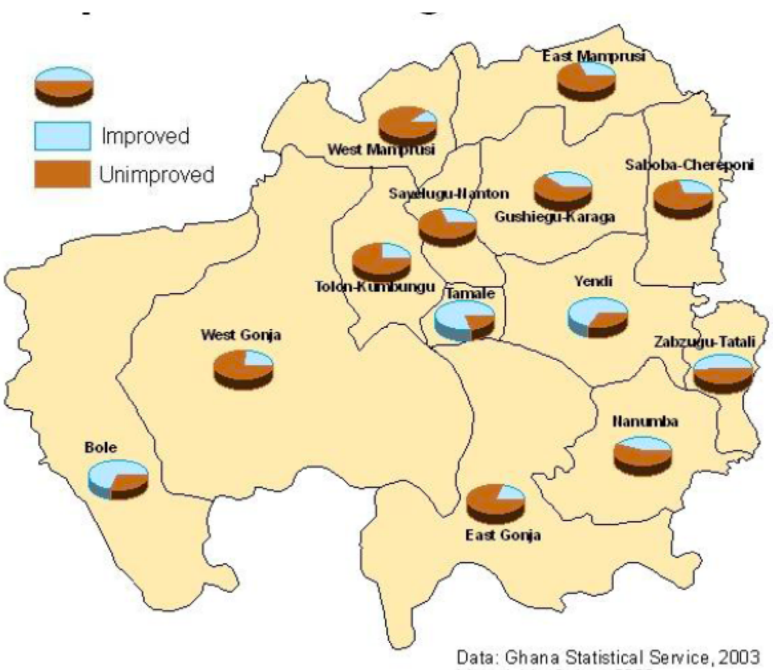
[4] These statistics use the definitions of improved and unimproved sources of water set by the United Nation's Millennium Development Goals. These terms are defined and discussed in detail in Chapter 2 of this paper.



Data: Ghana Statistical Service, 2003
Map: J. VanCalcar, 2006

Figure 4: Percentage of population with improved vs. unimproved drinking water sources in Northern Region Ghana (VanCalcar, 2006)

One common drinking water source in rural areas of Northern Region Ghana are shallow, stagnant, man-made ponds called “dugouts”. These sources, (see Figure 5), are sometimes shared with animals and are both highly turbid (many suspended particles) and contaminated with fecal coliform. Such contamination creates numerous risks for public health, particularly high incidence of diarrheal disease in children <5. While many organizations in Africa have been able to increase access to clean water by drilling boreholes or protected dug wells, these attempts have been only partially successful in northern Ghana due to challenging geological conditions, which lead to high percentage of dry wells (according to World Vision, success rates are typically 20-40%). Figure 6 illustrates the breakdown of main drinking water sources in three of the districts in Northern Region Ghana where PHW has sold the KOSIM filter.

Figure 5: Dugout in Northern Region Ghana (photo: author)

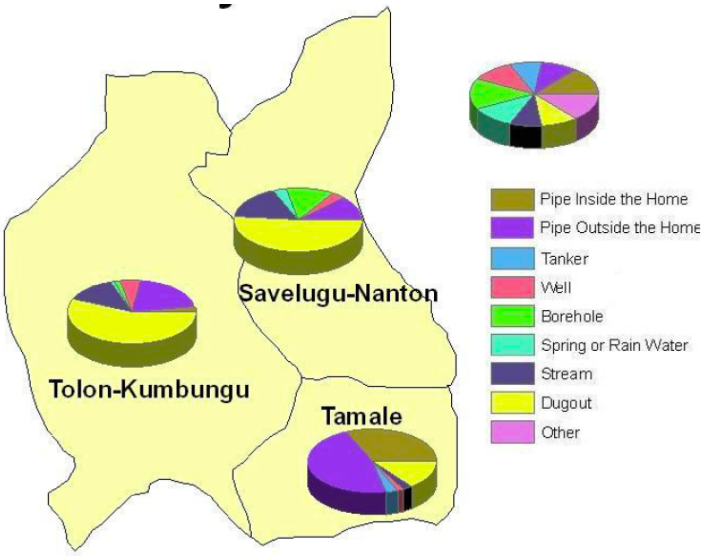


Figure 6: Types of water sources used by households (VanCalcar, 2006)

1.4 The Sustained Use Study: Goals and Hypotheses

As mentioned previously, I have conducted over 300 surveys in Northern Region Ghana during January, June and July 2008 to determine the factors associated with sustained use or disuse of the KOSIM ceramic water filter. Each survey respondent had purchased a KOSIM filter from Pure Home Water between 2005 and 2008. Based on previously published literature on ceramic pot filter use in Cambodia and Nicaragua, I hypothesized that the following factors could be associated with sustained filter use in Northern Region Ghana:

1. Filter breakage
2. Household income
3. Price paid for filter
4. Number of children drinking from the filter
5. Reported drinking water source
6. Total number of people drinking from the filter
7. Presence of training materials in the home
8. Filter maintenance
9. Demonstrated knowledge of safe water handling practices

In the following chapters of this thesis, I explain the current polices used to determine progress towards the Millennium Development Goals Drinking Water Target and document the work that has already been done to promote the use of HWTS technologies as an indicator for "access to safe drinking water," focusing on the ceramic pot filter intervention. I then outline the methods I used to determine the sustained use of the KOSIM filter in Northern Region Ghana as well as the factors that may contribute to use or disuse. Then I discuss how these results compare to similar studies that have been conducted in other regions of the world and recommend ways that Pure Home Water could increase the sustained use of the KOSIM filter. Finally, I explain how the methods I used to conduct this study could contribute to the set of monitoring and evaluations methods for organizations that are implementing HWTS technologies.

Chapter 2 Literature Review

Today, More than 1.2 billion people live under conditions of physical water scarcity where over 75% of the river flows are withdrawn. An additional 1.6 billion people live in areas of economic water scarcity, where there is physically enough water to meet human demands, but a lack of human, institutional and financial capital limit access to the sources (The United Nations, 2008). As a result 884 million people worldwide currently lack access to improved drinking water sources (WHO and UNICEF, 2008). Consequently, diarrhea, caused by fecally contaminated water, is the third leading cause of death and sixth of illness (see Figure 7). Each year, 1.8 million people die from diarrheal disease; 90% of these deaths are children under the age of five. Ninety four percent of these cases of diarrheal disease are preventable through improved water supply, water quality, sanitation, and hygiene practices (The International Network to Promote Household Water Treatment and Safe Storage, 2007). Over the past 25 years, the international development community has been working to provide a variety of different policies, initiatives, tools and technologies to combat this global water problem and work to ensure that everyone, regardless of their economic status or geographic location and physical surroundings, has access to safe drinking water – a fundamental condition for humans' well-being.

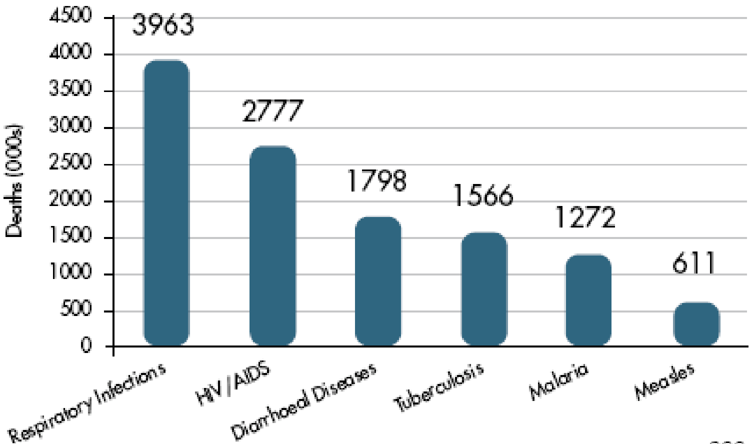


Figure 7: Leading causes of death from infectious diseases (The International Network to Promote Household Water Treatment and Safe Storage, 2007)

2.1 Drinking Water Quality and Diarrheal Disease

Over the past twenty years, there have been a number of studies conducted to investigate the impact of drinking water quality on diarrheal disease. Esrey et al. published the first several reports in 1985 and 1991. They analyzed 144 studies to determine the impact of improved water supply and sanitation facilities on a range of water-related illnesses and concluded that improved sanitation and hygiene were more important that water quality in diarrheal disease control (Esrey, Potash, Roberts, & Shiff, 1991). While Esrey's study provided a useful assessment of different broad categories of environmental interventions (water supply, water quality, sanitation, and hygiene) it only included water quality inventions at the source, not in the home, causing some to question the conclusions (Fewtrell et. al., 2005; Clausen, Rabie, Roberts, & Cairncross, 2007).

Fourteen years later, Fewtrell and Colford published a new systematic review and meta-analysis (essentially an update of Esrey et al's work) that compared the evidence of the relative effectiveness of different health and hygiene interventions to reduce illness, including point-of-use interventions in the home. They reviewed 46 peer-reviewed studies and found that all of the interventions reviewed reduce the risk of diarrheal and "water quality interventions (point-of-use water treatment) were found to be more effective than previously thought"(Fewtrell et al., 2005). Two years later, Thomas Clausen performed a second meta-analysis, which confirmed that interventions that improve water quality are effective in reducing childhood diarrhea. Clausen's study included several unpublished studies that had not been analyzed by Fewtrell and excluded interventions against epidemic diarrhea, which may have skewed the results of the Fewtrell study (Clausen et al., 2007).

2.2 The Millennium Development Goals

The global water problem first gained major international recognition at the 1977 United Nations Water Conference. At this conference, the United Nations General Assembly produced the Mar del Plata Action Plan and declared the 1980s the International Drinking Water and Sanitation Decade (The United Nations, 1992). The action plan stated that all people, regardless of their social status or economic conditions, have "the right to have access to drinking water in quantities and of a quality equal to their basic needs" (The United Nations, 1992). The goal of the International Drinking Water and Sanitation Decade was to have "clean water to all" by the year 2000. Despite the increased attention to water and sanitations during the 1980s, the progress made towards reaching the goal of "clean water for all" was offset by increases in population, and the proportion of people lacking access to this fundamental need remained relatively constant (E. Mintz, Bartram, Lochery, & Wegelin, 2001).

Although significant improvements in the proportion of the population with access to an improvement drinking water supply were yet to be accomplished, the United Nations (UN) remained committed to the water provision for all goal. In 2000, the General Assembly reaffirmed this commitment in the UN Millennium Declaration by pledging to halve the proportion of people who are "unable to reach or afford safe drinking water" by 2015 (The United Nations, 2000). Two years later, they confirmed this goal at the World Summit on Sustainable Development in Johannesburg (The United Nations, 2002).

2.2.1 Improved vs. Unimproved Sources of Water

In order to measure progress towards the Millennium Development Goal (MDG) drinking water target, international agencies and donors have focused on drinking water supply. They have broken supply into two main categories: "improved" drinking water sources and "unimproved" drinking water sources. Improved drinking water sources are sources that, "by nature of their construction or through active intervention, are protected from outside contamination, particularly fecal matter" (WHO and UNICEF, 2008). *Improved* sources include piped water, tube wells or boreholes, protected springs and rainwater collection while *Unimproved* sources include all surface waters (rivers, dugouts, lakes, ponds, streams, canals, irrigation channels etc), unprotected dug wells, and vended water from carts or trucks. Table 1 outlines the different types of improved and unimproved sources of drinking water (WHO and UNICEF, 2008).

Table 1: Examples improved and unimproved drinking water sources[5] (adapted from WHO and UNICEF, 2008)

Improved Drinking Water Sources	Unimproved Drinking Water Sources
Public tapes or standpipes	Unprotected dug well
Piped household water connection on premises	Surface Water (river, dam, lake, pond, stream, canal, irrigation channels)
Tube Wells	Unprotected spring
Boreholes	Tanker truck
Protected dug wells	Cart with small tank/drum
Protected springs	Bottled Water
Rainwater collection	

2.2.2 Progress Towards the Millennium Development Goal Drinking Water Target

Since the Millennium Declaration in 2000, the Millennium Development Goals have been "adopted by the international community as a framework for the development activities of over 190 countries in ten regions" (The United Nations, 2008) and significant progress has been made towards their achievement. Since 1990, 1.6 billion people have gained access to improved drinking water sources. (The United Nations, 2008), decreasing the number of people lacking access from 1.1 billion to 884 million. At this rate, the world is on track to meet the MDG drinking water target (The United Nations, 2008; WHO and UNICEF, 2008).

Despite this global progress, 784 million people worldwide still need to gain access to improved drinking water supplies by 2015 in order to meet the MDG (WHO and UNICEF, 2008). While almost every region in the world has increased access since the 2000 Declaration, Sub-Saharan Africa and Oceania are lagging behind and now accounts from more than 1/3 of those without improved drinking water supplies (The United Nations, 2008). Figures 8, 9, and 10 and Table 2 show current trends towards meeting the MDG global water target and illustrate the need for accelerated progress in Sub-Saharan Africa (The United Nations, 2008; WHO and UNICEF, 2008).

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[5] Bottled water is considered an unimproved source of water, unless the household has access to another improved source of water for their other water needs (i.e. cooking, washing, etc) (WHO and UNICEF, 2008).

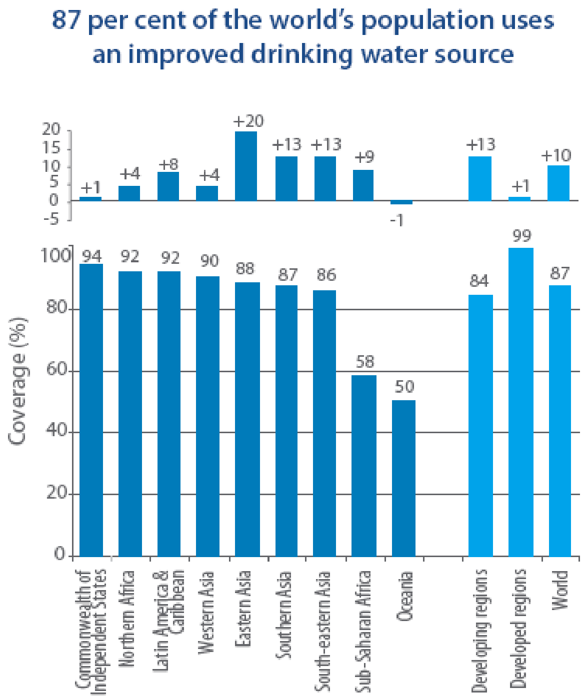

87 per cent of the world's population uses an improved drinking water source

Figure 8: Improved drinking water coverage, by region in 2006 and percentage-point change 1990-2006 (WHO and UNICEF, 2008)

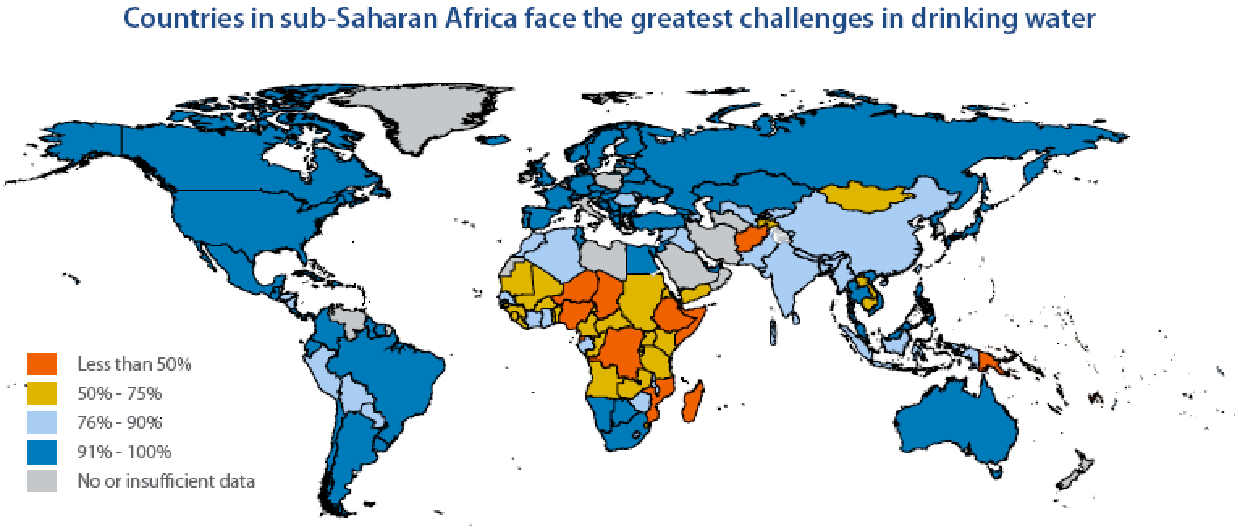

Countries in sub-Saharan Africa face the greatest challenges in drinking water

Figure 9: Drinking water coverage, 2006 (WHO and UNICEF, 2008)

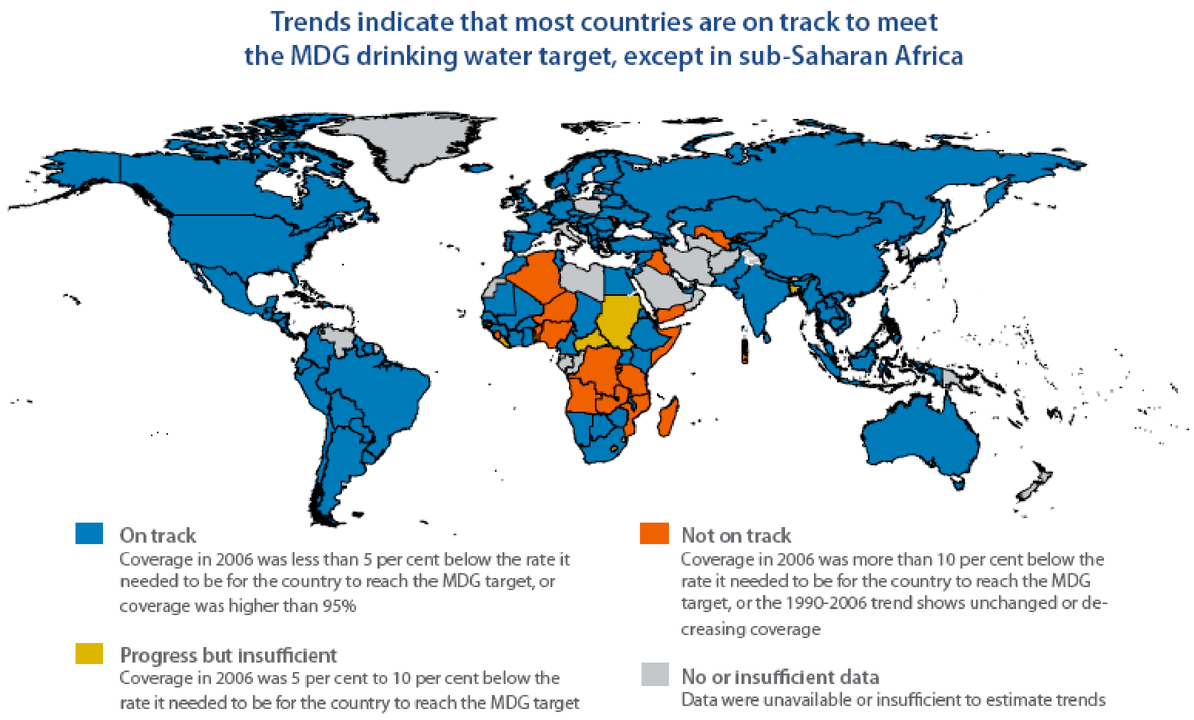


Figure 10: Progress towards the MDG drinking water target, 2006 (WHO and UNICEF, 2008)

Table 2: Regional and global progress towards the MGD drinking water target (WHO and UNICEF, 2008)

Region	Drinking water coverage (%) 1990	Drinking water coverage (%) 2006	Coverage needed to be on track in 2006 (%)	MDG target coverage (%)	Progress
Commonwealth of Independent States	93	94	95	97	On track
Northern Africa	88	92	92	94	On track
Latin America & Caribbean	84	92	89	92	On track
Western Asia	86	90	90	93	On track
Eastern Asia	68	88	78	84	On track
Southern Asia	74	87	82	87	On track
South-eastern Asia	73	86	82	87	On track
Developing regions	**71**	**84**	**80**	**86**	**On track**
Developed regions	**98**	**99**	**99**	**99**	**On track**
World	**77**	**87**	**84**	**89**	**On track**
Sub-Saharan Africa	49	58	65	75	Not on track
Oceania	51	50	67	76	Not on track

In addition to the regional differences, there is also a large disparity between urban and rural water supplies. Of the people using unimproved water sources, 84% reside in rural areas. This equates to about 746 million people living in rural areas without access to improved water supplies. Figure 11 shows the urban and rural water supply coverage in 2006 and illustrates that the urban-rural disparity is highest in Latin America, Sub-Saharan Africa, and Oceania (WHO and UNICEF, 2008).

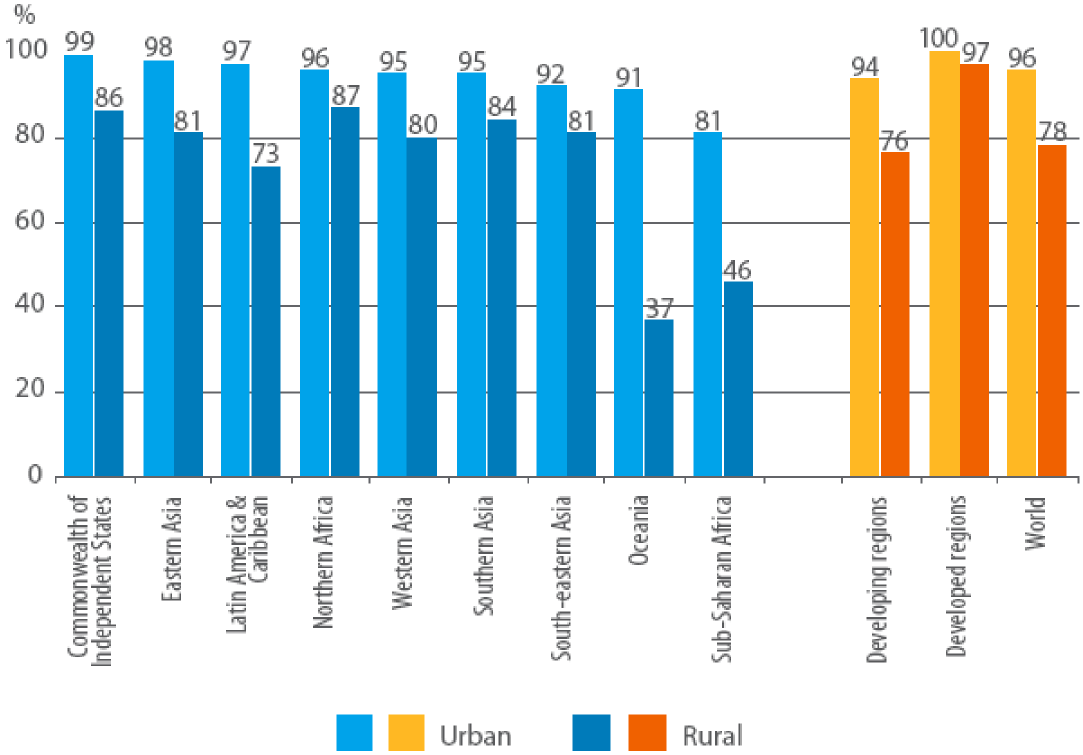


Figure 11: Urban and rural water supply coverage, 2006 (WHO and UNICEF, 2008)

2.3 Drinking Water Quality in the Home

Although recent statistics show that the world is on track to meet the MDG drinking water target, there has been much debate over the UN's use of water infrastructure indicators to measure access to drinking water. This debate is largely due to the high risk of contamination when water from improved sources is transported over long distances and stored in the home (Clausen, 2008; P. K. Jensen, Jayasinghe, van der Hoek, Cairncross, & Dalsgaard, 2004; P. Jensen et al., 2002; E. Mintz, Reiff, & Tauxe, 1995; Sobsey, Stauber, Casanova, Brown, & Elliott, 2008; WHO and UNICEF, 2008). The potential for contamination makes it extremely difficult to truly measure "access" because even people with "improved access" may not be drinking microbiologically safe water (Clausen, 2008; Sobsey et al., 2008). A study published by Peter Jensen in 2004 found no association between childhood diarrhea rates and *E.coli* counts in drinking water sources. There was, however, a possible trend relating the *E.coli* counts in household storage containers and diarrhea rates. These results combined with the high fecal contamination found in household water containers (when water source was clean), led him to question “whether public water treatment will have a significant impact on the incidence of endemic childhood diarrhea.” (P. K. Jensen et al., 2004).

2.3.1 Shortcomings of Water Supply Data

Although the current data on access to improved sources of water can be useful when quantifying the global water crisis, there are several inconsistencies that should be considered when using this data to measure access to improved water supplies. For example, although approximately 1 billion people around the world live in slums (the United Nations, 2008), however according to the JMP’s most recent report 776 million people without access to improved sources of water (88% of those without access) live in rural areas (WHO and UNICEF, 2008). This data would imply that only 108 million people in urban areas lack access to improved water sources. If we assume that all 108 million of these people live in slums (which they may not) then, according to the JMP’s data, 89% of slum dwellers have access to improved sources of drinking water.

According to Gulyani et al., these estimates for improved drinking water supplies in slums are incorrect and “seriously understate the level of problems on the ground” (Gulyani, 2006). In her study of slums in Kenya, she found that most slum dwellers (64%) rely on water kiosks for their drinking water. People in these areas must walk to the kiosks and pay very high prices to buy water in 20-35 liter quantities (often in jerry cans). Therefore, they tend to use very little water from this source. However, access to water kiosks is reported as access to “piped water” and households relying on these kiosks are often excluded from programs aimed at reaching under-served populations (Gulyani, Talukdar, & Kariuki, 2005; Gulyani, 2006). In addition to this problem water source of categorization, there are there are many opportunities for “improved” water sources to become microbiologically unsafe. For example, low water pressure and illegal connections in the distribution systems can often cause municipal piped water in developing countries to be unsafe by the time they reach the consumer (E. Mintz et al., 1995; Sobsey, 2002).

2.3.2 Household Water Treatment and Safe Storage (HWTS)

While universal access to piped-in water supplies should remain a long-term goal, the need for immediate and effective measures to provide safe water for all, and most especially for at risk populations has led to the public health engineering community to turn to Household Water Treatment and Safe Storage (HWTS) technologies (also known as Point-of-Use (POU) interventions) as an innovative new solution to the global water challenge. These inventions address water quality at the household level, enabling those people without access to improved water sources to treat their drinking water in the home and providing an extra barrier of protection at the point of consumption for those who already have improved water access. Examples of core technologies in this new cluster of interventions include household chlorination and safe storage, solar disinfection in PET plastic bottles (SODIS), and household filters, for example biosand filters, and ceramic water filters.

Although various household water management methods have been practiced for centuries, household water treatment and safe storage's "potential as a focused public health intervention is just emerging." (Clausen, 2008). From 2005 to 2007, the average annual growth of HWTS users was 15.1% resulting in approximately 15.5 billion liters of HWTS-treated water in 2007 (Clausen, 2008). In 2003, the World Health Organization recognized the potential of HWTS interventions in improving water quality, especially for the poorest of the poor, and initiated the International Network to Promotes HWTS ("the Network'). This public-private partnership brings together leading proponents of HWTS from governments, private and non-profit sectors. Over the past 6 years, the Network has grown to include over 120 different organizations from both the public and private sectors around the world. Figure 12 shows the results of a 2005 survey conducted by the Network to estimate the status of HWTS implementation around the world.

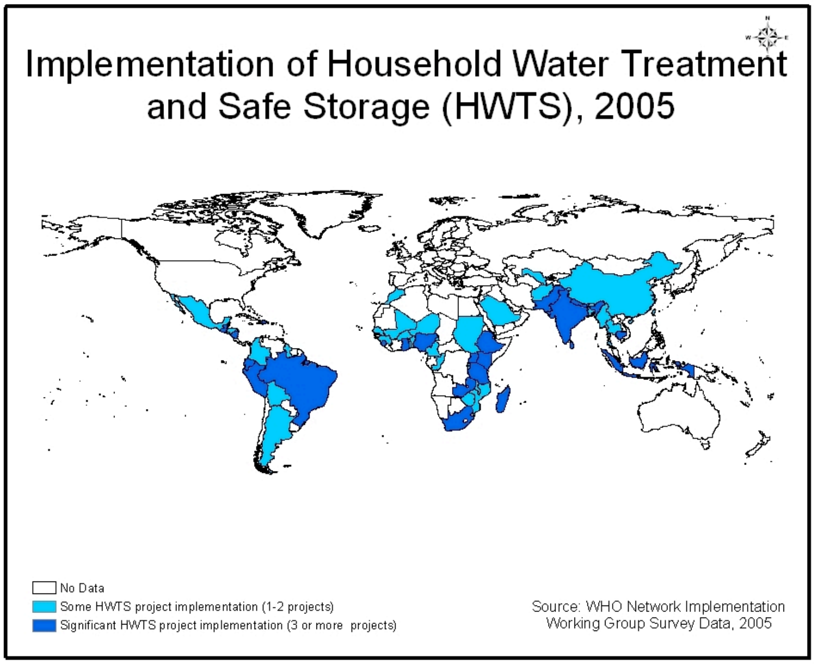
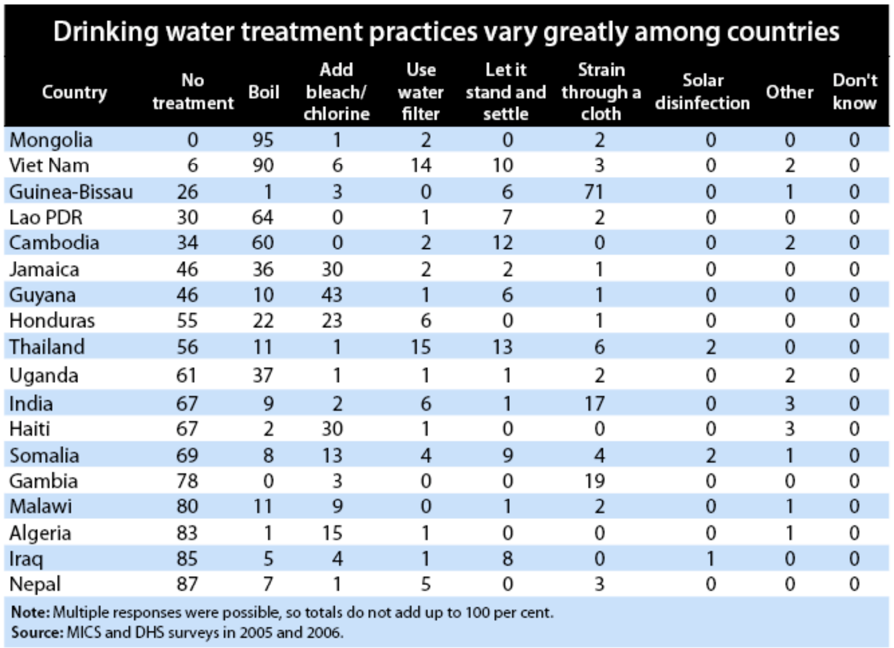


Figure 12: Implementation of Household Water Treatment and Safe Storage (The International Network to Promote HWTS, 2005)

Since its formation, members of the Network have been working to establish HWTS technologies as an effective complement to improved water sources for populations in dire need of immediate access to safe drinking water (Clausen, 2008; E. Mintz et al., 2001; Sobsey, 2002; The United Nations, 2008). While using HWTS has not yet been recognized as an MDG-indicator, the 2008 report by the WHO and UNICEF's Joint Monitoring Program (JMP) included a section on household water treatment. Additionally, the two main household surveys used by the JMP when gathering data about access to improved water now include questions about household water treatment. The results from these surveys are presented in Table 3 and show the wide range of HWTS methods and technologies used around the world. This report also states that WHO and UNICEF recognize that "unhygienic handling of water during transport or within the home can contaminate previously safe water" and that "household-level interventions can be very effective in preventing disease if they are used correctly and consistently" (WHO and UNICEF, 2008).

Table 3: Percentage of households using different water treatment methods (WHO and UNICEF, 2008)



Drinking water treatment practices vary greatly among countries

Country	No treatment	Boil	Add bleach/ chlorine	Use water filter	Let it stand and settle	Strain through a cloth	Solar disinfection	Other	Don't know
Mongolia	0	95	1	2	0	2	0	0	0
Viet Nam	6	90	6	14	10	3	0	2	0
Guinea-Bissau	26	1	3	0	6	71	0	1	0
Lao PDR	30	64	0	1	7	2	0	0	0
Cambodia	34	60	0	2	12	0	0	2	0
Jamaica	46	36	30	2	2	1	0	0	0
Guyana	46	10	43	1	6	1	0	0	0
Honduras	55	22	23	6	0	1	0	0	0
Thailand	56	11	1	15	13	6	2	0	0
Uganda	61	37	1	1	1	2	0	2	0
India	67	9	2	6	1	17	0	3	0
Haiti	67	2	30	1	0	0	0	3	0
Somalia	69	8	13	4	9	4	2	1	0
Gambia	78	0	3	0	0	19	0	0	0
Malawi	80	11	9	0	1	2	0	1	0
Algeria	83	1	15	1	0	0	0	1	0
Iraq	85	5	4	1	8	0	1	0	0
Nepal	87	7	1	5	0	3	0	0	0

Note: Multiple responses were possible, so totals do not add up to 100 per cent.
Source: MICS and DHS surveys in 2005 and 2006.

2.3.3 Monitoring and Evaluation (M&E) of HWTS

The statement above made by the WHO/UNICEF/JMP highlights the key problem with using HWTS as an indicator for the MDG drinking water target: unlike drinking water sources which require large investments, but the work of only a relative few to provide clean water for many, HWTS technologies require each user to perform new tasks in order to treat their own drinking water. If these tasks are not performed consistently or correctly, then the user will not obtain safe drinking water. Therefore, in order for the Network to prove that a certain population has "access to safe drinking water" through the use of HWTS, they must show:

1.) The technology is effective at treating drinking water
2.) Users are correctly using the technology
3.) Users are consistently using the technology

Thomas Clausen recognized the importance of these three factors in his 2008 report for the World Health Organization on scaling up HWTS. In this report he states, "the real potential for household water treatment to scale up depends not only on the extent to which it can be made available to the target population, but also the extent to which it is adopted by that population and used correctly and consistently" (Clausen, 2008).

While the effectiveness of the technology can be shown through laboratory and field studies, correct and consistent use require increased efforts by implementing organizations to monitor and evaluate HWTS implementations. In the USAID Hygiene Improvement Project's e-conference in 2007, Orlando Hernandez presented a variety of options to consider when measuring behavioral outcomes related to HWTS use. He established definitions for "ever," "current," "irregular" and "sustained" users as well as "partial" vs. "impartial," "incorrect vs. "correct," and "consistent" vs. "inconsistent" users. He also presented three alternatives for measuring user behavior (volume of sales, number of liters of water treated and percentage of households practicing effective water management) (Hernandez, 2007). In December of 2008, in response to UNICEF's decision to widely promote HWTS in their WASH programs world-wide, the UNICEF Indicators Task Force met to establish common indicators for M&E of HWTS. These indicators are as follows:

1. Percent of households correctly storing treated water
2. Percent of households correctly/effectively treating drinking water using HWTS
3. Percent of households practicing sustained use of recommended HWTS technology
4. Percent of respondents that agree that their drinking water needs to be treated
5. Percent of respondents that think others approve treating drinking water at home
6. Percent of respondents that feel confident they can improve the quality of their drinking water.
7. Percent of households with negative tests for *E.coli* in drinking water
8. Percent of household with positive chlorine residual in drinking water treated with chlorine.
9. Percent of households who know at least one location where they can obtain a HWTS product(s).

These indicators have also been adopted by USAID as part of their Hygiene Improvement Project (Hernandez, 2009)[6].

2.4 The Ceramic Pot Filters

As mentioned in Chapter 1, this thesis focuses on the KOSIM ceramic pot filter that has been implemented by Pure Home Water in Northern Region Ghana. These filters have been

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[6] These indicators have been slightly modified by USAID (see Hernandez, 2009).

studied in both laboratory and the field environments and have been found to be one of the effective core HWTS technologies and have been found to have the “greatest potential to become widely used and sustainable for improving household water quality to reduce waterborne diseases and death” (Sobsey et al., 2008).

2.4.1 Effectiveness of the Ceramic Pot Filter

Both laboratory and field testing has shown that the ceramic filter is capable of consistently removing over 97% of bacteria in water.

Lab tests in 2006 by Doris Van Halem found that no total coliforms were detected in 93% of the 144 300mL samples taken from ceramic pot filtered water. She also reported log10 reduction values (LRV) between 4 and 7 for spikes with *E.coli*, successful removal of all sulphite reducing Clostridium spores (103-105 n/100mL) by all ceramic pot filters, (with and without colloidal silver) and partial removal of MS2 bacteriophages (LRV 0.5-3.0) (Van Halem, 2006). Vinka Oyandel-Craver and Katherine Westphal found similar results when testing the filter in the laboratory setting. Oyandel-Craver reported that the filters removed between 97.8% and 100% of bacteria and (Oyanedel-Craver & Smith, 2008) and Westphal reported between 3.22 and 6.06 LRV of “spiked bacteria (Westphal et al., 2008).

Field tests of this filter in Nicaragua, Cambodia and Ghana have confirmed the results shown in the laboratory. In her 2001 study in Nicaragua, Daniele Lantagne showed that the ceramic pot filter is capable of removing 100% of bacteria and bacteria indicators of disease-causing organisms (Lantagne, 2001). Seven years later in Nicaragua, Westphal found that 53% of the filters in use 4 years after implementation removed 100% of *E.coli* and 78% of the filters in use removed more than 95% of *E.coli* present in the source water (Westphal et al., 2008). Joe Brown’s study in Cambodia concluded that the ceramic pot filters reduce *E. coli*/100 ml counts by a mean of 98% in treated versus untreated household water. In some cases, the demonstrated filter field performance exceeded 99.99% (Brown, 2007).

Sophie Johnson’s 2007 study shows that the KOSIM ceramic pot filter’s performance is on par with filters in the lab, Nicaragua, and Cambodia, removing 99.7% of *E.coli* and 99.4% of total coliform in “traditional rural households” and 85% of the *E.coli* and 90% of total coliform in “modern urban households” (water sources in the modern households was of higher quality which resulted in the lower removal rates) (Johnson, 2007).

2.4.2 Use of the Ceramic Pot Filter

Although sustained filter use is equally important as its technical efficacy at removing bacteria (Clausen et al., 2007; Sobsey et al., 2008), there has been much less work done in the investigating this aspect of the ceramic pot filter. Better information is needed on "the factors that influence filter uptake and continued use by communities and households" (Sobsey et al., 2008).

Joe Brown's study in Cambodia is the most in-depth investigation on sustained filter use to date. He found that the rate of filter disuse was approximately 2% per month after implementation, largely due to breakages. Additionally, his results showed a strong association between filter use and time since implementation. After controlling for time since implementation, sustained filter use over time was most closely positively associated with related water, sanitation, and hygiene practices in the home, cash investment in the technology by the household, and use of surface water as a primary drinking water source (Brown, 2007). Breakage was also found to be problem in Nicaragua, where 48.5% of filters implemented in the past four years had fallen into disuse mostly due to broken spigots, water receptacles or ceramic filter elements (Westphal et al., 2008).

While no other major studies on consistent use of the ceramic pot filter have been published, there has been some research regarding the use of other HWTS technologies in the field. In 2006, Paul Earwaker investigated the use of Biosand filters in Ethiopia and found that 29.8% of the users surveyed had stopped using their filter. Again, the biggest reason for disuse was breakage "beyond repair" (35.7% of permanent non-users) (Earwaker, 2006). In Bolivia, Stephanie Moser conducted a study on the use of solar disinfection in PET plastic bottles (SODIS) and found that the users "habits" had the biggest influence on use of the SODIS technology (Moser, Heri, & Mosler, 2005).

In the remaining chapters of this thesis, I describe the methods that I used to determine the sustained use of the KOSIM ceramic pot filter in Northern Region Ghana. I then discuss my key findings and make recommendations to Pure Home Water for improving the sustained use of the KOSIM ceramic pot filter. Finally, I make recommendations for including HWTS as an indicator for the MDG's drinking water target and highlight the future work needed to understand the sustained use of both the KOSIM ceramic pot filter and HWTS technologies in general.

Chapter 3 Survey and Water Testing Methods

During the months of January, June and July 2008, I surveyed 309 of Pure Home Water's rural customers to determine both the sustained use of the KOSIM ceramic pot filter and the factors that contribute to sustained use or disuse. I also conducted water quality testing to evaluate the performance of the KOSIM filter in the field. This chapter explains the methods used in the field and the laboratory during both the survey pretest in January 2008, and the sustained use study in June and July 2008.

3.1 Survey Pretest

I conducted the survey pretest in Northern Region Ghana from January 2 – 21st, 2008. During this time, I surveyed 88 of PHW's customers. I had two main objectives for the pretest:

1. To survey as many of PHW's rural customers as possible in order to determine the best survey questions for the sustained use study.
2. To practice testing water quality in the field.

During the pre-test I worked with two of PHW's staff members, Peter Alhassan and Bernice Senanu (see Figure 13). Alhassan was a KOSIM filter salesman for the district of Tolon and is fluent in both English and Dagboni, the dominant tribal language in Northern Region Ghana. He worked both as my ambassador/guide, making the proper introductions to the village chiefs, and as my survey translator. Bernice is a PHW intern who has worked at PHW since 2006, and a materials engineering undergraduate student at the Kwame Nkrumah University of Science and Technology in Kumasi, Ghana. Bernice observed each survey and offered valuable insight on which questions were working well and which questions did not translate properly into Dagboni or were not understood by the survey respondents.

Figure 13: Kate, Bernice, and Peter in the village of Kochim, Ghana (photo: Kochim villager)

3.1.1 Pretest Survey

The pretest survey addressed three main topics:

1. **Filter Use**: Is the respondent practicing sustained filter use[7]? Is the filter still working[8]? Is the respondent using the filter effectively[9]? How long has the respondent been using the filter?
2. **Filter Maintenance:** Has the respondent received the proper maintenance training? How often is the respondent cleaning the KOSIM filter? Can the respondent clean the filter properly?
3. **Perception:** Does the respondent like the taste of the KOSIM filtered water? Does the respondent believe that the filtered water is "clean?" Is the filter easy to use? Has the filter improved the health of people in the respondent's family?

Since one of the main objectives of the pretest was to determine the best questions to ask PHW's customers, the pretest survey went through many iterations based on my experiences and learning in the field during this time. Before conducting the survey, I reviewed the questions with Bernice who helped identify topics that would be hard for the respondents to understand and re-phrase sentences that would not translate well into Dagboni. I modified the survey even further based on Bernice's observations and the survey respondent's reactions during the first week. The final pretest survey is shown in Appendix A. All survey participants gave their informed consent.

3.1.2 Pretest Village Selection

As mentioned earlier, one of the main objectives of the pretest was to survey as many of PHW's customers as possible. In order to achieve this goal, I decided to only survey the villages in Peter Alhassan's sales district. At the time of this survey, Peter Alhassan was one of two PHW salespeople who targeted rural communities. I choose this approach for 3 reasons:

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[7] I defined "sustained filter use" as users with the KOSIM filter correctly installed in the storage unit, water in the pot filter and clear water (<5 TUs) in the storage unit at the time of the interview

[8] I defined "working filters" as filters that were: 1.) Reported as "working" by the survey respondent and 2.) Producing water with a "low" risk of final contamination according to the WHO guidelines (see Table 5).

[9] At the time of the pre-test survey, I defined "effective filter users" as users that: 1.) Let turbid water settle for 1 hour before pouring into the filter, 2.) Cleaned the filter regularly, 3.) Cleaned the safe storage container with filtered water and soap, and 3.) Only drank filtered water. In the months following this pre-test, Matt Stevenson determined new definitions for "effective filter use" which are published in his Master's thesis and influenced my later definition of "sustained use" (see Section3.2.1) (Stevenson, 2008).

1. **Village Relationships:** Alhassan has established relationships with the villages he had sold filters to. In each village, he had appointed a village liaison that was in charge of taking filter orders and checking in on past customers. Each of these liaisons is able to identify the households in their village that had purchased filters. While appointing a liaison is strategy applied in several PHW sales contexts (i.e rural sales, hospital sales and school sales), each salesman[10] only has the contact information for the liaisons in their own sales district. Most of the time, this information is not recorded, making it difficult to identify the village liaisons without that village's salesman. Since Alhassan was the only salesman available to work with me at the time of the pretest, working with his villages was the most convenient option. In addition to the village liaisons, Alhassan also knew the chiefs of each of the villages in his sales district. His relationships with these chiefs enabled us to enter a village without going through the traditional welcoming and introduction rituals, making it faster and easier for me to start surveying customers.
2. **Location:** The majority of Alhassan's villages are located in the district of Tolon (see Figure 6 in Chapter 1) and are located close to each other. The close proximity of these villages to one another allowed me to visit multiple villages per day.
3. **Incomplete Sales Records:** Since PHW is a young enterprise with a high staff turnover, and since accurate written record keeping has not been a strength of the PHW staff, the filter sales records are incomplete. However, each salesperson is able to accurately identify the villages or retailers that he or she has sold filters to. Again, since Alhassan was the only salesperson available to commit 100% of his time to my survey at the time of the pretest, it was faster to only go to his villages.

I attempted to survey every household that had purchased a filter in each village that I visited during the pretest. The final list of villages selected for the pretest and the number of households surveyed in each is shown below in Table 4. As this Table indicates, all but two of these villages (69% of survey respondents) are in Alhassan's sales district. The detailed pre-test survey results are displayed in Appendix B.

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[10] Muslim cultural norms have meant that women have not felt comfortable working as saleswomen in rural villages therefore, all of PHW's rural sales are all conducted by men.

Table 4: Villages surveyed during the survey pretest

Village Name	Salesman	Number of Households Surveyed
Kochim	Peter	13
Klariga	Peter	8
Sanga	Peter	12
Tonjinga	Peter	12
Gbalam	Shak	13
Taha	Shak	14
Tuunaayili	Peter	9
Kpilo	Peter	7
TOTAL		88

3.1.3 Pretest Water Quality Testing

The second objective of the pretest was to practice water quality testing in the field. I conducted these tests using the 3M^{TM} Petrifilm^{TM} Escherichia coli (*E.coli)* and total coliform (TC) test. *E.coli* is present in high numbers in both human and animal feces as well as water that has been recently exposed to fecal pollution, and is therefore one of the most commonly used indicators of fecal contamination. In the past, the fecal coliform assay was the most commonly used indicator to assess fecal contamination in food or water. However, since the definition of "fecal coliform" was based on the methods used to detect them (they are able to multiply in the presence of bile salts or other similar surface agents and are able to ferment and produce gas in 48 hours at 44 +/- ^{o}C), and there are other genera of bacteria with the same growth and fermentation properties that come from non fecal sources (e.g., plant material and pulp or paper mill effluents), there is a high likelihood of false positives when testing for fecal contamination. In an effort to reduce false positives, the term "fecal coliform" has been replaced with "thermotolerant coliforms" which is a more appropriate descriptor of the fecal coliform assay. However, despite this terminology change, it is still likely that positive thermotolerant results may be misinterpreted as fecal contamination. As a result, the United States Environmental Protection Agency has suggested using *E.coli*, which is a type of thermotolerant coliform, as an indicator for fecal contamination. The *E.coli* assay is a more reliable indicator of fecal contamination than the thermotolerant coliform (Doyle & Erickson, 2006).

Table 5 shows the risk of waterborne disease determined by the World Health Organization for various levels of *E.coli* contamination. Total coliform, on the other hand, include both fecal and other colony-forming bacteria that can exist in water and can be used to assess the effectiveness of the water treatment system (The World Health Organization, 2006).

Table 5: Risk of fecal contamination based on *E.coli* measurements (adapted from The World Health Organization, 1997)

WHO Risk Level	WHO *E.coli*[11] in sample (CFU per 100ml)
Conformity	<1
Low	1-10
Intermediate	10-100
High	100-1000
Very High	>1000

I collected samples of unfiltered and filtered water in Whirl-Pak® bags from each household surveyed. I took unfiltered samples from inside the KOISIM filter by dipping the Whirl-Pak® bag into the ceramic pot receptacle and I took filtered samples in the Whirl-Pak® directly from the tap of the KOSIM storage unit (see Figure 14). If there was no water inside the filter, I took the unfiltered samples from clay water storage pots located in most of the households surveyed (see Figure 15). The samples were kept on ice while in the field (approximately 2-4 hours) before being tested in the PHW lab.

Figure 14: Taking filtered water sample from a KOSIM water filter (photo: Amin Hussein)

Figure 15: Unfiltered water being stored in a traditional clay pot

The 3M™ Petrifilm™ *E.coli*/TC test use sample-ready plates that are coated with Violet Red Bile (VRB) nutrients, a gelling agent, an indicator of glucuronidase activity (a characteristic trait in *E.coli*), and an indicator that enables colonies to be counted. Each 3M™ Petrifilm™ plate requires 1 milliliter of sample water, which is then incubated at 35°C for 24 hours. I used a

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[11] This table has been adapted from the WHO guidelines by substituting *E.coli* for thermotolerant coliform.

Millipore Portable Single Chamber Incubator (Model Number XX631K203) to incubate my samples. Each 3M^{TM} Petrifilm^{TM} plate is equipped with a top film that traps the gas produced by lactose fermenting coliforms and *E.coli*. After incubation, the *E.coli* colonies can be identified as blue colonies surrounded by gas bubbles. Total coliforms are determined by summing the red and blue colonies surrounded by gas bubbles.

While the 3M^{TM} Petrifilm^{TM} *E.coli*/TC tests use 1 milliliter samples, the standard form for reporting coliform bacterial counts uses the unit of coliform forming units (CFU)/100 ml. Therefore, when reporting the results of my tests, I converted to this standard unit by multiplying all 3M^{TM} Petrifilm^{TM} results by 100. For each group of tests, I also performed one blank 3M^{TM} Petrifilm^{TM} test, using water than had been boiled and then cooled. This blank served as a control. I also selected one source water sample and one filtered water sample and performed a duplicated test to confirm my results.

3.1.4 Lessons learned from Pretest

The pretest provided me with valuable insight about conducting both customer surveys and water quality testing in the field. First, I learned that my pretest survey relied too heavily on anecdotal answers about filter use, making the results difficult to quantitatively analyze. This is largely due to the long sections on filter maintenance and perception. I noticed that respondents seemed to have a particularly hard time answering any questions having to do with time (i.e. "How long have you had the filter?" "When was the last time you cleaned the filter?"). Additionally, the survey was too long and the respondents often became distracted by family member or household tasks before I finished going through the questions. As a result, I drastically modified the survey to address these problems. These modifications are discussed in more detail in Section 3.2.1.

In addition to the lessons learned about surveys, the pretest taught me a great deal about the importance of a neutral translator. While Peter Alhassan's village connections were extremely useful in meeting the pretest goals to survey as many PHW customers as possible, his knowledge about the KOSIM filter and deep passion for PHW combined with his own desire to prove the success of his sales district posed many problems. Since Alhassan knew the "correct" answers to many of the filter use and maintenance questions, he would prompt the respondents to answer the questions "correctly." Despite numerous requests from both Bernice and I to translate my questions word for word, Alhassan continued to prompt the respondents throughout the pretest. Both Bernice and I came to the conclusion that I would need a non-PHW staff member to translate the final sustained use survey.

In addition, the pretest also helped me identify areas for improvement in my water quality testing methods. Since the focus of this report is on the sustained use of the KOSIM water filter, and not on the effectiveness of the filter in the field, I decided that the unfiltered water samples from the top of each filter were unnecessary. Instead, I planned to take one sample of unfiltered water from each water source in each village that I surveyed. I still planned to take a sample of filtered water from each household surveyed. This would drastically reduce the number of samples to process in the lab, while still providing data about the performance of the KOSIM filter in the field. Additionally, I decided to add turbidity measurements (measurements of the amount of particles in the water) to my water quality testing agenda. Although Northern Region Ghana has some of the most turbid water in the world, the KOSIM filter has proven to be very effective at removing this turbidity. Therefore, turbidity measurements could serve as a useful check to see if the survey respondents were actually filtering their water, or just using the storage unit to store unfiltered water. Lastly, while the 3M^{TM} Petrifilm^{TM} *E.coli*/TC test proved easy to use in the field, the results have a limit of detection of 100 CFU/100 ml (that is 1 CFU/1 ml sample). In the future, I planned to combine the 3M^{TM} Petrifilm^{TM} *E.Coli*/TC tests with the 10 ml pre-dispensed Colilert$^{®}$ tests in order to be able to evaluate KOSIM treated water at this tests' lower limit of detection of 10 CFU/100 ml (or 1 CFU/10 ml sample). Table 6 shows how the lower detection limit of the combined the Colilert$^{®}$ /3M^{TM} Petrifilm^{TM}/ Colilert$^{®}$ tests allow more accurate risks predictions of water bourn disease.

Table 6: Detection Limits of the Colilert$^{®}$ /3M^{TM} Petrifilm^{TM} Tests and the Corresponding Risk

WHO[12], 1997	WHO, 1997	Metcalf,2006	Metcalf,2006
Risk Level	*E.coli* in sample (CFU/100ml)	Colilert *E. coli Result*	Petrifilm *E.coli* Result (CFU/1mL)
Conformity	<1	- (Below detection)	0
Low	1-10	- (Below detection)	0
Intermediate	10-100	+	0
High	100-1000	+	1-10 (or 100-1,000 CFU/100mL)
Very High	>1000	+	> 10 (or > 1,000 CFU/ 100 mL)

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[12] This table has been adapted from the WHO guidelines by substituting *E.coli* for thermotolerant coliform.

3.2 Sustained KOSIM Filter Use Study

I conducted the sustained use study from June 3 – July 21, 2008. During this time I surveyed 221 of Pure Home Water's customers. Whereas the principle goal of the pretest was to survey as many of PHW's rural customers as possible and practice the water quality testing, the goals of the sustained use study were:

1. To determine how many of PHW's rural customers were still using the KOSIM water filter.
2. To identify factors that are associated with sustained use or disuse of the KOSIM water filter in rural Northern Region Ghana.

Despite the differing objectives, I was able to apply many of the lessons learned from the pretest to the final survey. First, I hired a translator, Amin Mohammed Hussein (see Figure 16), who, at the time, was not as familiar with the KOSIM filter and was not a PHW employee[13]. I also significantly modified the survey questions. These changes are discussed below in Section 3.2.1. Finally, I added turbidity testing and the Colilert® pre-dispensed water quality test to my water testing procedure in order to get more accurate counts of *E.coli* and total coliform. The new testing procedure is described below in Section 3.2.3.

Figure 16: Amin Mohammed Hussein (photo: author)

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[13] After this study Pure Home Water hired my translator, Amin Hussein.

3.2.1 The Final Survey

As mentioned earlier, I made many modifications to the sustained use survey based on the lessons learned from the pretest. First, I eliminated almost all of the questions regarding effective filter use and maintenance. While I recognize that these two topics are extremely important in any in-depth monitoring program, they are beyond the scope of this study. The objectives of this study were focused on *if* PHW's customers were using the filter and not *how* they were using the filter. Effective filter use and maintenance was the theme of the Maters thesis of my fellow student Matt Stevenson (Stevenson, 2008).

Second, I re-structured the survey so that it relied mostly on observations, instead of self-reports[14]. This drastically reduced the time to conduct each survey and reduced the risk for translation errors. As a result, I defined "sustained filter use" based on the following observations at the time of the interview:

1. KOSIM filter is correctly installed in storage unit.
2. Water is currently in KOSIM pot filter.
3. Clear[15] water is currently in KOSIM storage unit.

All three of these conditions needed to be met at the time of the interview in order to classify that household as a "sustained user."

Finally, I determined that most of the "perception" topics were out of the scope of this study and removed those questions from the survey. The resulting survey is attached to this report in Appendix C.

3.2.2 Village Selection

Since the main objective of this study is to determine the sustained use of the KOSIM water filter in rural Northern Region Ghana, selecting the correct sample of PHW customer's to survey was crucial to the applicability of the study's results. Having decided against undertaking my formal survey in Peter Alhassan's villages for reasons already discussed, I met with Shak, PHW's other main rural salesperson and their longest serving employee to determine the total

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[14] In general there are three major approaches for collection water, sanitation, and/or hygiene information about behaviors: 1.) self reports, 2.) spot checks or 3.) specific objective tests (such as water quality test) (Hernandez, 2009).

[15] Clear water is define as water having a turbidity measurement of < 5 TUs

number of filters that he sold in rural villages[16]. We reviewed his sales receipts and compiled the list shown in Table 7. Based on the receipts on file, Pure Home Water through Shak, had sold 852 filters in 28 different rural villages.

Table 7: Initial Pure Home Water rural sales estimate (2005-June 2008)

PHW Salesman	Community	Number of Filters
Shak	Kalariga	30
Shak	Chenshegu	25
Shak	Gbalahi	39
Shak	Kpawumo	3
Shak	Taha	26
Shak	Wovugu	6
Shak	Dohini	9
Shak	Wulanyili	44
Shak	Kukuo	21
Shak	Tampion	30
Shak	Dungu Yapalsi	14
Shak	Adubihiyili	4
Shak	Datoyili	4
Shak	Kunyavili	4
Shak	Foshegu	20
Shak	Sing	60
Shak	Kalpohini	30
Shak	Sagnarigu	60
Shak	Kpanvo	50
Shak	Tutengli	20
Shak	Kapkagyili	78
Shak	Dungu	20
Shak	Dungu Yeshee	8
Shak	Tugu	80
Shak/Wahab	Gbanyamni	10
Shak/wahab	Shishegu	7
Peter	Kpanduah	150
Total Villages		**28**
Total # of Filters		**852**

After determining the total number of filters sold, I then used the Raosoft® Sample Size Calculator to calculate the sample size needed for a 95% confidence interval with a 5% margin of error and a 50% response distribution. The calculator uses the following three equations to determine the corresponding sample size:

$$x = Z(c/100) * (2r) *(100-r)$$

$$n = \frac{N*x}{[(N-1) * E^2 + x]}$$

$$E = \mathrm{sqrt}\left\{ \frac{[(N-n) * x]}{[n * (N-1)]} \right\}$$

Where Z(c/100) is the critical value for the confidence level, *N* is the size of the population, *c* is the confidence level, *E* is the margin of error, *r* is the fraction of responses that we are interested in, , and *n* is the sample size. This calculation is based on a normal distribution and assumes a

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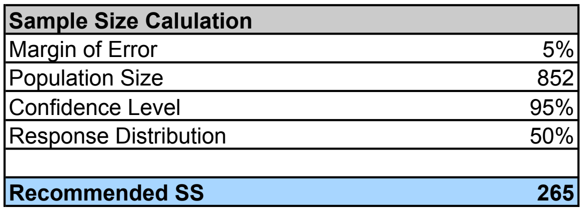
[16] As mentioned earlier, Peter Alhassan's prompting during the pre-test caused biased answers. Therefore, all but one of villages were excluded from the final consistent use survey.

population of more than 30 samples. Based on these calculations, I needed to survey 265 households for a 95% confidence interval (see Table 8).

Table 8: Summary of inputs for initial sample size calculations



Sample Size Calulation	
Margin of Error	5%
Population Size	852
Confidence Level	95%
Response Distribution	50%
Recommended SS	**265**

In order to understand how filter use varied across different villages, I decided to survey households from each of Shak's villages. Since the sample size (265 households) is approximately 32% of the rural households that had purchased filters, I surveyed 32% of the households with filters in each village. The households were selected randomly on the day of the survey.

After starting my fieldwork, I quickly learned that the sales receipts were not an accurate estimate of how many KOSIM filters were actually in the each village. Many times the village liaisons had sent back the filters to PHW that they couldn't sell. This was never recorded in the sales records. Additional, in some villages, the liaisons sold filters to random people from other regions. At the time of the survey, the liaisons did not know where these people lived, therefore I could not include them in my survey. I decided to continue visiting 32% of households with filters in each village, and would calculate this number the day of the survey after meeting with the village liaison to determine actual number of filters in his village. The resulting, actual population size was 661 filters and my final sample size was 221 surveys (see Table 9).

Table 9: Table 6: Revised PHW (Shak only, and 1 Peter village) rural sales estimate (September 2005- June 2008)

PHW	Community	Number of Filters Based on Sales Records	Actual Number of Filters	Need To Survey (32% of total)	Actual Number of HH Surveyed
Shak	Kalariga	30	30	10	10
Shak	Chenshegu	25	25	8	10
Shak	Gbalahi	39	39	12	15
Shak	Kpawumo	3	3	1	1
Shak	Taha	26	26	8	8
Shak	Wovugu	6	6	2	2
Shak	Dohini	9	9	3	4
Shak	Wulanyili	44	44	14	12
Shak	Kukuo	21	21	7	7
Shak	Tampion	30	19	6	6
Shak	Dungu Yapalsi	14	14	4	6
Shak	Adubihiyili	4	4	1	1
Shak	Datoyili	4	4	1	1
Shak	Kunyavili	4	4	1	1
Shak	Foshegu	20	20	6	6
Shak	Tolugu	60	60	19	19
Shak	Kalpohini	30	30	10	9
Shak	Sagnarigu	60	36	12	11
Shak	Kpanvo	50	10	3	8
Shak	Tutengli	20	20	6	8
Shak	Kapkagyili	78	66	21	21
Shak	Dungu	20	20	6	8
Shak	Dungu Yeshee	8	8	3	2
Shak	Tugu	80	12	4	4
Shak/Wahab	Gbanyamni	10	10	3	3
Shak/wahab	Shishegu	7	7	2	2
Peter	Kpanduah	150	114	36	36
Total Number of Villages		28			
Total Number of Filters		852	661	212	**221**

After finishing all 221 surveys I then used the Raosoft® Sample Size Calculator to determine the margin of error for 96% confidence interval with a population of 661 and a sample size of 221. The results show that for a 95% confidence interval, my sample size of 221 households has a margin of error of 5.79% (see Table 10).

Table 10: Table 7: Sample size and corresponding margin of error for a 95% confidence interval and population of 661 households

95% CI	SS	Error
	100	9.03%
	200	5.79%
	221	5.38%
	300	4.18%

3.2.3 Water Quality Testing

For the final sustained use study, I measured both water microbial contamination turbidity and of unfiltered and filtered water samples. the combined the 3M™ Petrifilm™

E.coli/TC test with the pre-dispensed Colilert® test to measure the microbial contamination and a turbidity tube to measure the turbidity of my water samples. This section describes the methods used to determine the turbidity measurements and to conduct the pre-dispensed Colilert® tests. The methods used for the 3M™ Petrifilm™ *E.coli*/TC are described in Section 3.1.3.

3.2.3.1 Sampling Techniques

I collected samples of filtered water in 100 ml Whirl-Pak® bags and performed turbudity measurements at each household that was identified as a "sustained filter user" (as long as they had enough water in their storage unit to sample). I filled both the turbidity tube and the Whirl-Pak® bags directly from the tap of the KOSIM storage unit and took unfiltered samples directly from the water sources in each the village (see Figures 17, 18 and 19). Since I performed these surveys during the wet season, many of the respondents were collecting and storing rainwater. If the respondent cited their main water source as rainwater, then I took the unfiltered sample directly from their rainwater storage pot. I kept all samples on ice while in the field (approximately 2-4 hours) before testing them in the lab.

Figure 17: Measuring the turbidity of unfiltered water from a local source in Northern Region Ghana (photo: Amin Hussein)

Figure 18: Measuring the turbidity of KOSIM filtered water (photo: Amin Hussein)

Figure 19: Collecting unfiltered water samples directly from the village source in Northern Region Ghana (photo: Amin Hussein)

3.2.3.2 Pre-dispensed Colilert® Test

The Colilert® 10 ml pre-dispensed test is a Presence/Absence test for coliform bacteria and *E.coli.* This test uses the Defined Substrate Technology (DST®), a method used in over 90% of all US drinking water municipality labs (INDEXX, 2009). DST® is a substrate medium that does not contain any organic sources of nitrogen and only two carbon sources: ONPG (ortho-nitro-phenol-beta D-Galactopyranoside) and MUG (4-methyl-umbelliferone-beta-glucuronidase (IDEXX, 2009). To conduct this test, a ten milliliter of sample is added to the Colilert® test tube vial and then incubated at 35°C for 24 hours. As in the pretest, I used a Millipore Portable Single Chamber Incubator (Model Number XX631K203) to incubate my samples. After incubation, tubes containing coliform bacteria turn yellow. Tubes that contain at least one *E.coli* turn yellow and fluorescent blue under long-wave UV light. Clear tubes contain no coliforms. For each group of tests, I also performed one blank Colilert® test and one blank 3M™ Petrifilm™ test using water than had been boiled and then cooled. This blank served as a control. I also selected one source water sample and one filtered water sample and performed a duplicated test to confirm my results. If the number of colonies on the 3M™ Petrifilm™ test was above 100, I labeled the test "too numerous to count" or "TNTC" and estimated the TC or *E.coli* counts by counting the number of colonies in one square of the petrifilm's grid and then multiplying by the total number of squares in the grid (which was 20).

As discussed in Section 3.1.4 the Colilert® test allows for lower limits of detection (i.e. 10 CFU/100 mL instead of the 100 CFU/100 mL 3M™ Petrifilm™ limit). Combining the Colilert® and the 3M™ Petrifilm™ tests allow detection of results over multiple orders of magnitude without having to perform dilutions (as seen in Table 6 in Section 3.1.4). If the 3M™ Petrifilm™ shows no TC, but the Colilert® test indicates that TC are present, then there could be anywhere from 10 – 99 TC CFU/100 mL in that sample. However, if the 3M™ Petrifilm™ shows no TC and the Colilert® test indicates no TC, that that sample could container anywhere from 1 – 9 CFU/100 mL. The same logic applies for *E.coli* counts as for TC counts. I analyzed my water quality test results at both the lower and upper limits of detection. I employed this method when analyzing the results of both water source and filtered water quality testing.

3.2.3.3 Turbidity Measurements

Turbidity is a physical property of water and an optical property that causes light to be scattered and absorbed by particles and molecules in the water, instead of transmitted in straight lines. It can be measured electronically by turbidimeters, with a turbidity tube, or via a no-cost method using a recycled PET plastic bottle.

Turbidity tubes are transparent, one-inch diameter and one-meter long polyethelene tubes. The bottom end is closed and labeled with a "bull's eye." The top end is open. The sample is poured into the tube until the "bull's eye" is no longer visible. After the gas bubbles from pouring in the water sample settle, the amount of water required for the "bull's eye" to disappear will determine the turbidity of sample being tested, based on the reading from the marked intervals along the length of the tube. Turbidity tube measurements are given in turbidity units (TU).

3.3 Data Analysis

I analyzed the survey responses using STATA®, a data analysis and statistical software package. In order to test the hypotheses listed in Chapter 1, I used the chi-squared statistical hypothesis test. This test is typically used test the independence of two nominal or categorical variables, such as sustained filter use and respondent roof type. The null hypothesis for the chi-squared statistical hypothesis test is that the two independent variables are unrelated (i.e. only randomly related). The alternative hypothesis is that there is an association or relationship between the two variables. If the p-value is greater than .05 than the null hypothesis is accepted. If the p-value is less than 0.05, then the null hypothesis is rejected. Since filter breakage is always associated with filter disuse, I removed the households with broken filters from my dataset before running the chi-squared test. This allowed me to test if the other factors in my hypothesis were associated with use or disuse.

In addition, I also ran a correlation test to determine the degree of the relationship between the different factors. The ouput of this test is an r-value. The closer the r-value is to +/-1, the stronger the correlation between the two variables. The correlation of the different factors in my hypothesis is important because if two factors are correlated with each other, and they both are associated with sustained use, then it is impossible to tell which factor is actually related to use. The results from this analysis are presented in Chapter 4.

Chapter 4 Sustained Use Study Results

During the months of June and July 2009, I surveyed 221 of Pure Home Water's rural customers. I then used the chi Squared statistical hypothesis test to analyze both the survey responses and my observations to determine what factors were associated with sustained use or disuse of PHW's KOSIM ceramic pot filter. As mentioned in the previous chapter, a p-value less than 0.05 indicates that the variable tested is associated with filter use or disuse. However, this test does not specify the structure of the association. I also conducted water quality testing to determine the KOSIM filter's performance in the field. The following sections summarize the results and observations from the survey, the chi-squared analysis and the water quality tests. The complete survey results can be found in Appendix D[17].

4.1 Survey Results and Analysis

As explained in Chapter 1, I hypothesized that the following factors would be associated with sustained use or disuse of the KOSIM filter:

1. Filter breakage
2. Household income
3. Price paid for filter
4. Children drinking from the filter
5. Reported drinking Water Source
6. Total number of people drinking from the filter
7. Presence of training materials in the home
8. Filter maintenance
9. Demonstrated knowledge of safe water handling practices

In this section, I first present a summary of the survey responses and then explain the results of the chi-squared hypothesis tests.

4.1.1 Respondent Demographics

Figures 20, 21, and 22 display a summary of the respondent demographics. 32% of the PHW customers that I surveyed were male and 68% were female. While the average respondent

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[17] I compare the results from the final sustained use study to the pre-test survey results in Appendix E.

age was 37 years old, the majority of survey respondents were in the 20-30 year old age range[18]. Respondent roof type was used as a measure of household income. Straw, traditional roofs indicate a lower-income household, a mix of zinc and straw roofs indicate a middle-income household, and zinc roofs indicate a higher-income household. Overall, the majority of the survey respondents lived in middle or low-income households (51% had straw roofs, 40% had a mix of zinc and straw roofs, and 9% had zinc roofs). Gbanyamni, Dungu, and Dungu Yeshee were the wealthiest villages while Tugu, Kpawumo, Wovugu, and Abubihiyilli were the poorest villages.

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[18] Most survey respondents were reluctant to report their age and many did not know their actual age. This reluctancy may be due to cultural factors that establish hierarchies based on age cohorts. The reported age was often a rough estimate made after heavy encouragement by my translator.

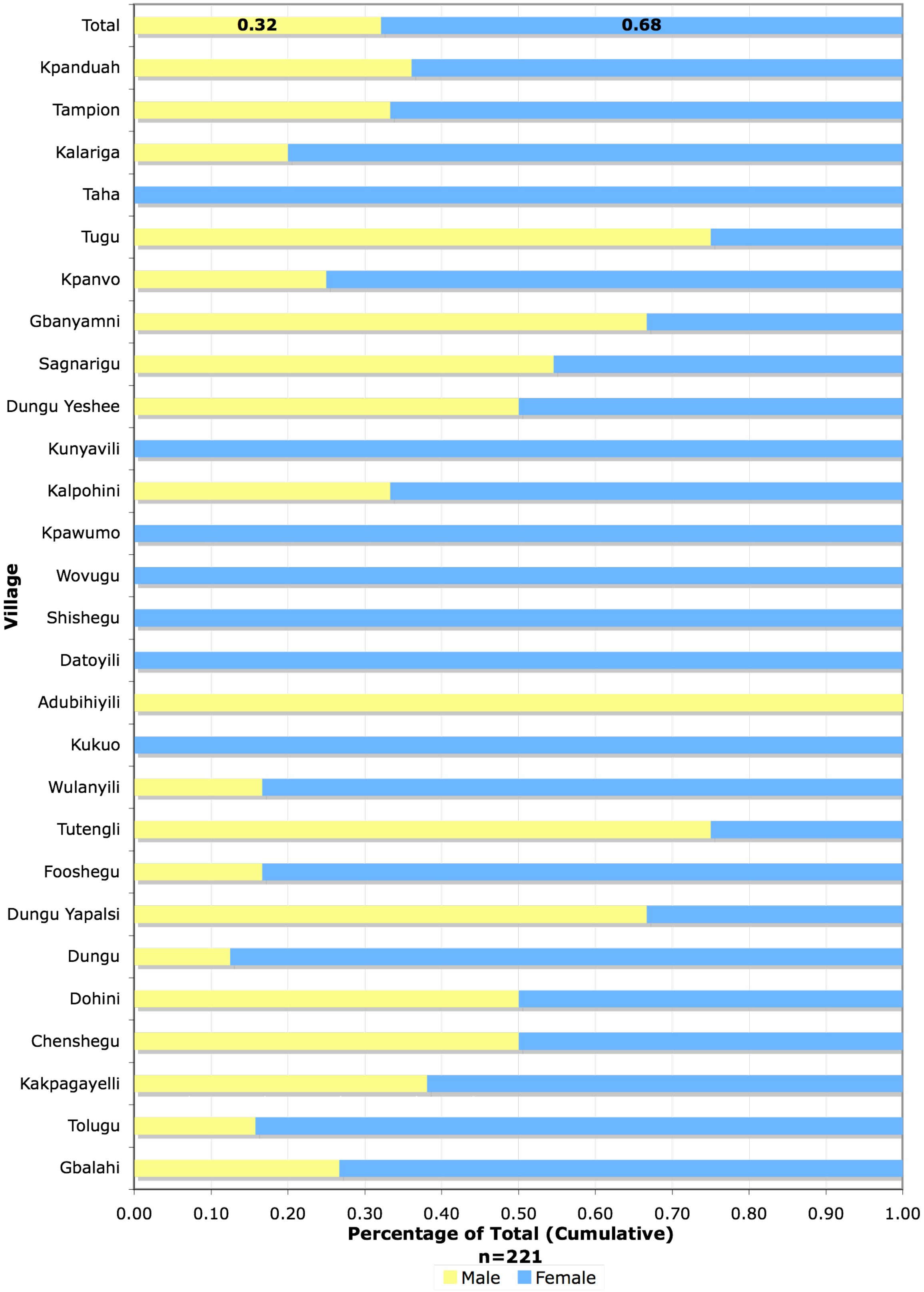

Figure 20: Survey respondent gender, by village

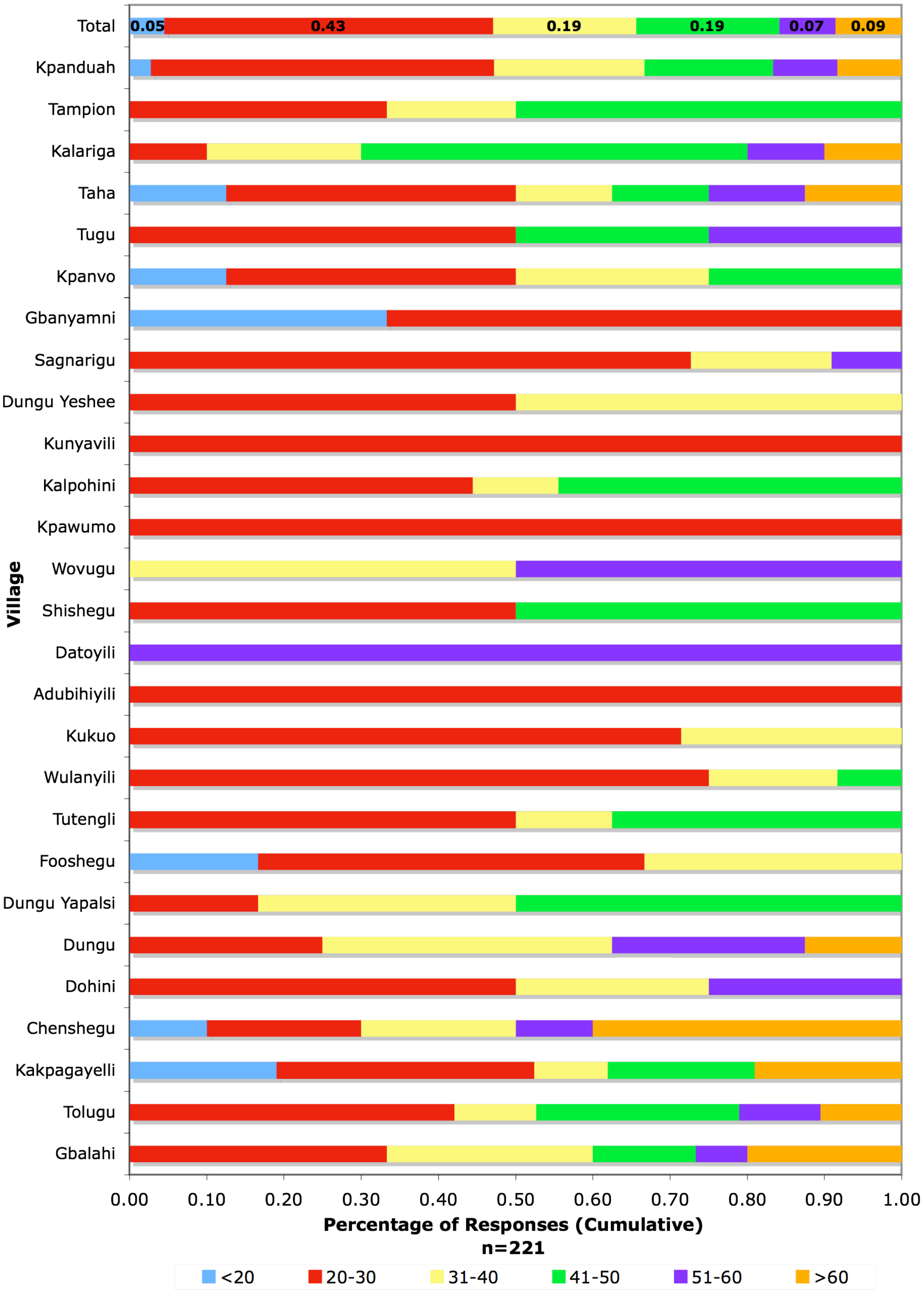

Figure 21: Respondent age, by village

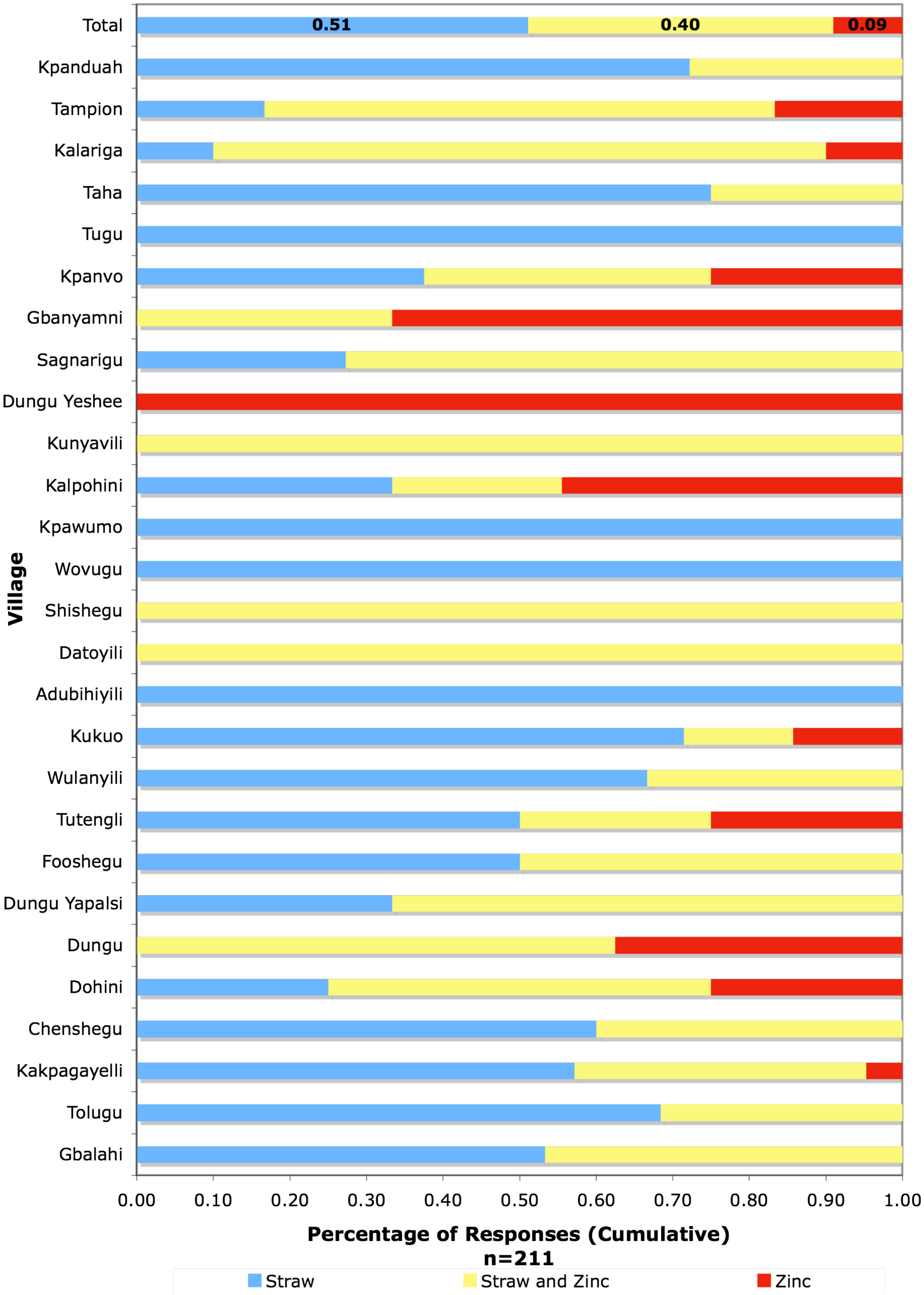

Figure 22: Respondent roof type, by village

Table 11 presents the results from the chi-squared hypothesis tests. Since the p-value is less than 0.05, respondent-roof type (a measure of household income) is associated with filter use (95% confidence interval). Although this test does not indicate the structure of the association, the resulting table shows that over half the lower-income households (67%) were using the filter at the time of the interview, while only 47% of middle-income households and 26% of higher-income households were practicing sustained use.

		Using Filter at Time of Interview		
		Yes	No	Total
Roof type (p-value = 0.001)	Straw	64	31	95
	Straw & Zinc	34	38	72
	Zinc	5	14	19
	Total	98	69	167

Table 11: Respondent roof-type chi-squared hypothesis test results

4.1.2 Drinking Water Source and Safe Storage

Figure 23 illustrates the drinking water source reported by the respondent on the day of the interview. Rainwater was the most prevalent drinking water source (36%), followed by dugouts (29%), unprotected, dug wells (26%), and public standpipes (8%). The "other" (2%) category includes sources that were not located in the village.

Although many respondents used multiple sources of water throughout the year, this data reflects the water that the respondent was filtering, (or had filtered), through the KOSIM filter or, if he/she was not using the filter, in a traditional safe storage pot at the time of the interview. Since I conducted the surveys during the wet season, the wide use of rainwater is not surprising. Five respondents reported mixed drinking water sources. As a result the total number of answers (n=226) exceeds the number of people surveyed during this study (221 people).

Table 12 shows the results from the chi-squared analysis, which indicates that water source is associated with filter use or disuse. As mentioned in previous sections, this test does not indicate the structure of the association, however, over half of the households collecting water from dugouts, unprotected dug wells, or rainwater were still using the filter at the time of the interview (69%, 52% and 55% respectively), only 33% of households collecting water from a public stand-pipe were practicing sustained use.

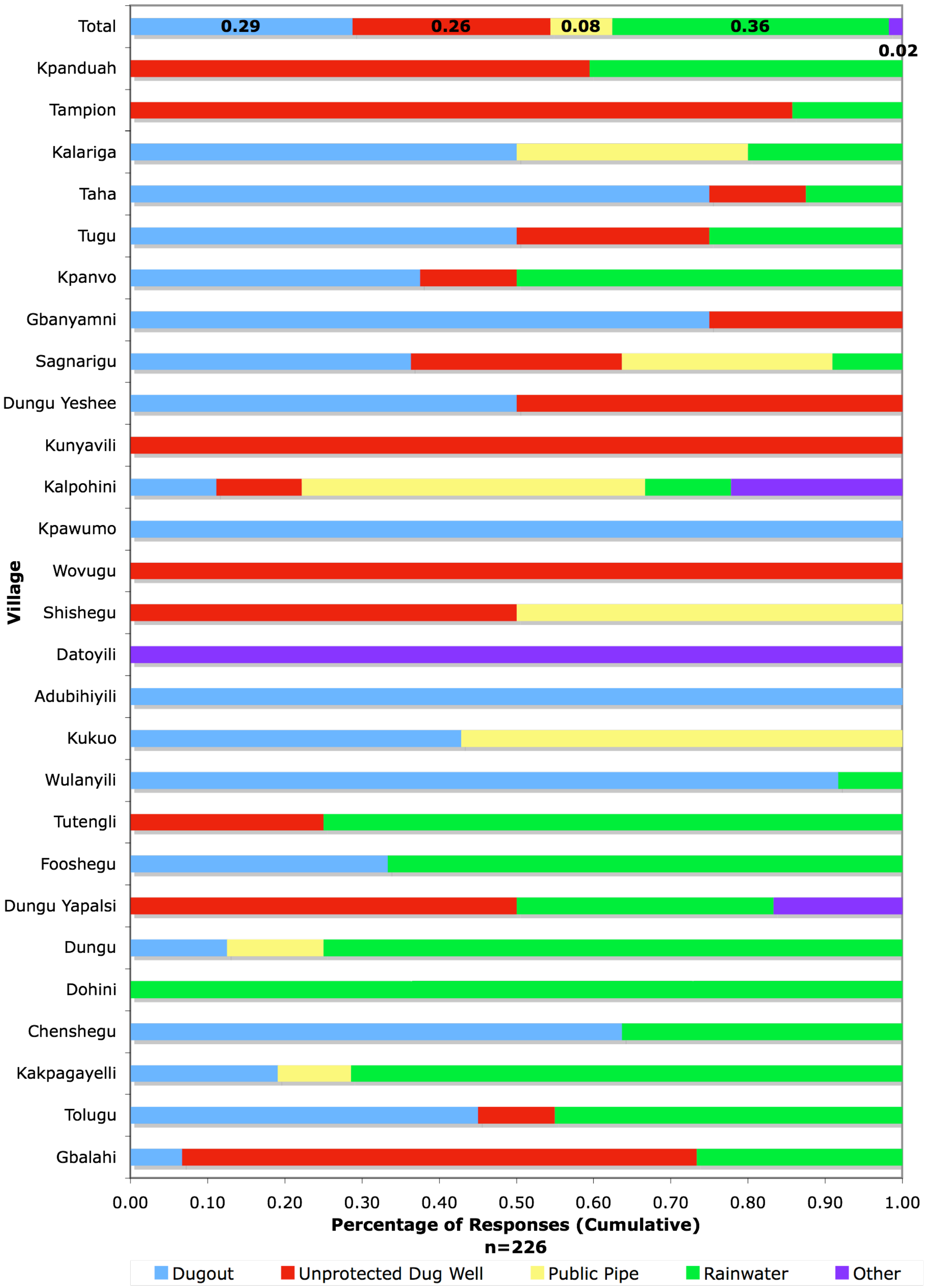

Figure 23: Drinking water source on day of interview, by village

Table 12: Water source chi-squared hypothesis test results

		Using Filter at Time of Interview		
		Yes	No	Total
Drinking Water Source on Day of Interview (p-value = 0.015)	Dugout	38	17	55
	Unprotected Dug Well	25	23	48
	Rainwater	35	29	64
	Public Stand Pipe	5	10	15
	Other	0	4	4
	Total	103	83	186

By observing the ceramic water storage pots located in each household, I was able to learn about each respondent's water storage practices. I can then use these practices to determine the overall knowledge about water contamination and health in the villages I surveyed[19]. If these pots were covered, then I reported the respondent to be "practicing covered storage at the time of the interview." As shown in Figure 24, only 23% of the survey respondents covered their water storage pots, indicating an overall low level of water contamination knowledge in the villages surveyed. Table 13 summarizes the results from the chi-squared hypothesis test and shows that covered storage is not associated with sustained use or disuse of the KOSIM filter (p-value = 0.333).

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[19] Just covering the clay pots is not technically considered "safe water storage," because people still have to dip cups into the pot to fetch water, which could contaminate the water (safe storage containers have taps to preventing dipping). However, it does show that the members of the household are making an effort to protect their water from contamination and may have some knowledge about the link between health and water quality.

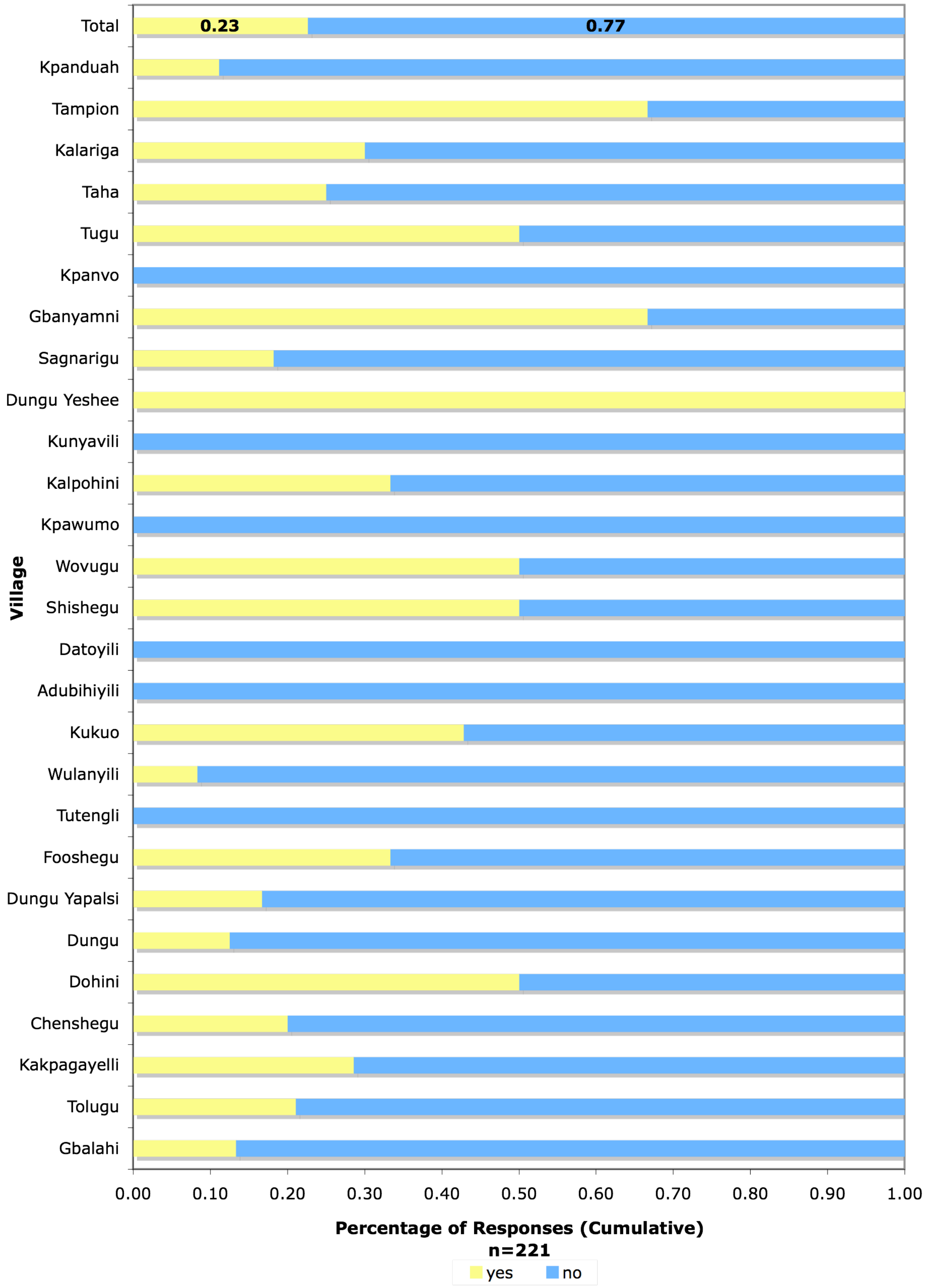

Figure 24: Covered storage practices, by village

Table 13: Covered water storage chi-squared hypothesis test results

		Using Filter at Time of Interview		
Water Storage Pots Covered at Time of Interview (p-value = 0.333)		Yes	No	Total
	Yes	26	16	42
	No	77	67	144
	Total	103	83	186

4.1.3 Filter Use

Figure 25 displays the sustained use of the KOSIM ceramic water filter. In total, 103 survey respondents (46%) were using the filter at the time of the interview. As explained in Section 3.2.1, I defined "sustained filter use" based on the following observations at the time of the interview:

4. KOSIM filter is correctly installed in storage unit.
5. Water is currently in KOSIM pot filter.
6. Clear[20] water is currently in KOSIM storage unit.

Wulanyili and Fooshegu had the highest percentages of sustained filter use (each had 83%) while Abubihiyili, Datoyili, Wovugu, Kpawumo, Dohini, Dungu Yapalsi, Kunyavili, and Dungu Yeshee had the lowest percentages (each had 0% use). Due to the low number of total filters sold in Abubihiyili, Datoyilim , Kpawumo, and Kunyavili, I only surveyed one person in each of these villages. The 0% sustained in each of these villages use reflects my observations in that one household.

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[20] Clear water is defined as water having a turbidity measurement of < 5 TUs

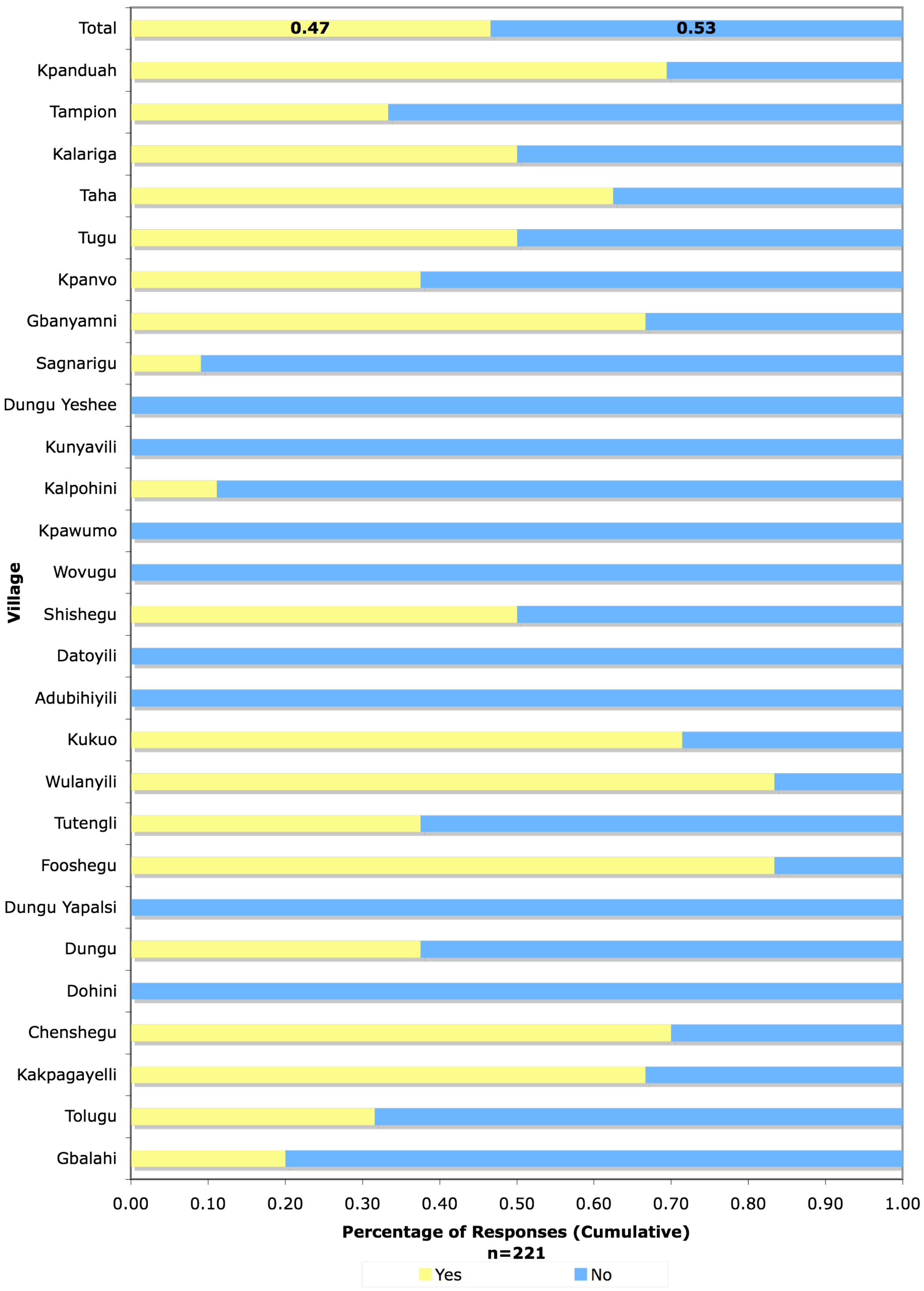

Figure 25: Filter use at time of interview, by village

Figure 26 illustrates the reported reasons for filter disuse in each village. Twenty-seven percent of the survey respondents cited breakage as the reason they had stopped using their filter. The ceramic filter pot was the most commonly broken element of the KOSIM filter unit (63% of breakage reports - see Figure 27). Twenty-two percent of respondents reported that they stopped using their filter because their water source had improved and they no longer needed the filter. Many of these respondents stated that they only use their filter in the dry season, when the water quality of their local source is worse. However, since I based my definition of sustained use on my observations at the time of the interview, these responses were counted as "disuse." Sixteen percent of respondents claimed that they were currently using the filter, but their filtered water had "just finished" and they had not filled the pot yet. Again, since I did not observe these respondents using their filters at the time of the interview, these responses were also counted as "disuse." Fifteen percent of respondents cited that the filter owner was traveling at the time of the interview and the remaining members of their household could not use the filter while the owner was gone. Five percent of respondents reported that they stopped using the filter because it was too slow. The remaining 15% of respondents reported a wide range of reason for disuse (e.g. taste of water, never learned how to use, uses "sometimes", etc) and fall into the "other" category.

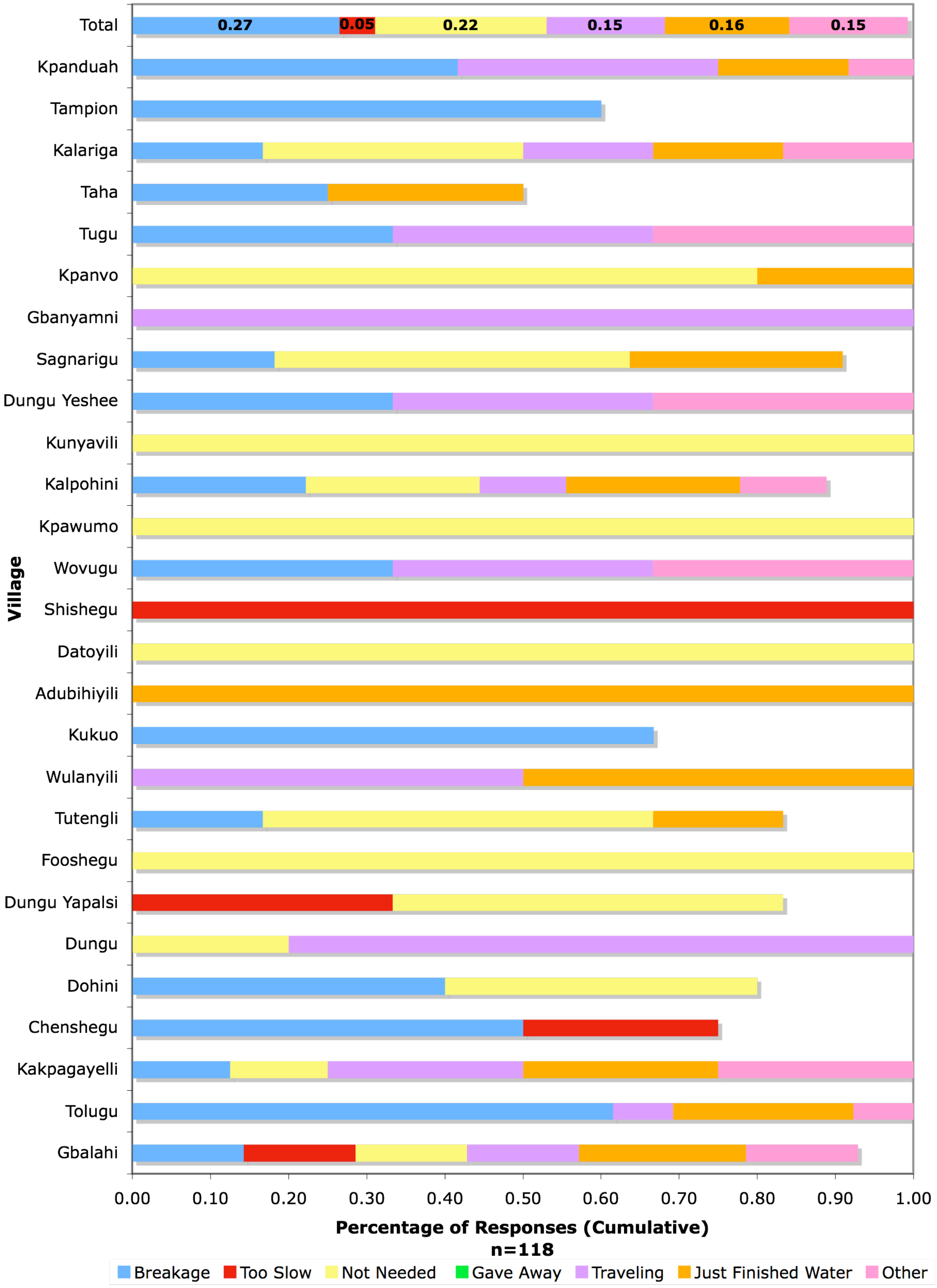

Figure 26: Reasons for disuse, by village

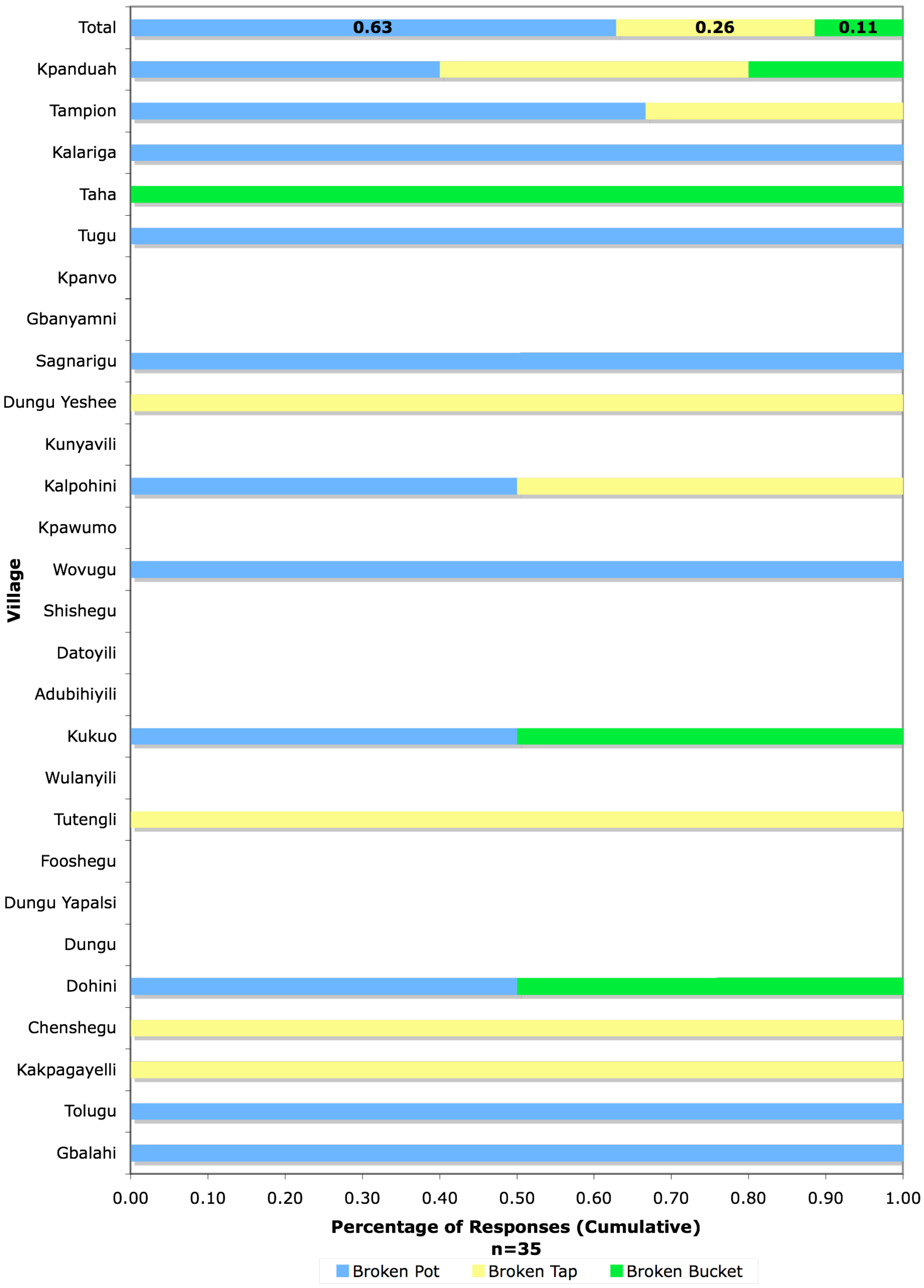

Figure 27: Filter element breakage, by village

On average about 8.35 people (4.44 children and 3.91 adults) were drinking from each KOSIM water filter. The percentages of children and adults drinking from each filter remained relatively constant over all of the villages surveyed (see Figure 28). Neither total family size nor the presence of children drinking from the filter are associated with filter use or disuse (see Tables 14 and 15).

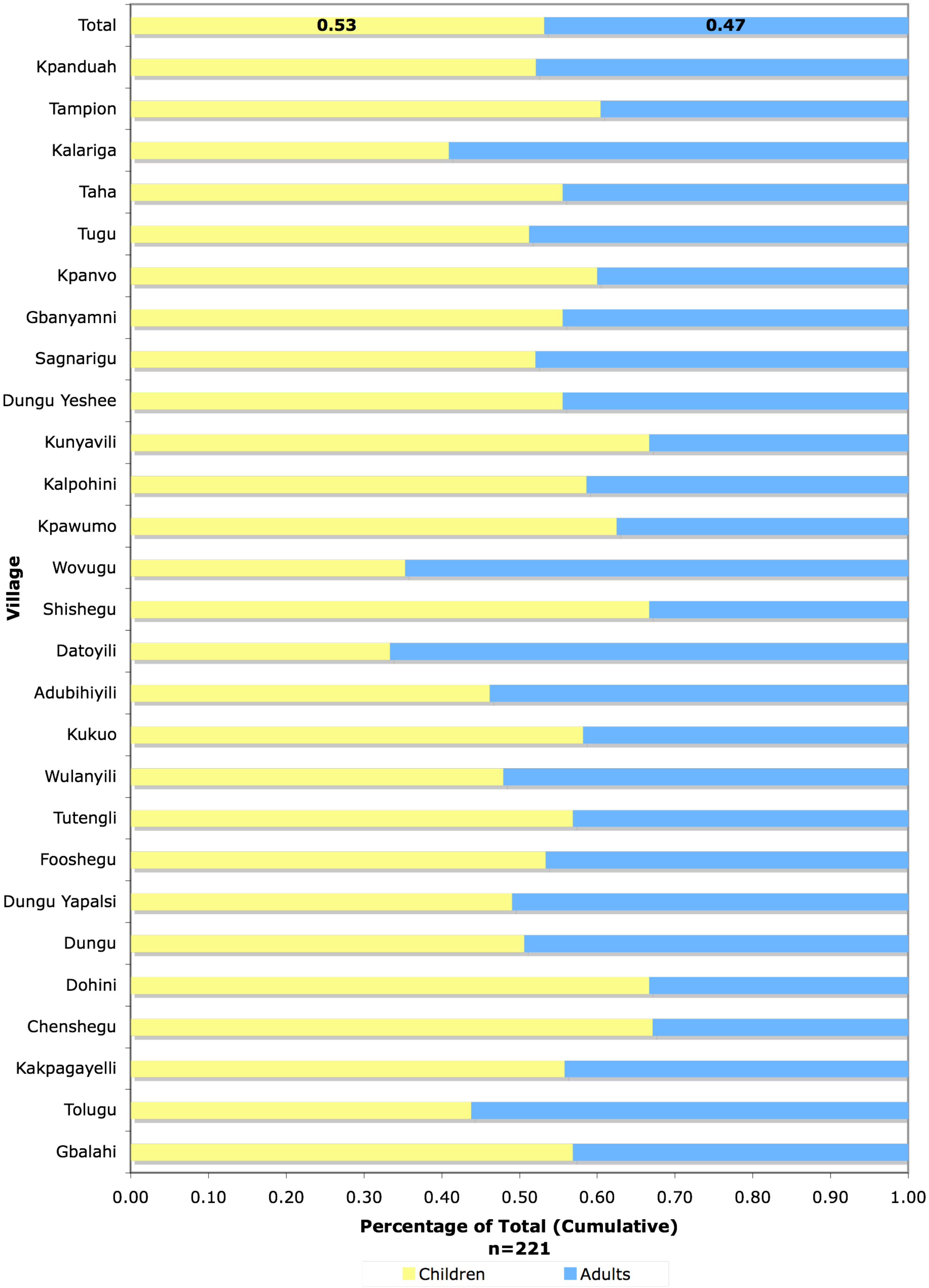

Figure 28: Who drinks from the filter, by village

Table 14: Total number of people drinking from KOSIM filter chi-squared hypothesis test results

		Using Filter at Time of Interview		
Number of People Drinking From Filter (p-value = 0.079)		Yes	No	Total
	< 8	58	36	94
	≥ 8	45	47	92
	Total	103	83	186

Table 15: Number of children drinking from KOSIM filter chi-squared hypothesis test results

		Using Filter at Time of Interview		
Children Drinking From Filter (p-value = 0.148)		Yes	No	Total
	Yes	93	69	162
	No	10	14	24
	Total	103	83	186

4.1.4 Retail Price Paid for Filter

The retail price of the KOSIM ceramic water filter has varied significantly over Pure Home Water's short four-year existence. In its first year, PHW charged 19 Ghana Cedis[21] (GHC) (full payment) or GHC 20 for households who purchased the filter on credit. When PHW stared explicitly targeting the KOSIM filter to low-income customers in Northern Region Ghana, they charged rural customers GHC 6 per filter. These customers were allowed to purchase filters on credit and were expected to pay PHW three installments of GHC 2 each. Payment collection proved to be a challenge for PHW, and as a result, some of these rural customers have not paid for their filters in full. Figure 29 illustrates the prices paid for the KOSIM by the survey respondents. 43% of respondents paid the full GHC 6 for their KOSIM filter, while 5% bought the filter on credit and have not yet paid in full. The delinquent customers reside in the villages of Sagnarigu, Kukuo, Tutengli, Dungu, Chenshegu, and Kakpagayelli. Twently-three of respondents received their filter for free. These respondents either lived in a village that had been sponsored by an aid organization or individual (i.e. someone outside of the village purchased the filters from PHW which were then distributed to households free of charge), were the chief of a village, or a village liason (PHW gives the village chief and the village liason each

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[21] While it can fluctuate, the exchange rate is approximately 1 GHC = 1 USD

a free filter). Seventeen percent of respondents reported that they paid more than GHC 6 for their filter and the remaining 13% either did not know or could not remember how much they paid.

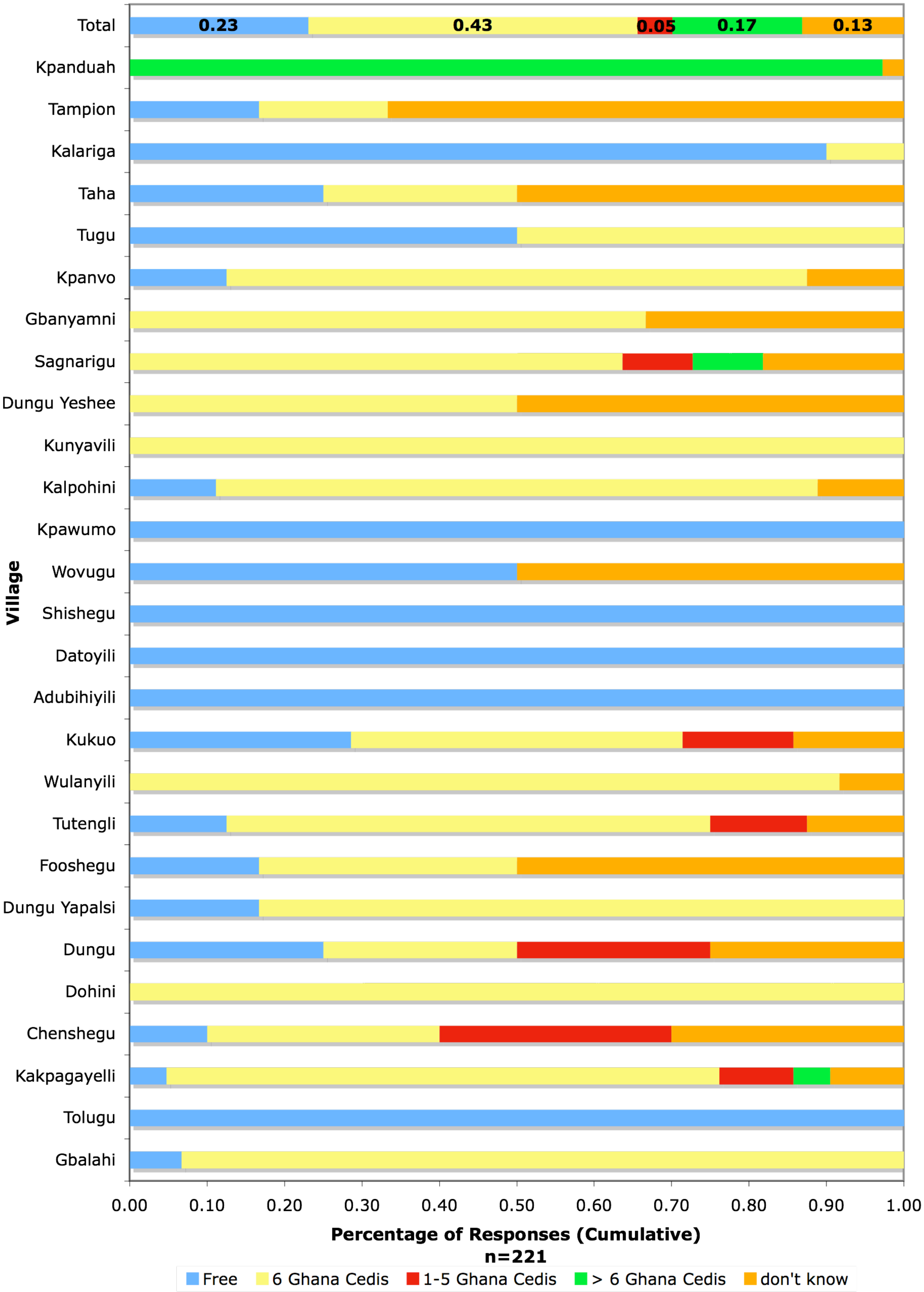

Figure 29: Amount paid for KOSIM ceramic pot filter, by village

Table 16 shows the results of the chi-squared hypothesis test for the price paid for the KOSIM ceramic pot filter. The price paid for the filter is associated with sustained filter use or disuse. Seventy-eight percent of respondents who paid greater than GHC 6 for their KOSIM filter were still using it at the time of the interview while, 47% of respondents who paid GHC 6 and 57% of respondents who paid less than GHC 6 were practicing sustained use. Half of the household who did not know the price they paid for the filter were still using the KOSIM at the time of the interview.

Table 16: Reported price paid for filter Chi-Squared hypothesis test results

	Using Filter at Time of Interview			
		Yes	No	Total
Price Paid for Filter (GHC) (p-value = 0.025)	6	38	43	81
	< 6	28	21	49
	> 6	25	7	32
	Don't know	12	12	24
	Total	103	83	186

4.1.5 Training Materials

Each Pure Home Water customer is supposed to received a training pamphlet and a filter brush with the purchase of their filter. The pamphlet explains, using both pictures and words, how to use and maintain the KOSIM filter. Figure 30 illustrates the results of these observations of possession of training materials and brush. While 89% of the respondents stated that they had received a brush, only 55% of respondents had the brush in their home at the time of the interview. These results indicate that 45% of the respondents are not maintaining their filter properly, which likely results in a slow flow rate. Sixty-one percent of the respondent claimed that they did receive a training poster, however only 24% still had the poster in their home at the time of the interview.

Tables 17 and 18 summarize the chi-squared hypothesis test results for the presence of the brush and training poster on the day of the interview. Neither of these materials are associated with filter use or disuse.

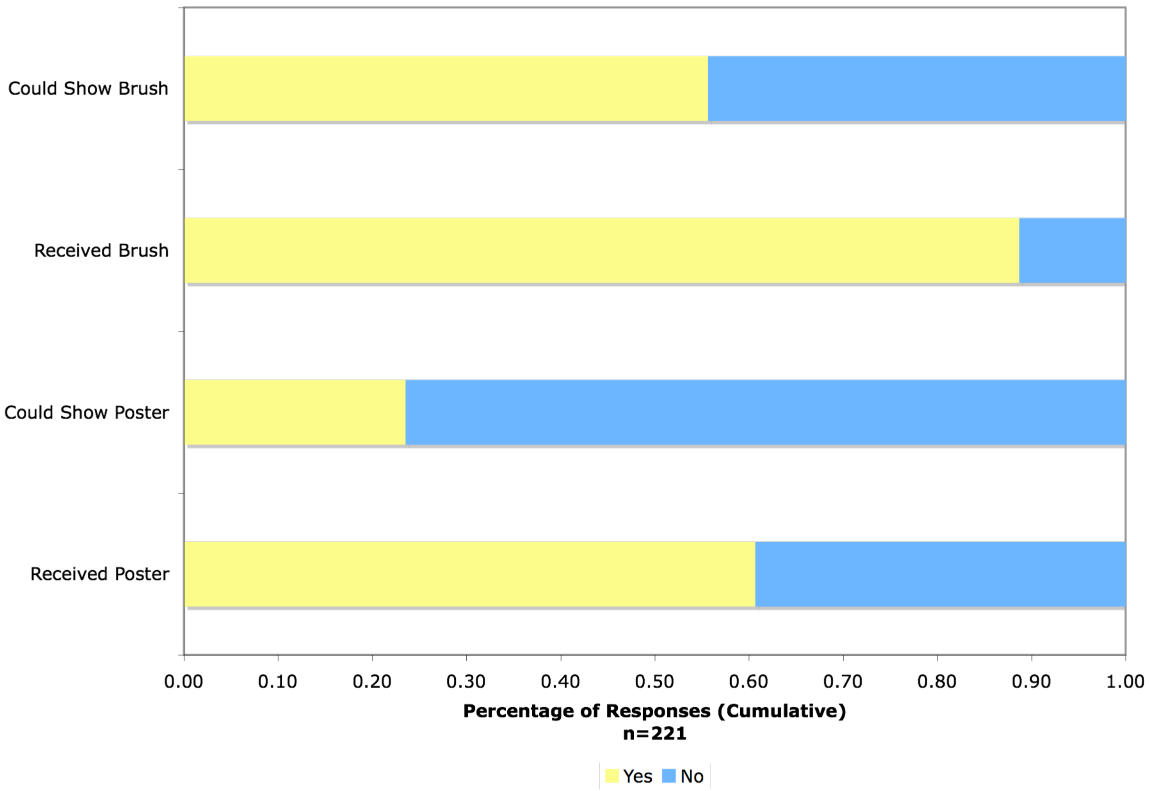

Figure 30: Training Materials

Table 17: Brush present at time of the interview chi-squared hypothesis test results

		Using Filter at Time of Interview		
Had Brush at Time of Interview (p-value = 0.140)		Yes	No	Total
	Yes	68	46	114
	No	35	37	72
	Total	103	83	186

Table 18: Pamphlet present at time of the interview chi-squared hypothesis test results

		Using Filter at Time of Interview		
Had Instructional Pamphlet at Time of Interview (p-value = 0.313)		Yes	No	Total
	Yes	29	18	47
	No	74	65	139
	Total	103	83	186

4.1.6 Time Owning Filter

Figure 31 displays the total number of months each respondent had owned the filter at the time of the interview (PHW sells filters to the whole village at the same time, so time owning the filter does not vary by respondent as long as they are located in the same village). The PHW sales records did not indicate the sales date for the village of Kpanduah, so that village data is not displayed in the figure. The average number of months owning the filter was 13 months.

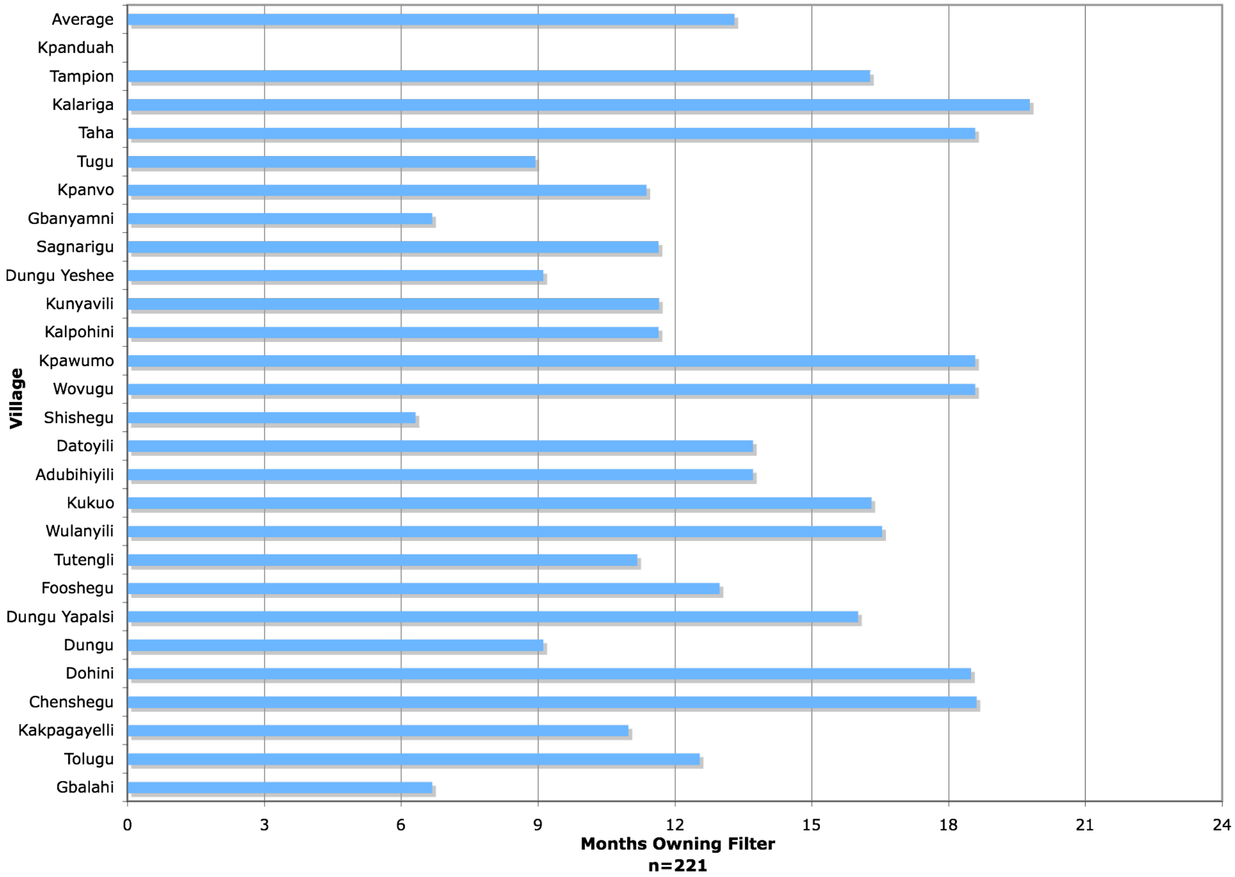

Figure 31: Number of months owning the KOSIM Filter at time of interview, by village

4.1.7 Correlation Results

Table 19 shows the results from the correlation test. A strong correlation is typically indicated by a r-value > 0.80. None of the factors tested for association with filter use for disuse were strongly correlated with each other (all r-values were <0.40).

Table 19: Correlation test results

	materials	brush	filter cost	H20 source	family size	children	pots	roof type
materials	1							
brush	0.18	1						
filter cost	0.16	0.13	1					
H20source	0.15	0.01	0.05	1				
family size	-0.07	-0.06	-0.17	-0.17	1			
children	-0.08	0.04	-0.03	-0.06	0.35	1		
pots	0.05	0.1	0	0.06	-0.17	0.09	1	
roof type	-0.01	0.08	-0.02	0.17	0.03	0	0.03	1

4.2 Water Quality Results

4.2.1 Water Source Testing

Figures 32 and 33 and Tables 20 and 21 show the average water quality test results for the reported water sources in each village using both the lower and upper detection limits of the Colilert® test and 3M™ Petrifilm™ *E.coli*/TC test. For dugouts and unprotected dug wells I tested both an undiluted and a 1:10 dilution using boiled, cooled water. This same water was also used for blanks (as discussed in Chapter 3). The final water quality results for these two sources are an average of both the diluted and undiluted results. According to these water quality tests, dugouts are the most turbid source of water with an average turbidity of 333 TU, while unprotected dug wells are the most microbially contaminated water sources with an average count of 39,100 total coliform CFU/100mL and an average count of 9,670 *E.coli* CFU/100 mL using the lower detection limit. Applying the upper detection limit did not significantly change the average results for each water source, as can be seen by comparing the source water quality test results in Tables 20 and 21. The source water quality test results, for each village can be found in Appendix F. Although some households reported a public standpipe as their source of water, no pipes in any of the villages were flowing at the time of my interviews, so I was unable to test the quality of the pipe water[22].

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[22] The public standpipes in rural, Northern Region Ghana, do not flow consistently. On average, respondents reported that these pipes would flow 2-3 times per week in the wet season (June – September) and less during the dry season (October – May).

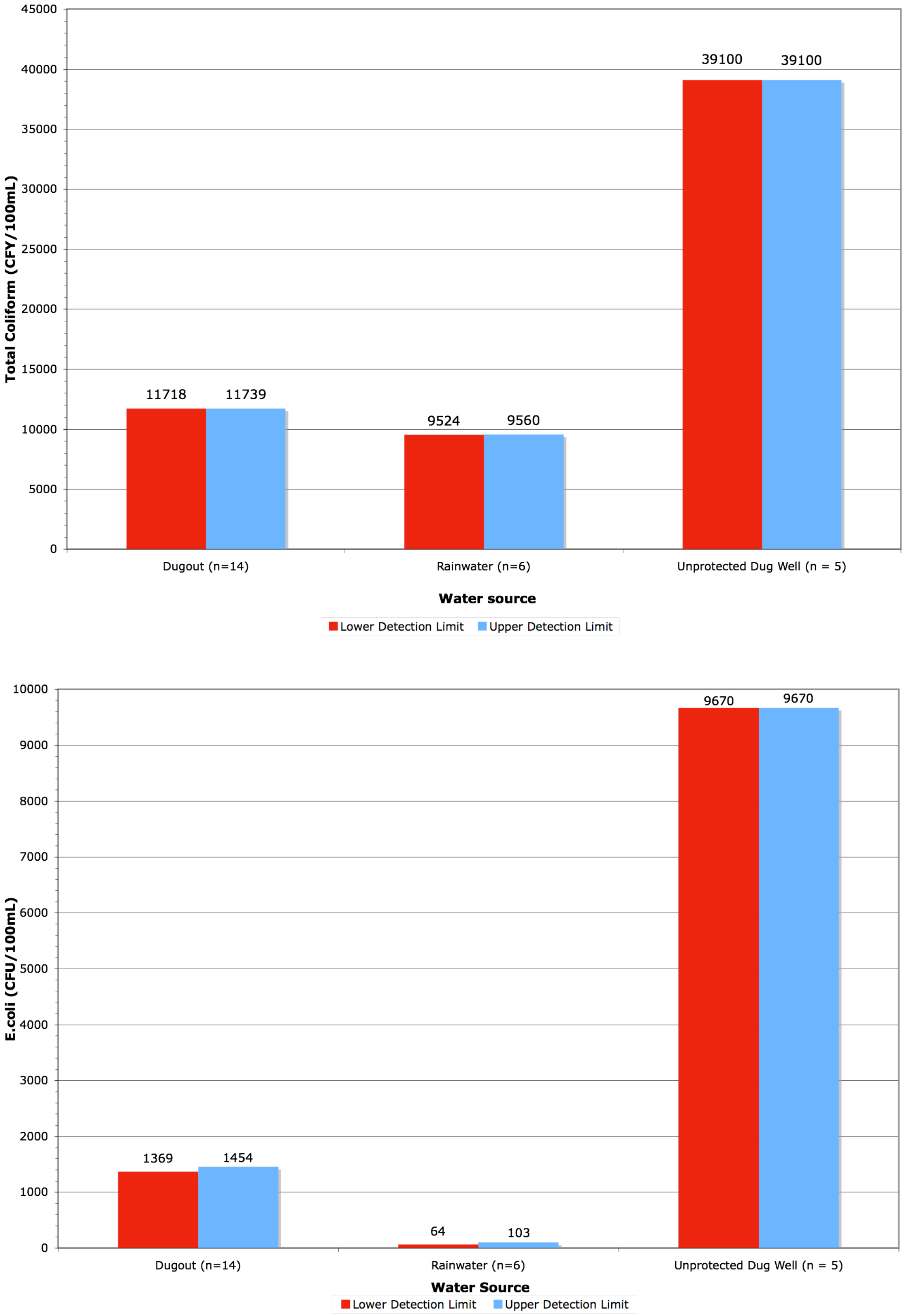

Figure 32: Average total coliform and *E.coli* test results for water sources

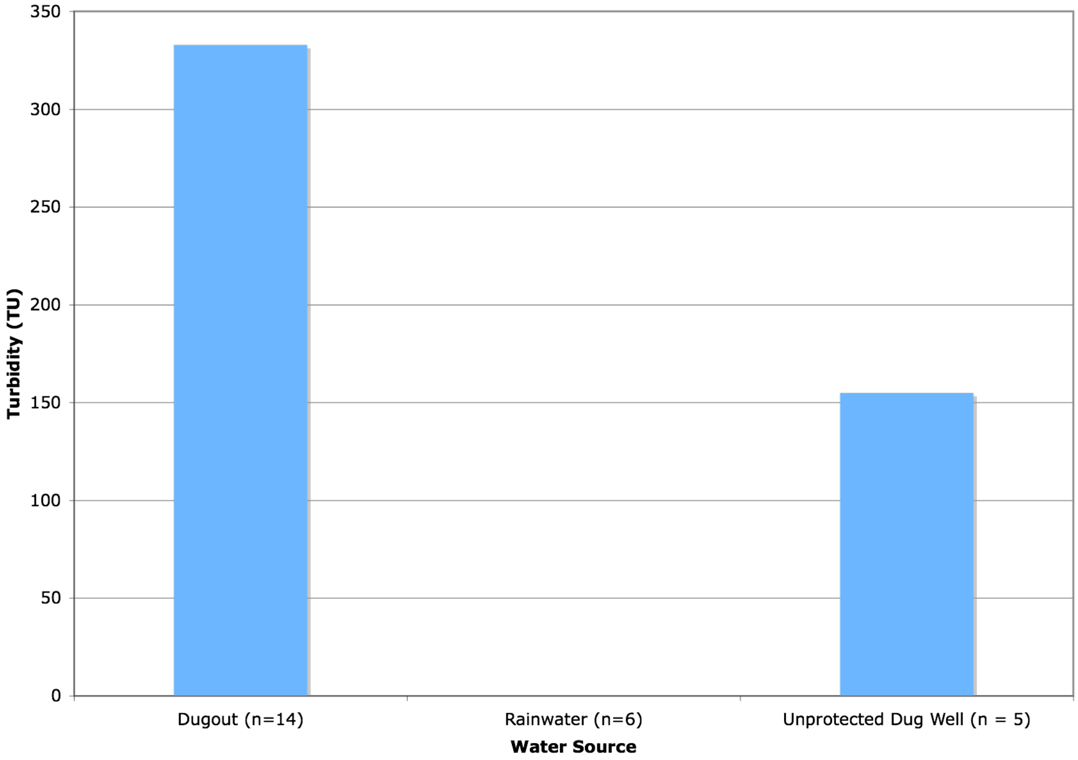

Figure 33: Average turbidity test results for water sources

Table 20: Source water quality test results, lower detection limit

Source Type	Average Total Coliform Count (per 100mL)	Average E.coli Count (per 100 mL)	Average Turbidity (TU)
Dugout (n=14)	11,718	1,369	333
Rainwater (n=6)	9,524	64	<5
Unprotected Dug Well (n= 5)	39,100	9,670	155

Table 21: Source water quality test results, upper detection limit

Source Type	Average Total Coliform Count (CFU/ 100mL)	Average *E.Coli* Count (CFU/ 100 mL)	Average Turbidity (TU)
Dugout (n=14)	11,739	1,454	333
Rainwater (n=6)	95,60	103	<5
Unprotected Dug Well (n=5)	39,100	9,670	155

4.2.2 KOSIM Filter Water Quality Testing[23]

As mentioned in Chapter 3, I tested filtered water from 72 KOSIM water filters. Figures 34 and 35 illustrate the average water quality test results for each village surveyed using the lower detection limit of the Colilert®/3M™Petrifilm™combination test. Overall, the average total coliform and *E.coli* results for the filtered water, using the lower limit detection limits, were 6,167 CFU/100 mL and 74 CFU/100 mL respectively. This *E.coli* count is classified as an "intermediate" risk level in the WHO's drinking water guidelines (see Table 6 in Chapter 2). While the majority of the filters tested reduced the total coliform and *E.coli*, 17 of the filtered samples showed higher counts of total coliform than the reported water sources[24]. Additionally, 11 of these filters showed higher counts of *E.coli* in the filtered samples than in the reported water sources. The results for these 17 "problem" filters, using the lower detection limit, are illustrated in Figures 36 and 37. If the 17 "problem" filters are removed from the data, then the average total coliform results for the KOSIM filtered water, using the lower detection limit, decreases to 323 CFU/100 mL. The average *E.coli* results decrease to 7 CFU/100 mL, which corresponds to a "low" risk level. The results for these "working" filters are shown in Figures 38 and 39.

Figures 40 and 41 display the average water quality test results for each village surveyed using the upper, more conservative detection limit of the Colilert®/ M™Petrifilm™ combination test (9 or 99 instead of 1 or 10 to determine the final counts). Overall, the average total coliform and *E.coli* results for the filtered water, using the upper detection limits, were 6188 CFU/100 mL and 107 CFU/100 mL respectively (a "high" risk level). Despite detection limit change, the same 17 "problem" filters showed increases in total coliform count after filtration (see Figures 42 and 43). The overall average total coliform and *E.coli* counts for the 72 KOSIM filters did not significantly increase when changing to the upper detection limit because most of the "problem" filters had positive Colilert® results and colonies present in the 3M™Petrifilm™ and therefore, did not have a range of results. Thus, changing from the lower detection limit to the upper detection had no effect on the TC and *E.coli* counts for most of the "problem" filters (only household 182 was affected by this change). If the 17 "problem" filters are removed from the

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[23] Since I only tested the filtered water quality of sustained filter users, every filter tested had a turbidity of < 5 TUs (a requirement for "sustained filter use'). Therefore I do not discuss the results of the turbidity tests in this section. This data can be found in Appendix ____.

[24] Possible reasons for this increase are discussed in Chapter 5

data, then the average total coliform results for the KOSIM filtered water, using the upper detection limit, decreases to 1097 CFU/100 mL and the average *E.coli* results decrease to 37 CFU/100 mL (most of the "working" filters did have a range of possible test results and therefore, were effected by the change in detection limit). This lower *E.coli* count corresponds to an "intermediate" risk level in the WHO guidelines. These results are shown in Figures 44 and 45.

The detailed water quality results for each household, including, the Colilert® presence/absences results and the 3M™Petrifilm™ test counts can be found in Appendix G.

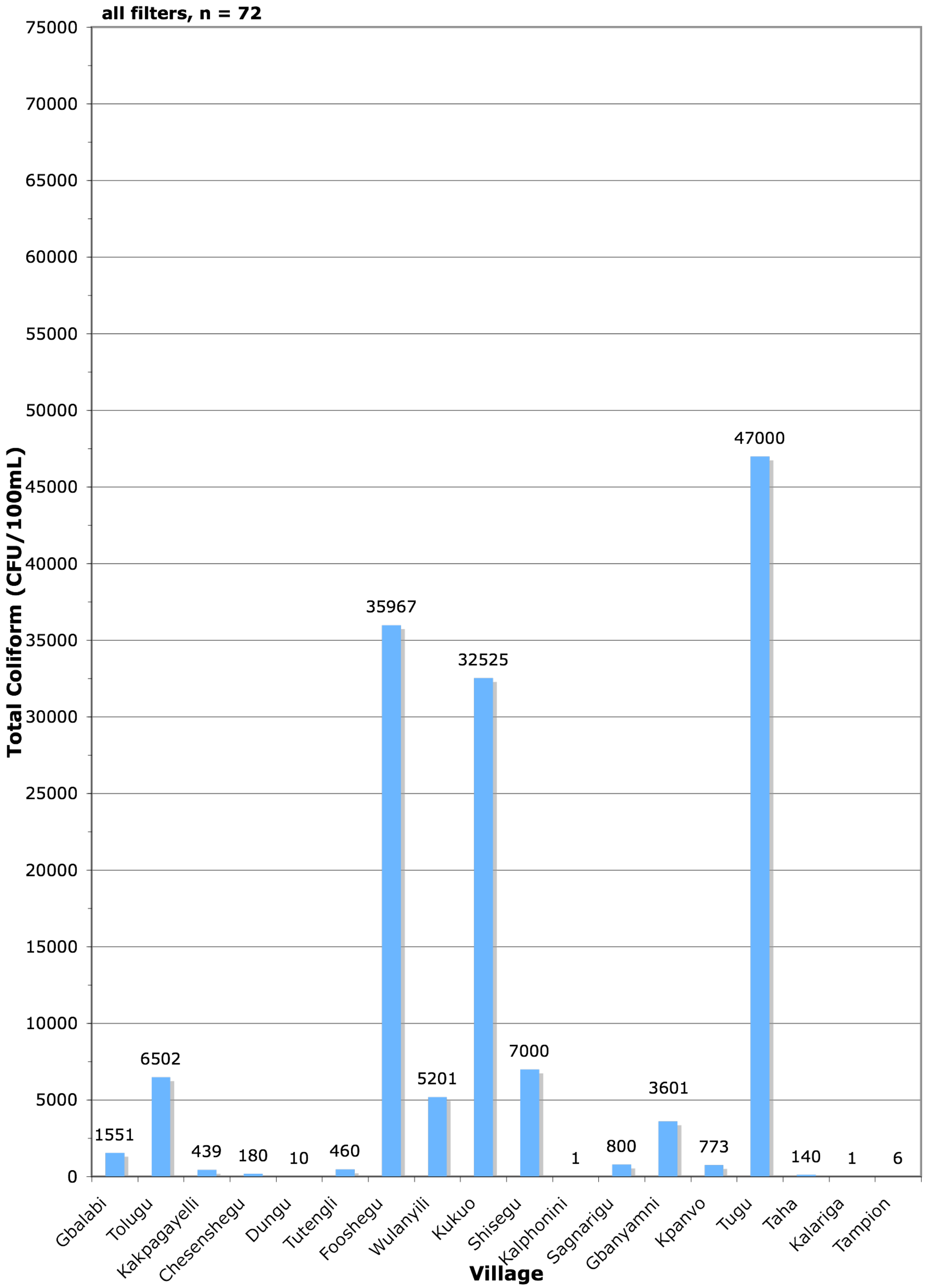

Figure 34: Average KOSIM-filtered water total coliform counts using the lower detection limit, by village for all filters tested

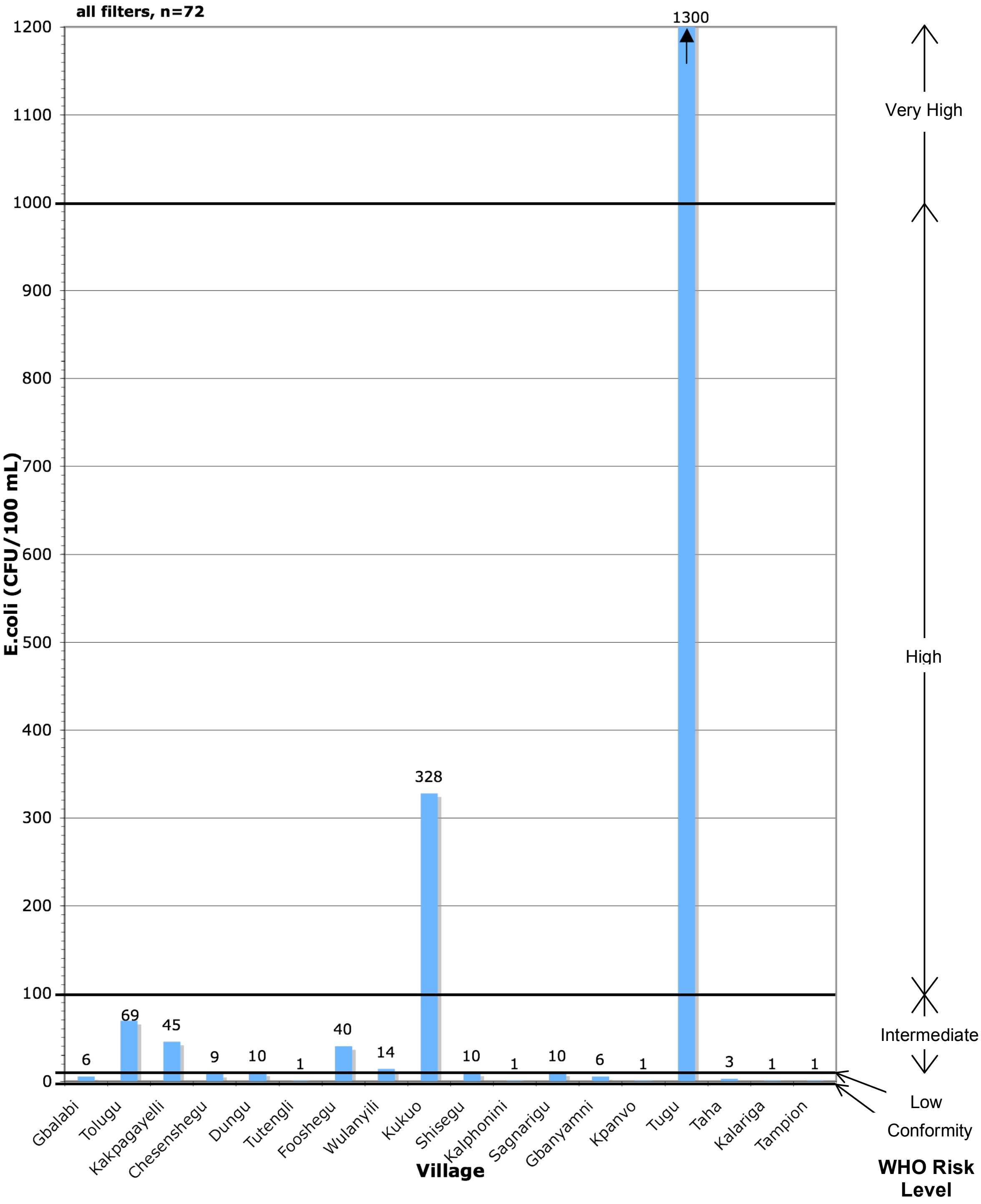

Figure 35: Average KOSIM-filtered water *E.coli* counts using the lower detection limit, by village for all filters tested

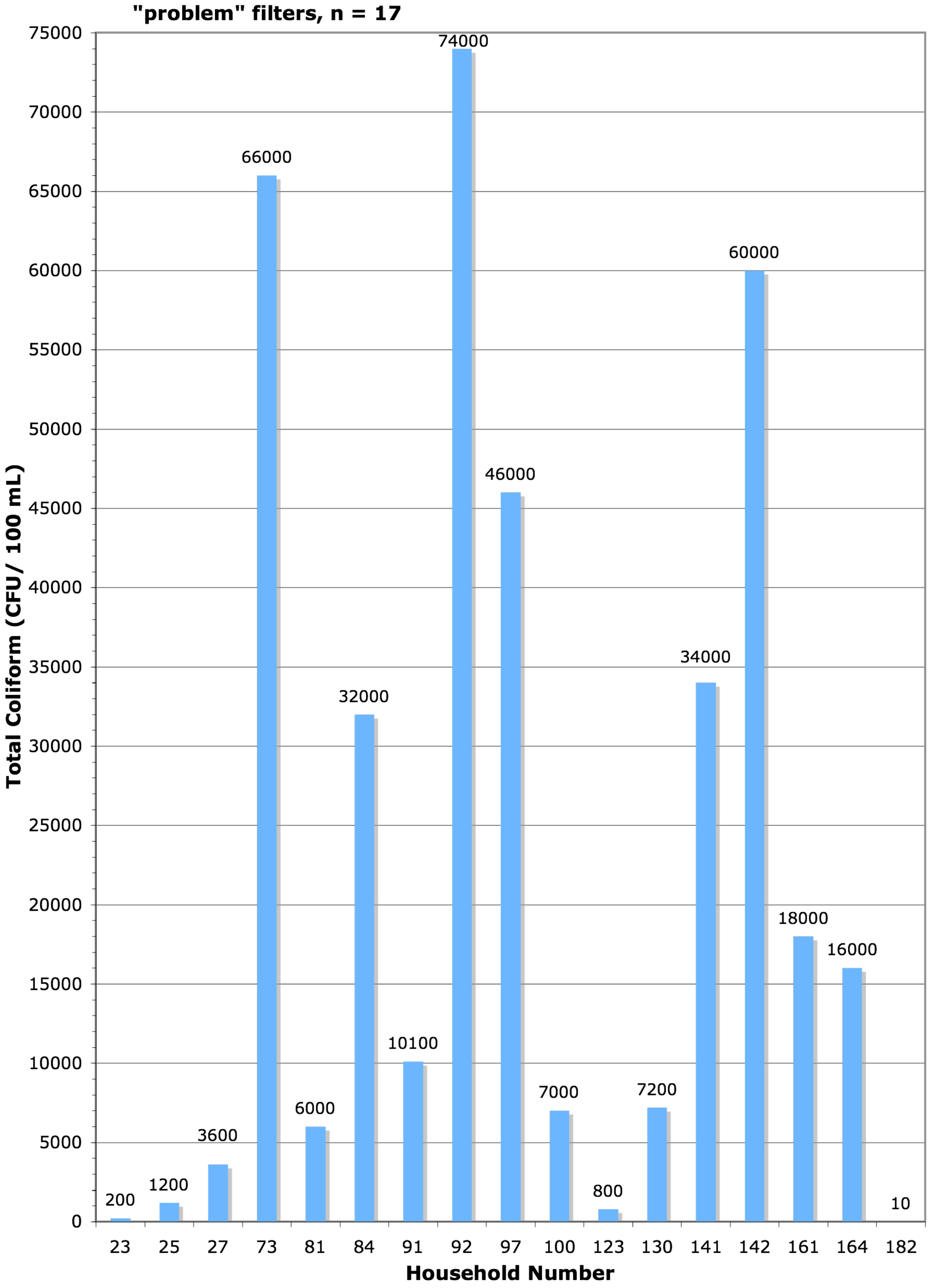

Figure 36: KOSIM-filtered water total coliform counts using the lower detection limit for the 17 "problem" filters with increases in total coliform after filtration

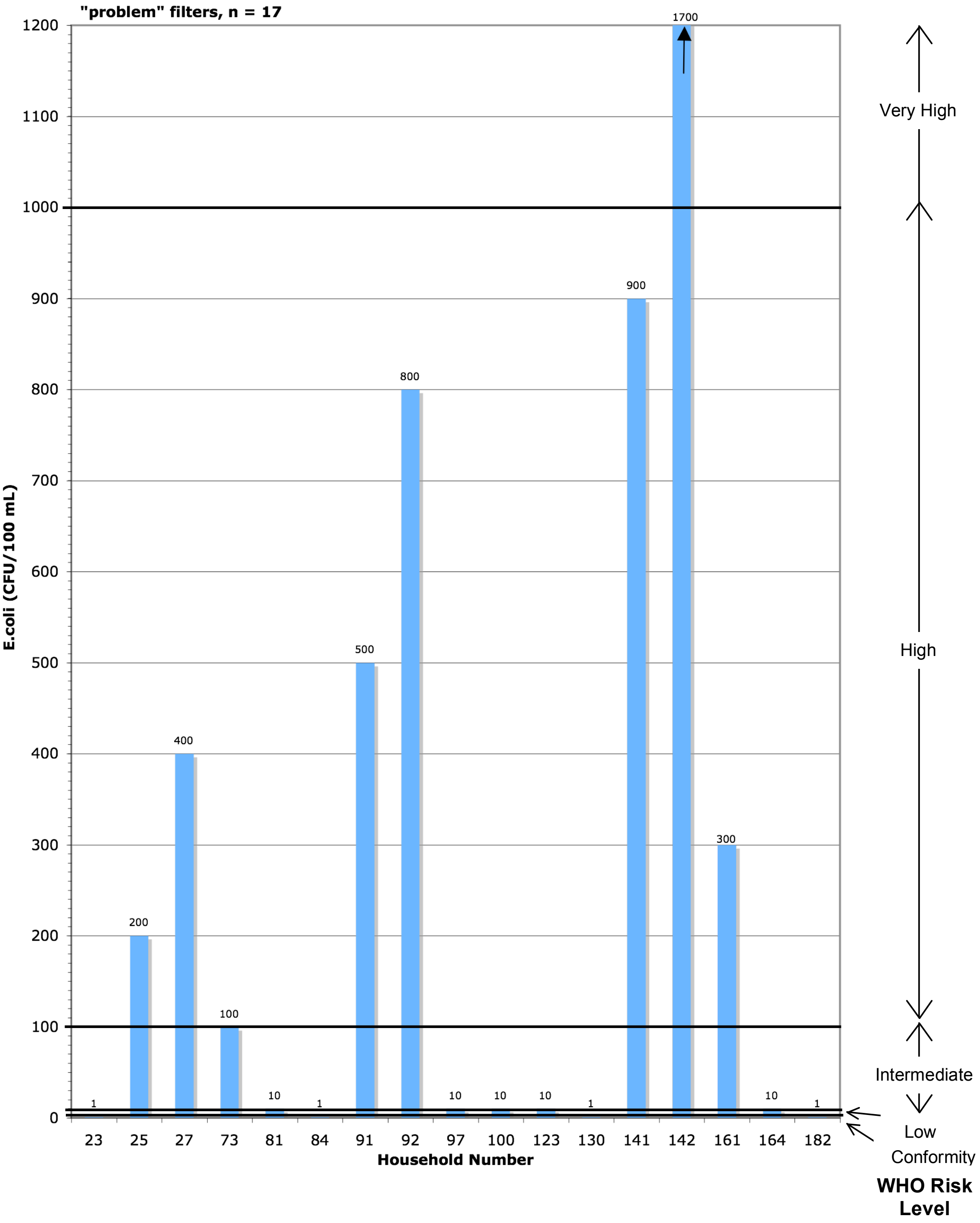

Figure 37: KOSIM-filtered water *E.coli* counts using the lower detection limit for the 17 "problem" filters with increases in total coliform after filtration

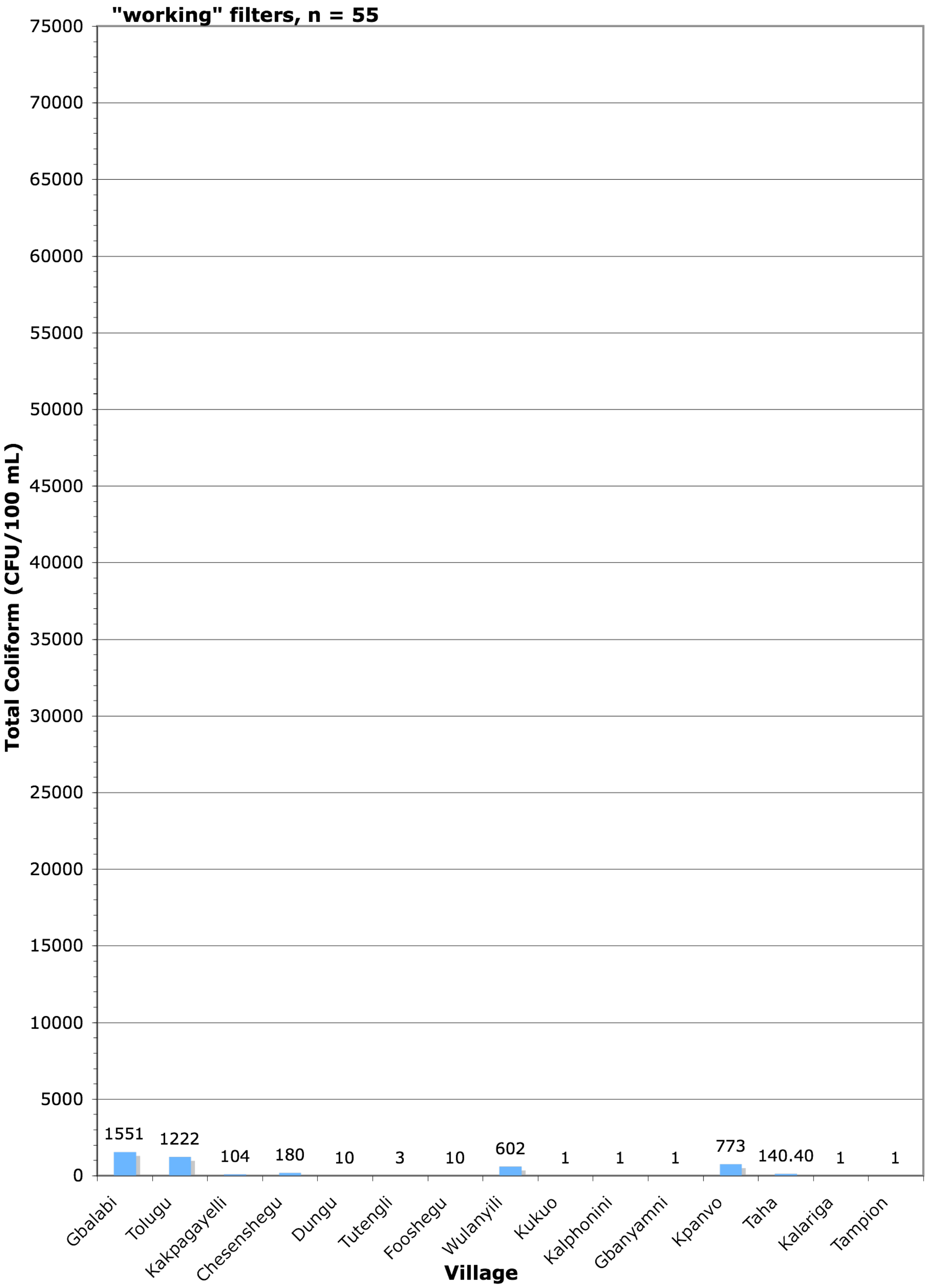

Figure 38: Average KOSIM-filtered water total coliform counts using the lower detection limit for the 55 “working” filters with decreases in total coliform after filtration, by village

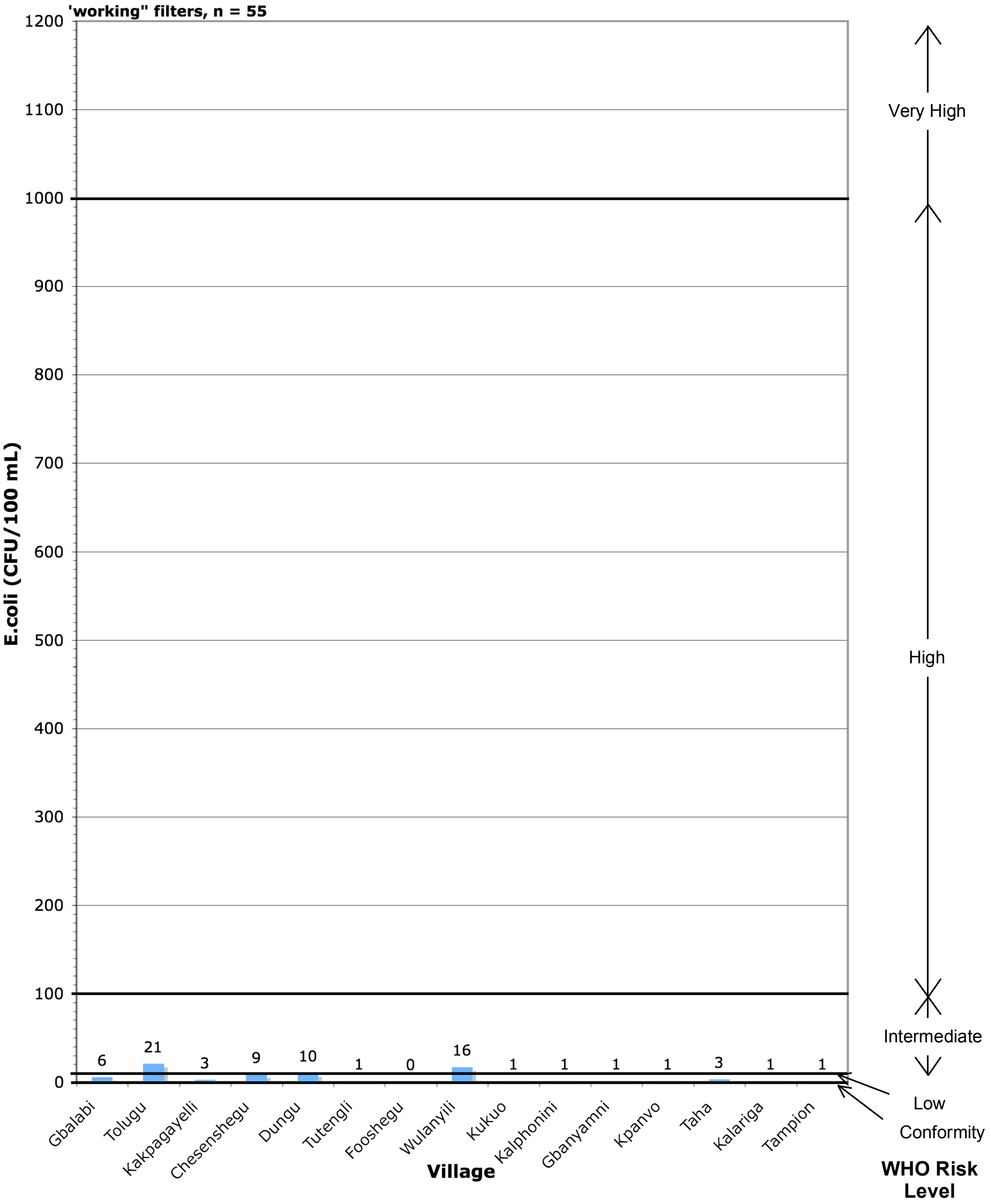

Figure 39: Average KOSIM-filtered water *E.coli* counts using the lower detection limit for the 55 "working" filters with decreases in total coliform after filtration, by village

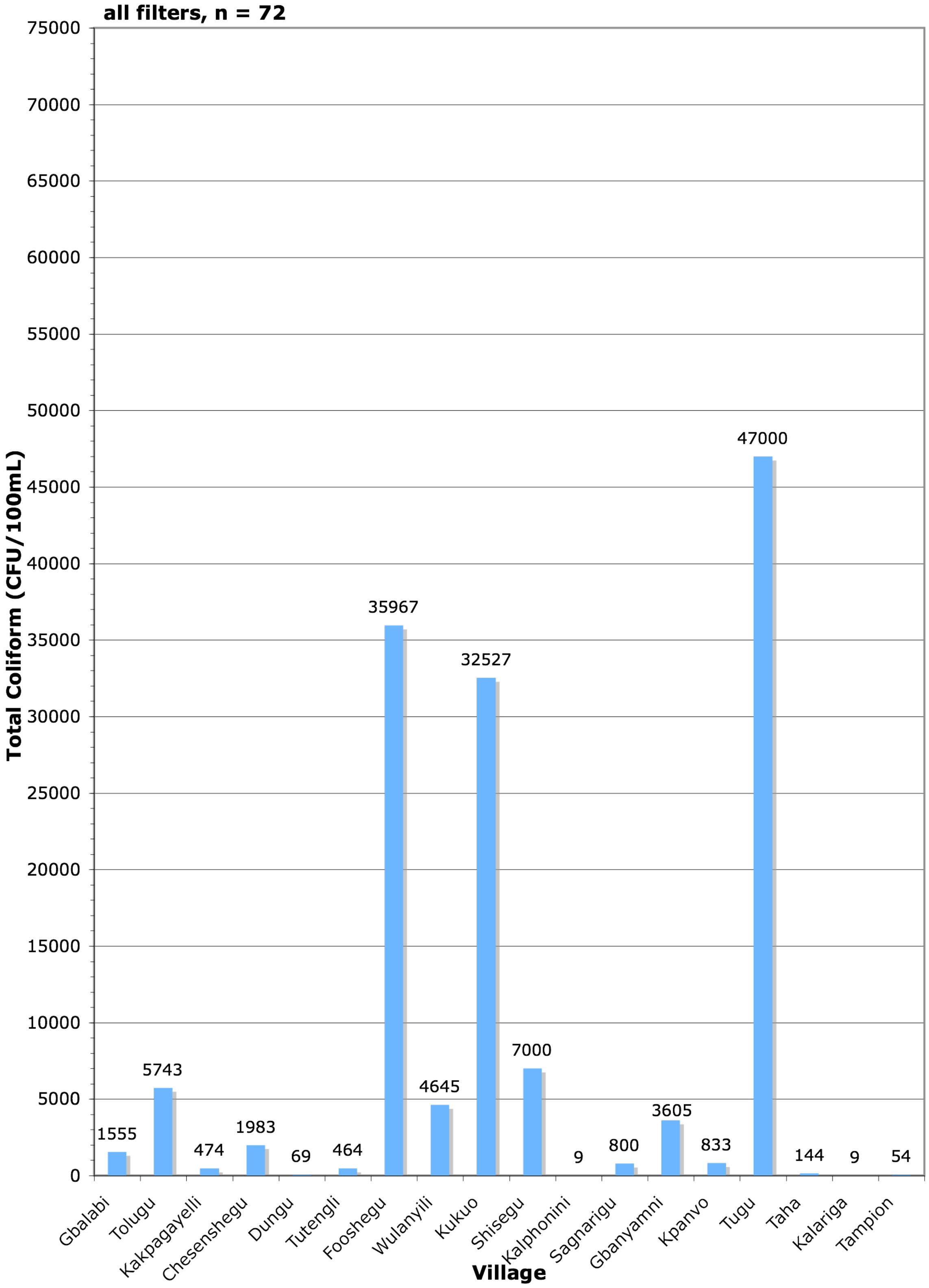

Figure 40: Average KOSIM-filtered total coliform counts using the upper detection limit, by village for all filters tested

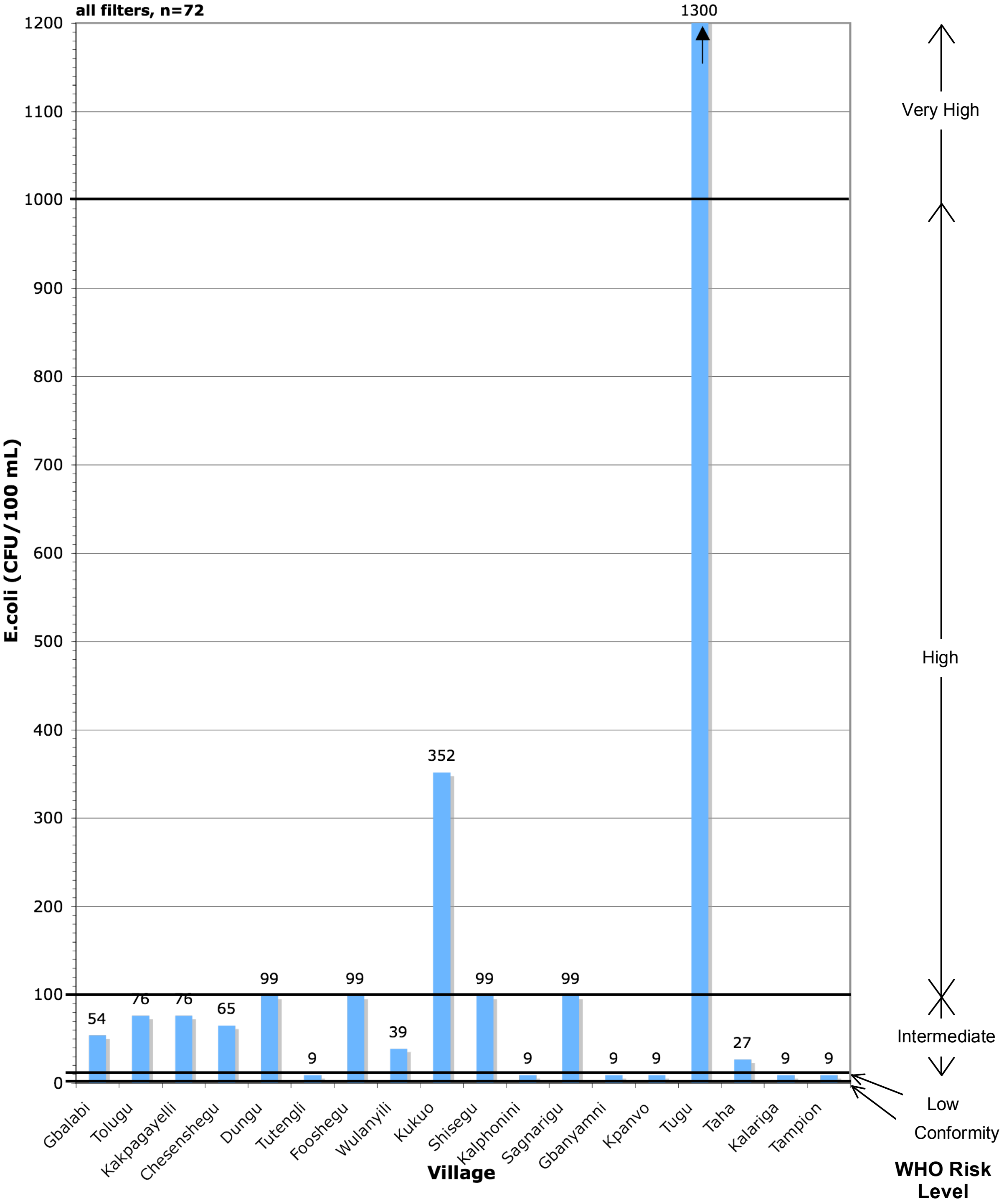

Figure 41: Average KOSIM-filtered water *E.coli* counts using the upper detection limit, by village for all filters tested

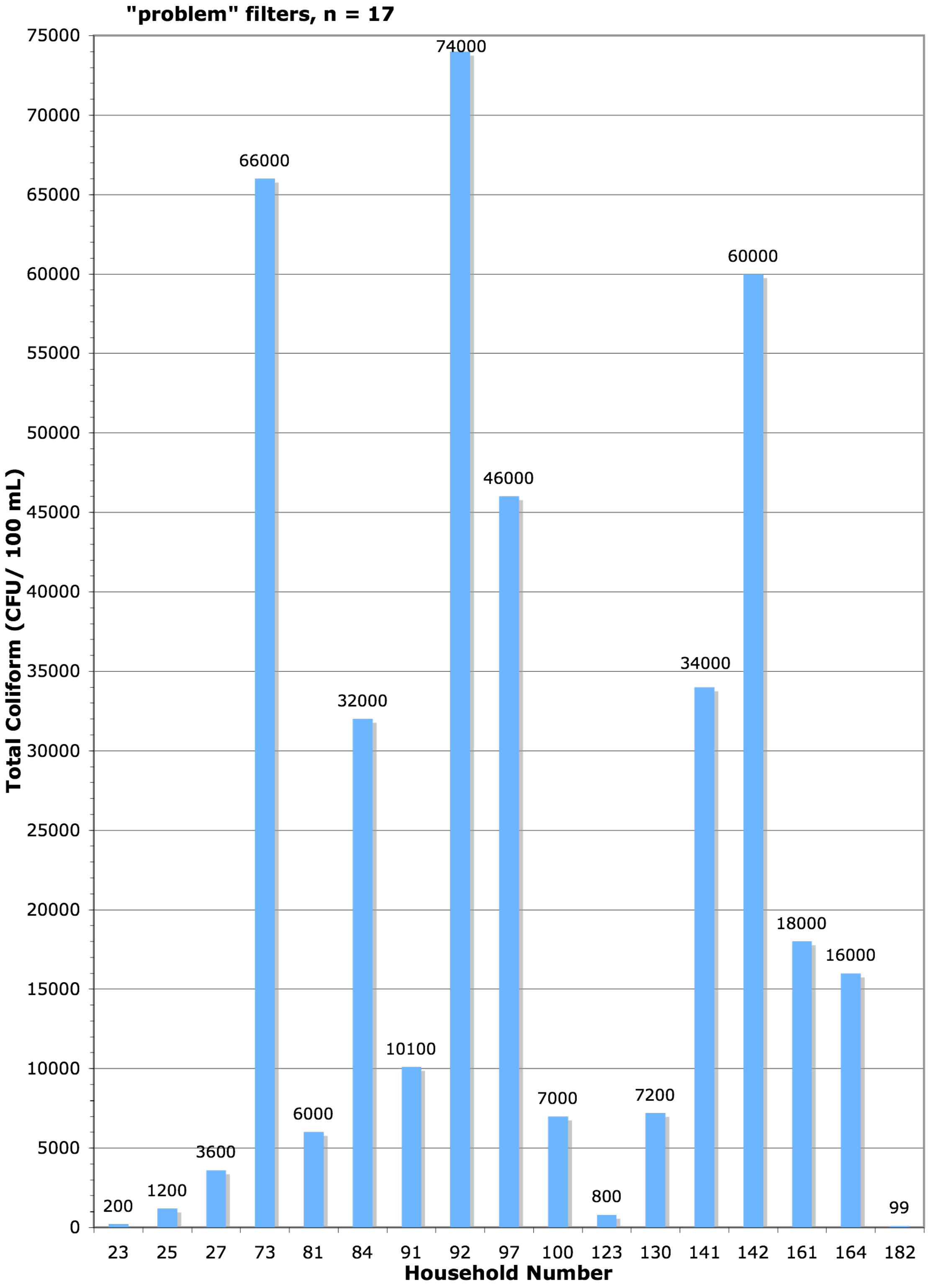

Figure 42: KOSIM-filtered water total coliform counts using the upper detection limit for the 17 “roblem” filters with increases in total coliform after filtration

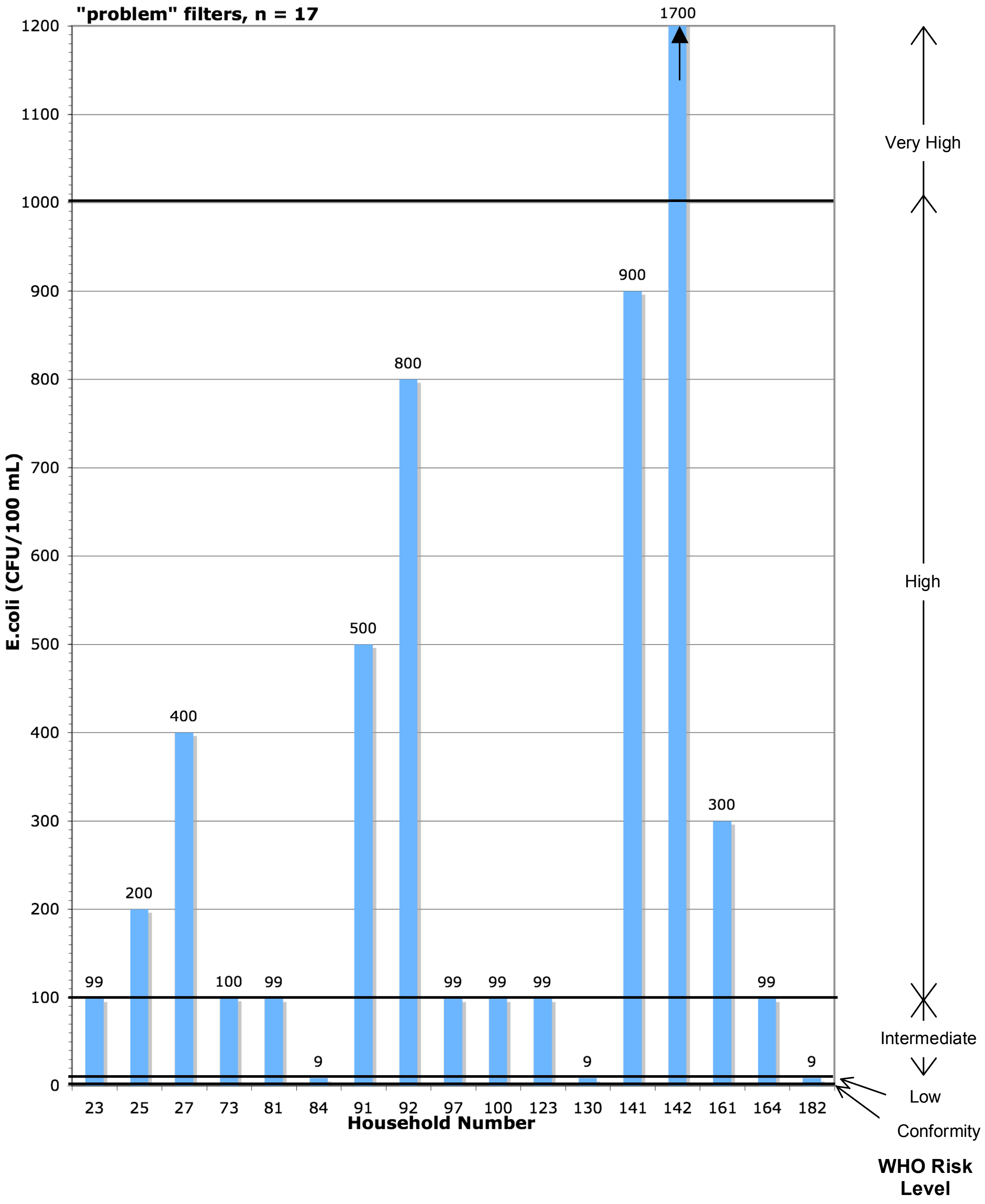

Figure 43 : KOSIM-filtered water *E.coli* counts using the upper detection limit for the 17 "problem" filters with increases in total coliform after filtration

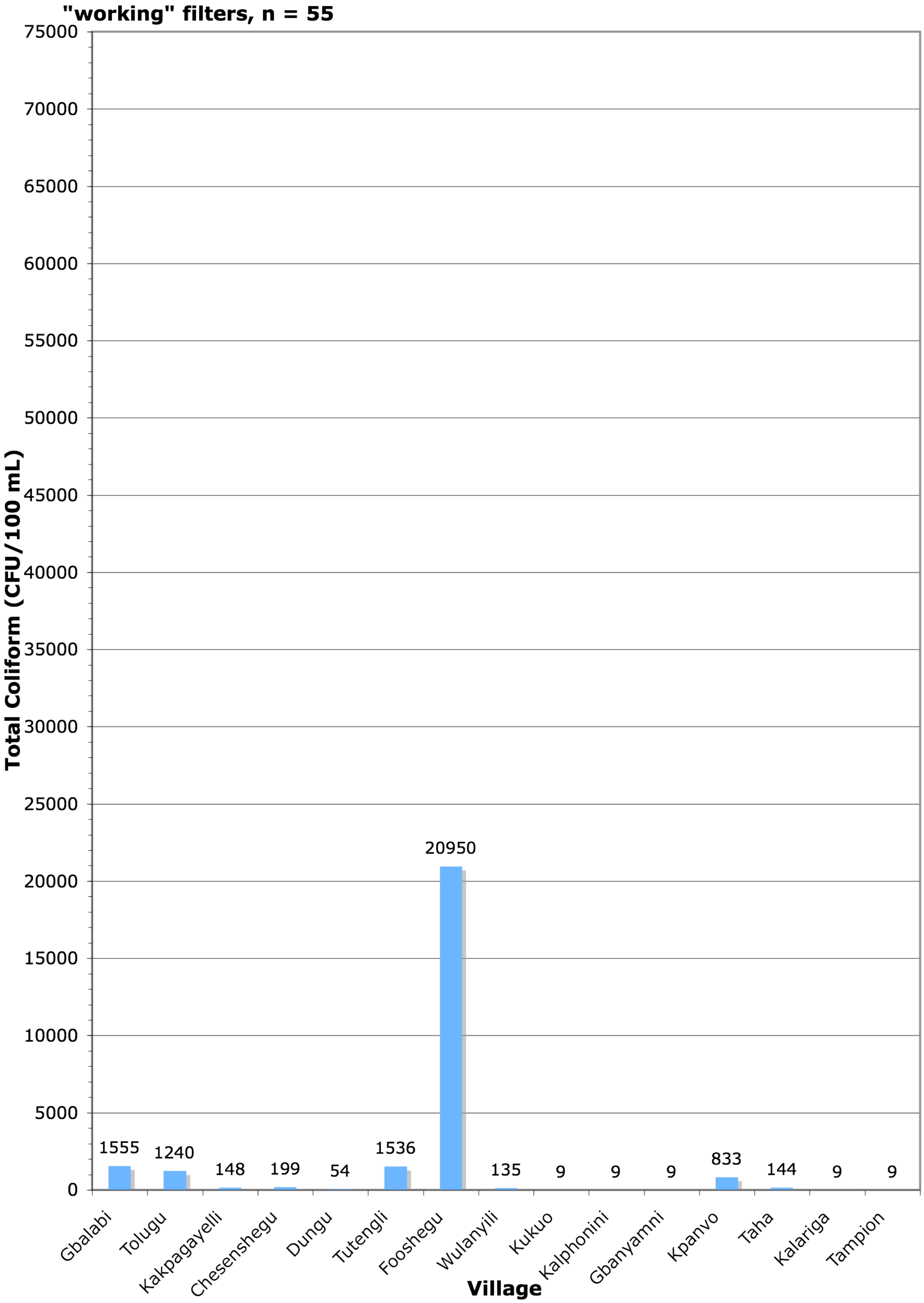

Figure 44: Average KOSIM-filtered water total coliform counts using the upper detection limit for the 55 "working" filters with decreases in total coliform after filtration, by village

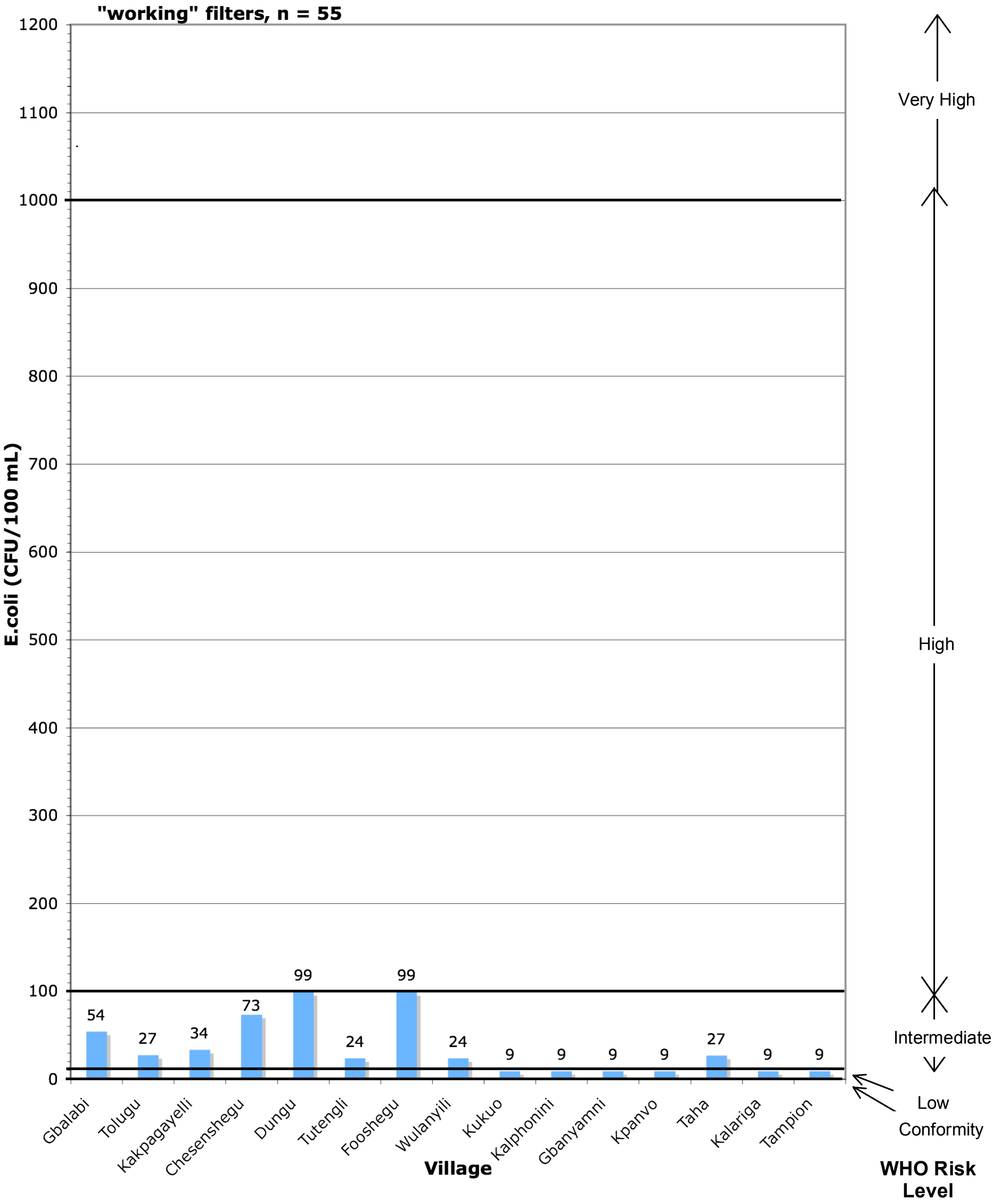

Figure 45: Average KOSIM-filtered water *E.coli* counts using the upper detection limit for the 55 "working" filters with decreases in total coliform after filtration, by village

Table 22 displays the average total coliform counts, average percent reductions and average log reductions for both the lower and upper test detection limits. The average total coliform reduction for all 72 KOSIM filters using the lower detection limit was -711.2% (i.e. an 711.16 % increase in total coliform). This percentage corresponds to an average log increase of 0.91. When using the upper detection limit, the total coliform reduction increases to -86.0% (i.e. an 86% increase in total coliforms). This percentage corresponds to an average log increase of 0.27. The average total coliform reductions for each village are illustrated in Figures 46, 47, 48, and 49.

Table 22: Average total coliform counts, average percent reductions, and average log reductions

	Filtered total coliform CFU/100 mL lower limit	Filtered total coliform CFU/100 mL upper limit	Filtered % removal lower limit	Filtered % removal upper limit	Filtered log removal lower limit	Filtered log removal upper limit
All filters (n=72)	6,167	6,188	-711.2%	-86.0%	-0.91	-0.27
Problem filters (n =17)	22,477	22,482	-3279.4%	-641.2%	-1.53	-0.61
Working filters (n = 55)	323	1,097	96.2%	88.8%	1.42	0.95

The significant increase in the average total coliform reduction when changing from the lower detection limit to the upper detection limit is due to the fact that many of the water sources (particularly rainwater sources) had a range of possible results while, as mentioned earlier, most of the "problem" filters did not. Therefore, changing from the lower limit to the upper limit decreased the difference in total coliform counts between many of the 'problem" filters and their corresponding water source[25]. This significant change in the reductions for the 17 "problem filters is shown above in Table 22 and illustrated in Figures 50, 51, 52, and 53. When these "problem" filters are removed from the data, the average total coliform reduction increases to 96.2% (1.42 log reduction) using the lower detection limit and 88.8% (0.95 log reduction) using the upper detection limit. The average "working" filters total coliform reductions for each village are displayed in Figures 54, 55, 56, and 57.

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[25] As discussed in Section 4.2.1 changing the detection limits did not significantly affect the *average* water quality test results for the reported water sources. However, when *individual* filters are paired up with a *single* source, this change can be quite large.

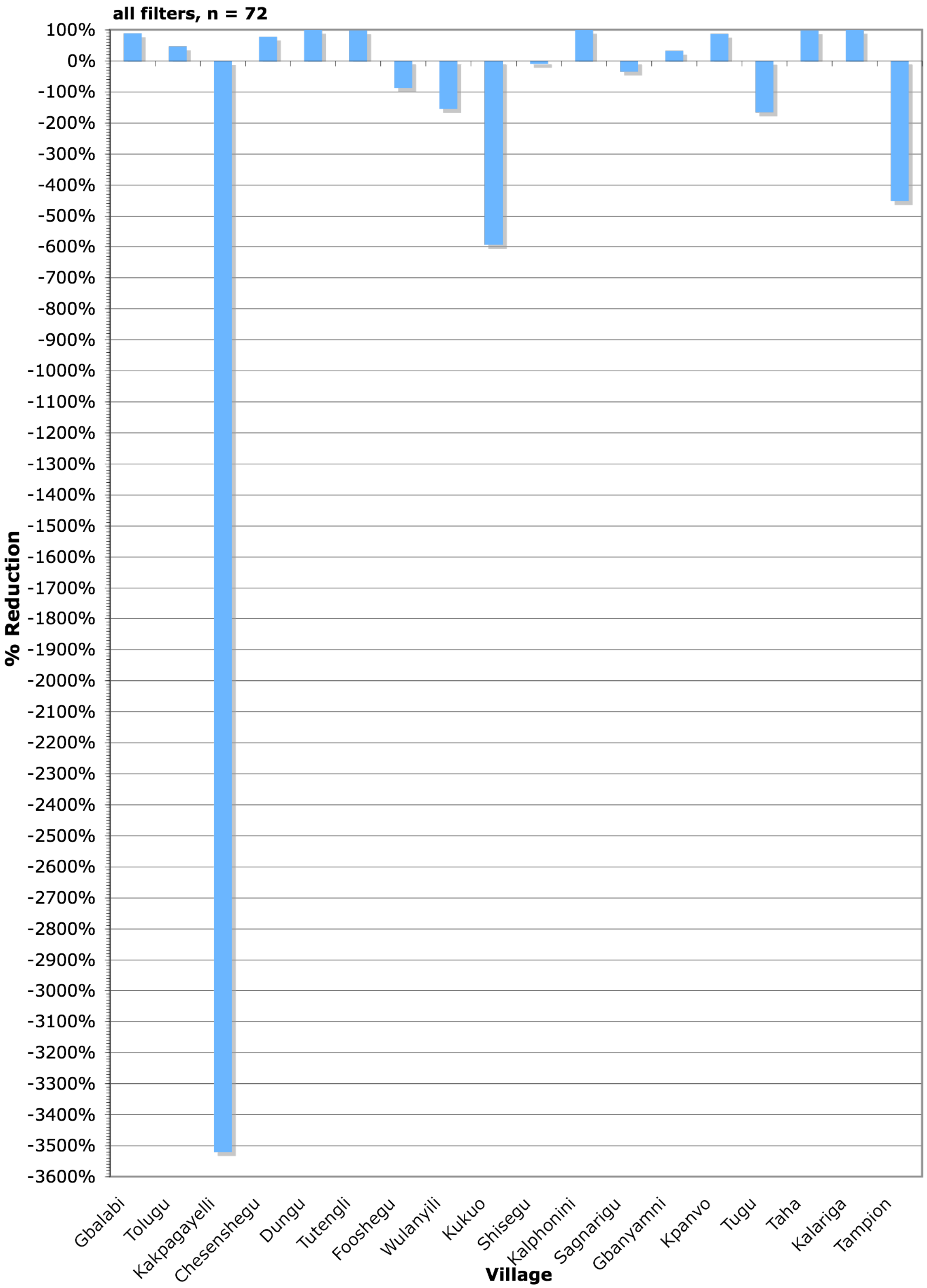

Figure 46: Average total coliform reduction in KOSIM-filtered water using the lower detection limit, by village for all filters tested

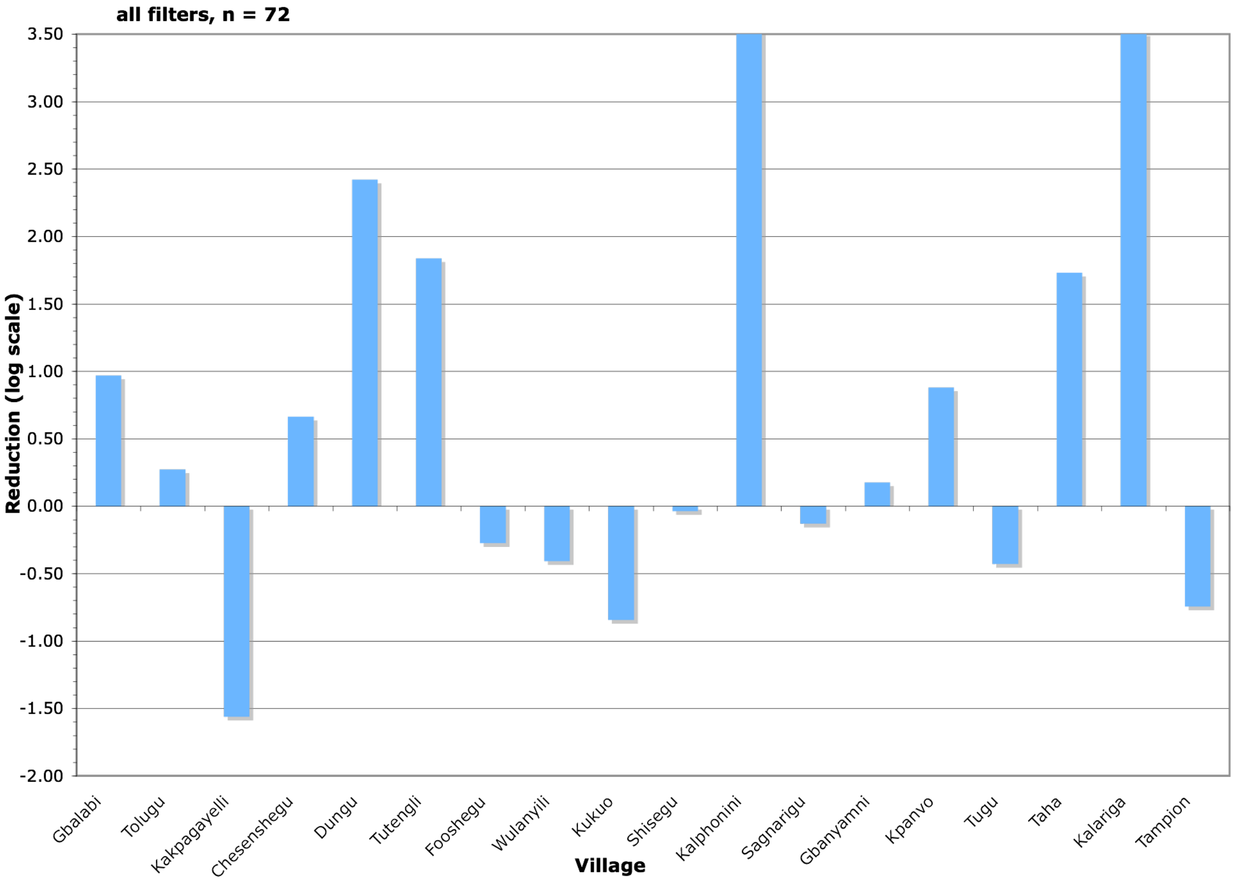

Figure 47: Average reduction in total coliform in KOSIM-filtered water using lower detection limit, by village for all filters tested (log scale)

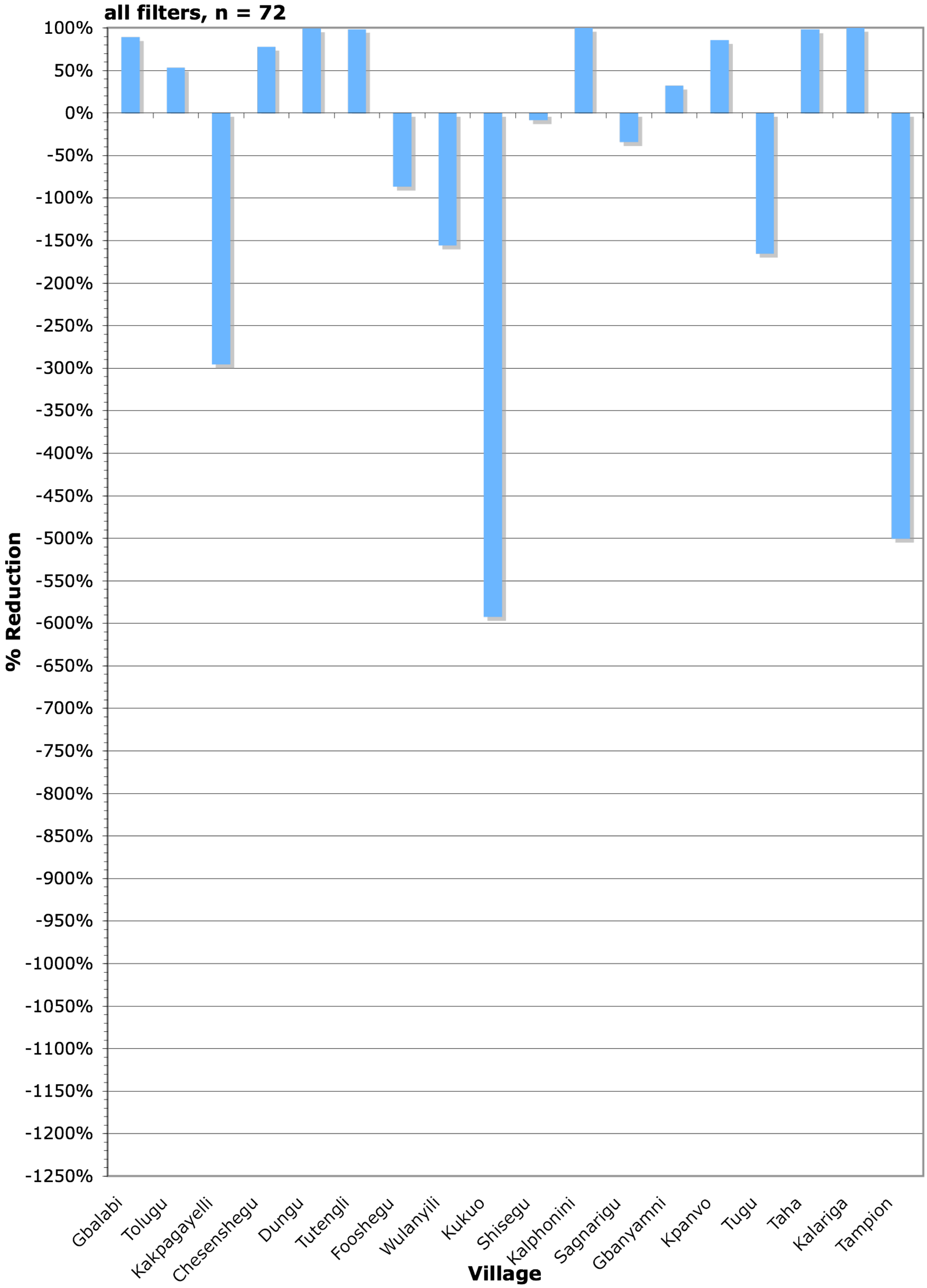

Figure 48: Average reduction in total coliform in KOSIM-filtered water using the upper detection limit, by village for all filters tested (note change in scale from previous figure)

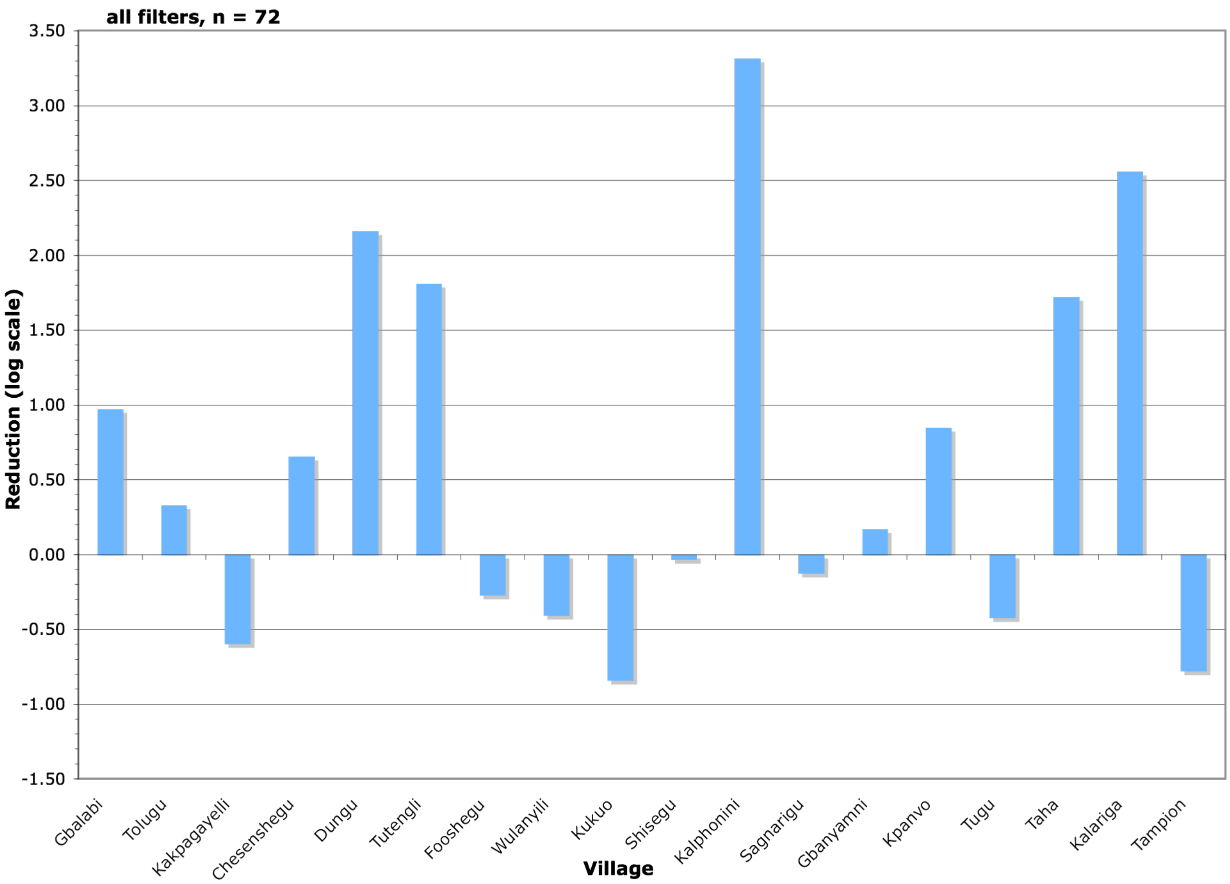

Figure 49: Average reduction in total coliform in KOSIM-filtered water using the upper detection limit, by village for all filters tested (log scale)

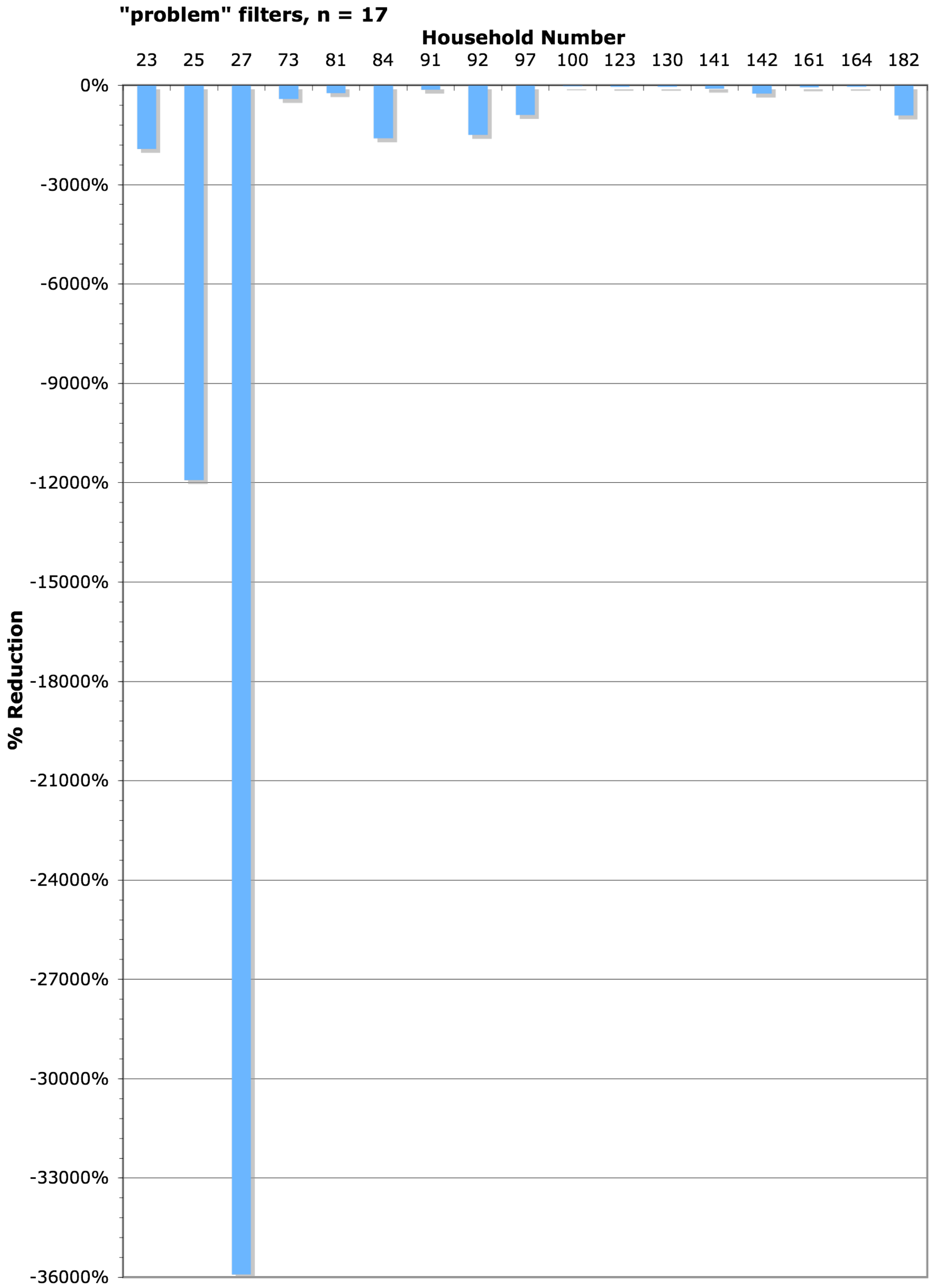

Figure 50: Reduction in total coliform in KOSIM-filtered water using the lower detection limit for the 17 "problem" filters with increases in total coliform after filtration (note change in scale from previous figures)

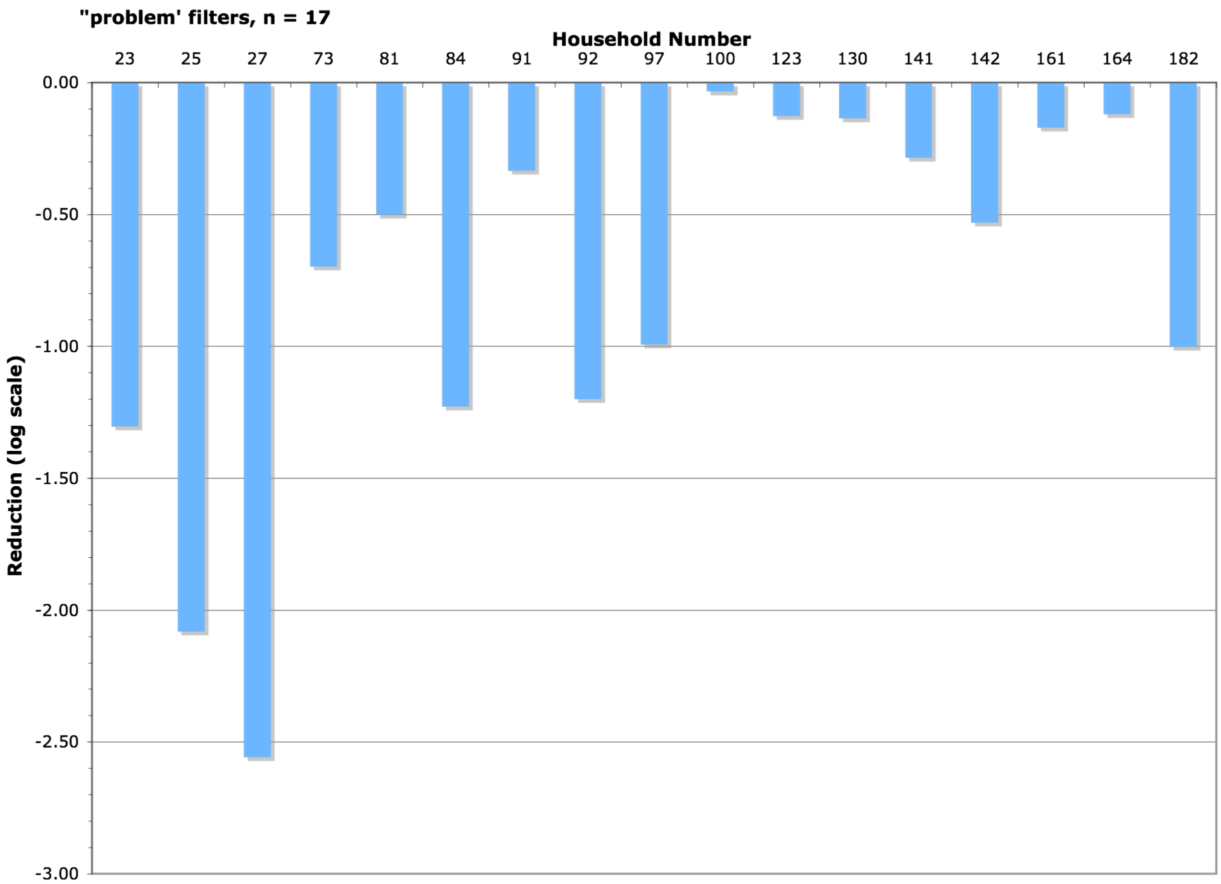

Figure 51: Reduction in total coliform in KOSIM-filtered water using the lower detection limit for the 17 "problem" filters with increases in total coliform after filtration (log scale) (note change in scale from previous figures)

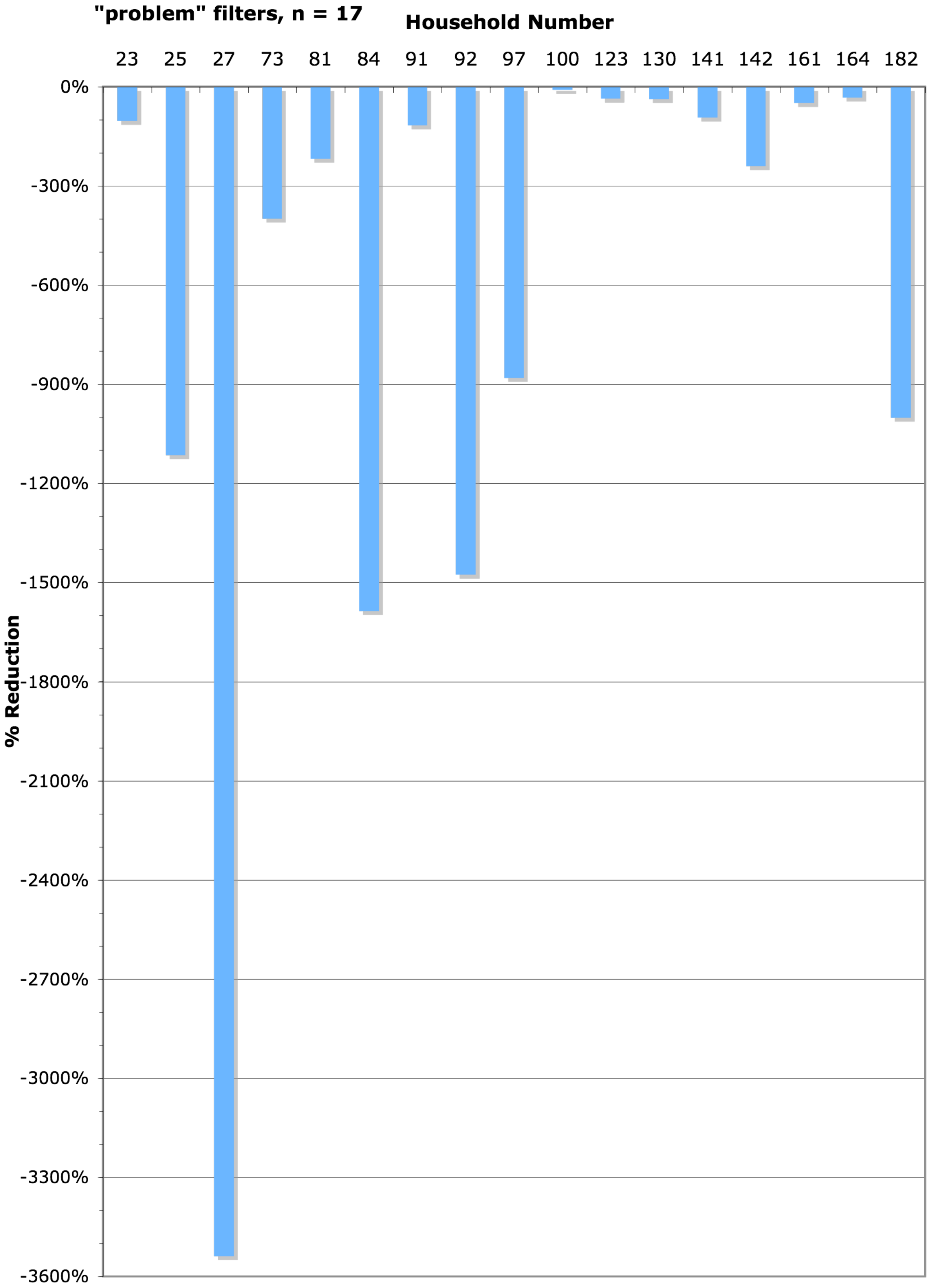

Figure 52: Reduction in total coliform in KOSIM-filtered water using the upper detection limit for the 17 “problem” filters with increases in total coliform after filtration

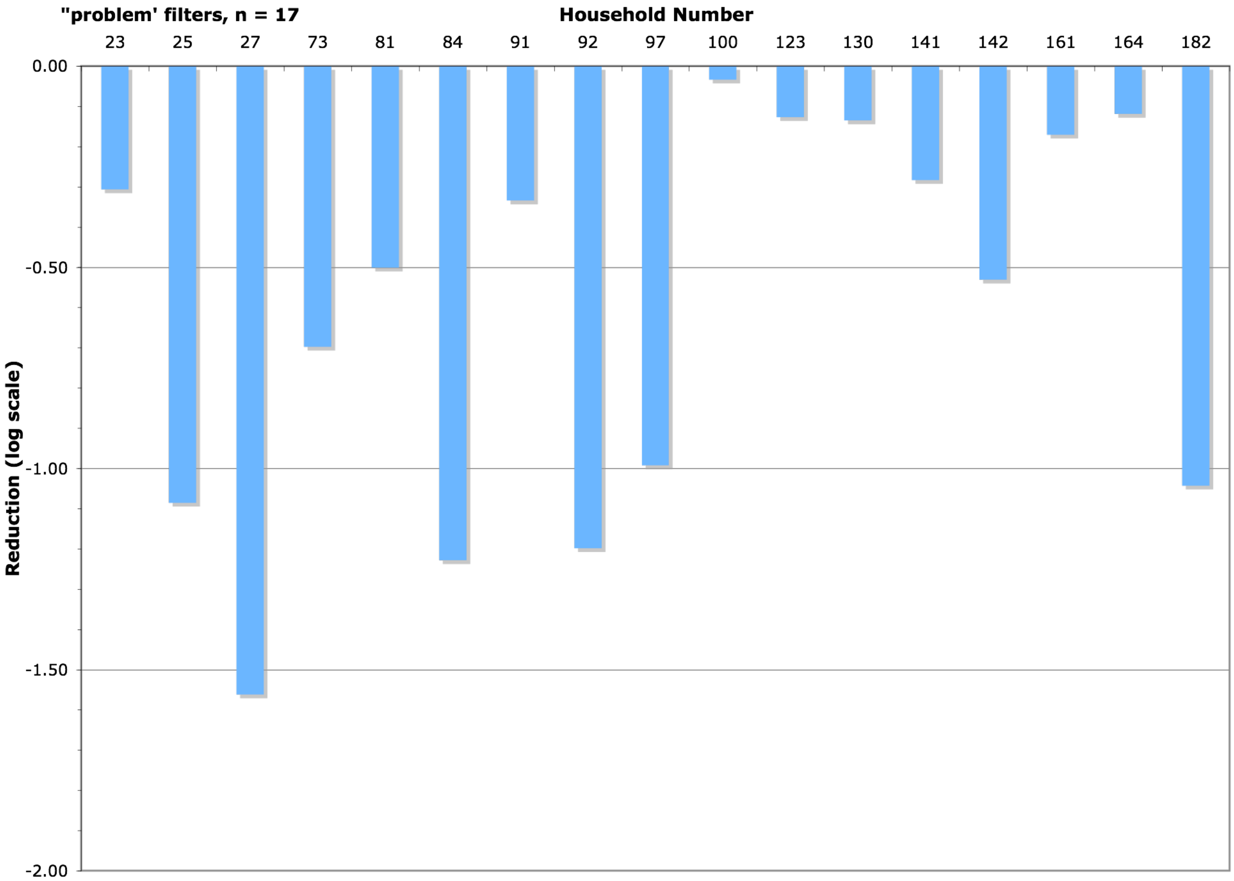

Figure 53: Reduction in total coliform in KOSIM-filtered water using upper detection limit for the 17 “problem” filters with increases in total coliform after filtration (log scale)

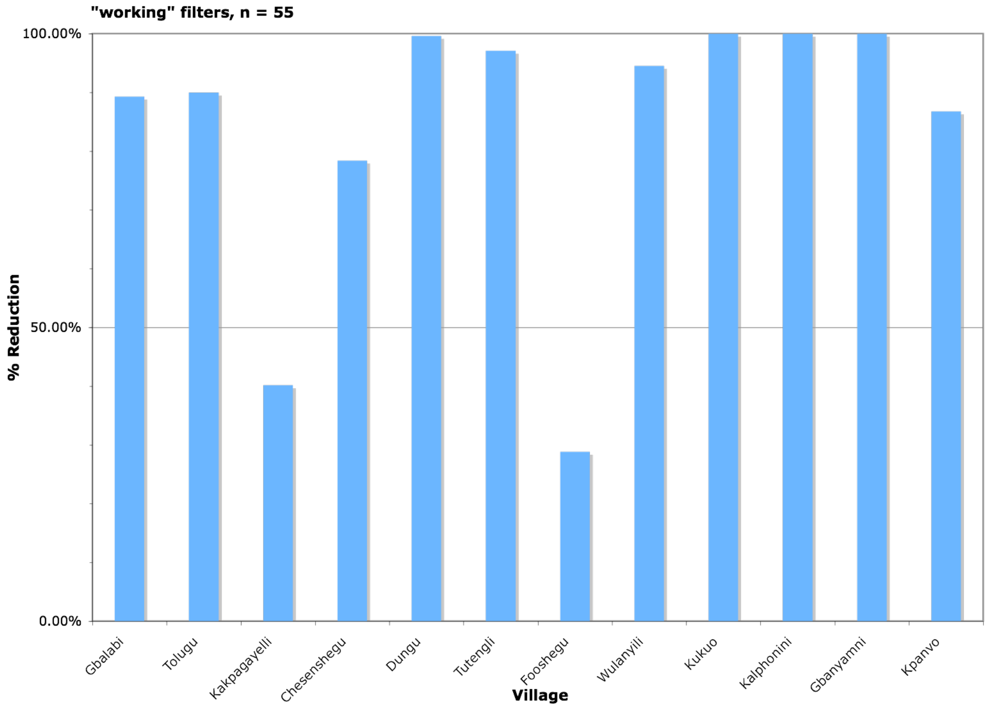

Figure 54: Average reduction in total coliform in KOSIM-filtered water using the lower detection limit for the 55 "working" filters with decreases in total coliform after filtration, by village

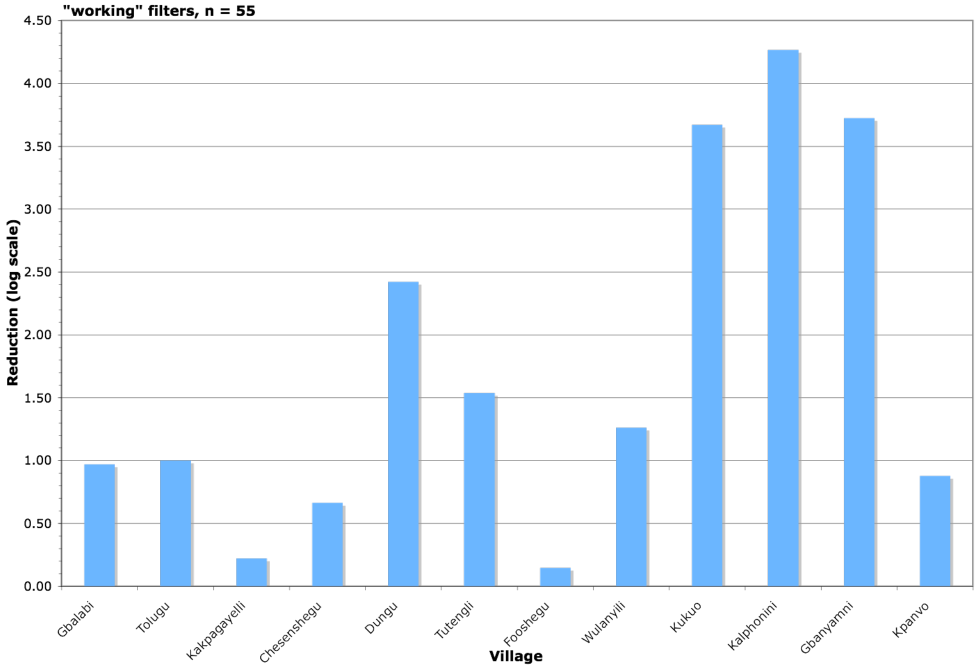

Figure 55: Average reduction in total coliform in KOSIM-filtered water using the lower detection limit for the 55 "working" filters with decreases in total coliform after filtration, by village (log scale) (note change in scale from previous figures)

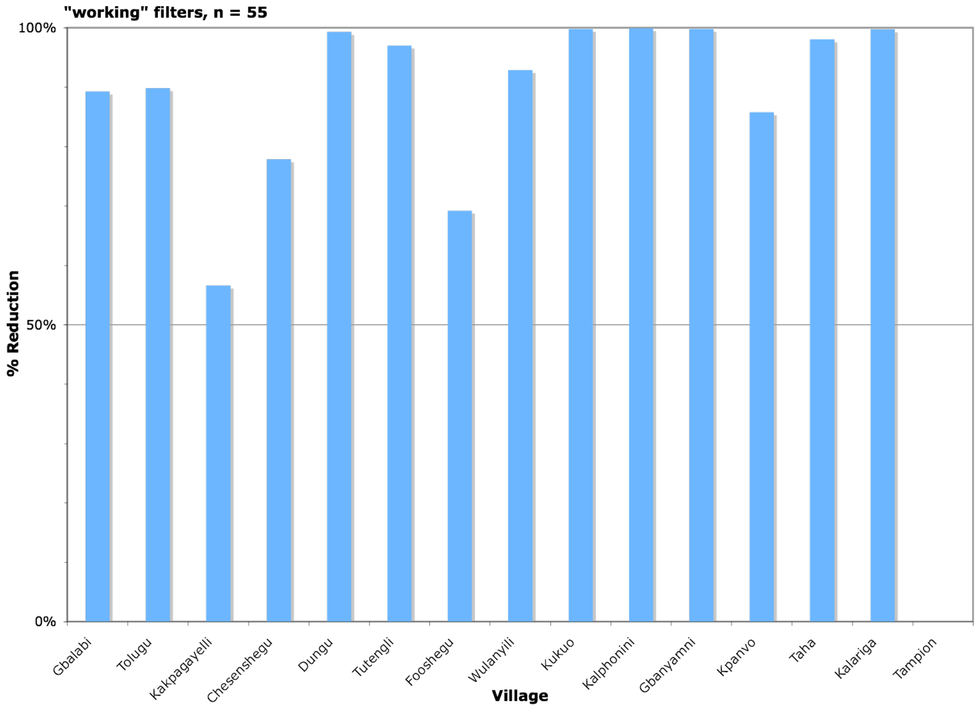

Figure 56: Average reduction in total coliform in KOSIM-filtered water using the upper detection limit for the 55 "working" filters with decreases in total coliform after filtration, by village

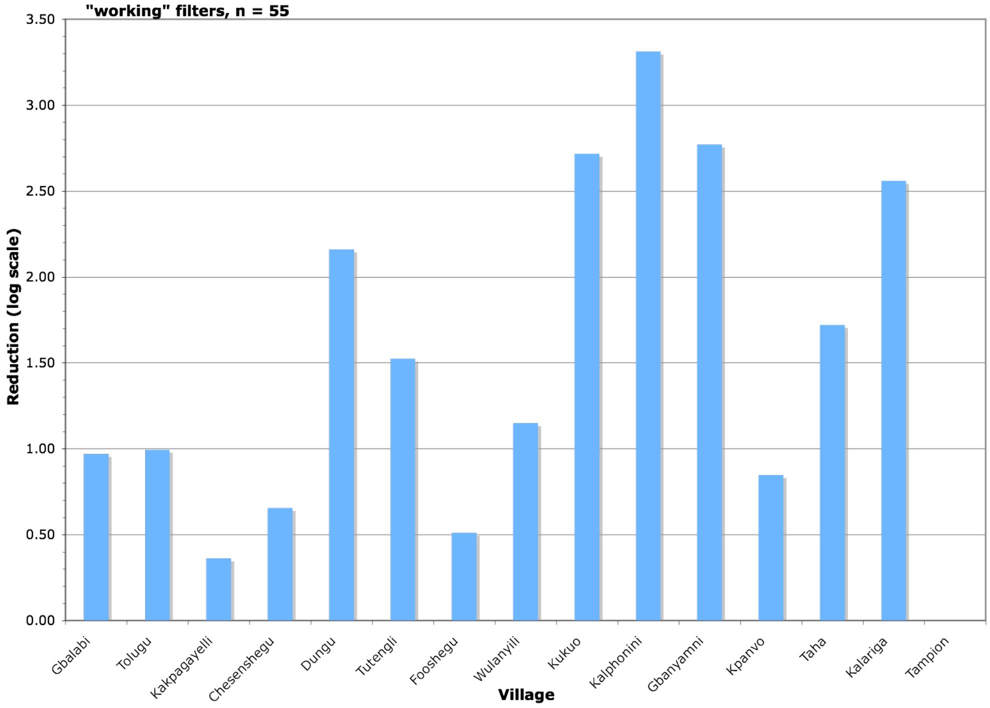

Figure 57: Average reduction in total coliform in KOSIM-filtered water using the upper detection limit for the 55 "working" filters with decreases in total coliform after filtration, by village (log scale)

Table 23 displays the average *E.coli* counts, average percent reductions and average log reductions for both the lower and upper test detection limits. The average *E.coli* reduction for all 72 KOSIM filters using the lower detection limit was -75.5% (i.e. an 75.5 % increase in *E.coli*). This percentage corresponds to an average log increase of 0.24. When using the upper detection limit, the *E.coli* reduction increases to 13.6% (0.6 log reduction). Similar to the increase in average total coliform reduction, the significant increase in average *E.coli* reduction when changing from the lower detection limit to the upper detection is due to the range of results for many of the water sources (particularly rainwater sources). The average *E.coli* reductions for each village are illustrated in Figures 58, 59, 60, and 61.

Table 23: Average *E.coli* counts, average percent reductions, and average log reductions

	Filtered *E.coli* CFU/100 mL lower limit	**Filtered *E.coli* CFU/100 mL upper limit**	**Filtered % removal lower limit**	**Filtered % removal upper limit**	**Filtered log removal lower limit**	**Filtered log removal upper limit**
All filters (n=72)	74	106	-75.5%	13.6%	-0.24	0.06
Problem filters (n =17)	291	323	-61.0%	-19.9%	-0.85	-0.47
Working filters (n = 55)	7	37	89.9%	82.2%	0.99	0.75

The *E.coli* reductions for the 17 "problem filters are illustrated in Figures 62, 63, 64, and 65. When these "problem" filters are removed from the data, the average *E.coli* reduction increases to 89.9% (1.42 log reduction) using the lower detection limit and 82.2% (0.75 log reduction) using the upper detection limit. The average "working" filters *E.coli* reductions for each village are displayed in Figures 66, 67, 68, and 69.

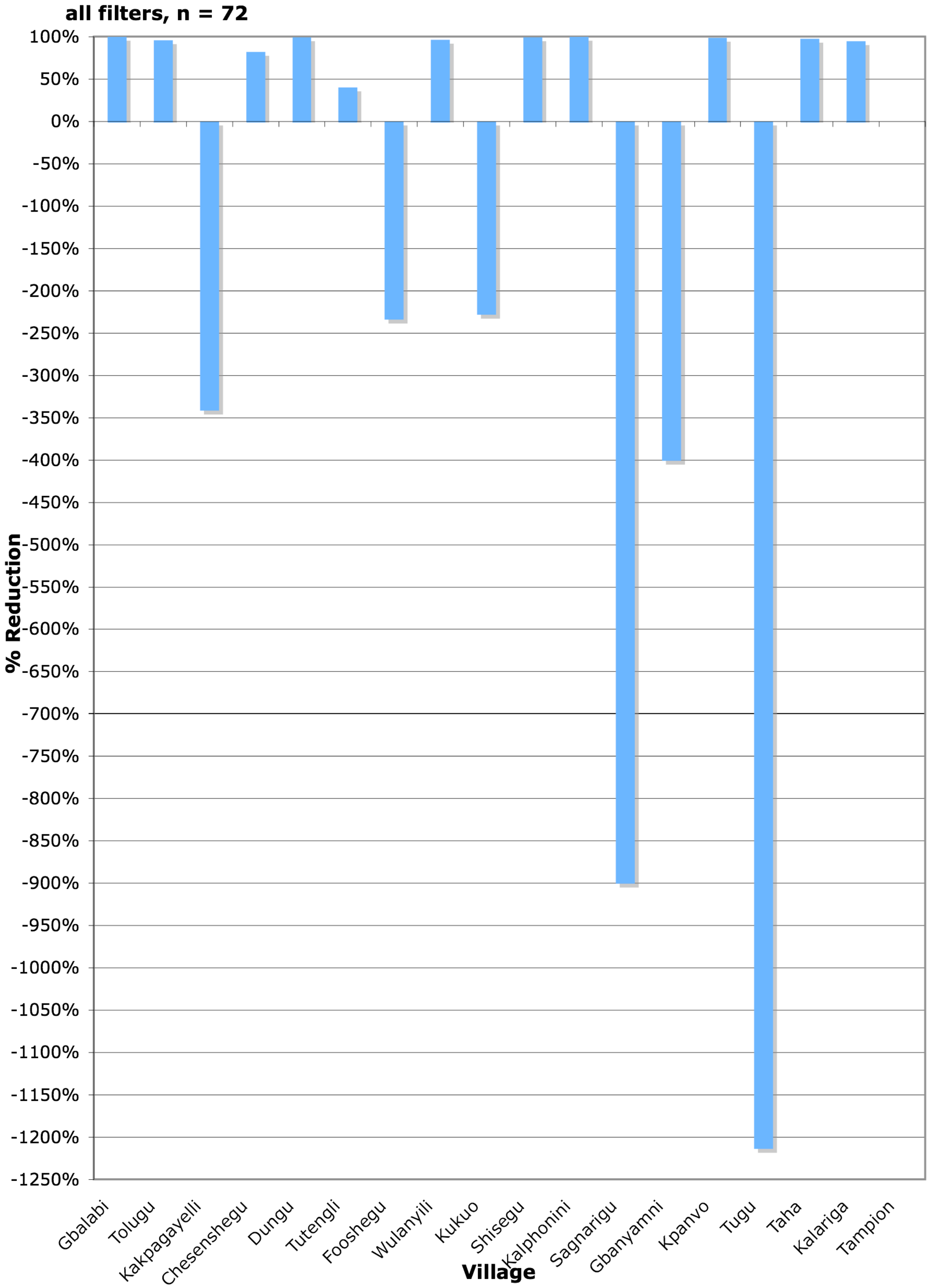

Figure 58: Average reduction in *E.coli* in KOSIM-filtered water using the lower detection limit, by village for all filters tested

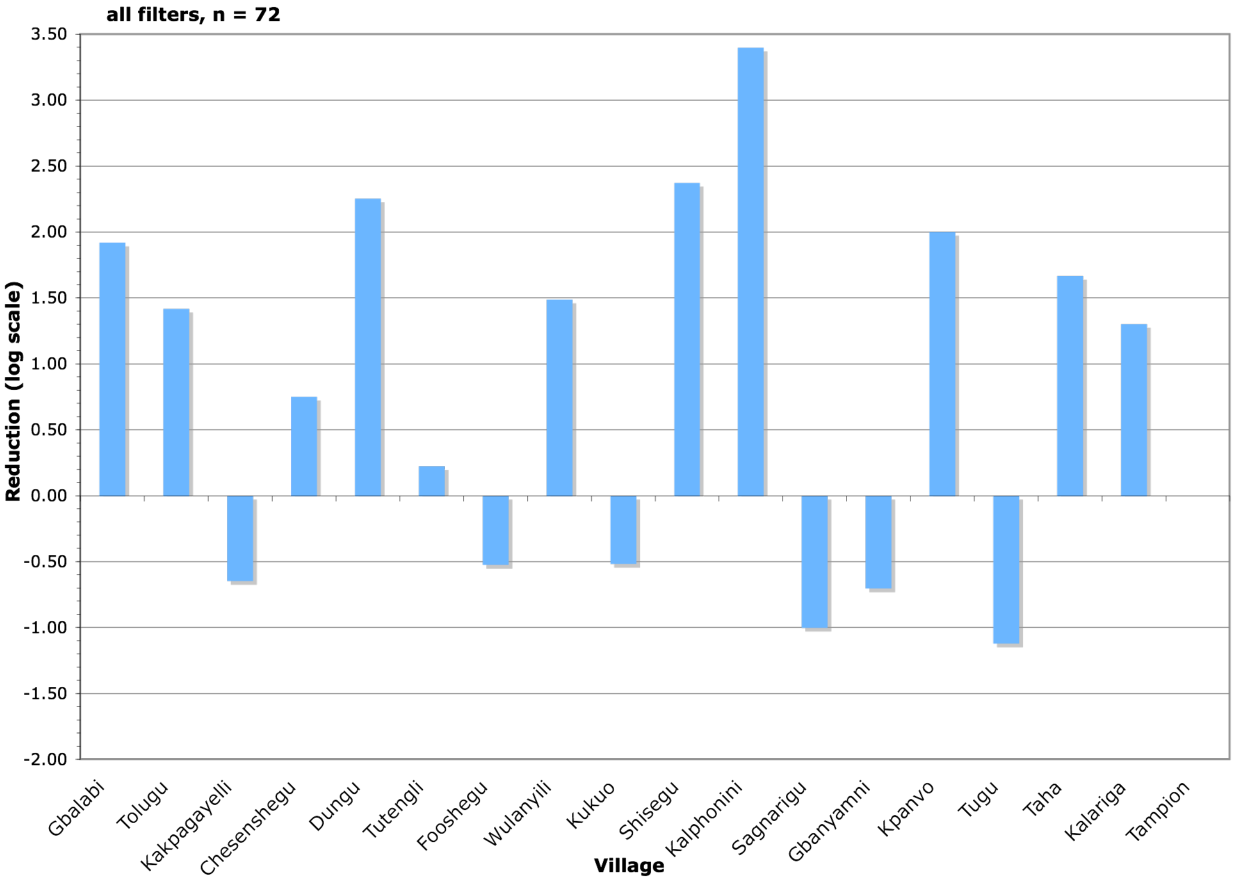

Figure 59: Average reduction in *E.coli* in KOSIM-filtered water using the lower detection limit, by village for all filters tested (log scale)

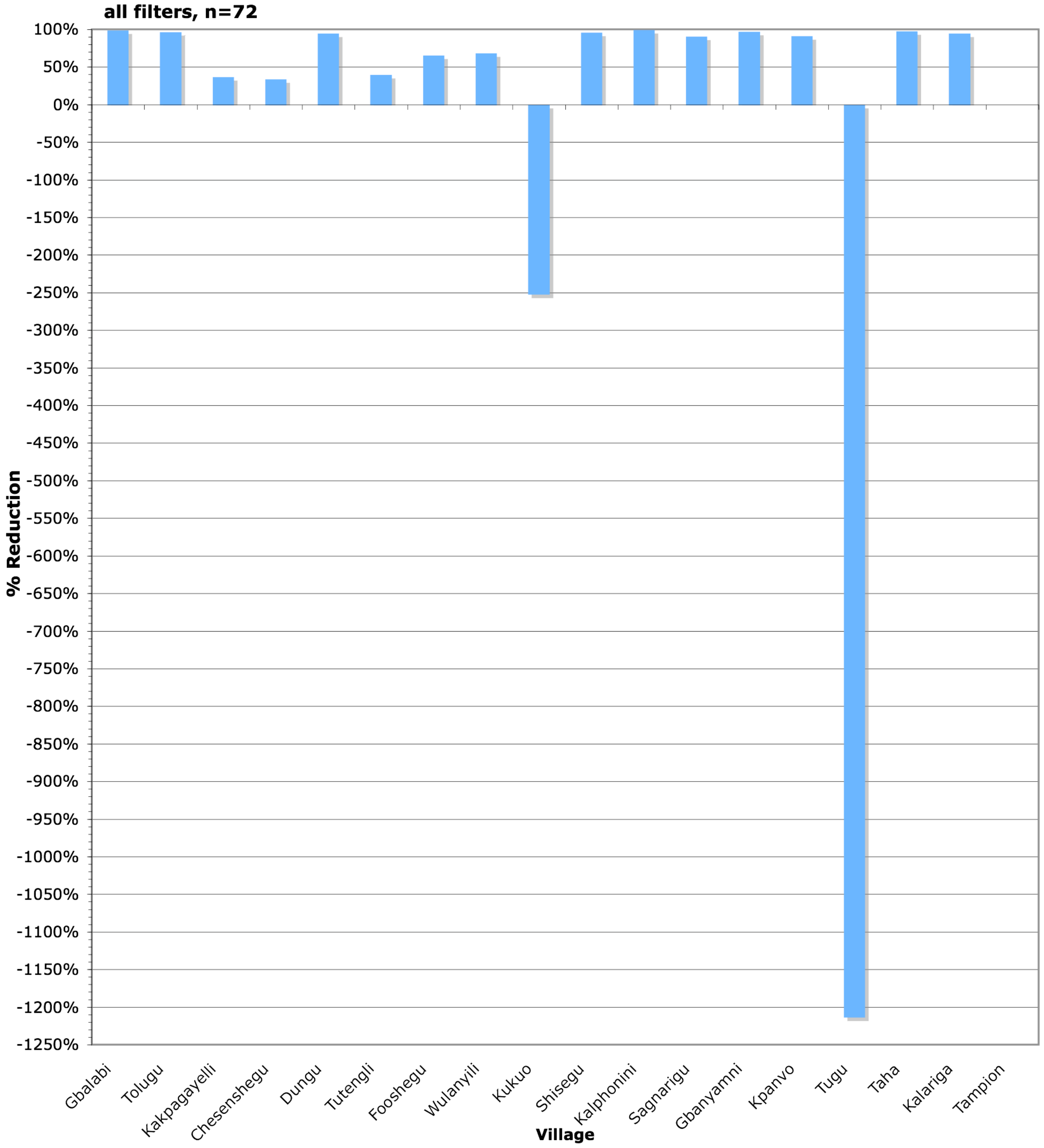

Figure 60: Average reduction in *E.coli* in KOSIM-filtered water using the upper detection limit, by village for all filters tested

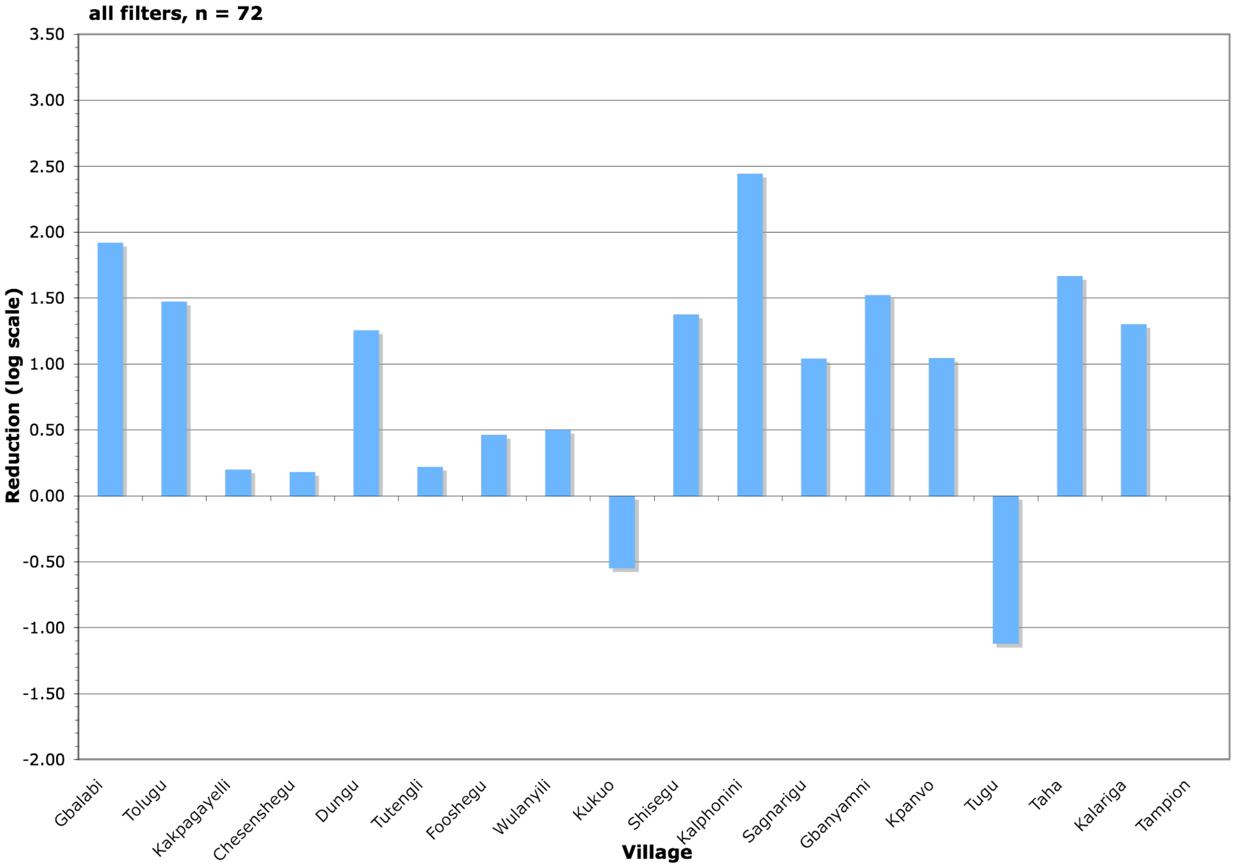

Figure 61: Average reduction in *E.coli* in KOSIM-filtered water using the upper detection limit, by village for all filters tested (log scale)

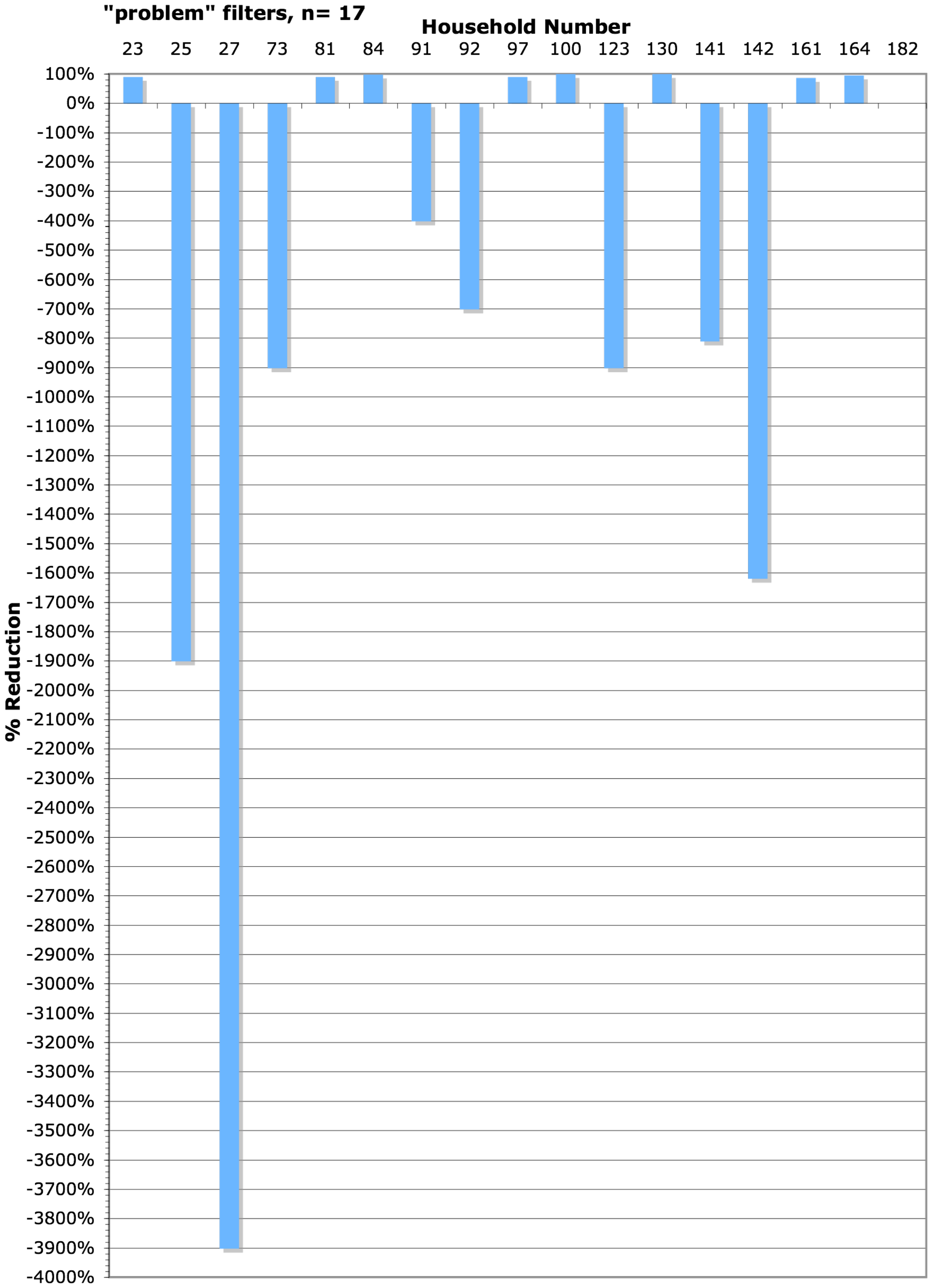

Figure 62: Reduction in *E.coli* in KOSIM-filtered water using the lower detection limit for the 17 "problem" filters with increases in total coliform after filtration (note change in scale from previous figures)

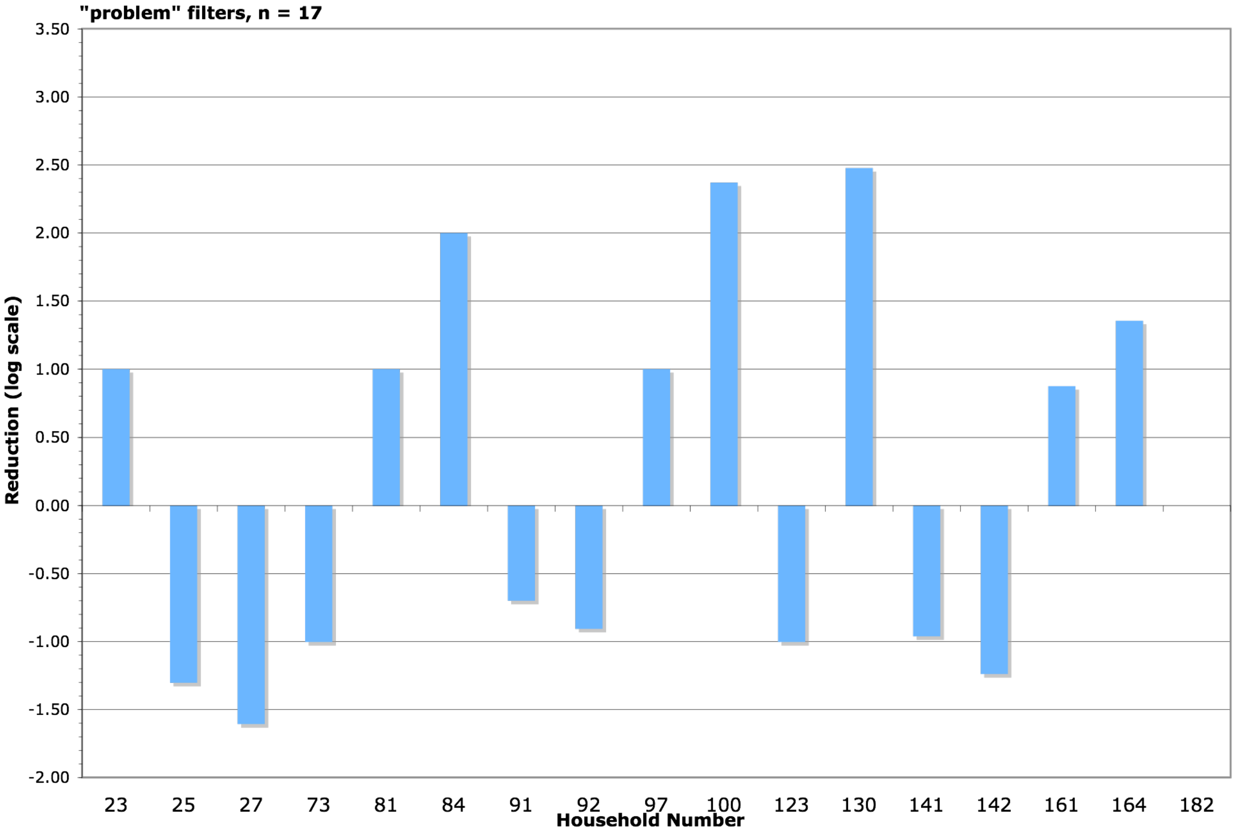

Figure 63: Reduction in *E.coli* in KOSIM-filtered water using the lower detection limit for the 17 "problem" filters with increases in total coliform after filtration (log scale)

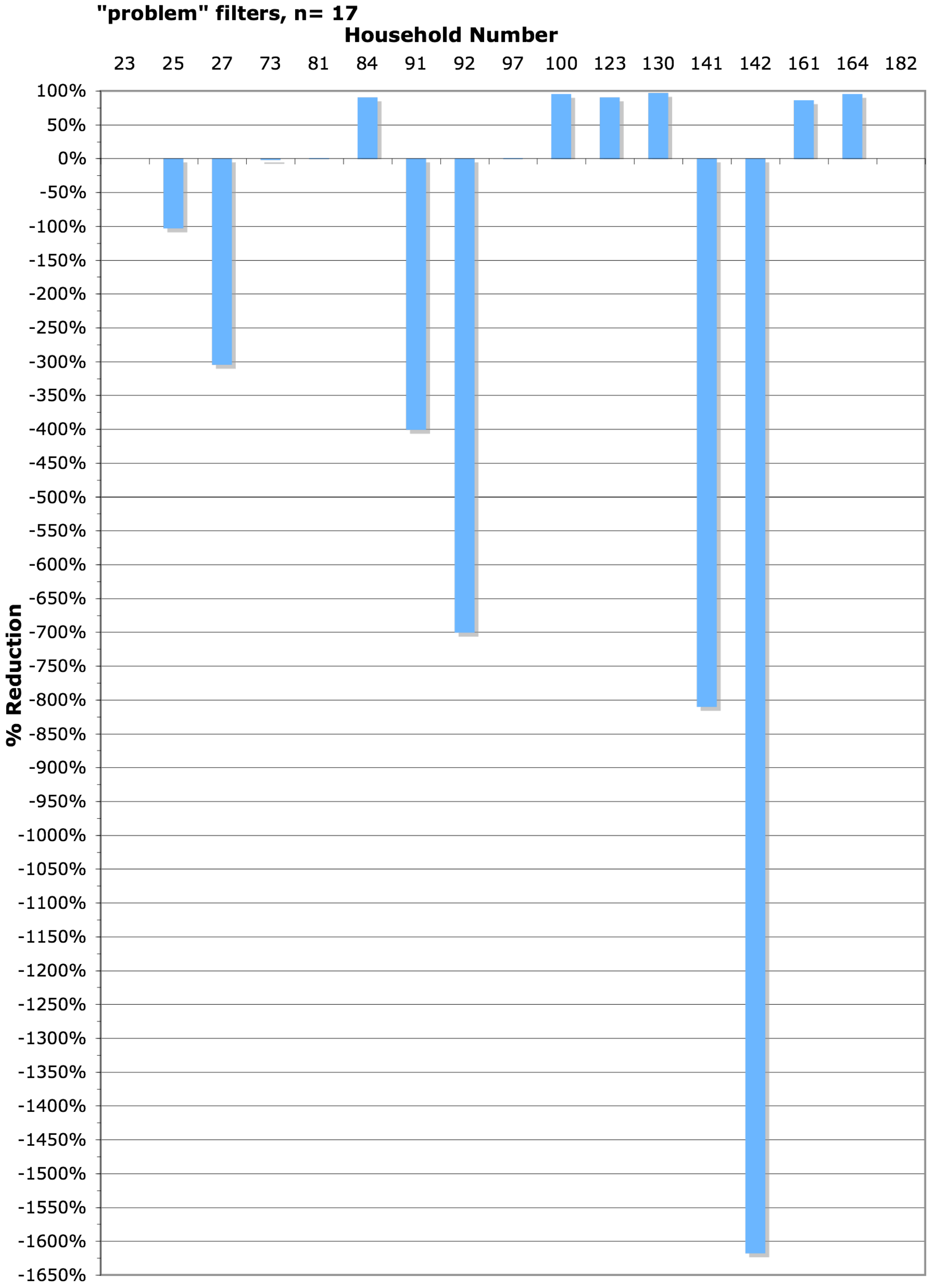

Figure 64: Reduction in *E.coli* in KOSIM-filtered water using the upper detection limit for the 17 “problem” filters with increases in total coliform after filtration

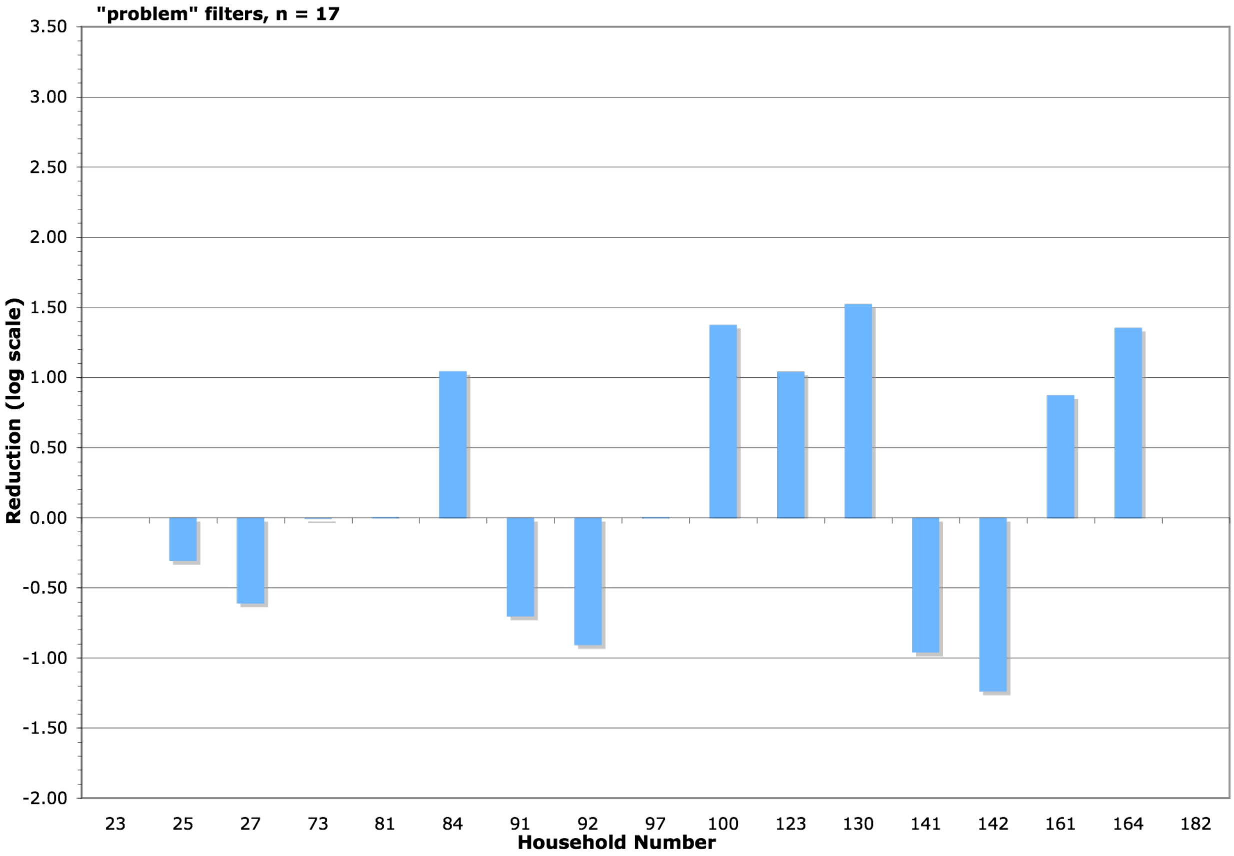

Figure 65: Reduction in *E.coli* in KOSIM-filtered water using the upper detection limit for the 17 "problem" filters with increases in total coliform after filtration (log scale)

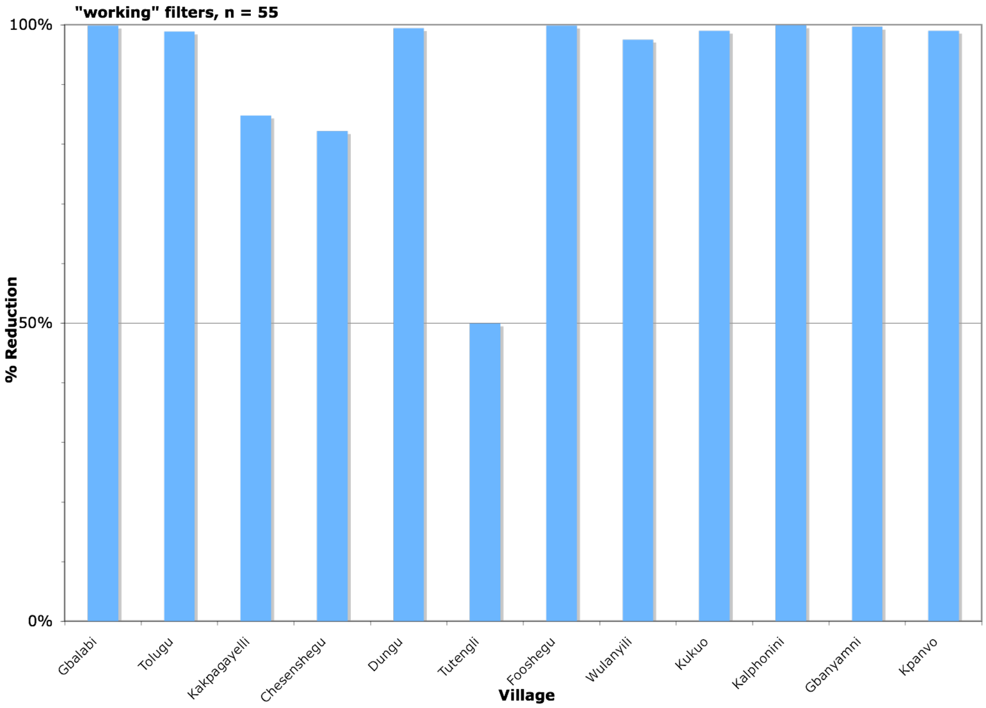

Figure 66: Average reduction in *E.coli* in KOSIM-filtered water using the lower detection limit for the 55 "working" filters with decreases in total coliform after filtration, by village

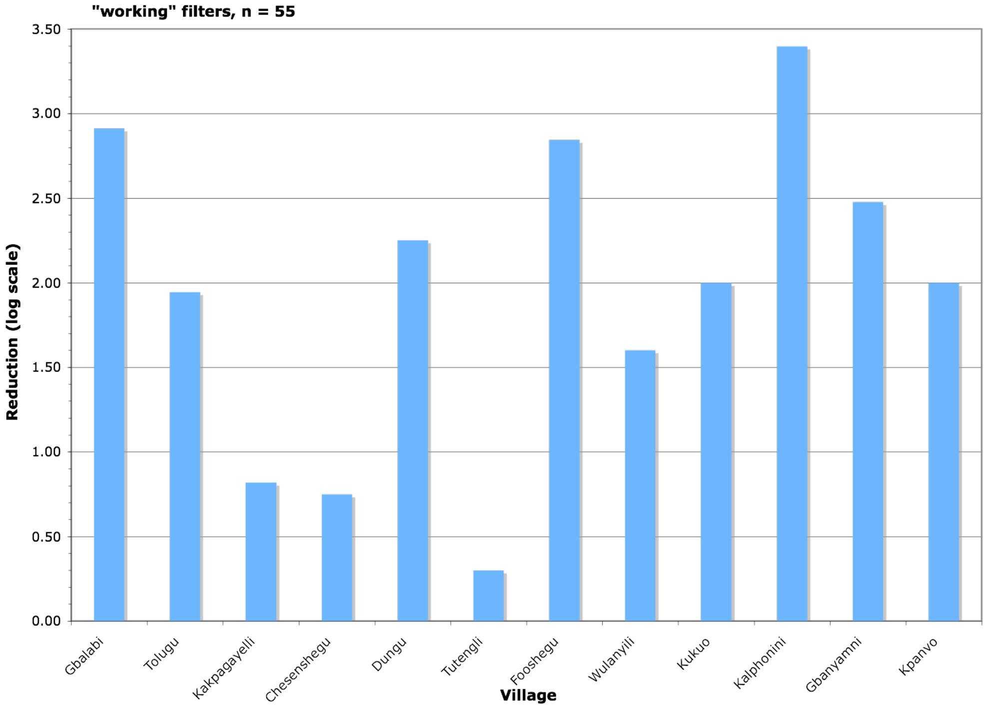

Figure 67: Average reduction in *E.coli* in KOSIM-filtered water using the lower detection limit for the 55 "working" filters with decreases in total coliform after filtration, by village (log scale)

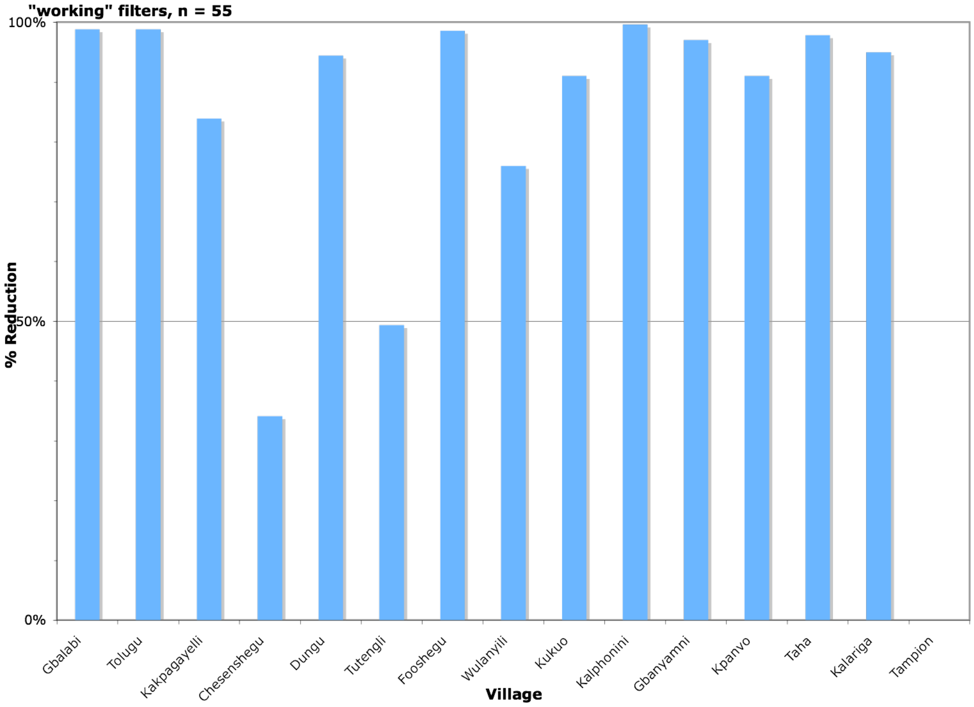

Figure 68: Average reduction in *E.coli* in KOSIM-filtered water using the upper detection limit for the 55 "working" filters with decreases in total coliform after filtration, by village

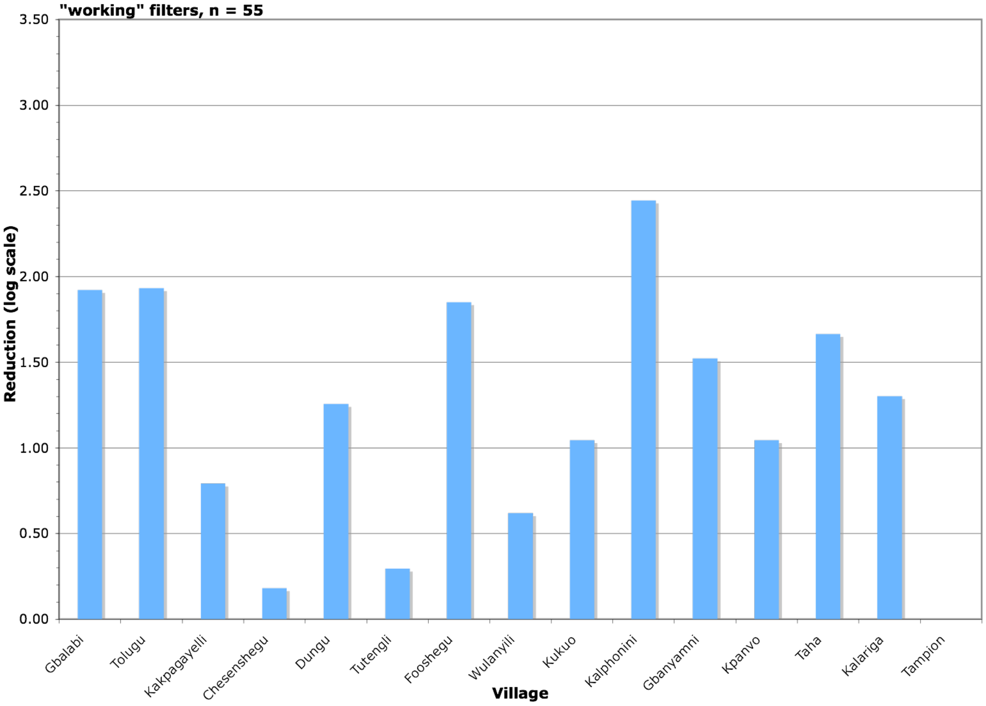

Figure 69: Average reduction in *E.Coli* in KOSIM-filtered water using the upper detection limit for the 55 "working" filters with decreases in total coliform after filtration, by village (log scale)

Chapter 5 Conclusions and Recommendations

5.1 Conclusions

During the months of January, June, and July 2008, I surveyed a total 309 of Pure Home Water's rural customers who had purchased a filter between 2005 and 2008 to determine both the sustained use of the KOSIM ceramic pot filter and the factors that are associated with filter sustained filter use or disuse. I defined sustained filter use based on the following observations at the time of the survey:

1. KOSIM filter is correctly installed in storage unit.
2. Water is currently in KOSIM pot filter.
3. Clear water (<5 TU) is currently in KOSIM storage unit.

5.1.1 Key Findings

Of the 221 rural Pure Home Water customers that I surveyed during the final sustained use study who had bought a KOSIM ceramic pot filter between 2005 and 2008, 46% are still using the KOSIM ceramic pot filter. The most frequent reason for disuse was filter breakage (27% of respondents not using the filter – see Figure 70). Sixty-three percent of the filter breakage was of the ceramic filter element (see Figure 71).

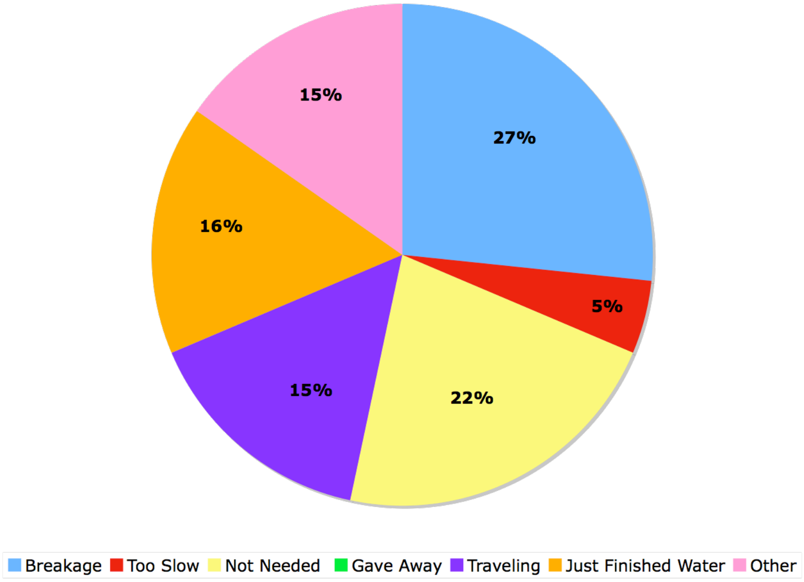

Figure 70: Reasons for disuse (n = 118)

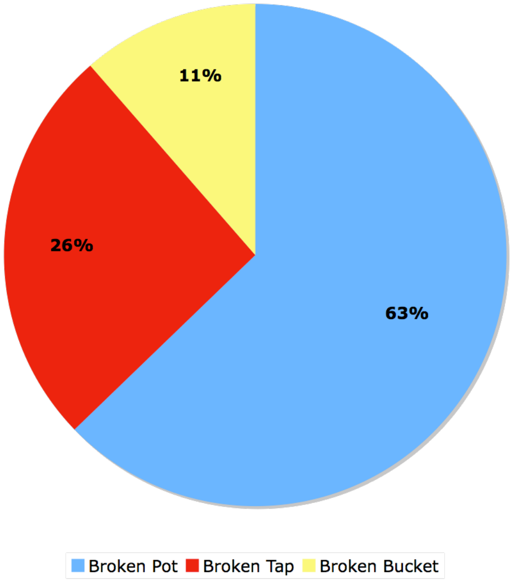

Figure 71: Filter element breakage (n = 35)

In addition to filter breakage the following factors were associated with sustained filter use or disuse:

1. Household income
2. Water Source
3. Price paid for filter

On average, the KOSIM water filter removes 96.2% of total coliform (1.42 log reduction) and 89.2% (0.99 log reduction) of *E.coli* using the lower test detection limit 3M^{TM}Petrifilm^{TM}/Colilert$^{®}$ test combination. The average total coliform and *E.coli* reductions using the upper test detection limits are 88.8% (0.95 log reduction) and 82% (0.75 log reduction) respectively. These removal statistics do not include the 17 filters that increased the total coliform count in the filtered water. Possible reasons for this increase are discussed in Section 5.1.2.

5.1.2 Discussion of Findings

Some of key findings of this sustained use study are very similar to the results of Joe Brown's study in Cambodia and Katherine Westphal's research in Nicaragua, both of which also found filter breakage to be most frequent reason for filter disuse (Brown, 2007; Westphal et. al, 2008). Since the filters investigated in each of these studies were all manufactured at different filter factories in different regions of the world (Central America, Asia and Africa), these results suggest a flaw in the overall materials and/or manufacturing of the ceramic filter (and not in the type of clay in a certain region or the manufacturing techniques of a certain filter factory).

While the chi-squared statistical hypothesis test does not indicate the structure of the association between these factors and KOSIM sustained use of the present study, the survey data provide useful clues. Over half the lower-income households (67%) were using the filter at the time of the interview, while only 47% of middle-income households and 26% of higher-income households were practicing sustained use. These statistics suggest that lower-income households may be more likely to practice sustained KOSIM filter use. The majority of households collecting water from dugouts, unprotected dug wells, or rainwater were still using the filter at the time of the interview (69%, 52% and 55% respectively), while only 33% of households collecting water from a public stand-pipe were practicing sustained use. These results imply that households with access to a piped water source may be less likely to practice sustained KOSIM filter use. While respondents who paid greater than GHC 6 for their KOSIM filter had the highest percentage of sustained use (78%), 47% of respondents who paid GHC 6 and 57% of respondents who paid less than GHC 6 were also practicing sustained use. Half of the household who did not know the price that they had paid for the filter were still using the KOSIM at the time of the interview. While these results seem to suggest that households paying more than GHC 6 are more likely to be practicing sustained filter use, over half of the respondents who paid less than GHC 6 were also using their filter. More work is needed to better determine the nature of the relationship between filter price and sustained filter use. Possible future research on this topic is discussed in Section 5.3.

Although the other three key findings, that household income, water source, and price are associated with sustained filter use, may seem related (i.e. higher income households may have access to piped water while lower income household may not; higher income houses may pay more for a filter than lower income households), the correlation test show that household income, water source, and price paid are not strongly correlated with each other. The results of this correlation test are consistent with the typical access to water sources in rural villages in Northern Region Ghana. If a pipe water source was available in a village that I visited during this study, than each household in that community had equal access, regardless of their income.

According to my survey respondents, the amount of water collected by each family is not recorded, and when the community is billed for the water, the cost will be split evenly between every household in the village. This collection and payment method is different in urban areas where users will pay a fee for each container that they fill at a standpipe. Therefore, the correlation between household income and water source may differ in urban and rural areas. These results are also consistent with PHW's pricing policies. Although PHW has changed the price of the KOSIM ceramic pot filter over time, they did not discriminate among rural households. Therefore, households in the same village were all charged the same price for the filter, regardless of their income[26].

In addition to the survey results, the water quality test results proved to be very revealing. While the majority of the filters reduced the total coliform and *E.coli* in the source water, the average reductions that I observed were significantly less than the reductions shown in previous studies (in the laboratory and in the field). The lower reductions could be the result of the follow reasons:

1. The KOSIM ceramic pot filter is less effective at removing microbial contamination than similar filters in other regions of the world. This could be due to flaws during the manufacturing of the filter. However, since the study conducted by Johnson in 2007 showed much higher removal rates for the KOSIM filter, in the same region of Ghana (99.4% of total coliform and 99.7% of *E.coli* in rural, Northern Region Ghana (Johnson, 2007)), my results may suggest that the KOSIM filter's effectiveness has decreased over time or in certain lots from the manufacturer. This decrease in effectiveness could occur in filters that have been used in the field for a longer period of time, or the filter manufacture may be producing less effective filters during certain runs that supplied the household surveyed in this study as opposed to the households studied by Johnson.
2. Unpaired samples could have affected the test results. As mentioned in Chapter 3, I was unable to use paired samples (i.e. unfiltered water directly from the ceramic pot element paired with the filtered water being stored in the KOSIM storage unit) sure to time restrictions. Instead, I paired my filtered samples with the sample taken directly

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[26] In the past, PHW did discriminate between urban and rural customers, charging urban customers more than rural customers. Since urban customers were not included in this study, this price discrimination is not reflected in the correlation test.

from the reported water source. Since water can often become more contaminated while it is being transported and stored in the household before filtration (see Section 2.3) the samples taken directly from the water source could be *less contaminated* then the water that is eventually filtered in the KOSIM ceramic pot filter. This would cause the total coliform and *E.coli* reductions to decrease.

Additionally, 17 of the filters tested showed increases in total coliform in the filtered water using both the upper and lower test detection limit. Many of these filters also showed increases in *E.coli.* There are three possible reasons for this increase in contamination:

1. The storage unit of these filters may be contaminated
2. These KOSIM filters are making the water more contaminated
3. Unpaired samples could have affected the test results (see previous paragraph)

More research needs to be conducted to determine the cause of this contamination.

The second of the three reasons listed above (that the KOSIM filter is making the water more contaminated) causes the most concern. Since the increase in total coliform was not seen all of the KOSIM ceramic pot filters that were tested, if these 17 filters were making the water more contaminated, it would be due to a manufacturing flaw in those filters, and not ceramic pot filters in general. Better quality control measures need to be taken to ensure that this is not the case.

5.2 Recommendations

5.2.2 Recommendations to Pure Home Water

Based on the results of the sustained use survey and the water quality tests, I recommend the following to Pure Home Water[27]:

1. *Investigate filter design improvements* – The greatest reason for the disuse of the KOSIM filter is filter breakage. Therefore, PHW should invest time and resources in improving the durability of both filter element itself, as well as the storage unit.

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[27] This recommendation assumes that, as a social enterprise, PHW is concerned with maximizing their social impact as well as their profits.

2. *Quality control* – Establish a formal agreement with the manufacturer, Ceramica Tamakloe Ltd., to guarantee quality filters. If this agreement cannot be upheld, seek alternate manufacturers or establish PHW's own manufacturing capability.
3. *Consider income and water sources when selecting sales districts* – Since PHW is a small organization with a limited number of salespeople, they may want to target filter sales in villages with the greatest potential for sustained filter use. Based on my sustained use survey results, rural villages with lower incomes (i.e. a larger number of straw roofs than zinc or zinc and straw roofs) without access to public standpipes (i.e. collecting water from dugouts, unprotected dugwells, or rainwater) have a greater potential for sustained filter use than villages with higher incomes and piped water sources.
4. *Follow-up with contaminated filters* – 17 of the filters tested showed increases in total coliform after filtration. PHW should follow up with these customers and with Ceramica Tamakloe Ltd. to investigate the reason for this contamination. If the KOSIM filter proves to be the source of this contamination, then PHW should implement quality-control tests to ensure that the filters they receive from Ceramica Tamakloe Ltd. do not cause increased contamination.
5. *Rely on structured observations when monitoring filter use* – Translation errors and leading questions can often lead to biased answers when relying on self-reports for filter monitoring (as I observed in the survey pre-test). In order to accurately determine the sustained use of the KOSIM filter in the future, PHW should use structured observations.
6. *Set sustained use targets* – In his report on water, sanitation and hygiene indicators, Orlando Hernandez suggest that organizations use a stepped series of targets to monitor and evaluate different aspects of HWTS implementation (Hernandez, 2009). The data provided by this thesis can be used by PHW as a baseline for a series of sustained use targets. My recommendations for PHW's sustained use targets are presented below in Table 24.

Table 24: Recommended sustained use targets for Pure Home Water

	Year 1 (baseline)	Year 2	Year 3	Year 4
Sustained Use Target	46%	56%	67%	77%

5.2.3 Recommendations for Including HWTS as an Indicator for the Millennium Development Goals' Drinking Water Target

Household Drinking Water Treatment and Safe Storage Technologies have proven to be effective at improving drinking water quality for many people living in areas without access to an "improved" source of water and should be included as an indicator for the Millennium Development Goals' Drinking Water Target. However, in order to have access to clean and safe drinking water, the users of these technologies must use them correctly and consistently. I recommend the following:

1. *The burden should be on the implementing organization to prove sustained use* – Proving that an HWTS technology has improved the drinking water in a household requires more time than to identify "improved" water sources. Since the implementing organizations have access to information about their customers and/or users, these organizations should be responsible for determining the sustained use of the technology implemented.
2. *HWTS implementers should rely on structured observations when monitoring use* – Although the steps required for consistent HWTS use may differ depending on the technology, it is preferable that any technology-monitoring program should rely on structured observations, and not self-reports when measuring the sustained use.
3. *Access to "safe water" should be included in the MDG water target* – as mentioned in Chapter 2, the MDGs use access to "improved water supply" as the indicator for the water target. This indicator is flawed because it does not take into account the contaminations that can often occur in developing countries when water is being transported from the water source (either through a piped infrastructure or when its transported by individuals) and stored in the home. This indicator also excludes access to improved drinking water through the use of HWTS technologies. By changing the MDG drinking water target to include access to "safe water" (i.e. ”low” risk of waterborne

disease as defined by the WHO 3rd edition guidelines), progress towards this target could be more accurately quantified.

4. *Organizations should use average sustained use statistics for HWTS impact* – If an HWTS implementer is not able to monitor the sustained use of their product, then the they should use average sustained use statistics to calculate the number of people with access to safe drinking water via that organization's HWTS technology (i.e. if another organization implements ceramic water filters in West Africa, but is not able to monitor use, they could use the results from this thesis (i.e. 46% sustained use) to calculate the number of people with access to safe drinking water.

5.3 Future Work

Although this study provides insight to the sustained use of the KOSIM ceramic pot filter in Northern Region Ghana, there are still many opportunities for future work on this subject. Since there was limited baseline data on the diarrhea incidence rates of PHW's customers before they purchased the KOSIM ceramic pot filter, I chose not to include health impact questions on my survey. Also, due to time limitations, I decided not to survey a matched control group. Future work could be done to determine the health impact of the KOSIM filter by gathering baseline health data before the purchase of the filter and conducting follow-up visits[28].

As mentioned in Section 5.1.1 more research is needed to determine the relationship between the price paid for the KOSIM ceramic pot filter and sustained use. The Poverty Action lab is currently conducting a study on the willingness-to-pay for a KOSIM filter in Northern Region Ghana. This study could provide baseline filter price data for future work in this area.

More work also needs to be done to determine the reason for decreased performance of the KOSIM ceramic pot filter compared to previous studies and, most importantly, to identify the source of contamination in the 17 filters with increased total coliform counts in the filtered water. Since unpaired samples could have been the cause for both the decreased filter performance and the contamination, I suggest starting with a study using paired samples take directly from the ceramic pot element and the KOSIM filter storage. Additionally, the large breakage rates in

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[28] Sophie Johnson's 2007 Master of Engineer thesis tackles this subject, but due to time limitations, she was limited to small sample size population.

Ghana, Cambodia, and Nicaragua indicate that work still needs to be done to improve the durability of ceramic pot filters.

This thesis only investigates the sustained use of the KOSIM ceramic pot filter in rural areas of Northern Region Ghana. Future work could also be done to determine the sustained use of this filter in urban areas. Unlike my study, which utilizes PHW's sales receipts to identify household with filters, new methods would need to be developed for a urban sustained used study because the KOSIM filter is sold to urban customers through retail stores, who do not record the address of their customers.

In general, implementing organizations need to focus more of their efforts on determining the sustained use of HWTS technologies. Over the past fifteen years, HWTS advocators have focused most of their effects on demonstrating the effectiveness of these technologies at removing microbial contamination. Now that a significant number of studies have been conducted to prove HWTS efficacy, this community needs to shift to proving the use of these technologies in field via monitoring and evaluation. Many organizations view sustained use as a target to aim for during implementation (i.e. an organization may set staged targets as per the example shown in Table 24 for PHW's region). While high rates of sustained use are optimal for showing the success of an HWTS project, *knowing* the rate of sustained use is the first step toward the ultimate goal of achieving a high target when monitoring progress towards the MDG's drinking water target. If average sustained use statistics can be determined for each technology, then the use of HWTS as an indicator for access to "improved" water supplies could be more easily included as progress towards the MDG drinking water target.

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