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Socioeconomic Factors' and Water Source Features' Effect on Household Water Supply Choices in Uganda and the Associated Environmental Impacts

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Socioeconomic Factors' and Water Source Features' Affect on Household Water Supply
Choices in Uganda and the Associated Environmental Impacts

by

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A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Environmental Engineering
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ABSTRACT

Over the last twenty years or more, Uganda has benefitted from significant strides in water and sanitation initiated by the United Nations' Millennium Development Goals. While the rapid progress towards development has been vastly beneficial, it is also important that it does not occur at the expense of the environment. The environmental impacts of these water sources must be evaluated and understood. However, to develop a robust understanding of the impact requires inclusion of the community members who use these sources and their perceptions of them. Consequently, the goal of this research is to investigate the interrelationships between socioeconomic factors, water source features, and household water source and treatment choices, along with the associated environmental impacts of those choices.

This research focuses on two villages in Wakiso District, Uganda—Nalugala and Kitala and includes: (1) development and implementation of a country-specific survey of 200 households to gain qualitative and quantitative accounts of socioeconomic factors (e.g., education, gender of the head of household, number of household members), water source features (e.g. cost, convenience, quality, quantity of water) and community members' water supply choices; (2) statistical analysis to investigate any correlation between socioeconomic factors, water source features, and household source choice; and (3) a life cycle assessment of each water source and treatment method used in the surveyed communities to highlight their associated environmental impacts.

Based on statistical findings, the water source features which are considered most significant to impacting household choice are convenience, visual water quality (turbidity), and cost. When inspecting socioeconomic factors using the Progress out of Poverty Index (PPI), no

significant correlation was determined between the PPI levels and source choice.

Consequently, the PPI was disaggregated to further analyze any significant correlations between socioeconomic indicators in the survey (social, economic, and educational) and water source choice. Three factors (i.e. gender of head of household, number of household members, and construction material of the house's external walls) were significantly correlated with the household's choice for their water source.

The combination of qualitative and quantitative survey data underscores the disconnection between community members' perceptions of water quality and the actual, laboratory-tested data. This notion (perception vs. reality) asserts itself because the treatment techniques that respondents use for local sources are based on their perceived ideas of water quality. The techniques sometimes contradict the theoretical treatment methods (based on water quality tests) needed to raise a source's water to potable standards.

A life cycle assessment (LCA) was conducted on each source and (1) the treatment methods community members most frequently used in comparison to (2) the theoretical treatment methods which would be necessary to raise each source to potable standards. Tap water was found to have the highest environmental impact based on actual community practices. Although it was tested to meet drinking water standards, community members boiled it, increasing its impacts in the categories of land use and global warming. On the other hand, rainwater and surface water had the highest impacts in the same categories (global warming and land use) based on the theoretical treatment which is required for the source water to be potable. The impact of the various fuel sources used to treat water by boiling was also evaluated. The greatest impact was for the use of propane gas followed by charcoal.

CHAPTER 1: INTRODUCTION

1.1 Research Motivation

In the recent past, there have been a plethora of studies which cite popular international statistics like “1.1 billion people have no access to improved water sources” (Brikke, 2003). However, between the years 1990 and 2010 more than 2 billion people have gained access to improved sources which currently means ~89% of the world’s population is served by this type of drinking water. It is difficult to characterize an improved source based upon its water quality parameters due to the fact that there are many technical and financial constraints in developing nations. As a result, the United Nations’ Children’s Fund (UNICEF) and the World Health Organization (WHO) defined a proxy indicator (drinking from an improved source) that is more appropriate for measuring the water quality based on the nature of the source’s construction and its protection from outside contamination, especially that of fecal matter (UNICEF/WHO, 2012). These strides in improved water provisions were made to address a United Nations’ initiative called the Millennium Development Goals (MDGs). During the 2000 General Assembly, the MDGs were developed as a framework to facilitate worldwide collaboration on issues of poverty and access to education, health, and water as shared burdens between UN member-countries (UN, 2000, Ministry of Water and Environment, 2011). These goals were set as an ambitious bar with targets to meet in areas such as ensuring environmental sustainability, achieving universal primary education, promoting gender equality, empowering women, and improving maternal health before 2015.

Goal 7—Ensuring Environmental Sustainability—encompasses Target 7C which seeks “to halve, by 2015, the proportion of the population without sustainable access to safe drinking

water and basic sanitation” (UN, 2012). As a result, many international aid agencies, governments, and academics focus a great deal of time and resources on improving the access to safe drinking water. Many of these projects have helped reach the target for drinking water, with some developing countries even surpassing their 2015 goal years in advance (UNICEF/WHO, 2012, UN, 2012). Figure 1 shows the percentages of various geographical populations and their progress with the drinking water target (UN, 2012).

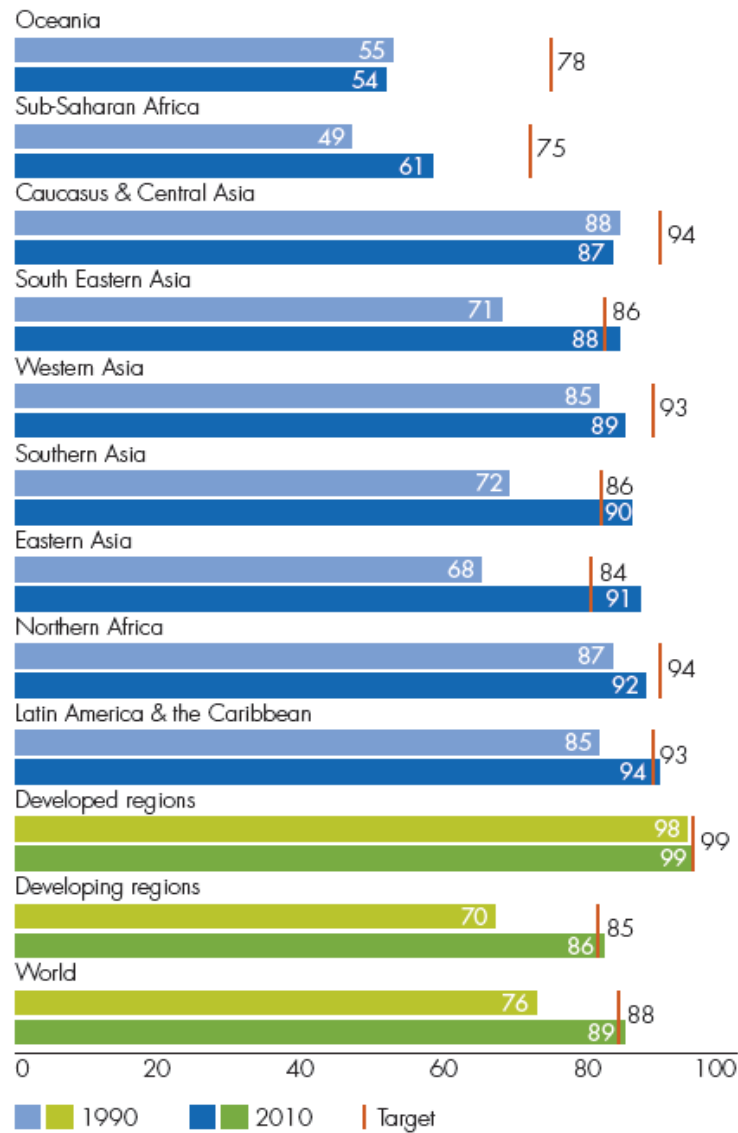


Figure 1: Percentage of population using an improved water source, 1990 and 2010 from Progress on Drinking Water and Sanitation 2012 Update, by WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation, copyright 2012, United Nations. Reprinted with permission of the United Nations.

While the rapid progress towards development has been vastly beneficial, it is also important that it does not occur at the expense of the environment. The environmental impacts of these projects must be evaluated and understood. A study in rural Mali evaluated the embodied human and material energies of household water treatment interventions and source supply systems. The particularly unique aspect of this study is the inclusion of human energy as it proves to be a significant contributor, more than half, to the total embodied energy (Held et al., 2012). The study from Mali shows environmental consequences associated with individual use of local technologies and treatment options. However, in order to understand environmental impacts of those technologies at a macroscale, like that of communities or countries, a conceptual model such as the IPAT equation, as listed below, is useful.

$$I = P \times A \times T \quad (1)$$

In Equation (1), I is the environmental impact, P is population (e.g. number of persons), A is affluence (e.g. product/person), and T is technology (e.g. environmental impact/product). IPAT's multiplicative formulation indicates equal weight of each of the three independent variables while calculating the impact as a linear relationship (Hummel & Lux, 2009). Curran & de Sherbinin (2004) argue that there is no explanation for any interaction among the terms and it lacks specific reference to other variables. Responding to such criticisms, the original IPAT equation has been modified through the introduction of new weighting factors, variables, and mathematical manipulation. ImPACT (Waggoner & Ausubel, 2002) is one of the primary modified IPAT equations as shown below:

$$I_m = P \times A \times C \times T \quad (2)$$

where I_m is environmental impact (e.g. carbon emissions), P is population (e.g. number of persons), A is affluence (e.g. GDP/person), C is consumption (e.g. energy consumption/GDP), and T is technology (carbon emissions/energy consumption).

This equation introduces a new term, consumption, which reflects a person's behavior with respect to their use or sparing of resources. This moves the IPAT formula one step forward through the consideration of human behavior (Waggoner & Ausubel, 2002, York & Rosa, 2003).

Lastly, STIRPAT (stochastic impacts by regression on population, affluence, and technology) is another modified IPAT equation and likely the most mathematically sophisticated.

$$I_i = a \times P_i^b \times A_i^c \times T_i^d \times e_i \quad (3)$$

In Equation (3), terms b, c, and d are the exponents of P, A, and T, respectively, and e is the error term, all of which must be determined through regression (York & Rosa, 2003).

These modified IPAT equations are presented with some of their strengths and weaknesses. They introduce more factors and different weights to reflect relative importance of the variables. This gives credibility to theories and allows for mathematical testing of hypotheses (Waggoner & Ausubel, 2002, York & Rosa, 2003). On the other hand, an independent, compartmentalized look at each of these P, A, and T variables will not lead to a comprehensive understanding of their dynamics. Instead, gathering field-related research to understand the inter-variable relationships and synergies within the IPAT equation is needed.

As a result, the goal of this study is to investigate socioeconomic factors (related to P), water source features (related to T) and their impact on a household's choice (related to A) for their water source. In addition, the associated environmental impacts (I) of their water source and treatment choices are evaluated.

The terms below are defined according to the unique way in which they are used in this study.

- Economic indicator—a question from the Progress out of Poverty Index (PPI) with an economic focus used to characterize households as explained in Section 3.3.2.
- Education indicator— a question from the Progress out of Poverty Index (PPI) with an educational focus used to characterize households as explained in Section 3.3.2.

- Household choice—the selection made by/for the group of individuals living in one dwelling. These phrases “household choice” or “people’s choice” (defined below) are not meant to be synonymous or used interchangeably.
- Person/people’s choice—a decision made by a single person or multiple people on their own behalf which reflects their personal preference.
- Water source—the point where the household collects water. Although a water source is typically considered the source of raw water, in this study it is generalized as the water collection point which is explained in further detail in Section 4.1.1.
- Water treatment—the household-level method(s) used to improve water quality.

1.2 Research Questions and Hypotheses

The following are three research questions to be answered through this study, each with an associated hypothesis:

- How do the features of water sources impact the household’s decision about which to use?

Hypothesis—the cost of a water source will have a major impact on the decision to use a particular source followed by the convenience.

- How do socioeconomic characteristics impact the household’s decision about which water source to use?

Hypothesis—the household economic and education indicators will have a major impact on the decision to use a particular source.

- What types of water source and treatment will have high environmental impacts?

Hypothesis—advanced water source and treatment systems will have greater environmental impacts.

1.3 Objectives and Tasks

The objectives of this research are to understand the impacts of socioeconomic factors and the features of water sources on household choices for their water. Furthermore, the study will evaluate the environmental impacts of water source and treatment systems based on people's choices.

This research includes the following tasks: (1) development and implementation of a country-specific survey of 200 households to gain qualitative and quantitative accounts of socioeconomic factors (e.g., education, gender of the head of household, number of household members, etc), source features (e.g. cost, convenience, quality, quantity of water) and community members' water source choices; (2) statistical analysis to investigate any correlation between socioeconomic factors, water source features and household choice; and (3) life cycle assessment of each water source and treatment method used in the surveyed communities to highlight their associated environmental impacts. Figure 2 below shows the objectives, tasks, and the ways in which they are linked.

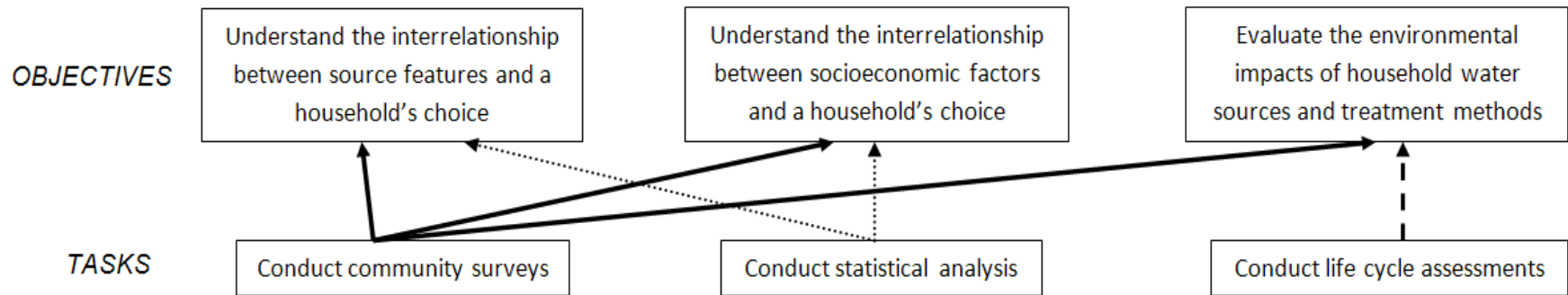


Figure 2: Graphical representation of the links between this study's objectives and tasks

CHAPTER 2: STUDY SITE

2.1 Overview

Uganda is a country located in east Africa with a population around 33.5 million people. Its capital city is Kampala in the south central part of the country along the shore of Lake Victoria. This city serves as its primary economic and industrial hub using the Ugandan Shilling (UGX) as the national currency (UBOS, 2012).

Uganda's geographical area is 241,550 square kilometers, split into 112 districts. These districts are decentralized extensions of the central government. Historically it functioned under the authority of British leadership as a colony until 1962. The subsequent twenty years (or more) proved to be very tumultuous as dictators, militarized coups, human rights tragedies, and public health crises plagued the youngest years of Uganda's independence (UBOS, 2012). More recently, however, Uganda is moving forward and even surpassing the regional averages for indicators of health and welfare as it makes efforts to develop (WHO, 2006).

2.2 Geography

This study was conducted in Wakiso District in the central portion of Uganda. It is located in the cultural Buganda region, the largest traditional kingdom of Uganda. Geographically, Buganda is bordered on the north by the swampy Lake Kyoga, which separates it from the cultural Lango region. To the west, Buganda's border lies approximately midway between Kampala and Fort Portal. To the south, Buganda is bounded by Lake Victoria. (UBOS, 2012, Ministry of Water and Environment, 2010)

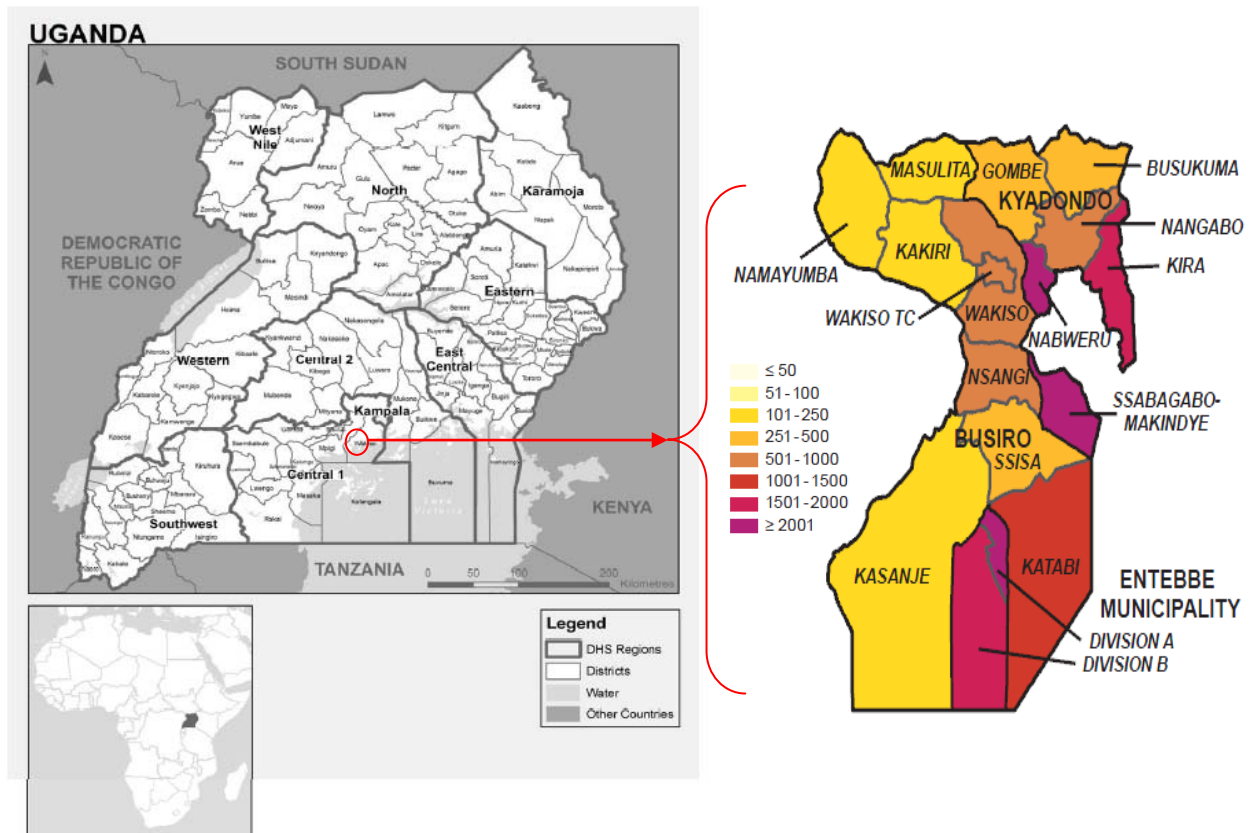


Figure 3: Geographic context of the East study and population density of Wakiso District with units of people/km² (Ministry of Water and Environment, 2010)

The two villages selected for this study are Nalugala and Kitala in the southern county of Busiro and its eastern-most sub-county Katabi. The population of Katabi Sub-County is approximately 80,000, with a population density of 1,001-1,500 people/km² as seen in Figure 3 (Ministry of Water and Environment, 2010). The study site is characterized by significant urbanization along the highway corridor from Entebbe to Kampala, immediately followed by lush vegetation, rolling hills, family farms, and red clay roads or footpaths.

2.3 Water Sources

The primary water source used throughout this region is the shallow well. Other supply options include groundwater from deep boreholes or protected springs, tap water from piped networks, rainwater harvested from roofs, and surface water collected from Lake Victoria.

Figure 4 shows the percentages of people served by most of these sources or technologies, reasons for non-functionality, and the type of management for the primary water sources found in Wakiso District.

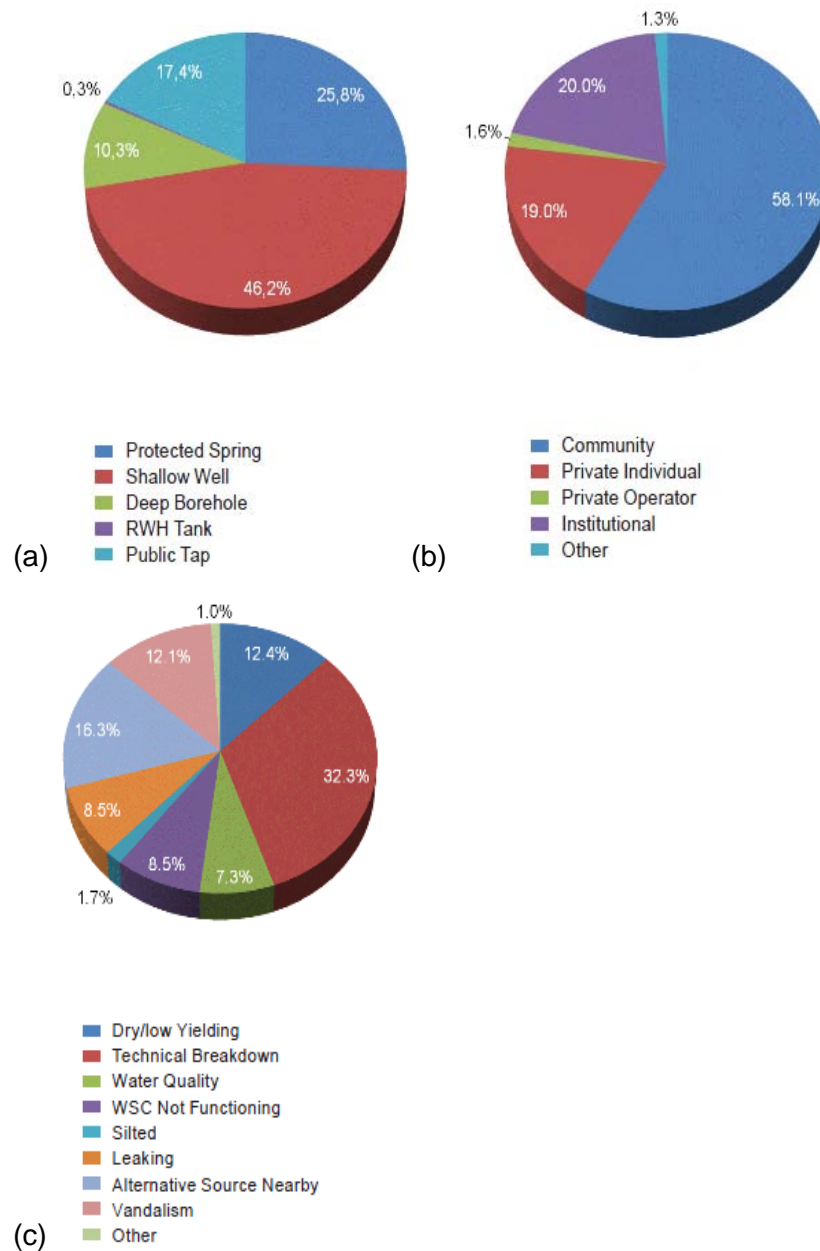


Figure 4: Percentages of (a) people served from each water source, (b) the type of management for Wakiso District water sources, and (c) reasons for non-functionality (Ministry of Water and Environment, 2010)

Katabi Sub-County has a drinking water coverage of 78% out of which 80% of these sources are functional (Ministry of Water and Environment, 2010). From Figure 5, Katabi's access and functionality can be compared to that of neighboring sub-counties. Coverage is defined by the 2005 Uganda National Water Development Report, as the "percentage of the population with access to an improved water source within a walking distance of 1.5km" (Ministry of Water and Environment, 2005).

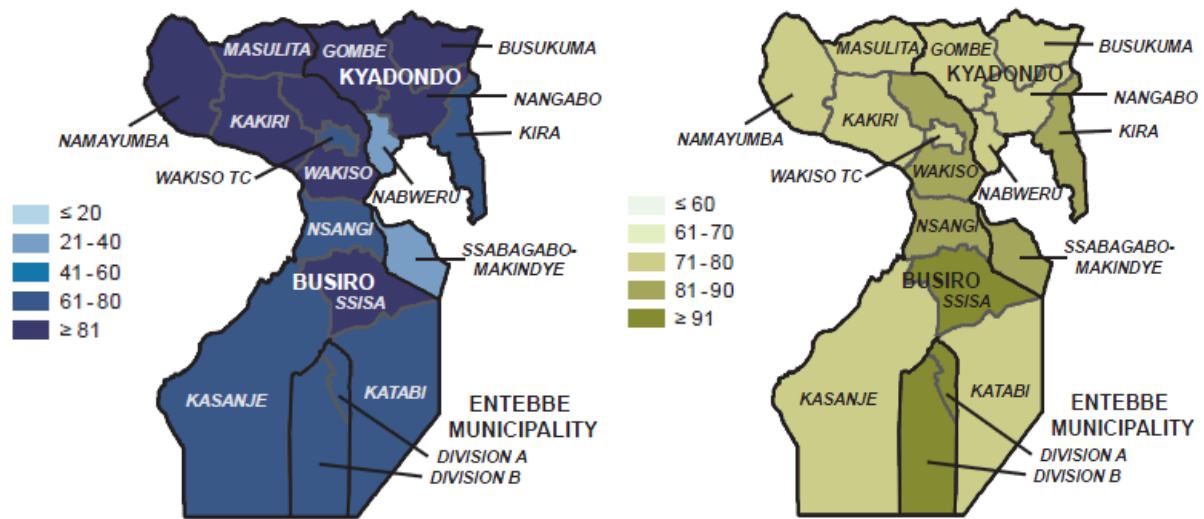


Figure 5: Maps of Wakiso District showing access (left) and functionality (right) of improved water sources (Ministry of Water and Environment, 2010).

2.4 Socioeconomic Status

According to the Urban Labor Force Survey conducted by the Ugandan Bureau of Statistics in 2009, Katabi Sub-County lies within a small cluster of districts around the capital city with a 13.3% unemployment rate (UBOS, 2010). The average monthly take-home pay is 150,000 UGX or ~60 USD (~2,500 UGX / 1 USD). Wakiso District was surveyed as one of the districts with more than half of its residents owning electronic equipment (cell phone, lamps, etc). Frequently these types of equipment are proxy indicators of wealth. Both Nalugala and Kitala villages are teeming with small businesses, subsistence farming, rock quarrying, day laborers, and fishing communities.

Katabi Sub-County has an 80% literacy rate with the 2010 net primary education accessibility at 78.8%. Furthermore, in these classrooms, pupils are at a 28:1 student to teacher ratio. While private schools are available and widely thought to be of better quality than public schools, both are easily accessible for community members of Kitale and Nalugala (UBOS, 2010).

While this area has many modernized infrastructures like cell phone towers and is widely considered a “well-to-do” area, many villagers still struggle with meeting basic financial needs (e.g. paying for quality schools for their children, unexpected health needs, or the rising costs of food prices and cooking fuel).

CHAPTER 3: WATER SOURCE FEATURES' AND SOCIOECONOMIC FACTORS' IMPACT ON HOUSEHOLD CHOICE

3.1 Introduction

Although shallow wells are considered the most widely used water source throughout Wakiso District, more often than not, households rely on various sources. Identifying and using multiple water sources enables households to meet their water usage needs; this is done as a way of compensating for the unreliability of their primary source (Howard & Teuton, 2002). A study characterizing urban water in East African countries has grouped water usage in three ways—consumption, hygiene, and amenities (Thompson & Porras, 2000). However, Mihelcic et al. (2009) further expands these categories by incorporating productive water use and including examples of the four water use categories in Table 1 (Mihelcic et al., 2009, Howard & Bartram, 2003).

Table 1: Categories of water use and examples of each use

Water Use Category	Examples
Consumption	Drinking and cooking
Hygiene	Personal and domestic cleanliness (i.e., bathing, laundry, washing floors, dust suppression)
Productive	Gardening, brewing, animal watering, construction (e.g., manufacturing concrete)
Amenity	Washing a vehicle or motor scooter, lawn watering

While it is obvious that communities seek multiple water provisions out of necessity, several studies have focused on understanding their choices or preferences for these water sources (Thompson & Porras, 2000, Mu et al., 1990). Sections 3.1.1 and 3.1.2 summarize

those studies by classifying them into two distinct groups (1) numerical modeling or (2) qualitative analysis of choice.

3.1.1 Numerical Modeling of Choice

A characteristic modeling study based in Kenya (Mu et al., 1990) was conducted to understand the impact of significant factors on household choices for water sources. The study first compared traditional water demand modeling in the U.S. and developing countries. Typically, the theory governing water choice and demand modeling is grounded in the optimization of water quantity and quality for a given investment. This study argues that drinking water in the U.S. and other industrialized countries can be viewed as a homogeneous good, with little variability in the source features and performance. However, due to the array of features and numerous source options that impact household choices in Kenya, their water provisions proved to be better characterized as heterogeneous. As a result, the research proposed discrete choice modeling as an alternative which incorporated dichotomous variables and choice options into its calculations. Community surveys were conducted to collect information about socioeconomics, perceived source qualities, and other factors that researchers hypothesized to impact choice. Results showed that certain water supply features like the time it takes to get to a source and its price had a significant impact on household choices whereas household income did not. These modeling results showed a way to calculate the impact that changes in water sources features and household characteristics would have on people's choices (Mu et al., 1990).

Like Mu et al.'s study in Kenya, other research has implemented discrete choice modeling for technology adoption (Caswell & Zilberman, 1985, Nieswiadomy, 1992, Lichtenberg, 1989, Negri & Brooks, 1990). While numerical modeling statistically quantifies the impact of various factors on technology choices, it does not provide the insight or understanding of why people make their choices. Qualitative information from surveys is useful at eliciting

responses which help to reveal perception, behavior, and preference (Ding & Hauser, 2011, Foltz, 2003) that influence people's choices. Numerical modeling alone cannot provide a full understanding of both quantitative and qualitative factors that impact a household's decision (Madanat, 1993). Therefore, it is important to incorporate qualitative information into the quantitative analysis to provide a better understanding.

3.1.2 Qualitative Analysis of Choice

Qualitative analysis, on the other hand, frequently involves a human component and is more complex (Doria, 2010). Qualitative data usually comes from community surveys that elicit responses through open-ended questions. This type of data adds a new dimension to analysis as community dynamics, varied opinions, and cultural perceptions prove to be valuable factors (Doria, 2010, Dynes, 1971). Although added complexities may arise, qualitative data analysis is an important part of a comprehensive, well-rounded study (Hartley, 2006).

A study (Rainey & Harding, 2005) in Nepal on the adoption of solar disinfection (SODIS) of drinking water echoes the added value of qualitative information in analyzing choice. The researchers initially conducted a basic survey to collect information about local water sources and community behavioral data to help pinpoint factors likely to impact technology adoption. They found inconsistencies when comparing the answers from the community in Nepal to previous responses from communities in other regions. The previous study (EAWAG, 2002) concluded that a distrust of the treatment method, unpleasant taste, or complaints about the method taking too long were major contributors in people's unwillingness to adopt the technology. The researchers in Nepal later conducted semi-structured household surveys during and after SODIS implementation with open-ended question that revealed hidden factors such as cultural, social, and economic opinions. The study found that the perceived benefits and shortcomings of SODIS technology included improvements in health and hygiene, frustrations with water access, and difficulty in adapting to the new water treatment. Primarily, the open-

ended responses brought community-specific perceptions and preferences to light. Unlike the previous study, the Nepalese SODIS adoption rates were low because of the workload for women, a conclusion providing more insight into aspects of community choice, which came to light only through qualitative data collection and analysis.

Another study conducted by Doria (2010) found that perception of water quality has a great impact on people's choice of water sources. Many qualitative variables are influential on community perception of water quality (Doria, 2010) as explained below:

- Prior experience with the source—this aspect is primarily impacted by the community member's positive or negative experience with water collection or quality from the source. The study mentioned that, "familiarity [with the source]...influences perceptions of risk" (Doria, 2010).
- Influence by personal or impersonal information—context matters when considering a community member's influence. Sometimes a family member or neighbor's viewpoint about a specific source could carry more weight than what is depicted in the media or by a politician.
- Sensorial cues—odor, taste, and visual appeal are viewed with varying preference when considering the circumstances of culture, geography, and local history. The importance of sensorial cues varies from person to person and community to community. The United Nations Educational Scientific and Cultural Organization (UNESCO) study attributed the variance in these preferences to a notion as basic as "liking what you are used to" (Doria, 2010).
- Cultural background and world views—cultural backgrounds function as the social constructs that influence personal interpretations of many things in daily life (e.g. water quality of locally available resources, treatment methods). This framework is further

impacted by religion, trust of institutions or governments, and a culture's view of individuality versus collective action (Doria, 2010).

Without incorporating such qualitative information, it is difficult to truly understand community members' choices. This notion is further investigated in a developing country study about the decision-making processes of Tunisian farmers and their technology choice of drip irrigation systems as a function of water resources, quality, and farm/farmer characteristics. Foltz (2003) implemented direct questioning of community farmers to elicit their preferences as a way of evolving out of traditional modeling and towards a more flexible, holistic form of research. In an effort to build a rich understanding of farmers' choices, community perceptions are partnered with their action or inaction to adopt a certain technology in order to "triangulate" findings that are more profound than "statistical artifacts."

An interesting feature of this study is its immodest implication of bias and realistic shortcomings associated with qualitative data collected through community surveys. Key factors which Foltz cited as frequently discrediting qualitative surveys are:

- Unclear wording or leading questions;
- Respondents' inability to properly articulate their choice process
- Preferences, themselves, as highly subjective in nature and frequently variable from person to person.

However, the author argues that the problematic nature of qualitative data collection and analysis does not have to negatively influence its use in future research. Foltz explains that although long surveys and open-ended questions may be cumbersome, they allow for direct revelation of community perceptions. This alleviates instances where research enumerators assume to know another "person's mind better than he does" (Foltz, 2003). The study found that when partnering quantitative statistics with the qualitative information from Tunisian farmers,

unknown intricacies, both socially and economically linked, were exposed. For example, statistical analysis showed a weak correlation between a farmer's choice to invest in a resource-conserving drip irrigation system and the increasing cost of water. Through directly asking farmers about resource conservation and its importance, they said it did matter to them and they were interested in the new irrigation system, but were constrained by other factors (e.g. access to loans for financing such an investment) which took precedent. Other studies (Dogaru & Zobrist, 2009, Rainey & Harding, 2005) also confirm that site-specific survey data provides qualitative information that is unique to each community and can help to understand their choices.

Consequently, this research will incorporate qualitative responses into the quantitative results from statistical analysis of community survey data from Nalugala and Kitale. This will provide a better understanding of how socioeconomic factors of local households and water source features influence community choice.

3.2 Methodology

For the purpose of this research, a community survey was developed in order to obtain household qualitative and quantitative information concerning water source choices. Statistical tests were conducted to investigate the potential influence of water source features and socioeconomic factors on people's choices for their water provisions. The following sections discuss in detail the methods used in community surveying and statistical analysis.

3.2.1 Community Survey

3.2.1.1 Development of the Survey: Progress out of Poverty Index Used to Reflect Household Socioeconomics

For this portion of the survey, socioeconomic characteristics of the households in Kitala and Nalugala were evaluated based upon a Uganda-specific questionnaire developed by the Grameen Foundation Initiative. The households' survey answers corresponded with weighted scores (Schreiner, 2011). These scores were summed and referenced as the Progress out of Poverty Index (PPI).

The PPI value is a compound indicator which reflects a household's economic, educational, and social status. Ten questions were chosen for the scorecard based upon the most recent (2009-2010) Uganda National Household Survey (UNHS). The criteria for selecting the questions from the UNHS include their ability to reflect the greatest change in poverty over time and to reduce the level of variance so as to remain as unbiased as possible (Schreiner, 2011). The survey questions are grouped into the specific socioeconomic subsets including economic, education, and social, as listed in Table 2.

The PPI estimates the likelihood that interviewed households fall below the national poverty lines. Here, "likelihood" can more specifically be explained as, "the probability that the household has per-capita or per-adult-equivalent expenditure below a given poverty line," of either \$1/day/purchasing power parity (PPP) or \$2/day/PPP (Schreiner, 2011).

Currently, many local organizations rarely implement the long, sophisticated national household surveys to collect data about the demographics of the communities in which they serve (Schreiner, 2011). This PPI tool, however, was developed particularly for Uganda and is best used in a field setting. It can function as a template because it is easy for local organizations to modify to make it more compatible to their particular needs.

Table 2: Economic, education, and social survey questions from the Progress out of Poverty Index

ECONOMIC
What is the major construction material of the roof?
What is the major construction material of the external wall?
What is the main source of lighting in your dwelling?
What is the type of toilet that is mainly used in your household?
Does any member of your household own electronic equipment (e.g. TV, radio, cassette, etc.) at present?
Does every member of the household have at least two sets of clothes?
Does every member of the household have at least one pair of shoes?
EDUCATION
Do all the children (ages 6-18) currently attend school (government, private, NGO/religious, or boarding)?
What is the highest grade that the female head/spouse completed?
SOCIAL
How many members does the household have?
What is the gender of the head of the household?*
What is the age of the head of the household?*

*These questions were not originally included in the PPI survey, but were included for the purpose of this study

Because Ugandan survey data was used in creating the questionnaire, the indicators reflect factors that have cultural and economic importance in the villages. It also makes for an easier translation into the local languages in order to effectively communicate in the field. A short list of the other methods that were considered for the study are described in Table 3, specifically outlining the number of indicators, method implemented, the accuracy (as reported from the analysis of each tool), and relevant comments for comparison. In the end, the PPI was chosen as the most stream-lined and up-to-date tool for the researcher's needs and purpose in the field (Schreiner, 2011).

Table 3: Comparison of various poverty measurement tools (Schreiner, 2011)

Poverty Measurement Tool	Number of Indicators	Method	Comments	Accuracy
Gwatkin et al. (2007)	20	asset indices	uses older (2007) national survey data; difficult to collect/compute score in the field; difficult scoring system to introduce/transfer to local staff	Unknown, "proxy for long-term wealth/economic status"
IRIS Poverty Assessment Tool	16	direct-expenditure scorecard	quick, easy to use in the field; not affective in measuring change in poverty over time	77.30%
Mathiassen (2011)	31	poverty likelihood scorecard	uses older (1993-2006) national survey data to determine poverty trends	decreases over a period of time
Progress out of Poverty	10	poverty likelihood scorecard	quick, easy to use in the field; affective in measuring change in poverty over time; easy to collect/compute score in the field; easily transferrable to local staff; uses most current national data (2009-2010)	90%

3.2.1.2 Development of the Survey: Characterizing Water Source and Treatment Options

In addition to the socioeconomic questions derived from the PPI, there were also survey questions designed to obtain information about water source and treatment options. The first portion of these questions in Table 4 is related to a household's source choice, perceptions, logistics, operation, and maintenance performed on their local water sources and treatment options.

Table 4: An excerpted portion of the community survey with questions pertaining to water source and treatment logistics

WATER SOURCE AND TREATMENT LOGISTICS
What water source(s) do you use?
What are the positive and negative effects of using another source besides your primary?
Why do you choose your primary source?
Does your source change with the seasons? Why or why not?
Do you have different sources for drinking/washing; why or why not?
Who is responsible for maintenance?
How often does the source have to be maintained?
Does this person/org also pay for maintenance?

The next section of questions is found in Table 5 and has two primary goals. The first is to characterize water treatment methods and quantify water usage. The answers to those questions are used to provide the quantitative data for the life cycle assessment of the household's chosen water source and treatment method(s). Specifically, the questions inquire about the amount, frequency, and materials used for the household's water treatment method(s).

The second goal is less technical and more qualitative as the study investigates local perceptions concerning the factors that motivate a household's choice to treat their drinking water or not. A full example of the household survey can be found in Appendix A.

Table 5: An excerpted portion of the community survey with questions pertaining to water usage, treatment methods, and household perceptions

WATER USAGE, TREATMENT METHODS AND PERCEPTIONS
Do you treat your water?
How is your water treated?
What kind of materials are used for treatment and how much of each material?
What are the use(s) for treated water?
Why is this treatment method used?
Is all of the water treated the same way?
If you used a different source would you still treat your water?
How much water do you use per day (utility water) and treat per day (drinking water)?
How often do you treat water?
Why do you treat water?
If you do not treat water all of the time, what are your reasons?
Do you think the quality of your water affects your health; why or why not?

3.2.1.3 Pre-Implementation of the Survey: IRB Application and Approval Process

Before going into the field, it was necessary to obtain Institutional Review Board (IRB) clearance for the intended research. In order to do this, the Primary Investigator (PI) worked with an existing local organization which professed similar goals as that of this research. The organization, Bega Kwa Bega (BKB, English translation from Swahili is Shoulder to Shoulder), was chosen and a research team was formed.

The team served in vital roles alongside the PI by acting as liaisons to the local community members, participating in the data collection as field staff translators, and in development of the questionnaire. The research team helped the PI to write, proof-read, translate, and assure that the survey was culturally appropriate, easy to understand, and efficient in the field as a means of data collection.

After completion of the survey, a field staff translator was trained in ethical practices for interviewing human subjects. This step was required prior to the submission of the full IRB

application. Following multiple iterations of edits by the University of South Florida's IRB panel, the IRB application was approved and field data was ready to be collected in June 2012 (Appendix B).

3.2.1.4 Conducting the Survey

When conducting the survey, the PI and field translator were equipped with folders containing the English and Luganda versions of: (1) the informed consent script, (2) the 3-part survey, and (3) a brochure for BKB. Both parties would greet potential homes, introduce one another and the research, and wait to be invited to stay. During the survey, questions were clarified for respondents by the translator after prior instruction from the PI. This was to ensure that all intention was made not to lead the respondent into any specific answers.

The PI was the only field staff member who recorded answers because it was done in shorthand in order to capture as much qualitative data in as little time as possible. Many of the questions, however, were quantitative and the PI's working knowledge of Luganda was substantial enough to confidently keep up with and understand the survey's progress. As a result, if more clarification was necessary to improve the quality of the data, the PI and field translator would work together at the time of the interview to seek more information from the community member.

At the end of each day, the recorded answers were entered into electronic format using Microsoft Excel in order to keep the exact wording from the qualitative responses.

3.2.1.5 Collecting Samples for Water Quality Analysis

Two water samples were collected from each of the five primary sources and taken to the Ugandan National Laboratory in 250mL sterile plastic containers (which the laboratory provided) where basic water quality tests were conducted (e.g. turbidity, conductivity, total dissolved solids, pH, total fecal coliforms, total suspended solids). Each container was first

labeled prior to sampling in duplicate. Proper field data collection procedures were taken to minimize sampling errors. The samples from open water sources were taken with the mouth of the container directed upstream. For water samples from rainwater harvesting systems, boreholes, or tap water faucets, the valve was opened and allowed to run for 30 seconds prior to collection. After samples were collected, within two hours they were taken to the National Laboratory for testing. However, as per the water quality testing certificate in Appendix C, the samples' tests were not completed until 4 days after their initial collection. It is assumed that in order to assure the integrity of the results the samples were properly stored in the National Laboratory until their tests were conducted.

3.2.2 Statistical Analysis

The purpose of statistical analysis in this research is to determine whether or not there were any significant relationships between surveyed variables. The software used to analyze the researcher's community survey data is IBM's SPSS Statistics 20 (Armonk, NY). It is the primary software for performing various statistical tests. However, before tests could be conducted, it was necessary to fine-tune all of the data that had been collected by grouping and processing it.

3.2.2.1 Grouping Values

The community survey was semi-structured, but had some questions that allowed for open-ended responses. As a result, grouping terms was necessary to streamline the statistical analysis of the data and improve the general coherence of the research.

- Surface Water— includes open ponds, Lake Victoria, and shallow wells. The local term is “oluzzi,” which most often refers to any unimproved source, but might sometimes

encompass an improved, but less developed source (e.g., shallow well with little to no quality infrastructure to prevent contamination).

- Convenience—includes respondents' answers concerning distance, time, and their ability to access their primary water source, "ease of use". However this factor will be reflected by the numerical measurement of the time it takes to get to/from, wait in line and collect water from the source.
- Availability—this term was developed as a result of the open-ended question "Why do you choose your primary source?" Many respondents answered, "Because it is the only source available." Therefore, it was imperative to define a new term under the technology features section to bring to light the perceptions of these community members.

3.2.2.2 Processing Data: Cost

Water volumes were recorded in liters (L). Furthermore, the storage options for nearly all interviewed households were 20 L plastic containers called "jerrycans," thus, that volume will be the reference point for unit pricing of water for this research.

- Tap Water + Borehole Buyers—the costs for purchasing water either from local tap stands or boreholes could span a wide range depending on many factors such as the variability of the season. As a result, the respondents' reported costs were averaged to reflect the mean costs to the community for water from the tap and borehole.
- Tap Water Owners—the cost of owning a tap was determined from the National Water and Sewage Corporation's price report listed in the Water and Environment Sector Performance Report of 2011 through the Ugandan Ministry of Water and Environment (Ministry of Water and Environment, 2011).

3.2.2.3 Processing Data: Convenience

- Time—this variable was calculated based upon average values obtained from Uganda's Demographic and Health Survey (DHS) 2012. These values include the time to get to, from, wait in line, and collect the water from the associated source. For each source represented in the DHS study, their unique answers were grouped based upon the way they aligned with this study's source categories (i.e. borehole, surface water, rainwater harvesting, tap water, and spring). For instance, the DHS study referenced an open pond, but this study grouped it under "Surface Water" as discussed in Section 3.2.2.1. All the responses for the time it took to get to, from, collect water, and wait in line based upon each source were averaged and used as the indicator of convenience. Time was chosen as the only quantitative value indicating convenience because time is a function of both distance and speed, thus those two variables are implicit in the term.
- Distance—while respondents mentioned distance as a reason for choosing their primary source, the actual distances were not recorded, as mentioned above, but considered implicitly in the variable of time which, in this case, indicates convenience.
- Ease of Use—this phrase was mentioned by community members to reflect their ability to physically collect water from the source. Some community members who gave this response were elderly individuals who found it difficult to pump water from the boreholes and, as a result, went to rainwater harvesting systems instead because the spigots were more manageable. In addition, some mothers with children chose tap water systems over the cumbersome chore of carrying a small infant to the surface water collection point because taps were easier to use while their babies were swaddled on their backs. In a similar fashion to the discussion point above where "availability" became a technology feature after its extrapolation from several open-ended community responses, so, too, was the notion of a water source's ease of use. When community

members gave this reason for choosing their source, it was also coded as “Convenience.”

3.2.2.4 Processing Data: Quality and Quantity

Concerning water quality of the rainwater harvesting tanks, data was taken from both plastic and metal tanks, but through observation during the household surveys, metal tanks were frequently seen as the more affordable option by community members. As a result, the water quality parameters of a metal rainwater harvesting tank were chosen to represent the group at large. Below are responses for water quantity questions:

- Don’t know—the households whose responses were “Don’t know,” to the question about their average daily volume of drinking and utility water will receive a value based upon the mean answers of all the other community respondents—3.57 L for drinking water and 60 L for utility purposes (washing, cleaning, cooking per household).
- Varying volumes—some respondents used much less than a full jerrycan for drinking water purposes, and felt uncomfortable trying to estimate what portion of a jerrycan they consumed. As a result, they expressed their daily drinking water based upon the vessels which they used daily and with which were more familiar (e.g. one kettle, saucepan, or cup). The associated volumes were estimated based upon observation and inspection of the vessels and simple calculations were conducted to determine the actual values.

Lastly, the volume for rainwater was normalized over the yearly average for a more accurate description of household availability regardless of the season. A value of 20% loss was assumed due to the observed functionality of local rainwater catchment infrastructures.

3.2.2.5 Statistical Tests

A Pearson’s Chi-Squared Test is performed in the case where the research calls for comparison of two categorical or scale variables. This test determines whether there is

statistical independence between the values, or, more basically, whether they are correlated. Mathematically the Chi-Squared value can be calculated using Equation 4 where f_o is the frequency of observed values and f_e is the frequency of the expected values. The sum of the squared difference of these values divided by the frequency of expected values determines the Chi Squared term.

$$\chi^2 = \sum \frac{(f_o - f_e)^2}{f_e} \quad (4)$$

Using SPSS, Chi-Squared scores are noted as conclusive and relevant when the significance is less than 0.050. In such a case, the null hypothesis of statistical independence is rejected in favor of the alternative hypothesis signaling some significant correlation.

Analysis of variance (ANOVA) tests were completed in order to determine whether more than two categorical variables differed in a significant degree along some other scale variable. In addition, cross-tabulation tables were used as a method of bivariate analysis to show the distribution of cases with one variable (dependent) in terms of another (independent). These tables allow users to quickly see associations between variables, although significance cannot yet be inferred.

The Pearson's Correlation coefficient (r) is calculated to determine the affect of the change in an independent scale variable on a dependent scale variable. Again, as mentioned above, significance is signaled by <0.050 values, but the magnitude of the value matters as well (its closeness to +1 or -1). The closer to +1 means the stronger the positive correlation, whereas the converse is true for the closer the value get to -1.

Lastly, creating visual presentations of the data allows for quick inspection of general trends like minimum and maximum categories. This was done with bar graphs to summarize the survey responses.

3.3 Results and Discussion

3.3.1 Technology Features

The community surveys elicited responses about the local water sources, including qualitative information about source choices and perceptions of source features. However, it also engaged respondents in discussion about objective, quantitative information which is summarized in Table 6 and includes the number of household respondents using each source, the average cost per jerrycan, the average collection time for one roundtrip, water quality parameters, and the daily collection volume. Statistical analysis using Pearson's Correlation was performed on the data from Table 6 and is presented in Table 7.

As shown in Table 7, three factors show strong correlations with household choices: average collection time, turbidity, and cost. The average collection time and turbidity have negative correlation indicating that more household choose the sources that require less collection time and are less turbid. In contrast, the cost shows a strong positive correlation with choices. More households choose a primary water source which has a high cost.

Statistical analysis showed that there was a positive correlation between the cost of a source and community choice; as the price increased, so, too did the number of households using that source. However, the statistical analysis was based upon the selections that community members are currently making for their primary source. In contrast, when they were asked why they made these choices, inconsistencies were discovered. It was initially hypothesized that the survey respondents' choices for household water sources were based upon the cost of an available source followed by its convenience; it appears in Figure 6 that convenience is actually the leading factor with cost in a secondary role. The term "convenience" is based on a broad definition of factors from the qualitative survey question (see section 3.2.2.3). However, for the statistical portion of this study the qualitative answers are distinguished from the quantitative measure of convenience since the indicator there is time.

Table 6: Summary table of water source features

Primary Water Source	Number of Households	Average Cost per Jerrycan	Average Collection Time	Water Quality						Daily Usage	
				TDS	TSS	Turbidity	E. Coli	T.coliforms	Conductivity	Utility	Drinking
				(UGX)	(minutes)	(mg/L)	(105°C)	(NTU)	(ct/100mL)	(µS/cm)	(L)
Borehole	11	150	50.3	85	0	2.1	< 1	< 1	122	58.38	2.01
Spring	4	0	40	151	0	2	< 1	< 1	215	64.38	4.38
Rainwater Harvested	9	0	2.59	76	0	3.4	3	>2420	108	87.92	3.47
Surface Water	9	0	48	60	1	2.4	178.5	>2420	85	89.93	4.37
Tap	167	258.62	16.93	66	0	0.6	< 1	< 1	94	69.84	3.61

Table 7: Pearson's correlations of water source features and household source choice

Statistical Significance of Household Survey Data		Cost	Average Collection Time	Turbidity	TDS	TSS	T.Coliforms	E.Coli	Conductivity	Quantity
Number of Households	Pearson Correlation	.941	-.637	-.661	-.297	-.100	-.143	-.101	.091	-.351
	Significance	.000	.000	.000	.000	.160	.043	.153	.198	.000

Figure 6 shows the percentages of responses from surveyed households who answered the question, “Why do you choose your primary source?” Convenience as a response has nearly three times the households, as compared to cost, expressing it as the paramount source feature impacting their primary water source choice.

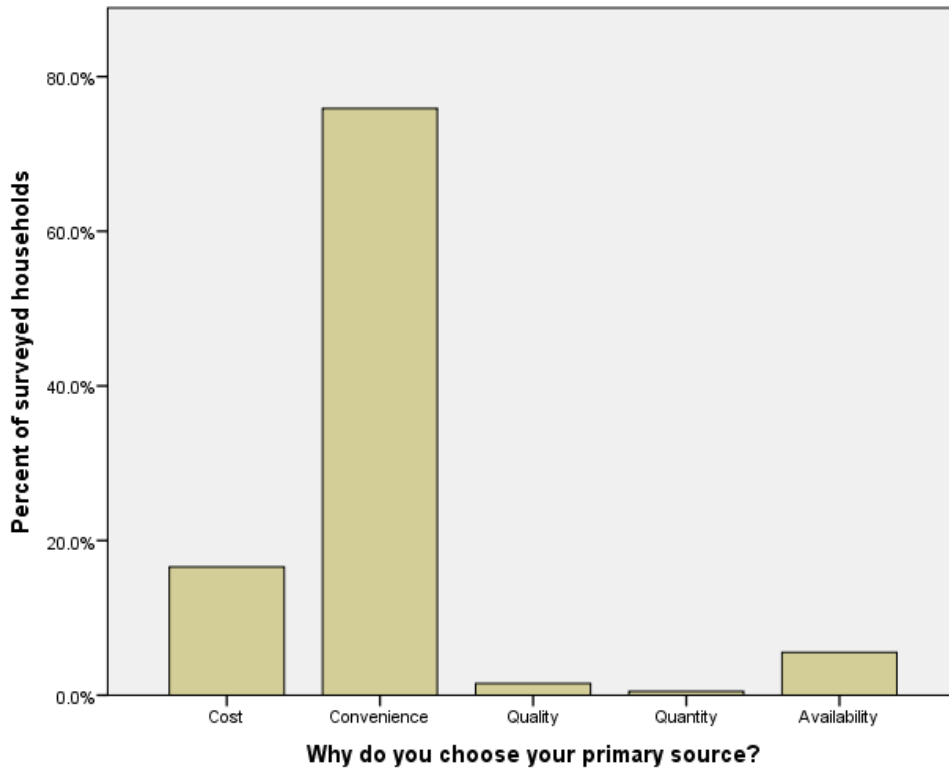


Figure 6: The survey responses in terms of water source features impacting their decision on primary water source choice

While the community members are recorded in surveys saying that they choose their primary source based on what was most convenient, followed by the most affordable; in reality, this is inconsistent with what was seen above through the Pearson's Correlation tests. Statistical analysis of those objective responses showed that they are actually choosing a source which requires less time and has the least visible water quality impairments, but requires the most money.

In an effort to more closely understand the results, each individual water source feature is discussed in the following sections.

3.3.1.1 Cost

As shown previously in Table 6, tap water has the highest average price, but is also the most populated source chosen by households in Nalugala and Kitale. Borehole water comes next when ranking preference by both cost and popularity. Analysis of variation (ANOVA) tests showed that there was statistical significance in the difference of the mean cost for each source. The cost of the water source, however, seems to be a secondary factor for households when considering whether or not to choose one source over the other.

As a matter of fact, survey responses lend credibility to the idea that households are making their source choices based upon various factors. Several community members mentioned that they coupled their water provisions, especially during the rainy season, with the collection of rainwater from their roofs. Many households mentioned that this was done in order to save money on purchasing water. Some rainwater collection and storage systems were sophisticated with metal or plastic piping, gutters, and a cement slab for the tank, while others implemented a more common method using a recycled metal barrel called a “pipa”. Furthermore, some households mentioned that they would quickly use plastic basins or old jerrycans, even an old bathtub was seen, as collection vessels for rainwater. One respondent said while rainwater can help to save money during the rainy season, it is an unreliable primary source unless the household can invest in a large tank.

As tap water is the most popular source, it is also important to note that it branches into two groups, households who own a tap (either in their yard or in their home) and those who purchase water from tap owners as shown in Figure 7. Approximately 26% of households who use tap water as their primary source own a tap, whereas 74% purchase it from tap owners.

Whether tap water is a household’s primary source or not, the associated costs of owning a tap and purchasing water are quite different. Tap owners purchase water from the Ugandan National Water and Sewage Corporation (NWSC) for 32.76 UGX (Ministry of Water and Environment, 2011) per jerrycan (20 L—standard volume of a household drinking water

container) whereas the average value from surveyed community members for purchasing the same volume of water from tap owners is 258 UGX. The price range for tap water reported in the survey is 200 UGX to 350 UGX. Tap water has the highest cost and is relatively convenient; both of these source features were statistically shown to affect choice. When surveyed, a few respondents mentioned the fact that cost deterred them from choosing tap water as their primary source. However, they said it was preferred over other traditional sources (i.e. protected spring, surface water) when they had enough money to afford it.

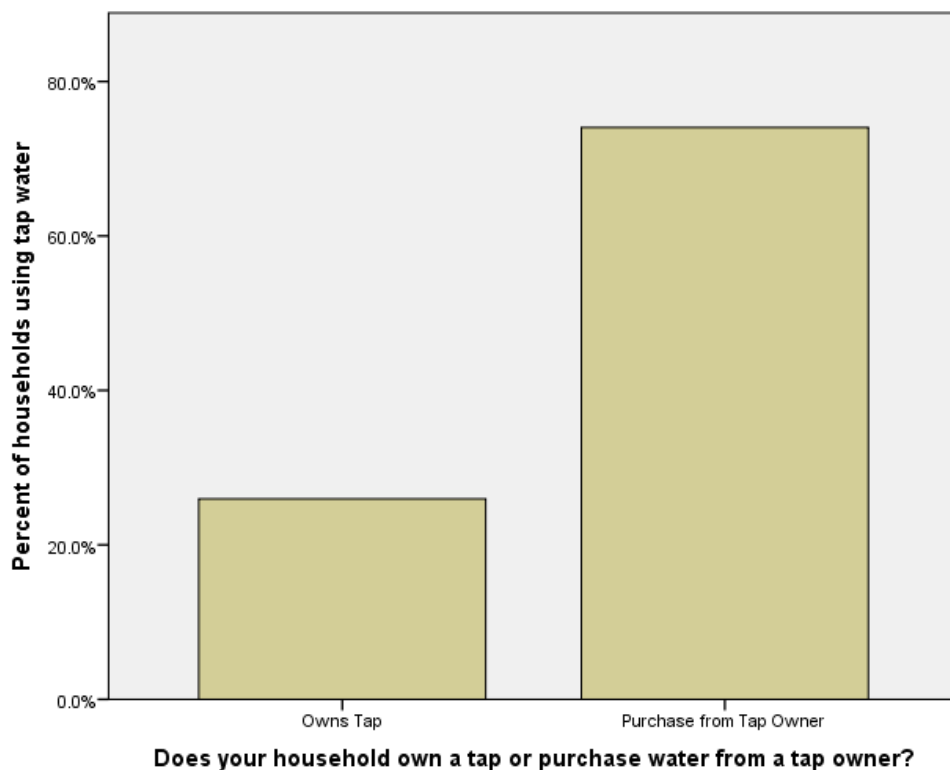


Figure 7: Ownership of tap water and collection time

Table 8 shows the monthly cost and the percentage of the take-home pay households spent on water from boreholes and purchasing water from tap owners. Based on the average usage volumes for utility and drinking water combined, households that chose boreholes for

their primary water source were spending, on average, 9% of their monthly take-home pay, whereas those choosing to purchase water from the tap were spending 19%.

Table 8: Monthly cost and percentage of take-home pay households spend on water from boreholes and purchasing water from tap owners

Primary Water Source	Average Cost per Jerrycan (UGX)	Daily Usage (L)		Monthly Cost (UGX)	Percentage of Average Monthly Take-Home Pay (%)
		Utility	Drinking		
Borehole	150	58.38	2.01	13,587.75	9.06
Tap	258.62	69.84	3.61	28,493.46	19.00

With respect to the cost of the other sources not specifically mentioned – spring, surface water, and harvested rainwater —many community members reported no charge for water collection from these sources. However, there were occasions during the interviews when someone mentioned either paying a small fee or charging for water from rainwater harvesting systems. Typically these cases stemmed from unexpected, high demand from neighbors, the need to purchase water during the dry season, or as a result of problems with their local taps. There were also other scenarios when respondents reported no charge for water (from various sources) due to the fact that they were elderly.

3.3.1.2 Convenience

As previously explained, convenience was the main feature mentioned by households (refer to Figure 6) as the most influential factor affecting their water source choice. This water source feature encompassed responses given during the community survey where people cited their source choice based upon the time, distance, and ease of use of the source. However, as previously mentioned, when convenience is quantified, it is measured in units of time. Figure 8 shows the mean time (in minutes) it takes for community members to make one round trip, wait in line, and collect water from their primary water sources (UBOS, 2012).

The sources ranked in terms of mean water collection time needed (maximum time required to minimum time required) are the borehole, surface water, protected spring, tap, and rainwater harvesting systems. While rainwater harvesting has the lowest collection time and a similar ease of use as a tap water source, the volume collected from the rainwater harvesting systems changes seasonally and is not seen as a reliable primary source.

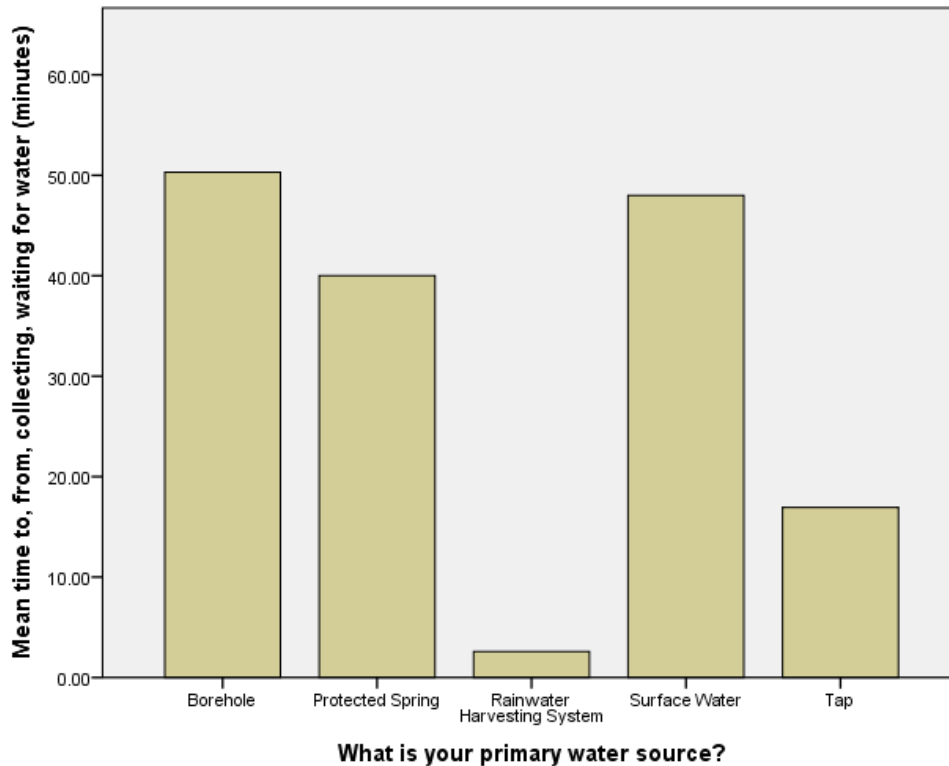


Figure 8: Mean water collection time needed for each source

Furthermore, after disaggregating tap water users, those individuals who buy from a tap take more than five times longer to get their water than those who own the tap themselves as shown in Figure 9. Consequently, the hypothesis associated with the first research question—the cost of water sources will have a major impact on the household’s decision to use it followed by convenience—was not supported by the results. This is found to be inconsistent with Mu et al.’s (1990) study in Kenya where researchers found statistically significant correlations between the prices of the water sources and community members’ choices. Furthermore, Putnam (2013)

presents the results of a case study in Peru and explains that quality and availability were significant water source features mentioned during the household surveys. As a result, there is no consistent conclusion within the literature concerning the cost of a source and its impact on household choice. The variable importance of source features is dependent upon the community context in which they are being studied.

The most popular water source chosen in both Nalugala and Kitale was purchasing water from tap owners. Figure 9 supports this action as being a more timely investment (less convenient) than owning a tap and while Figure 7 showed it as a more costly investment as well.

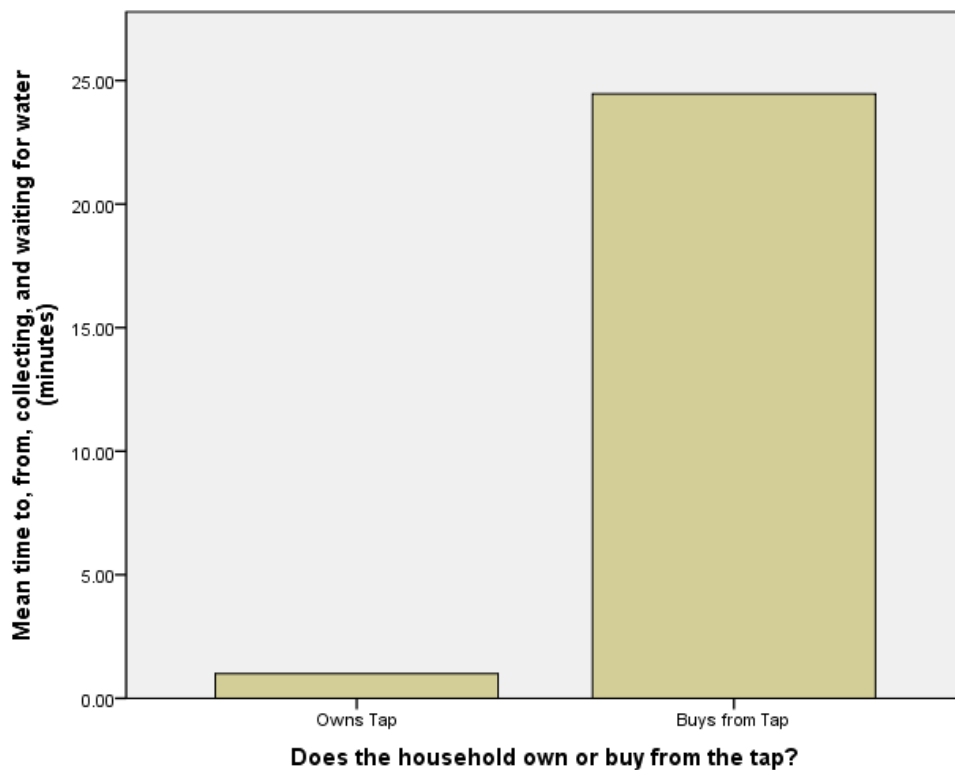


Figure 9: Mean water collection time needed for tap owners and buyers

However, when community members were asked about their personal reasons for making their choice based upon convenience, some of the respondents who were very elderly

and lived alone made decisions that were not unique as was revealed by the surveys. One female respondent in particular said that the water source closest to her was too difficult not only to pump up and down (the motion necessary to operate a borehole), but they were also too heavy to carry all of the jerrycans needed for daily chores. As a result, she had neighbors or local school children help her. This scenario was seen on more than one occasion where community members felt their water access was inconvenient due to old age and required assistance from neighbors.

Furthermore, some women (as mentioned in Section 3.2.2.3) had small children and could not go to a less expensive, more affordable sources (e.g. protected spring, surface water) because they posed drowning risks for young children or made bending to fetch water difficult with a swaddled baby on her person. Instead, the women who mentioned these scenarios normally chose the more convenient, but also more expensive source—tap water.

3.3.1.3 Water Quality

As shown in Table 6, the sources with total dissolved solids ranked from highest to lowest are—protected spring, borehole, a rainwater harvesting system, tap, and surface water. Turbidity was also measured and the source with the most turbid water to the least is— surface water, rainwater harvesting system, borehole, protected spring, and tap. Lastly, a total fecal coliform test was performed, showing three of the sources as equal, all with values less than one—tap, protected spring, and borehole—but the other two sources, surface water and rainwater, yielded values of greater than 200 and less than 5 coliforms per 100mL of water sampled respectively. Based upon these three parameters, the water quality of the borehole and tap are similar.

Community responses which cited water quality concerns vary significantly. One female community member explained that, regardless of the price (which she quoted at ~300 UGX per jerrycan), she purchases water from the tap stand because she prefers its quality

compared to the other sources available to her. She is particularly concerned about this because her husband has HIV which makes his immune system incredibly susceptible to waterborne illnesses. Although she knows that there is “medicine” in the tap water for disinfection, she boils the source as a precautionary measure, followed by re-chlorination with the locally available Waterguard.

In comparison, another female head of household was asked about the reason for her source choice as she had recently purchased a tap connection to her home. According to the 2011 Ministry of Water and Environment’s Sector Performance Report, the average per capita investment cost for a new piped water system is ~\$40 per person (Ministry of Water and Environment, 2011). During the installation, an official who was there with the NWSC explained that their agency treated the water with a “medicine” that killed any germs, so no extra treatment for tap water was necessary. As a result, she said that her family did not boil, filter, settle, or dose their water with chlorine, but would only treat water from another sources should the tap ever be unreliable. She said this helped to save her household money on fuel for boiling.

Furthermore, a young professional male was interviewed at his home and expressed very similar reasons for his decision of choosing tap water and not needing to boil it. He said that he expected the tap water which is provided to him from the government should be safe and already treated when it comes from the pipe.

On the other hand, another community member explained that he thought tap water was not as safe as people thought it was, especially since the government was responsible for adding the chemicals during the treatment process. He mentioned that tap water was less safe than that from the borehole. As a result, he thought it should be used more as a secondary source even though it was convenient to access. He said tap water should still be boiled to improve the taste and kill the remaining bacteria.

Apart from a general distrust in the government’s ability to adequately operate the water treatment system, the next gentleman cited previous knowledge of his time living in Kampala,

the capital city, as having an effect on his views of water quality. He discussed the frequency that he saw drinking water pipes passing through very unsanitary areas with open sewage or an excess of stagnant water. Consequently, he said it was difficult to put those sights out of his mind when deciding whether or not to trust the nearby tap water and consume it without any pretreatment from the home. He knew the smallest leak would cause contamination, and he did not think it was likely that such an extensive piping network was flawlessly constructed. In the end, this household purchased water from the tap but also treated it by boiling.

3.3.1.4 Water Demand and Availability

The amount of utility and drinking water each household uses in terms of their primary source choice is shown in Figure 10. Utility water is that which is required for all household uses besides drinking and cooking. The following list ranks the source with the most total volume being used to the least—surface water, springs, tap, rainwater harvesting systems, and borehole. While the largest volume of water is being collected from the surface water source, it does not discredit tap water as the primary source being chosen by the majority of local households. This means household that choose surface water sources are collecting more water, on average, as compared to households with other primary water sources. This is likely true because surface water is free, allowing households to collect as much as they want from this source without incurring a financial burden. For drinking water from greatest to least they rank as follows—spring, surface water, tap, rainwater harvesting system, and borehole.

Lastly, of those respondents who said that their chief reason for choosing their primary source was because it was the only available option, the majority chose tap water followed by an equal amount mentioning rainwater, surface water, and water from a borehole. However, no respondents said their primary source due to availability was a spring. Tap water is likely the primary choice here because it is both convenient and readily available to community members

(based on time), a relationship that is revealed as important to community members through the open-ended survey questions.

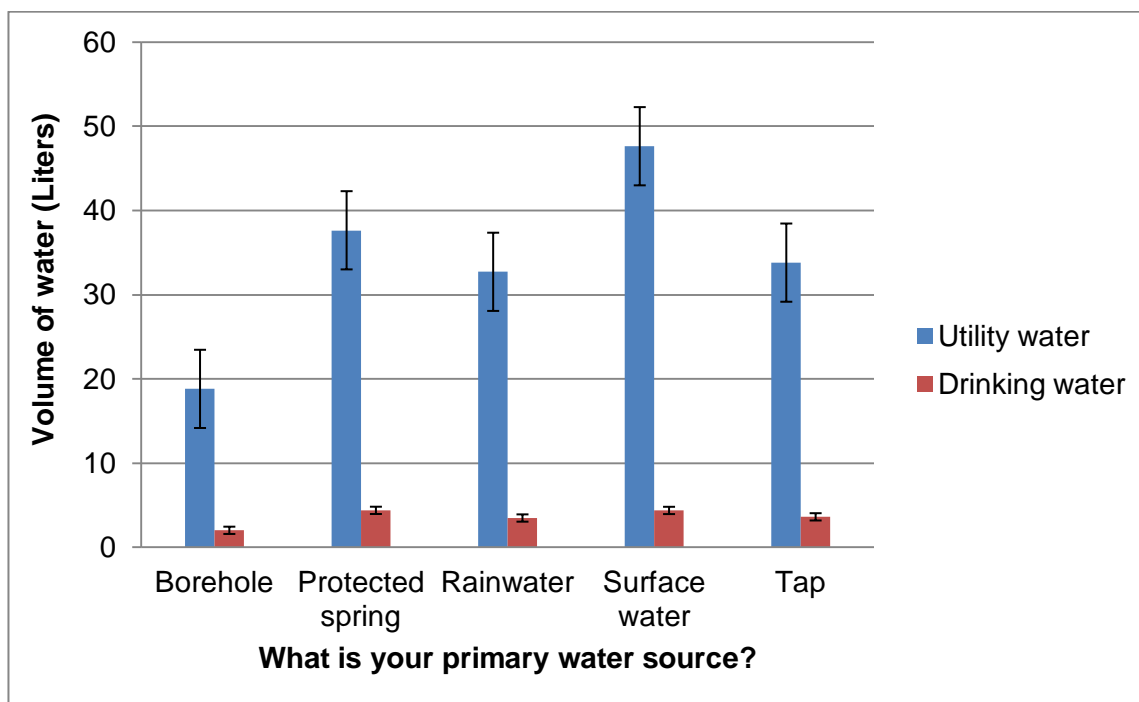


Figure 10: Volume of water treated for drinking or used for utility purposes for households choosing different water sources

3.3.2 Socioeconomic Factors

Table 9 is a crosstabulation of the aggregated PPI values and household source choices. The PPI is grouped into quintiles (5 equal groups) based on the cumulative scores associated with each of the indicator groups forming the PPI survey—social, economic, and educational. For each quintile (20, 40, 60, 80, and 100), the number of households within that PPI level who chose each source are shown in the row labeled “Count,” followed by its associated percentage. Using the Pearson’s Chi-Squared test to investigate the correlation of these values (PPI quintile and source choice), a significance of 0.405 was calculated signaling no significant correlation.

Table 9: Crosstabulation of the PPI quintiles and household source choice

PPI Quintile	Parameters	Primary Water Source					Total
		Borehole	Protected Spring	Rainwater Harvesting System	Surface Water	Tap	
20.00	Count	3	1	0	4	32	40
	% within quintile	7.5%	2.5%	0.0%	10.0%	80.0%	100.0%
40.00	Count	1	0	3	3	33	40
	% within quintile	2.5%	0.0%	7.5%	7.5%	82.5%	100.0%
60.00	Count	1	2	1	0	36	40
	% within quintile	2.5%	5.0%	2.5%	0.0%	90.0%	100.0%
80.00	Count	2	1	2	1	34	40
	% within quintile	5.0%	2.5%	5.0%	2.5%	85.0%	100.0%
100.00	Count	4	0	3	1	32	40
	% within quintile	10.0%	0.0%	7.5%	2.5%	80.0%	100.0%
Total	Count	11	4	9	9	167	200
	Cumulative Percentages	5.5%	2.0%	4.5%	4.5%	83.5%	100.0%

As a result, the groups of socioeconomic indicators (social, economic, and education) comprising the PPI were disaggregated in order to determine the potential correlation individual indicators had with a household's source choice. The socioeconomic indicators from the PPI, their Pearson's Chi-Squared statistics, and associated significance values are presented below in Table 10. Highlighted are one economic indicator and two social indicators that have significance scores < 0.050 —construction material of the external walls, gender of the head of household, and size of the head of household respectively. Each of these scores highlighted shows a significant correlation between the household responses to these questions from the community surveys and their water source choice. Each will be discussed in detail in Sections 3.3.2.1 and 3.3.2.3.

Table 10: Economic, educational, and social indicators with Pearson’s Chi-Square values and significance

Socioeconomic Indicator from PPI	Pearson’s Chi Squared	Significance
ECONOMIC		
Construction material of roof	*	0.000
Construction material of external walls	10.506	0.033
Type of toilet	*	0.000
Source of household light	7.406	0.116
Household owns electronic equipment	7.623	0.106
Household (all members) has 1 pair of shoes	1.433	0.838
Household (all members) have 2 pairs of clothes	0.807	0.938
EDUCATION		
Children’s level of education	5.913	0.657
Highest level of education of female head of household	15.275	0.227
SOCIAL		
Gender of head of household	12.480	0.014
Size of household	19.245	0.014
Age of head of household	18.020	0.323

*SPSS didn’t compute the value because the surveyed population’s answer was a constant.

3.3.2.1 Economics

Two economic indicators in particular stand out as their response rate among the surveyed community was completely homogeneous—construction material of the house’s roof and the type of toilet facility the household uses. In each case, the consistent choice for all households was the “highest” possible ordinal value scripted in PPI’s survey tool—the one indicating more advanced development—tin sheets for the roof and a personal or shared latrine for the toilet. The author makes two inferences concerning the homogeneity of these economic variables: (1) perhaps the households might have all benefitted from some comprehensive water and sanitation campaign, or (2) they are demonstrating an ingrained set of priorities for meeting basic needs of sanitation and shelter prior to addressing other structural needs of their

households. Regardless, these cases showed no variance (were constants), and were omitted from analysis.

Aside from those indicators, the only other economic factor which seemed to have significant correspondence with respondents' source choice was the construction material of the external walls of the household. Again, as a portion of the PPI, this value was a proxy indicator for economic status. The response to the question was answered in a binary fashion, either households had external walls signifying less economic means—unburnt bricks, mud bricks, timber, or stone—or the other, more costly construction materials—burnt bricks or cement blocks—demonstrating their higher economic status. The Pearson's Chi Squared term had a significance of <0.050 which means that the null hypothesis—construction material of the house's external walls is independent of the water source choice—is to be rejected. Instead, the alternative hypothesis would remain, leading to the conclusion that in the surveyed population, the construction material of the household's external walls, representing household economic status, has an impact on their primary water choice. Figure 11 shows the percentage of households with each type of construction material grouped by their primary water source choice. The majority of households has external walls made of burnt bricks and chooses tap water—nearly 80% of the total surveyed population. Furthermore, only 6% of the total population chose the construction materials associated with a lower economic status.

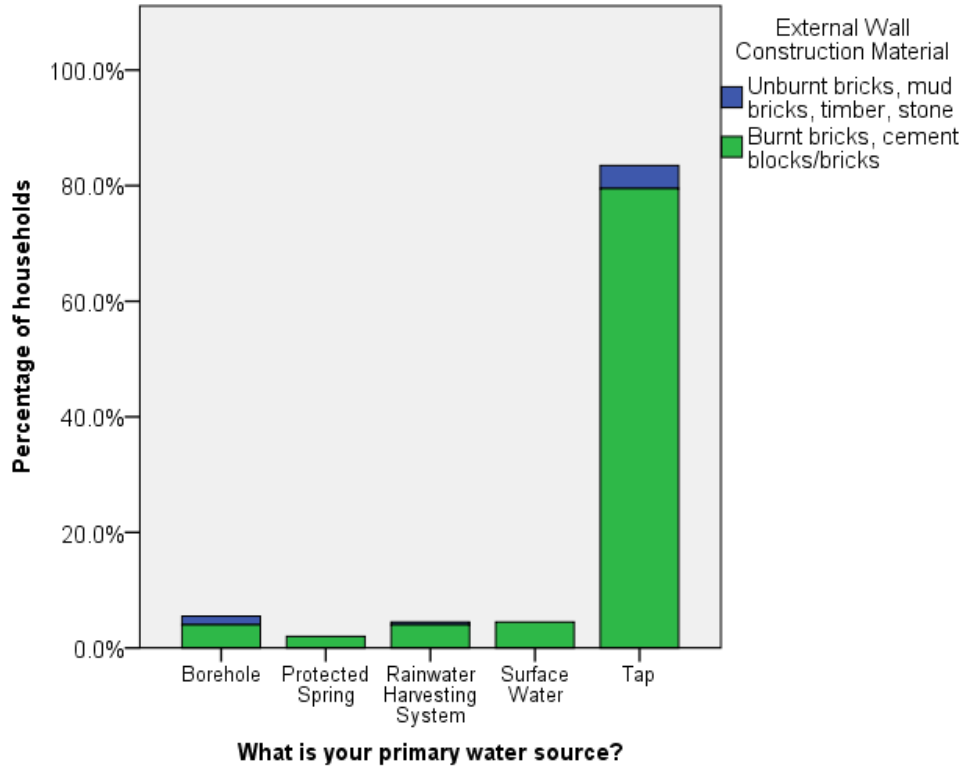


Figure 11: Percentage of households and their primary source choice separated by construction materials of the household's external walls

3.3.2.2 Education

Concerning the education level of the household and its impact on source choice, neither the education level of the children of the household nor that of the female head of household had any significant impact on choice. Figure 12 shows the normalized percentage of female heads of house and their associated source choices. Among each source, the bars represent the highest education level attained by each female head of house. Graphically, it would be difficult to draw any conclusions about the impacts of education on choice from Figure 12 as it does not look significantly different than the other groups; however, Pearson's Chi squared test reveals that it does not have a significant correlation.

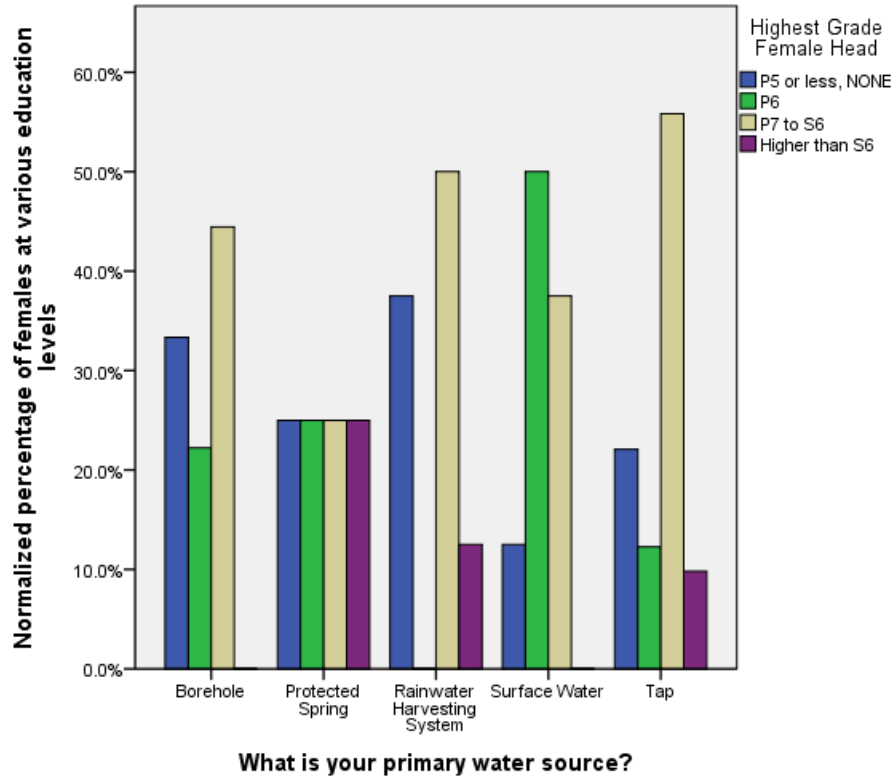


Figure 12: Highest grade of female head of household and primary water source

3.3.2.3 Social

To inspect the social features of the household against the primary water source choice, ages of the head of house and populations of the entire household were grouped into ordinal clusters to implement the Pearson's Chi-Squared test. The test explored whether or not the household's primary source was significantly related to the age and gender of the head of household or the number of household members. Consequently, the test showed that age was not a characteristic impacting their source choice. However, there is a significant relationship between the gender of the head of household and their water source, with a reported Chi Squared value of 12.480 and an associated significance of 0.014 ($<<0.050$ to qualify as significant). This means that the null hypothesis—gender of the head of household is independent of the household's water source choice— is to be rejected. Instead, the alternative hypothesis can be adopted, leading to the conclusion that in the surveyed population, the

gender of the head of household is, in fact, related to primary water choice of a household. Below in Figure 13, the households are broken down into normalized percentages within each source of men and women's primary choices. In both categories of the springs and surface water, 100% of respondents were male, whereas rainwater harvesting was the only system where women chose it more frequently than the men.

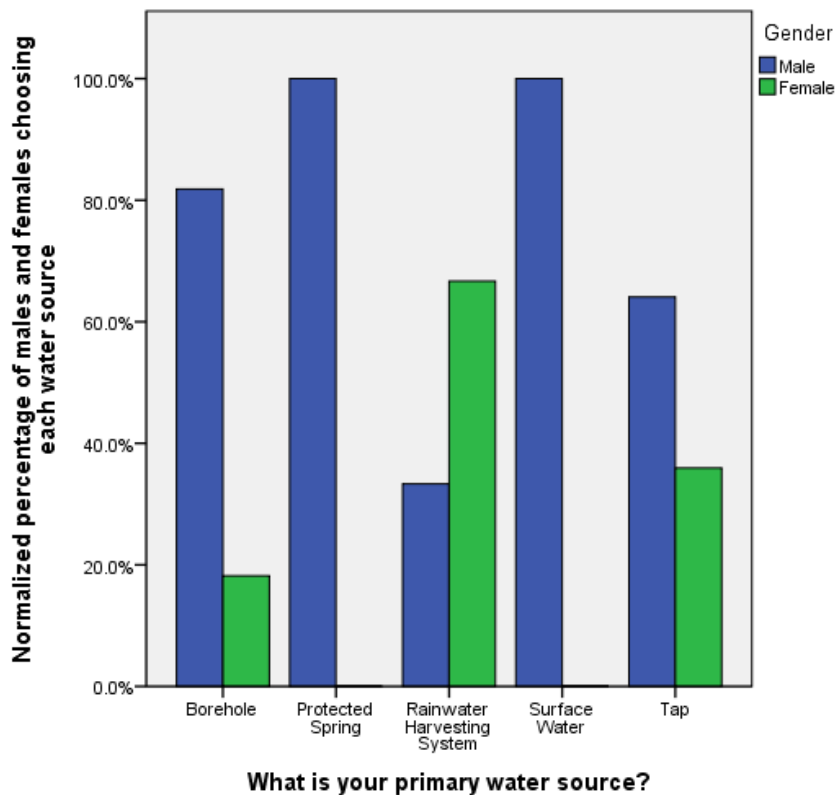


Figure 13: Community members' source choice based upon gender

The significance of the gender of the head of household seems to be consistent with household surveys and previous literature (Whittington & Briscoe, 1990). Survey respondents mentioned rainwater as an inherently cleaner source, as compared to local alternatives (e.g. borehole, surface water, springs), and Whittington & Briscoe (1990) explained that women, because they are the ones most frequently collecting water, better understand water quality than other household members (likely husbands) who are fetching water much less frequently.

Lastly, similar results (as compared to gender) are true concerning the size of the household (number of people per household) and its relationship to source choice. The household size has a strong correlation with the source choice. Table 5 shows the same significance value that was produced for gender and a Pearson's Chi-Squared value of 19.245. As a result, the null hypothesis—size of the household is independent of the household's water source choice—is to be rejected and the alternative hypothesis which indicates some significant relationship exists is adopted.

In Figure 14, the primary water sources associated with the largest household sizes (tap, surface water, and springs) are consistent with those same sources having the highest water demands (Figure 10). Tap water, for instance, is one of these sources, and, as mentioned in section 3.3.1.4, is chosen based on its convenience and availability. Thus, larger households can be considered to choose their sources along these same lines—convenient, readily available, and producing enough water to meet their household demand.

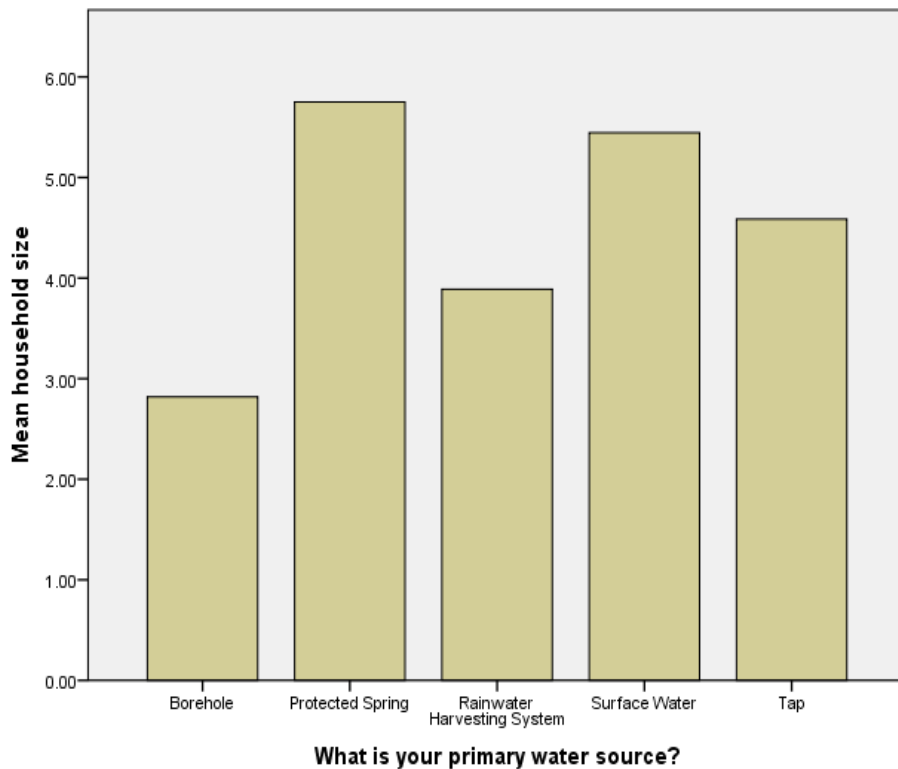


Figure 14: Average household size based on primary source

3.4 Conclusions

The Pearson's Correlation Tests showed community members chose the source that was the most expensive (19% of average monthly take-home pay), with low turbidity, and that required a fairly short average collection time. However, when comparing statistical data about source choice and qualitative responses from community members during the survey, some discrepancies arise. The survey showed convenience as the most popular source feature of local water supplies, followed by cost. Convenience is defined in a holistic fashion in the surveys as it encompasses distance, time, and the source's ease of use. In the statistical analysis, however, it is indicated by the average collection time for one roundtrip to the source.

Concerning socioeconomic factors, Pearson's Chi-Squared Tests demonstrated significance in the relationships between the following characteristics and source choice: the construction materials of a house's external walls, the size of a household, and the gender of the head of household.

Additionally, qualitative responses concerning community perceptions and practices around local water sources enhance the quantitative results by framing the findings in a relevant, local context which showed their emphasis on other source characteristics like quality.

Overall, it seems that households make their primary water source choices based on a combination of the factors of convenience, availability, and quality—all features attributed to tap water.

CHAPTER 4: ENVIRONMENTAL IMPACTS OF WATER SOURCES AND TREATMENT

4.1 Introduction

As mentioned in Section 1.1, water source expansion is happening at a rapid pace in an effort to address the MDGs for sustainable access to improved water for underserved communities. To ensure environmental sustainability, it is important to understand the environmental impacts associated with such developmental projects. There have been previous studies that evaluated environmental impacts of other types of projects in developing countries, such as biofuels in China (Xunmin & Xiliang, 2009), solar water heaters in Pakistan (Asif & Muneer, 2006), leather tanneries in Chile (Rivela & Moreira, 2004), and landfill options in various developing countries (Barton & Issaias, 2008). However, only a few studies (Held et al., 2012; Friedrich & Pillay, 2007; Landu & Brent, 2006) were found to evaluate the environmental impacts associated with community water supply and treatment in developing countries. Held et al. (2012) compared the embodied energies of point of use (POU) water treatment and source protection interventions in rural Mali. The study demonstrated the large contribution of human energy to the overall embodied energy— up to 97% for some sources— primarily due to the influence of water collection and transport.

In an urban context in South Africa, Landu & Brent (2006) analyzed the extraction, purification, storage, and distribution of water from the Vaal River. In this study, the impact indicators were normalized using geographic-specific factors. They found that the normalized water use indicator contributed most to the overall environmental impact and was more significant than other indicators like global warming potential (Landu & Brent, 2006). This is because of the significant water losses due to collection. As a result, the study suggests that

effort should be focused on water loss control. Also in South Africa, Friedrich & Pillay (2007) investigated the environmental impacts of the collection, treatment, distribution, and reuse of eThekweni Municipality's water. The study concludes electricity consumption contributes the most to the environmental consequences because of the amount of pumping required by the municipality's system. As a result, it was proposed that the electricity index be used as an indicator of environmental performance for other similar systems in South Africa (Friedrich & Pillay, 2007). While all of the studies used the life cycle assessment (LCA) method to evaluate the environmental impacts associated with water supply and treatment in African countries, there is no study incorporating the unique influence of human perceptions on source choice and treatment techniques into the assessment.

Consequently, this section will consider practical treatment techniques (due to community perception) in the calculation of life cycle environmental impacts associated with water provision for households in Uganda. LCA is used in the study as a method to determine the environmental burden of products, services, and processes across their life (Jørgensen & Le Bocq, 2008). Responses from the community surveys have been incorporated into the calculations of LCAs through the following ways:

- Impact based on water provision function—the environmental impact of each water source was determined based upon functional performance of the source to provide potable water at the level outlined in the Ugandan National Bureau of Standards specifications (UNBS, 2008). When the actual water quality from community sources failed to meet the national standards, household treatment methods were used and included in the process for LCA calculations.
- Impact based on community perception of water quality—the environmental impact of each water source was calculated based upon the practical treatment steps employed by community members due to their perceptions of water quality.

- Impact based on various types of fuel—the environmental impact of various local types of fuel used for boiling was investigated since it is the primary water treatment method described in the surveys.

4.1.1 Community Water Sources

Below are the community water sources whose impacts will be considered in this section:

- Borehole—this source requires community members to pump the lever up and down to lift groundwater to the surface. It has a typical lifespan between 20-50 years. The production capacity may vary due to depth and each source’s specific groundwater capacity, the performance ranges from 0.1-10 L/sec. The suggested population served by this technology is 300 people (Danert & Armstrong, 2010).



Figure 15: Borehole that consists of groundwater extraction by manual pumping (Photo: C. Prouty)

- Protected spring—as seen in Figure 16, this source is protected through the use of concrete and metal piping to construct a springbox and collection reservoir. This helps to prevent contamination by livestock, runoff from local farming, and individuals collecting the water. Mihelcic et al. (2009) explains that variability exists with local definitions of sources and their level of protection. For this study, the source will be called a protected spring, although its protection (not pictured) is through the use of locally available eucalyptus boards which attempt basic prevention of contamination at the collection point. These boards function in a less effective way as the protected spring pictured in Figure 16, but contribute to the water quality values mentioned in Table 6. The protected spring source in this study serves approximately 50 households.



Figure 16: Protected spring water is collected through a springbox and reservoir constructed using metal pipes, cement, and bricks (Photo: C. Prouty)

- Rainwater harvesting—this method of water collection is unpredictable as Uganda’s rainy season spans the months of March to May and September to November. During this time there is variable rainfall, averaging between 185-190 mm per month (UBOS, 2010). Collection tanks are manufactured as metal or plastic holding as much as 5000 L like the ones in Figure 17. Frequently houses use recycled 55 metal gallon oil drums as catchment vessels (Blanchard, 2012).



Figure 17: Household rainwater harvesting systems constructed of corrugated metal (left) and plastic (right) (Photo: C. Prouty)

- Surface water—the primary surface water source for Nalugala and Kitala is Lake Victoria. It has no protection from contamination and is frequently used for watering animals, washing clothes, and sometimes as a point of open defecation. Community members use jerrycans to collect stagnant water from near the banks rather than wading out further from the shore.



Figure 18: Lake Victoria as the primary surface water source in Kitale and Nalugala (Photo: C. Prouty)

- Tap water—Figure 19 is a depiction of the outdoor tap water system that homes in Kitale and Nalugala use for water collection, rather than an indoor systems. These sources typically served as many as 20 households when tap owners sold water to neighbors.



Figure 19: Tap water source piped into a household's yard (Photo: C. Prouty)

4.2 Methodology

4.2.1 Goal and Scope

The goal of the life cycle assessment portion of the research is to determine the environmental impacts associated with the water source choices and treatment methods based on function and practice implemented by community members due to the perception. System boundary for each supply system includes the water source and its infrastructure, collection, and treatment implemented. Table 11 listed water source and its supply infrastructure.

Table 11: Water sources and their supply infrastructure

Borehole	Protected Spring	Rainwater	Surface Water	Tap
groundwater, piping network, pump head	groundwater, local coverings for headspring	average rainfall, gutters, collection tank	surface water	water treatment plant infrastructure, piping network to village

The functional unit of this life cycle assessment is 3.57 L of potable water treated by a household to a quality defined by the Ugandan National Bureau of Standards (UNBS) for drinking purposes. This volume was determined by averaging the amounts of drinking water that households in Kitala and Nalugala consume on a daily basis as determined through survey results. Lastly, the size of the household is assumed to be consistent with the national average of ~5 people (UBOS, 2010).

4.2.2 Inventory Analysis

The inputs for each water supply system are compiled in Table 12 with the sources from which information was gathered.

Table 12: Summary table of LCA inventory based on functional unit (3.57 L of potable water)

Phase	Input	Components	Amount	Units	Source
Source	Borehole	Groundwater	3.57E+00	L	(UNICEF, 2002), (Sloots et al., 2010), (Danert & Armstrong, 2010), (IRC, 1991), SimaPro database
		Pump	1.46E-06	USD	
		PVC pipe	2.24E-09	kg	
		Transport	1.12E-10	tkm	
		Valves	1.13E-06	USD	
	Protected spring	Groundwater	3.57E+00	L	Sima Pro database, Community Survey
		Eucalyptus planks	1.97E-11	m ³	
	Rainwater harvesting	Rainwater	3.57E+00	L	Sima Pro database, Community Survey, National map, (Ministry of Water and Environment, 2011)
		Metal sheets	5.97E-04	kg	
		Transport	1.68E-05	tkm	
Surface water	Surface water	3.57E+00	L	Sima Pro database	
Tap	Tap water	3.57E+00	L	Sima Pro database	
Collection	Jerrycan	Plastic for container	4.93E-01	km	Sima Pro database
		Transport	1.39E-02	tkm	
Treatment	Disinfection	Plastic for NaClO bottle	2.46E-02	kg	Sima Pro database, (CDC, 2012)
		Sodium hypochlorite (NaClO)	1.67E-01	kg	
		Transport	5.39E-03	tkm	
	Filter	Plastic	6.24E-02	km	Sima Pro database
		Transport	1.76E-03	tkm	
	Tea kettle for boiling	Aluminum	2.64E-13	km	Sima Pro database
	Fuel for boiling	Charcoal	3.45E-02	km	Community surveys, (Rugumayo, 2005), (Robinson, 2011), (Yean & Ritter, 1974), (Akena, 2012)
		Transport	1.39E-02	tkm	
		Electricity	2.78E-01	kWh	
		Propane	1.99E-02	kg	
	Firewood	5.92E-02	kg		

4.2.3 Impact Analysis

The impact assessment method used to calculate environmental impacts for this study was Eco-Indicator 99 (H) Version 2.07 (Amersfoort, Netherlands). This is a single score value for a product or process that demonstrates the cumulative impact to the environment. The value is calculated by weighting and adding the individual environmental effects from each of its inventory components (The Netherlands Ministry of Housing, 2000). The units are Eco-Indicator Points which are dimensionless and enable relative comparisons between factors. It is broken down into impact categories such as land use, climate change, or carcinogenic contributions.

4.3 Results and Discussion

4.3.1 Analysis Based upon Function

In this study, the locally available tap water had the best quality of the five tested sources and successfully achieved the UNBS potable water standards. The environmental impact of water provisions from each source was analyzed over its life through the consideration of collection and treatment of an average household's daily volume consumed. The locally practiced treatment techniques include filtering with a plastic sieve, settling out particulates using a jerrycan, boiling with various fuels, and dosing with chlorine. Assorted combinations of these four methods were chosen to address the unique water quality parameters for each source in the survey. The water quality characteristics considered are turbidity, total fecal coliforms, and total dissolved solids (see Appendix C). Achieving potable water standards for different water sources requires household treatment by filtration, dosing with chlorine (NaClO—sodium hypochlorite, bleach), and boiling respectively. More detail of these methods can be found elsewhere (e.g., Mihelcic et al., 2009). For extremely high levels of turbidity, settling is also incorporated into the treatment process. The treatment combinations needed to address each source's functional water qualities (as it differs from the potable standards) are below:

- Surface water—settle, filter, boil, dose with chlorine—this water had high turbidity, so it was first settled in the collection container and then filtered, followed by boiling to address high fecal counts, and dosed with 10 mL of the NaClO solution per 20 L jerrycan (CDC, 2012).
- Borehole—filter—while this groundwater source is fairly low in fecal counts and dissolved solids, there are some suspended solids which should be filtered out.
- Rainwater—filter, boil, dose with chlorine —water quality comparisons show rainwater and surface water are similar. However, rainwater has less suspended solids and does not require settling.
- Protected spring—filter—the turbidity for this source is not unreasonably high; however, it is possible that there are debris from around the source which can be sufficiently addressed with filtering.
- Tap—no treatment necessary as it achieves UNBS potable water standards.

In Figure 20 the individual impact categories associated with each source and treatment method are shown. Figure 21 shows the individual phase contributions for each water system and treatment associated with its function. It is clear that the rainwater harvesting system has the highest environmental impact followed by surface water. The major impact is associated with the use phase for each of these sources whereas the collection and infrastructure contribute much less to the overall impact. The primary process contributing to the high environmental impact is boiling due to the use of charcoal. The detailed discussion for each water provision system is below.

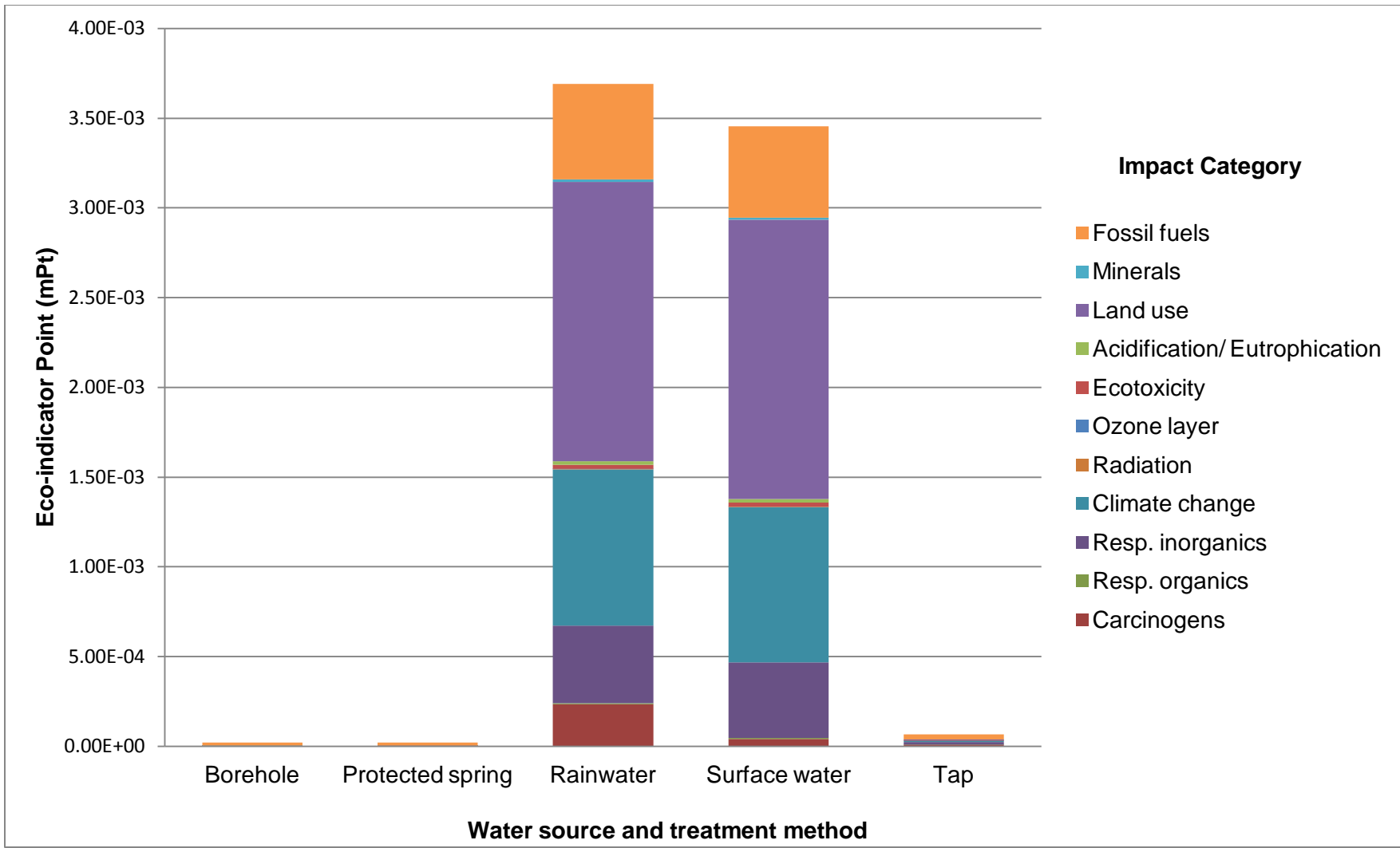


Figure 20: Contribution of individual impact categories to the overall environmental impacts of water sources and treatment processes based on functional water quality measurements

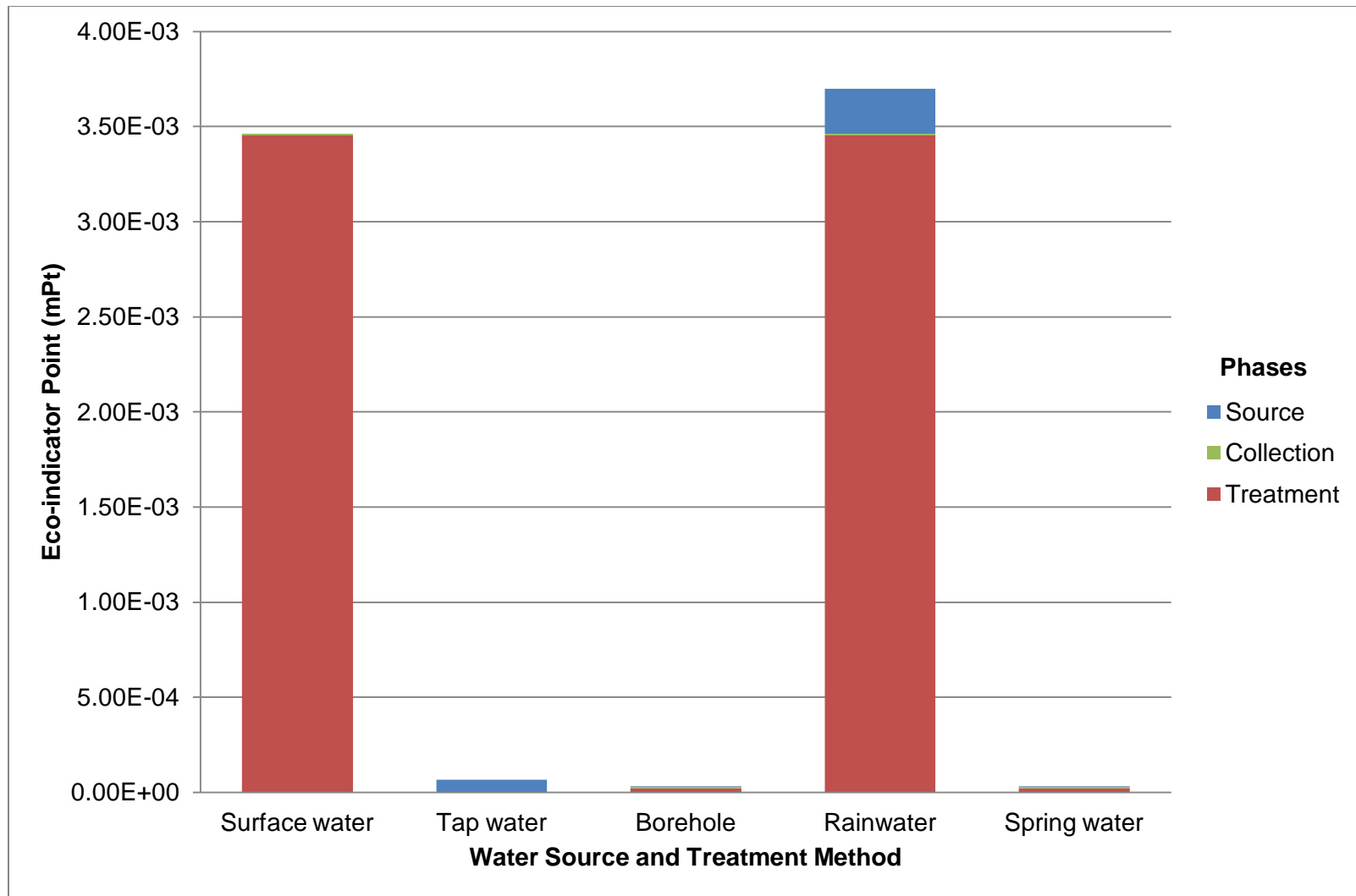


Figure 21: Individual phase contributions to the overall environmental impacts of water sources and treatment methods based on functional water quality measurements

4.3.1.1 Rainwater Harvesting System

Rainwater collection, storage, and treatment has the highest environmental impact as shown in Figures 20 and 21. Figure 22 shows the contributions from the individual impact categories. The largest contributing factor, boiling using charcoal, is primarily comprised of the following impact categories ranked from greatest to least—land use, climate change, fossil fuels, and respiratory inorganics. The next contributing factor is the rainwater harvesting infrastructure with primary impact category as “carcinogens”. This is due to the manufacturing of the metal collection/storage tank. Lastly, NaClO is used to disinfect the water after collection and primary treatment; its biggest impact component is from fossil fuels used in producing and transporting chlorine and the plastic bottle in which it is contained. The contributions made by the filter, tea kettle, and jerrycan are minor in comparison with the other factors, and thus will not be discussed in detail for this water source.

Previous research completed by Dean and Hunter (2012) inspected the risk of gastrointestinal illness associated with untreated rainwater used for human consumption and found that significant levels of pathogenic organisms are typically present in rainwater which could pose threats to consumer health. However, the potential health threat posed by poor water quality can be alleviated by the household level treatment (Dean & Hunter, 2012) depending on interventions that are country-, technology-, and community-specific. For this study, treating rainwater is necessary to improving the water quality to a potable standard.

4.3.1.2 Surface Water

For surface water; the environmental impact arises primarily from the treatment process. Surface water is treated by basically the same method as that of rainwater and uses the same amount of charcoal. Charcoal is also the greatest contributor to the overall impact for both systems. As a result, the real difference between the two sources comes from the variance in materials used for the collection/storage systems. For surface water, only a jerrycan is required,

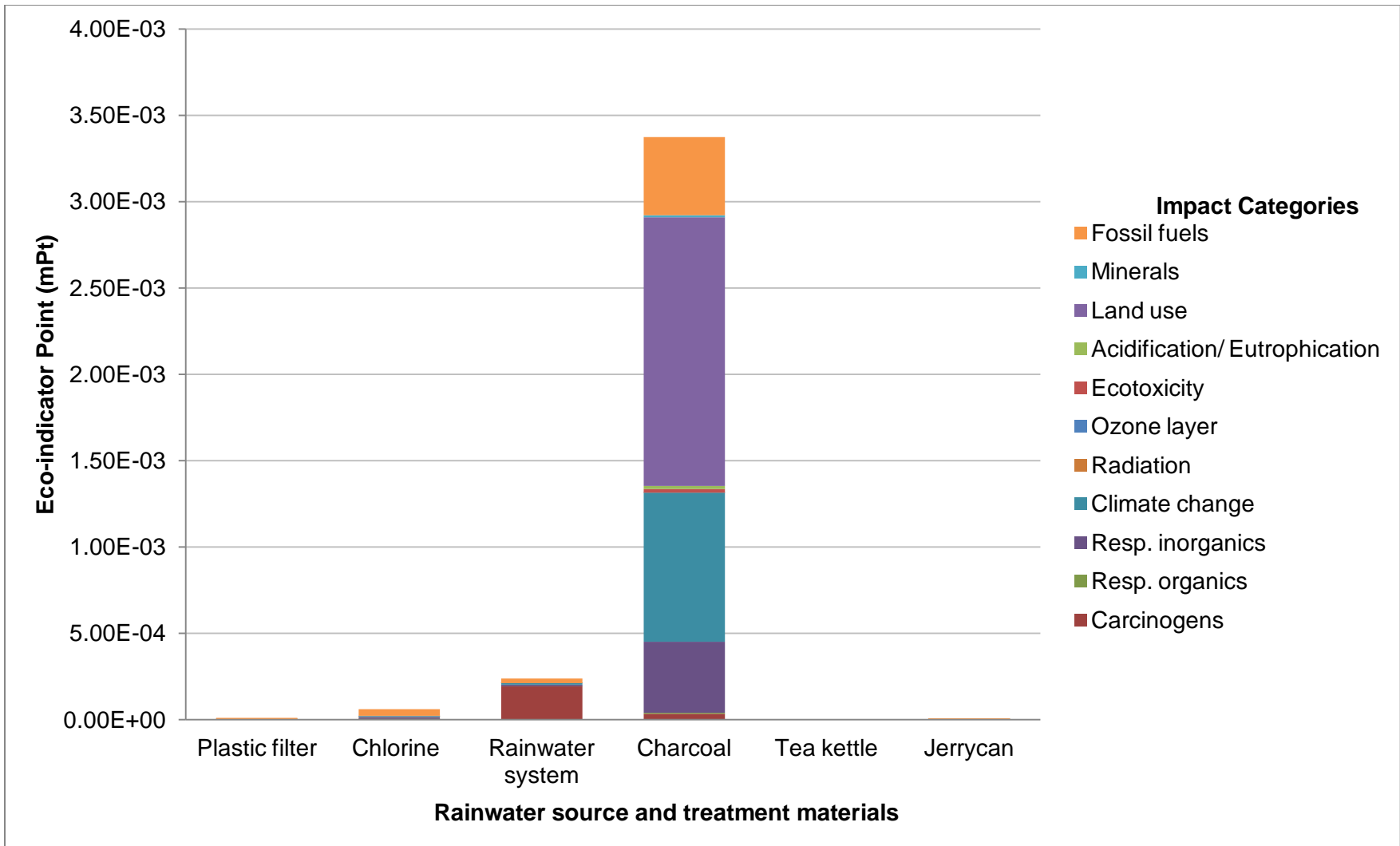


Figure 22: Rainwater harvesting impact categories for collection and treatment based on function

but for rainwater, metal gutters and a 5,000L metal tank are a part of the system. Although this source requires the most steps to be elevated to potable standards—settling, filtering, boiling, and dosing with chlorine—it does not yield the highest environmental impact. Figure 23 shows the impact categories associated with collection and treatment of surface water based upon its functional water quality.

In Figure 23, land use and climate change are the greatest impact categories associated with charcoal use. An impact to land use is unavoidable when cutting trees, not to mention a decrease in CO₂ uptake due to the deforestation that intensifies climate change. Furthermore, during the process of making charcoal, the harvested wood must be burned which creates byproducts of smoke/CO₂ emissions that also contribute to climate change.

4.3.1.3 Borehole and Protected Spring

Groundwater sources produce high quality water because of the natural filtration that occurs when the water percolates through the soil. The same water quality features are consistent in this study with both the borehole and protected spring. Both sources require the same treatment process, filtering, to improve the water to potable standards. As a result, their impacts are similar with the primary contributors as a jerrycan and the plastic filter associated with the water collection and use phases respectively (Figure 24). However the borehole yields a slightly higher environmental impact over its lifetime. This is because a borehole is made of metal pipes and PVC whereas the natural groundwater spring is unsophisticatedly protected by a basic layer of locally available eucalyptus planks.

Figure 25 and 26 show the contribution from individual impact categories to the overall environmental impacts associated different components used in collection and treatment of water from boreholes and protected springs. The greatest impact category is fossil fuels which are associated with the plastic manufacturing process for both the plastic filter and the jerrycan.

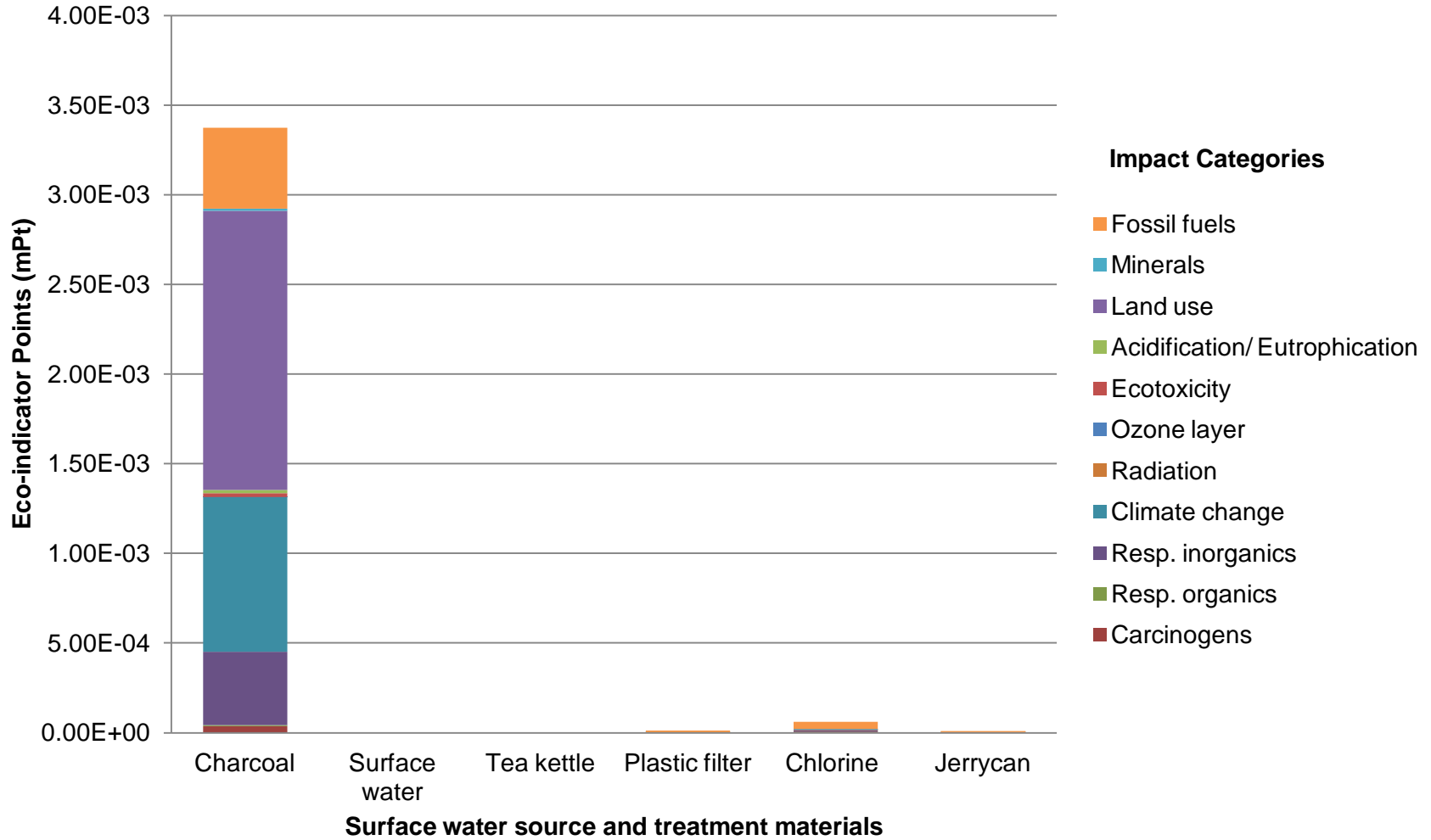


Figure 23: Surface water impact categories for collection and treatment based on function

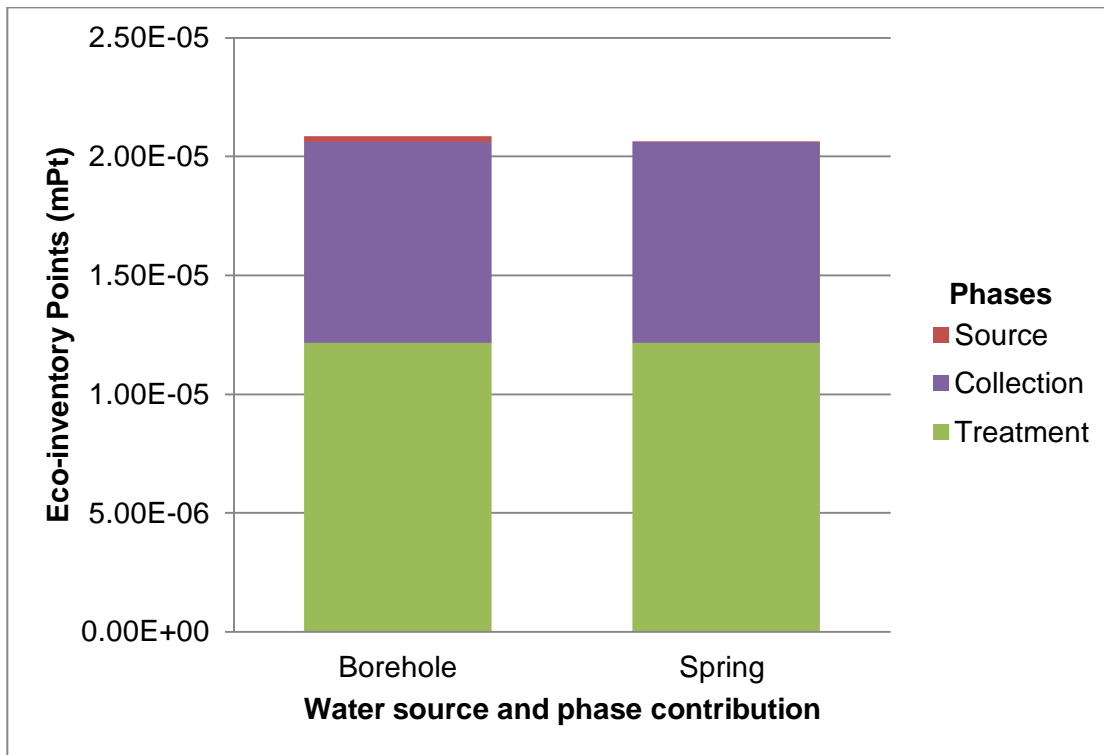


Figure 24: Environmental impact of various phases in borehole and protected spring water treatment

4.3.1.4 Tap Water

Lastly, the tap water source is considered. In Figure 27, the primary impact categories from largest to smallest are fossil fuels, respiratory inorganics, and carcinogens. The tap water system is comprised of mechanized treatment processes, pumping, and a piped distribution network, but it has lower impacts compared with water provision systems from rainwater and surface water. As discussed early, the primary contribution to rainwater water and surface water systems are household level treatment. This reveals that centralized water treatment may have lower environmental impacts compared with decentralized household level treatment.

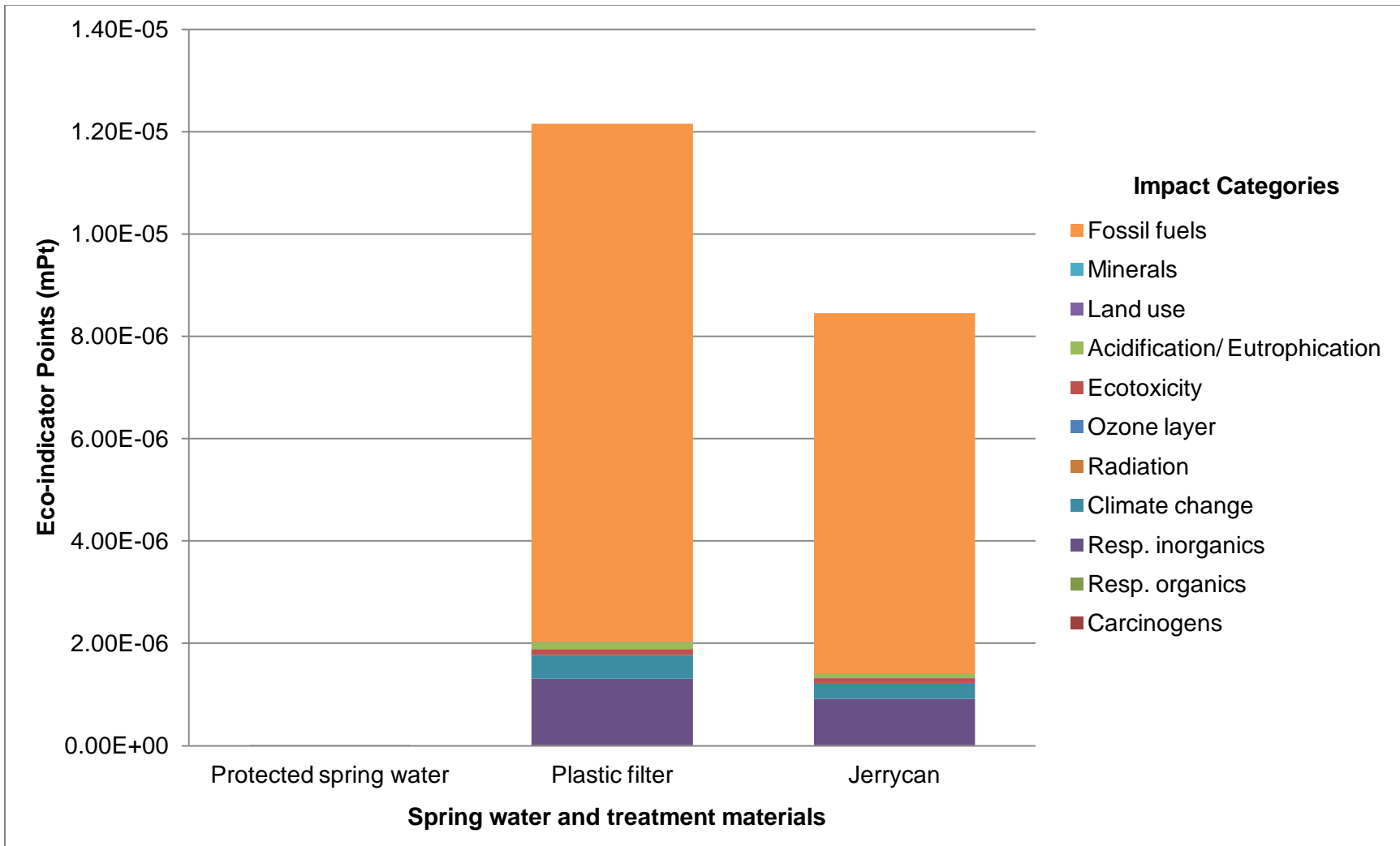


Figure 25: Spring water impact categories for collection and treatment based on function

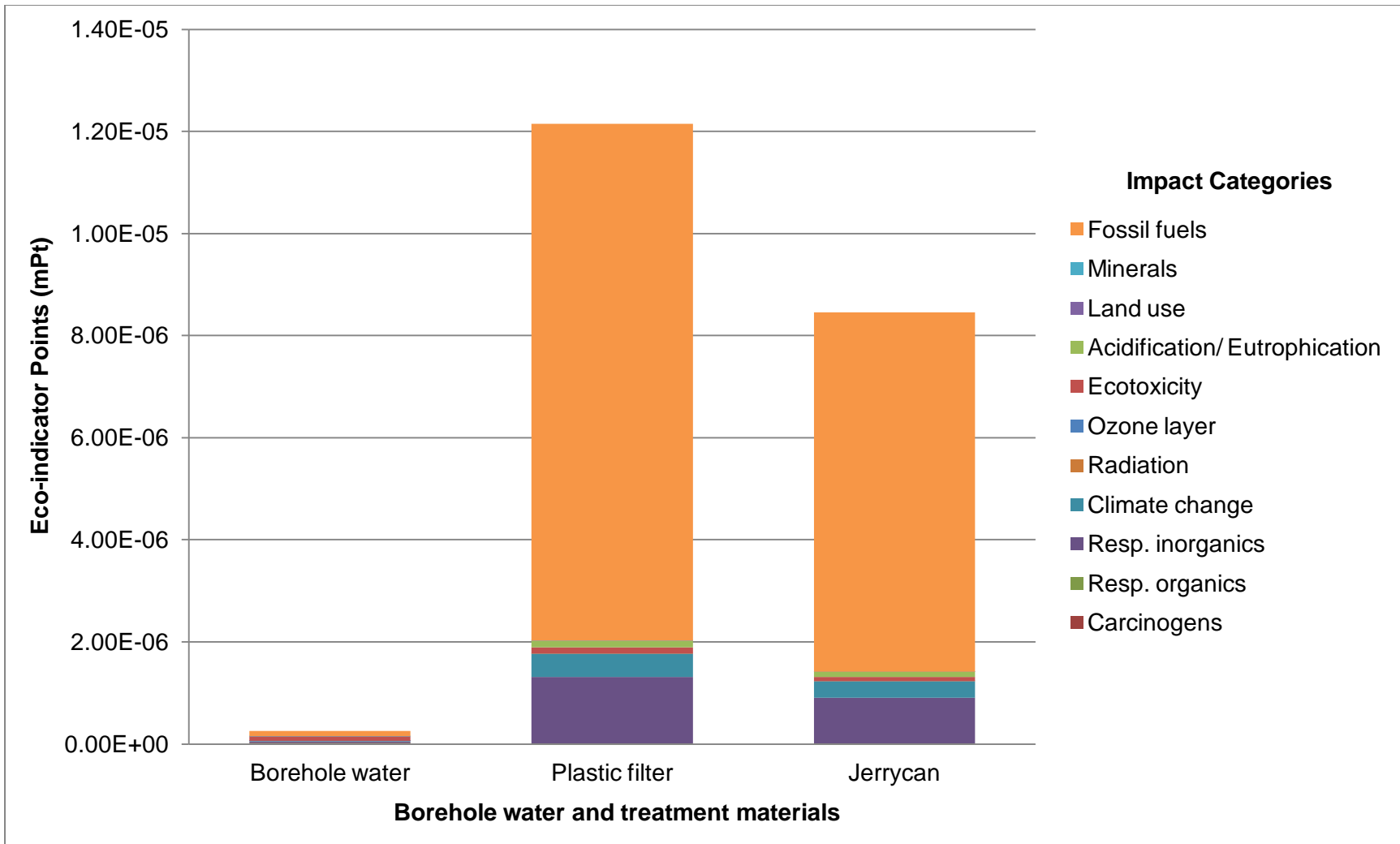


Figure 26: Borehole water impact categories for collection and treatment based on function

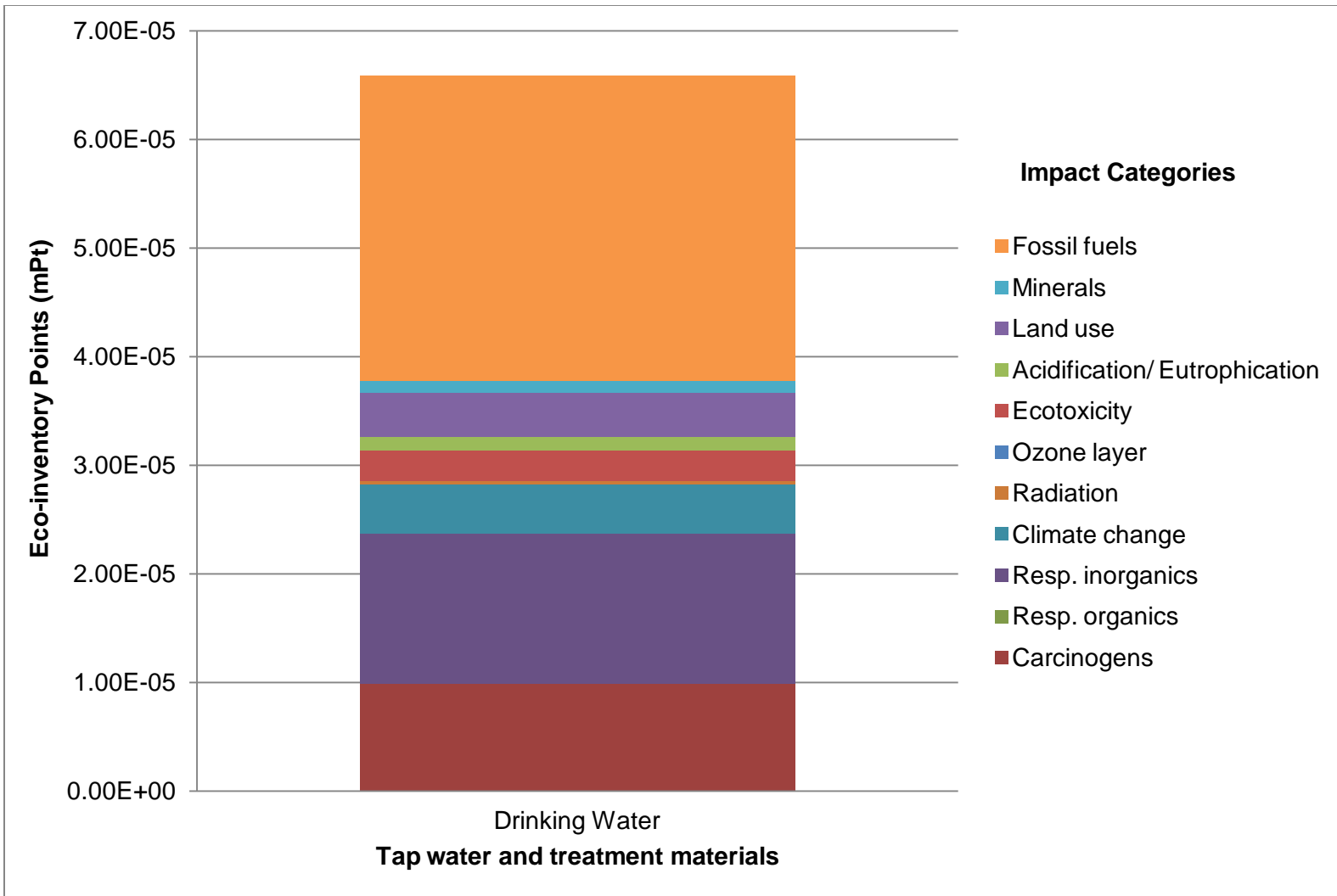


Figure 27: Tap water impact categories for collection and treatment based on function

4.3.2 Analysis Based Upon Perception

While it is important to understand the environmental impacts based on the theoretical treatment households should perform, it is more important to examine the actual impacts of community water treatment based on the current methods households are practicing. The cross-tabulation in Table 13 shows that out of the 200 households surveyed, 194 of them (96%) mentioned boiling as their primary treatment method.

Table 13: Cross-tabulation of household boiling for water treatment and primary source

		How is water treated?		Total
		Boil	Doesn't Boil	
Primary Water Source	Borehole	10	1	11
	Protected Spring	4	0	4
	Rainwater Harvesting System	9	0	9
	Surface Water	9	0	9
	Tap	162	5	167
Total		194	6	200

Furthermore, Figure 28 shows charcoal as the most popular fuel type for boiling water for the households in the two surveyed communities.

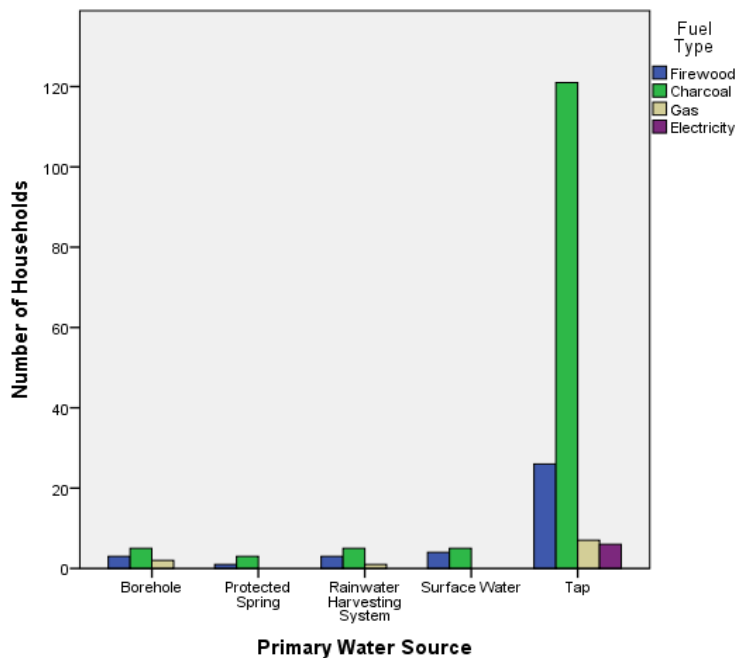


Figure 28: Fuel types used for boiling water from each source

When households were asked what other treatment methods were used, their responses, both qualitative and quantitative, provided the information used to characterize the actual household treatment methods practiced for each source. Furthermore, this quantitative information along with household observations were used for LCA purposes (e.g. how much fuel is purchased, what types of filters are used). Synopses of the qualitative responses concerning the water treatment methods for each source are below. Where a step in the treatment method is not described, quantitative data was used to justify its inclusion.

- Surface Water—boil—the vast majority of the time, community members expressed a preference of almost any source over surface water. It is widely known to be contaminated by community members doing laundry, from the feces of nearby houses, or from grazing animals. However, in boiling the water, it is thought to address these issues sufficiently enough for it to be safely consumed.
- Tap Water—filter + boil + NaClO—during the community surveys, a large portion of households said that they used tap water, but felt that it needed to be treated. This was addressed by a combination of methods. Community members expressed their distrust of the government-run treatment process, piping network, and chemicals used in tap water treatment and distribution. They also mentioned that the water had a bad odor and taste due to the “medicine” (NaClO), both of which were reasons to boil. When asked what affect boiling had on the taste of their water, some said that, it gave the water a flat taste, but that it was preferred to the alternative, strong chemical flavor. However, the steps community members are taking to boil the water to remove the taste/smell of chlorine followed by their actions of re-dosing for disinfection shows a disconnect in their understanding of chlorine’s properties and function.
- Borehole—boil—as previously mentioned in Section 4.3.1.3, groundwater is seen as a naturally filtered source requiring little treatment. However, there is healthy skepticism from households about contamination and poor water quality of this source as they

mentioned seeing groups of children playing on the lever and around the collection area after school.

- Rainwater—no treatment—many community members responded to survey questions about treating rainwater only if they had extra time, if there were small children, or sick members of the household. Otherwise, it was most common for people to say that they would readily drink fresh rainwater without any extra treatment.
- Protected Spring—filter + boil—while some protected springs are fully covered in cement and bricks (see Figure 16), the source in these communities was not. As mentioned in Section 4.3.1.3, the protected spring had modest coverings. As a result, more treatment was used to account for potential contamination that was not prevented by the eucalyptus covering.

Figure 29 shows the environmental impacts of water provision from different sources based on the various treatment methods typically practiced by community members. As shown in Figure 29, water provisions from tap water have the highest environmental impacts followed by surface water, boreholes and protected spring water. The major contribution to the impacts of land use and climate change is from charcoal being used for boiling. These impact categories account for 68-71% of the total impact for each of the other water sources (besides rainwater systems). Water supply through rainwater harvesting has the lowest environmental impacts, about 7 times less compared with tap water. This is due to the fact that there is typically no household treatment practiced for rainwater. However, Dean & Hunter's study (2012, see Section 4.3.1.1) explains that there can be significant amounts of pathogens contaminating this source which would require treatment to become potable. As a result, for this study, boiling rainwater is a healthy option available to households in Nalugala and Kitale to prevent waterborne illnesses.

The comparison of the actual water treatment being carried out in communities versus the ideal/theoretical treatment is one way to reveal the discrepancies between perceived water

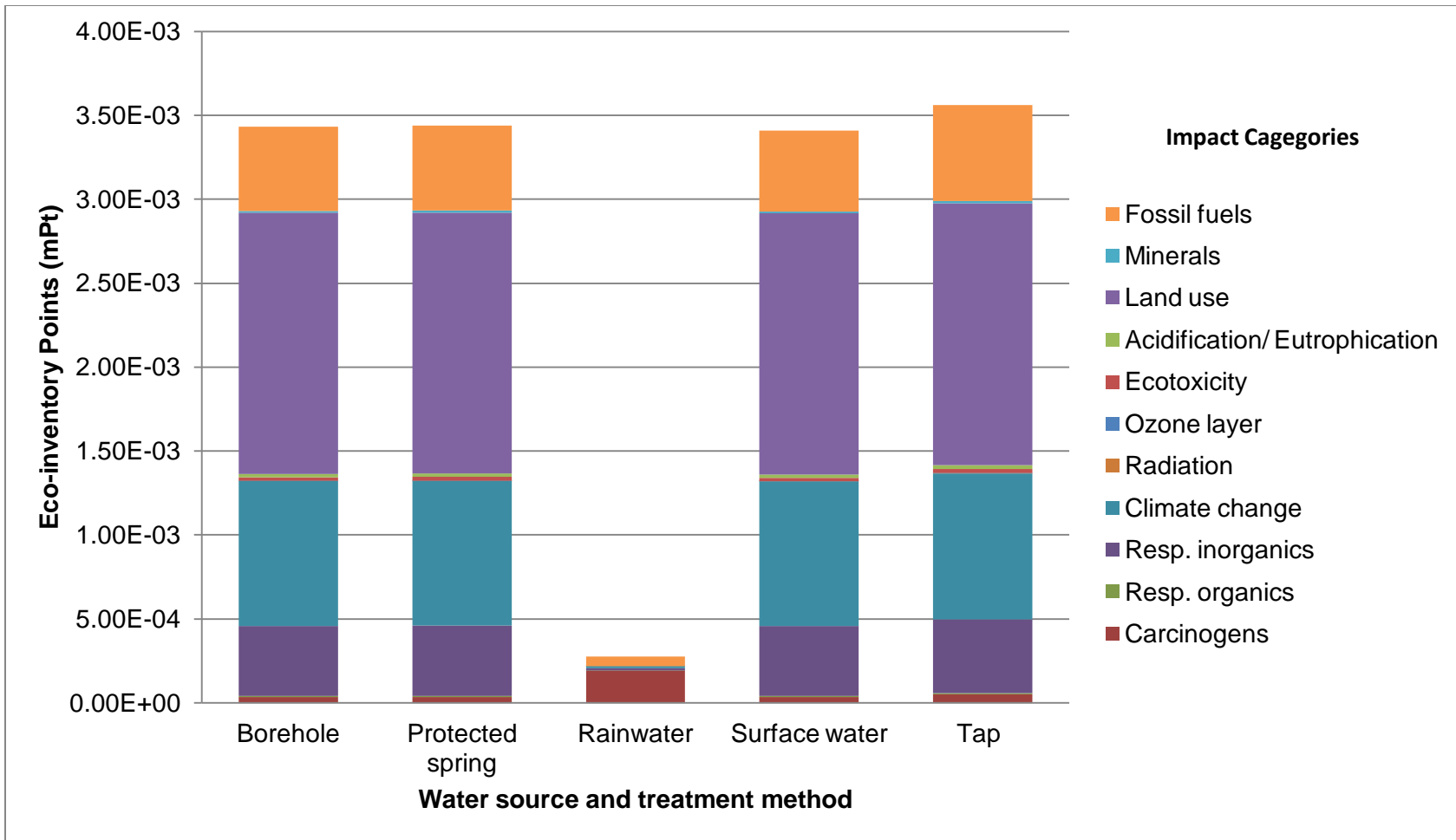


Figure 29: Environmental impacts associated with water treatment methods based on perceived water quality

quality and actual water quality. The survey responses reveal that the more steps taken by a household to treat the water, the lower the community's perception is of that source's quality.

4.3.3 Varying Fuel Types

Since the major environmental impacts associated with water provision through tap water is from boiling with charcoal (discussed in Section 4.3.2), this section analyzes the potential reduction of environmental impacts using different fuels based on the functional unit (3.57 L of water for drinking) as seen in Figure 30.

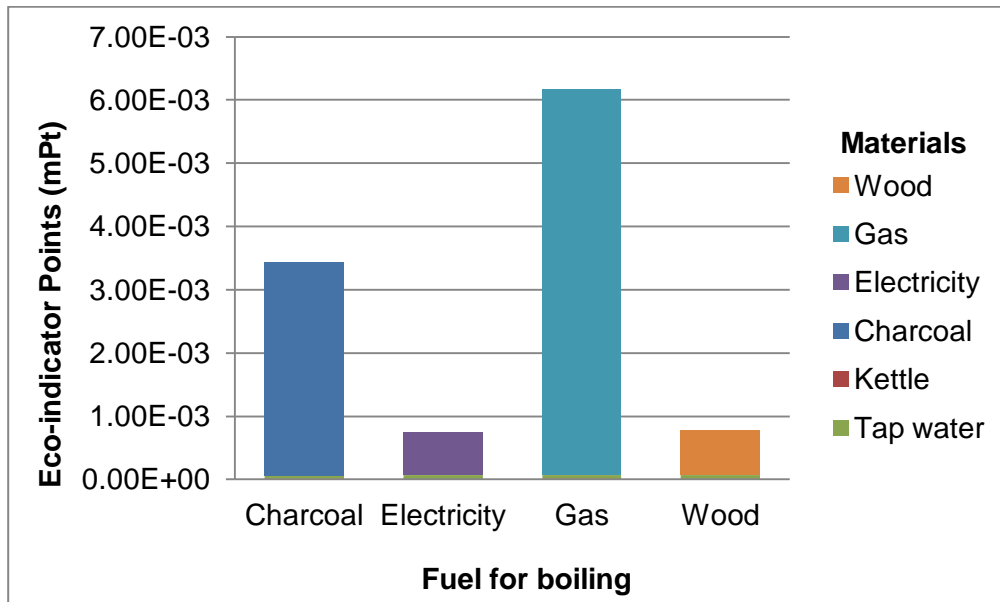


Figure 30: Environmental impacts of local fuel types used for treating water by boiling

Three locally available fuel sources in addition to charcoal which are considered are electricity, gas, and wood. Tap water was the source chosen for this comparison because it was the most popular source.

Gas, has the greatest environmental impacts followed by charcoal, wood, and electricity. Using electricity to create the heat for boiling has the lowest environmental impact because hydropower is the means for power generation in much of Uganda. It is also important to note that while gas is the largest contributor, it is also the least frequently used fuel for boiling. This is likely due to the fact that petrol stations oftentimes experience shortages in propane tanks, thus increasing demand and price. Additionally, cooking with gas also has a high buy-in threshold; things such as a stove top or gas-powered oven is required to contain and harness the heat from combusting the gas. Figure 31 shows the impact categories characteristic to each fuel type. Obviously fossil fuels associated with gas makes the largest environmental impact of the group. Land use is the most significant contributor to the impact of burning charcoal, followed by climate change. However, climate change is the greatest impact category from electricity use and burning wood.

When surveyed about the fuel used for boiling, community members mentioned the following as reasons for choosing the types they used—convenience, cost, availability and familiarity. These qualitative themes will be discussed in section 4.3.3.1, 4.3.3.2, and 4.3.3.3 by incorporating responses from survey respondents.

4.3.3.1 Qualitative Analysis: Convenience

Rarely were there households that mentioned using gas or electricity, but those who chose those fuel sources did so because they heated water and food more quickly than charcoal, thus saving time. However, charcoal-users mentioned the same notion of convenience when they explained their choice of that fuel over firewood; purchasing charcoal from a kiosk saved time as compared to collecting wood from nearby forests. Furthermore, one community member noted that collecting firewood was not as easy as going into one's backyard. He said that it was important to ask permission of land-owners, otherwise community quarrels over stealing resources would likely erupt.

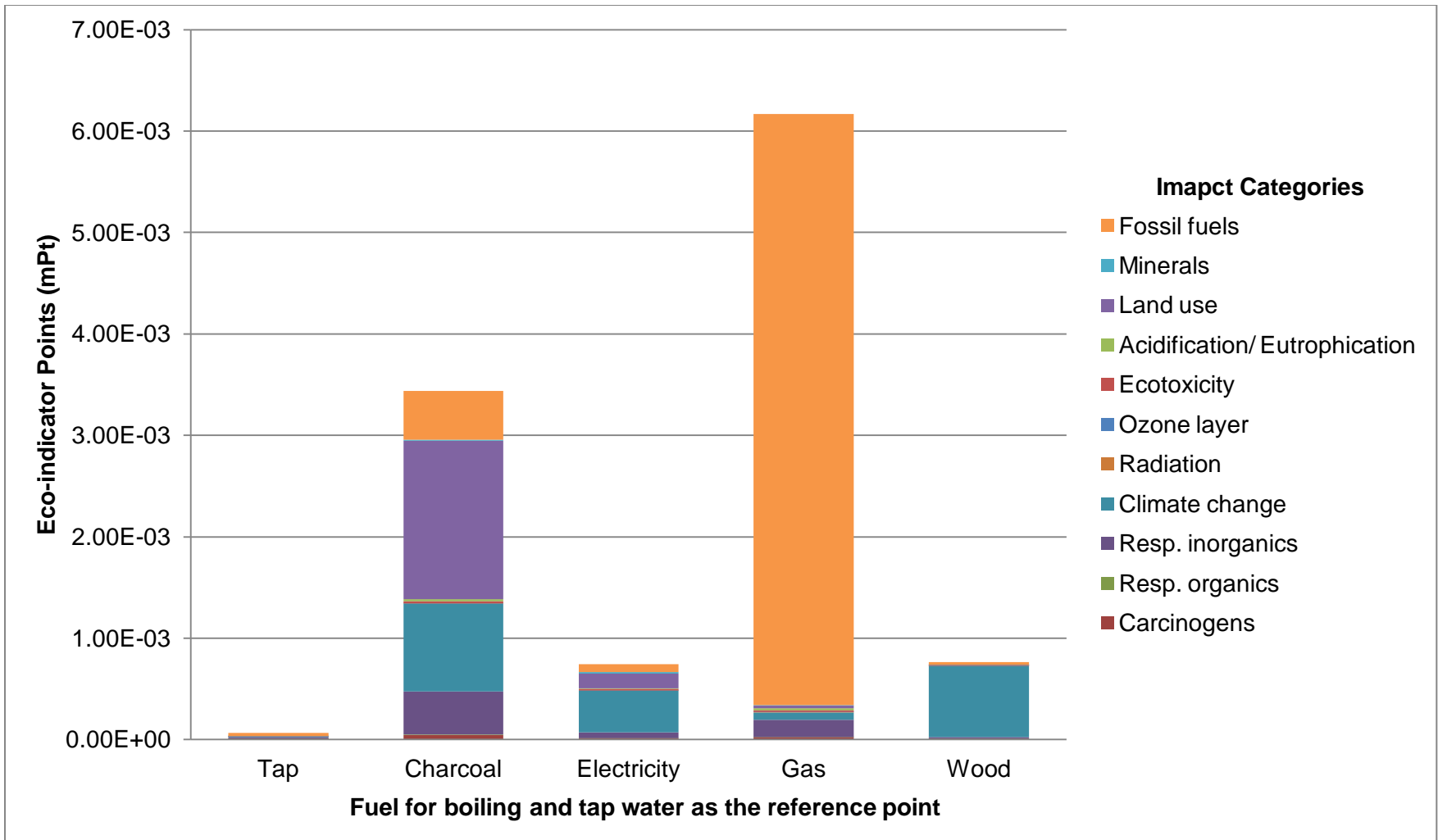


Figure 31: Environmental impact by categories for local fuel types used for boiling with tap water as reference point

Overall, many respondent households said that their fuel source was not as much of a conscious choice as it was based upon convenience. The vast majority of those interviewed used charcoal for cooking and, in turn, boiled water with the same type of fuel.

4.3.3.2 Qualitative Analysis: Cost

Some households did not have the luxury of choosing between different types of fuel because they were restricted by their finances to use the least costly options. Table 14 shows the average daily costs and percentage of take-home pay for households based upon the primary fuels mentioned in the survey. Families that said they were very financially strained would frequently collect firewood, but cited ever shrinking local forests as a challenge. On the opposite end of the spectrum, a minority of households used propane gas to treat water by boiling, but this fuel type was uncommon because of the large buy-in costs. Furthermore, electricity was used by a few households to power electric kettles. It is less expensive than charcoal, but respondents said that it is frequently inconsistent to use as their primary fuel option and requires a large fee to get connected to the power grid.

Table 14: Average daily cost and percentage of take-home pay for different fuel types

Fuel Type	Average Daily Cost (UGX)	Percentage of Average Take-Home Pay (%)
Firewood	28	0.56
Charcoal	352	7.04
Gas	792	15.84
Electricity	238	4.76

4.3.3.3 Qualitative Analysis: Availability and Familiarity

Survey respondents mentioned that their fuel source was chosen based upon availability or familiarity. Some households were previously noted as saying forests were scarce so the availability of their fuel source, wood, was slim. Others had similar responses about the use of

charcoal, saying that it was their only available option. Furthermore, community members, particularly those who are older, said that they used the fuel with which they had the most practice.

4.4 Conclusions

In this chapter, environmental impacts associated with water provision through different sources were evaluated based upon function, practice, and fuel types. Surface water and rainwater-sources had the highest environmental impacts based on function because these two sources require more treatment steps compared with other sources. The impact categories of land use and climate change contributed most to the overall environmental impacts. In terms of process contribution, boiling with charcoal is the primary contributor.

The evaluation based on practice revealed that the environmental impact associated with using tap water is the highest followed by surface water, boreholes, and protected springs. The major contributor is the boiling process using charcoal. This is because the treatment methods in practice are based on community perception on water quality. Community members' perceived quality frequently resulted in over treatment and thus a higher impact when compared to the basic treatment required in light of actual water quality data.

Lastly, since boiling proved to be the most consistent treatment method for each source, the fuel types were varied to compare impacts. Propane gas had the highest impact due to the contribution of fossil fuels. The fuel type with the second largest environmental consequence was charcoal where, land use and climate change attributed the most to its impact. However, the lowest environmental impact was associated with boiling water with electricity providing the heat source. This was because Uganda uses hydropower as a means of energy generation. A renewable energy source such as this, however, has its own shortcomings with social, cultural, economic, and ecological repercussions (Tilt et al., 2009). These impacts were not taken into consideration in this study as the SimaPro database considers only the environmental impacts

of hydropower associated with land use occupied by the dam and the air emissions from the water in the reservoir were considered.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

The first portion of this research explored the impacts of technology features and socioeconomics on households' decisions about the type of water supply technologies they chose. It was found from quantitative statistical analysis and qualitative data that convenience and cost are the primary factors impacting community members' choices. Statistical analysis revealed that more community members choose sources that required less collection time, have lower levels of visible turbidity, but were accompanied by high costs. When comparing the results from statistical analysis to the qualitative data from surveys, it reveals that community members' preference was primarily based upon convenience—75.5% of households said the primary source feature impacting their choice was convenience, followed by 16.5% choosing cost, 5.5% availability, 1.5% quality, and 0.5% chose their source based upon quantity.

Overall, when trying to understand a household's choice for their water source, consideration of opportunity costs is important. For example, the water collection time associated with a household's source choice has a particular value—an opportunity cost. For this study it is the amount of money which could be made during the time it takes to collect water. The person likely had to forego wages that could have been earned during that time (e.g. wages from farming, washing clothes, working in a shop), and the associated wages are approximately the opportunity cost (Whittington et al., 1992). Furthermore, Whittington et al. (1992) explains that households may choose to collect water from an improved drinking water source instead of an unimproved source because they are constrained in some way (e.g. time, money, distance). As a result, they are valuing these other factors or constraints as a substitute for money. This study's qualitative data revealed that convenience the most important source

feature, which is consistent with this notion of minimizing the opportunity cost. If it takes less time to fetch water from a tap source as compared to a borehole, the time saved can be spent doing something else. This reasoning helps to better understand a somewhat counterintuitive action of households in Nalugala and Kitale choosing the most expensive source.

Furthermore, the research discovered that the economic indicator “construction material of a household’s external walls” showed statistical significance as did the social indicators “gender of the head of household” and “number of household members”. The households that had construction material of burnt bricks and cement blocks tended to choose the tap water source. Women who were the heads of households chose rainwater more frequently than the men. The larger households (large number of household members) were more likely to choose surface water, tap water, and protected springs.

While the Progress out of Poverty Index was an appropriate questionnaire of Ugandan-specific indicators, expanding the socioeconomic factors to include one or more site-specific questions would add value to future studies (e.g., ownership of an expensive cell phone, solar panels, or a local storefront). These could be implemented during preliminary field testing to evaluate their ability to enhance nationally representative questions with locally appropriate ones. Another improvement that could be made to the survey process is the need to clarify the variable “convenience.” Future studies should collect specific information to better describe this grouped term by requesting quantitative data (e.g. distances to the primary source, the estimated collection time, and factors attributing to its ease of use). This would allow researchers to better pinpoint the specific factors (or combinations) impacting user choices. Due to time and resource constraints, it was not possible to collect and verify such in-depth data during this study. The last suggestion for survey improvement is to view it as an iterative step in the overall research. When planning for it this way, the interviewer is more apt to synthesize common themes and incorporate new questions as the survey is underway which could improve the quality of survey data.

The last portion of the research requires a look into both the function of local sources to provide potable water and the perception of source quality. When gauging environmental impact based on function, the most advanced technology—tap water—has lower impacts, just slightly higher than protected springs and boreholes. This is because the water quality associated with this source already meets potable standards, unlike that of the surface water and rainwater sources which require various steps of household level treatment to achieve potable water standards. This reveals that centralized water treatment may have lower environmental impacts compared with decentralized, extensive household level treatment. In this study, the tap water infrastructure and treatment is obtained from the Ecoinvent Database which is a European database. In the future, a detailed life cycle study on tap water should be conducted using the local data to improve the estimation of environmental impacts associated with tap water supply. In addition to this, further water quality testing on treated water at the household level from other sources would be valuable to confirm that treated water achieves the drinking water standards.

When measuring impact based upon community perception, tap water has the highest environmental impacts, because its perceived quality is not high. This result is revealed by the additional treatment of tap water at the household level because of one or some combinations of the widely held community perceptions: tap water is of poor quality; the “medicine” in tap water tastes, smells, and is bad for your health; the government is not to be trusted to functionally treat tap water. The qualitative information helped to shed light on reasons why so many community members chose tap water as a convenient source, but also used their finite resources to treat it. This lends further credence to the earlier discussion of centralized versus decentralized systems of water supply and treatment. One case study from Uganda in 2010 (Danert & Sutton, 2010) underscores self-supply—household initiatives to improve drinking water quantities—as a means of augmenting local, communal sources to affordably meet the varied needs of their family. The study concludes that self-supply allows for household problem-solving (e.g. low flow systems, high costs of purchasing water) and ownership of water

provision issues rather than reinforcing a dependency based relationship with local organizations, branches of the government, or foreign aid agencies (Danert & Sutton, 2010). A balanced coupling of household water, both using high quality tap water from the piped system and supplementing this source with rainwater or some other self-supply source could keep water costs low during seasons of excess rain. With proper education of the quality of tap water and self-supply sources, users could lessen their environmental impact by only treating the water that does not have quality of potable water.

Lastly, various fuel sources are used to boil water and the impact of difference fuels was examined. Propane gas has the highest environmental impact, followed by the most popular fuel source for community members, charcoal. Boiling with charcoal proves to be the largest environmental impact contributor in household water treatment systems when this method is chosen in Nalugala or Kitale.

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APPENDICES

Appendix A Household Survey

A1. What water source(s) do you use? Circle primary source.							
	BH	(Pr/Upr) spring	RWH (type)	Oluzzi	Owens Tap	Buys from Tap	OTHER/Notes
1							

A2. What are the + and -- effects of using another source besides your primary?

A3. Why do you choose your primary source?					
	Cost	Distance	Quality	Quantity	OTHER
1					

A4. Does your source change with the seasons? Why or why not?
Y / N

A5. Do you have different sources for drinking/washing; why or why not?
Y / N

A6. Who is responsible for maintenance?							
	household or individual	community	government	community org.	school	business	Other
1							

A7. How often does the source have to be maintained?				
Daily	Weekly	Monthly	Yearly	Other / Notes

A8. Does this person/org also pay for maintenance?
YES NO

Appendix A (continued)

		B2. How is your water treated?							Other / Notes	B3. What kind of materials are used for treatment and how much of each material?
B1. Do you treat water?		boiling	chlorine	coagulant (PUR)	Filter (type)	Settling	SoDis			
1	YES NO							If answer is NO move B8		

B4. Use(s) for treated water...							B5. Why is this method used?					B6. Is all of the water treated the same way?		B7. If you used a different source would you still treat your water?	
drinking	cleaning	washing	bathing	cooking	selling	Other/ Notes	Cost	Save time	Quality	Quantity	Other/ Notes	YES	NO	YES	NO
1															

B8. How much water do you...		B9. How often do you treat water?				Other/ Notes	B10. Why do you treat water?
use per day (number of jerry cans?)	treat per day	daily	weekly	monthly			
1							

Appendix A (continued)

B11. If you do not treat water all of the time, what are your reasons?							
Cost	Time	Materials hard to find	Don't know how to treat the water	Treating water does not work	ALWAYS treat water	Other	
1							

B12. Do you think the quality of your water affects your health; why or why not?
Y / N

C1. Gender of head of household (M/F)	
---------------------------------------	--

C2. Age of head of household	
------------------------------	--

C3. Number of members in household	
------------------------------------	--


C4. Do all the children aged 6-18 attend school (government, private, NGO/religious, or boarding)?	1. not all attend	
	2. all go to gov. sch	
	3. none 6-18 yrs	
	4. all go to school ≥ 1 go to private/boarding	



C5. What is the highest grade that the female head/spouse completed?	1. No female head/spouse	
	2. P5 or less, NONE	
	3. P6	
	4. P7 to S6	
	5. Higher than S6	

C6. What is the main source of lighting in your dwelling?	1. firewood	
	2. tadooba, or other	
	3. paraffin lamp, electricity (grid, generator, solar)	
C7. Major construction material for roof?	1. thatch, straw, other	
	2. iron sheets, tiles	
C8. What is the major construction material for the external walls?	1. unburnt bricks/mud, timber, stone, burnt brick/mud	
	2. burnt bricks/cement, cement blocks	
C9. What toilet is used by the household?	1. bush	
	2. latrine	
C10. Does any member of your household own electronic equipment at present? (1. Y 2. N)		
C11. Does every member of your house have at least two sets of clothes? (1. Y 2. N)		
C12. Does every member of your house have at least one set of shoes? (1. Y 2. N)		

Appendix B IRB Study Approval

eIRB: Study Approved RESEARCH x 🖨️ 📧

 eirb@research.usf.edu 6/10/12 ☆ ↶ ▾
to me ▾



IRB Study Approved

To: Christine Prouty
RE: Case Study of Household Water Supply Technologies Mayuge District, Uganda
PI: [Christine Prouty](#)
Link: [Pro00007256](#)

You are receiving this notification because the above listed study has received Approval by the IRB. For more information, and to access your Approval Letter, navigate to the project workspace by clicking the Link above.

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University of South Florida
Division of Research Integrity & Compliance - Office of Research and Innovation
3702 Spectrum Blvd Suite 155 - Tampa, FL 33612

Appendix C Water Quality Results



Form A

NATIONAL REFERENCE WATER QUALITY LABORATORY - ENTEBBE

Certificate of Analysis

Client Name: M/S Drew Rountree

Client Address: Entebbe, Katabi

Source Type	Potable water	Surface water	Potable water	Deep Well	Rain water	Spring water	Spring water
Parish	Nalugala	Nalugala	Nalugala	Nalugala	Nalugala	Nalugala	Nalugala
Sub-County	Katabi	Katabi	Katabi	Katabi	Katabi	Katabi	Katabi
County	Busiro	Busiro	Busiro	Busiro	Busiro	Busiro	Busiro
District	Wakiso	Wakiso	Wakiso	Wakiso	Wakiso	Wakiso	Wakiso
Sample source	Tap water,	Lake water, Nalugala	Plastic Rain Tank	Borehole, Nalugala	Metal tank, Rain water	Oluzzi	Protected spring
Date received	3/9/2012	3/9/2012	3/9/2012	3/9/2012	3/9/2012	3/9/2012	3/9/2012
Analysis Completed	7/9/2012	7/9/2012	7/9/2012	7/9/2012	7/9/2012	7/9/2012	7/9/2012
Lab No	E19864	E19865	E19866	E19867	E19868	E19869	E19870
Turbidity (NTU)	0.6	2.4	3.6	2.1	3.4	15	2
Electrical conductivity (µS/cm)	94	85	15	122	108	52	215
Total Dissolved Solids (mg/l)	66	60	11	85	76	36	151
Total suspended solids (105°C)	0	1	0	0	0	8	0
Total suspended solids (500°C)	0	0	0	0	0	4	0
E.Coli	<1	178.5	8	<1	3	206	<1
T.Colliforms	<1	>2420	2420	<1	>2420	>2420	<1

NOTE:

1. S.D. = Standard Deviation; AQC = Analytical Quality Control; NR = not Required; ND = Not Done
2. S. D. values have been quoted only from methods that have been validated in our laboratory.
3. The type of sample container and sample holding time affect the integrity of the sample and hence the results of analysis

Checked:

Laboratory Manager

Date:



Directorate of Water Resources Management Department
 P.O. Box 19, Entebbe
 Tel: 041-321342
 Fax: 041-321368

WATER RESOURCES POLLUTION CONTROL LABORATORY

Issued: [Signature]
 Principal Analyst
 Date: 9/9/12

DATE: _____ REMARK: _____

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Book: Field Guide to Environmental Engineering for Development Workers: Water, Sanitation, and Indoor Air
Author: James R. Mihelcic; Lauren M Fry; Elizabeth A. Myre; Linda D. Phillips; Brian D. Barkdoll
Publisher: American Society of Civil Engineers
Date: 2009
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