EQUITABLE ACCESS TO WATER IN A RURAL COMMUNITY IN KENYA

EQUITABLE ACCESS TO POTABLE WATER IN A RURAL MAASAI COMMUNITY IN KENYA: A DISCRETE CHOICE ANALYSIS

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Abstract

Water, a fundamental human right, impacts human health through its quantity (i.e., physical amount and ability to access it) and quality. Consumption of poor-quality water can lead to a variety of waterborne illnesses, often manifested as diarrhoea. Millions of individuals worldwide lack access to drinking water that is free from contaminants and is available and accessible when needed. In areas where water is not piped to homes, several physical, demographic, socio-economic and health factors affect access to potable water. These factors may also influence which water point an individual fetches water (i.e. their waterpoint choice) from in the presence of multiple alternative waterpoints. Through this study, effects of various physical, health, demographic and socio-economic factors on waterpoint choice were explored.

This study, based on datasets from a rural Maasai community in Kenya, implements a multinomial logit model to explore effects of various physical (travel time and water quality), health (aggregate frequency of self-reported diarrhoea stratified by age groups), demographic (average household age, household population, number of children under 5, number of women between 8-45 years of age and ratio of household population to number of women between 8-45) and socio-economic factors (education and income) on waterpoint choice. Travel time to the most probable waterpoint as predicted by the model was compared with the travel time to a household’s chosen waterpoint. Both travel times were calculated using the least-resistance path function incorporating slope and landcover.

Results from model optimization showed that combinations of travel time, average household age, diarrhoea among adult women, income, education and number of women between 8-45 years were significant contributors to the three waterpoint choice models. The expected travel time to the most probable waterpoint predicted by these models and actual travel time to chosen waterpoint fit well, showing that the models explain waterpoint choice well.

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List of all Abbreviations and Operational Definitions

- Boma: Maasai term for household/homestead
- GIS: Geographical Information Systems
- IGR: Il Ngwesi Group Ranch
- JMP: Joint Monitoring Programme
- Landcover: Vegetation, water bodies, snow and ice etc.
- LMIC: Lower- and Middle-Income Countries
- MDGs: Millennium Development Goals
- Potable Water: water that is free from contaminants
- SDGs: Sustainable Development Goals
- UN: United Nations
- WaSH: Water, sanitation and hygiene
- Waterpoint: water sources present outside the household premises, e.g., open springs, single drilled wells (with hand pumps), rivers

Declaration of Academic Achievement

I, Zoha Anjum, declare this thesis to be my own work. The dataset used for this thesis was collected by Hilary Barber and Jessie Newton. I am the sole author of the chapters 1-5 and the appendix of this document.

To the best of my knowledge, the content of this document does not infringe on anyone's copyright. My supervisors, Drs. Sarah Dickson and Corinne Schuster-Wallace, and the members of my supervisory committee, Dr. Antonio Paez and Dr. Susan Watt, have provided guidance and support throughout the progress of this project.

Chapter 1. Introduction

1.1.Background

Adequate water, sanitation and hygiene (WaSH) is critical for human health and wellbeing. However, access to WaSH is a challenge globally (World Health Organization & UNICEF, 2019). One consequence of this lack of access is high diarrhoeal disease morbidity and the consequent mortality. In 2016, approximately 829,000 diarrhoeal deaths were attributed to inadequate WaSH, accounting for 2.8 % of deaths from all causes (Prüss-Ustün et al., 2019). One of the countries where access to WaSH is a concern is Kenya (Achoki et al., 2018). According to the Global Burden of Disease study, lack of access to WaSH has remained the number one risk factor to human health in Kenya from 1990 to 2016, and has contributed notably to the age- and disability-adjusted life years within the country (Achoki et al., 2018). A component of adequate WaSH is drinking water, which was established as a human right by the United Nations (UN) General Assembly in 2010 (United Nations, 2010). Although inadequate access to drinking water is one of the underlying causes of poor health, only 59% of the Kenyan population had access to at least a basic water service in 2017 (World Health Organization & UNICEF, 2019). According to the Joint Monitoring Programme (JMP) report on drinking water, a basic water service consists of an improved water source (structurally designed to deliver safe water) located within 30 minutes roundtrip, including the waiting times. However, a basic water service, by definition, does not indicate potability (World Health Organization & UNICEF, 2017).

Therefore, access to a basic water source does not necessarily translate into better health outcomes.

The Sustainable Development Goals (SDGs), a people-centered agenda introduced by the UN, were designed to allow countries to grow economically and socially, while paying special attention to equity and human rights(Kumar, Kumar, & Vivekadhish, 2016). SDG 6.1 is aimed to provide universal and equitable access to safely-managed drinking water, which includes accessibility, availability, and quality, by 2030 (World Health Organization & UNICEF, 2017). Nonetheless, certain physical, demographic, socio-economic and health factors can act as barriers to equitable access to potable water. Physical factors include topography, which may affect ability to access water, and seasonality, which may affect both the quantity of and ability to access water (Blanford, Kumar, Luo, & MacEachren, 2012; Nygren et al., 2016). For instance, seasonal variation in temperature and precipitation affect travel, especially in the wet season, through mud, expanded or ephemeral rivers, and standing water.

From a demographic and socio-economic access perspective, the barriers can be on an individual or a regional level. On an individual level, overall health and certain demographic (e.g., age, sex) and socio-economic factors (e.g., education, income) may impact an individual’s ability to access water (Mahama, Anaman, & Osei-Akoto, 2014; Noor et al., 2010; World Health Organization & UNICEF, 2019). For example, a person with poor health may not be able to travel long distances to collect water or an individual with a lower income may not be able to purchase potable water if it costs more money than they are able to afford (Mahama et al., 2014; Nygren et al., 2016). Examples of regional level barriers include disparities in water services in urban and rural areas, disproportionate water collection burden placed on women, and legislation and perceptions surrounding water (Noga & Wolbring, 2013; Roche, Bain, & Cumming, 2017; World Health Organization & UNICEF, 2019).

Overall, these barriers to potable water access have many implications for human health. From the quantity perspective, an insufficient amount of water affects health through poor sanitation and hygiene practices (Prüss-Ustün et al., 2019). From the quality perspective, lack of sanitation contaminates water and contaminated water directly exposes individuals to the risk of contracting waterborne infections and developing consequent long-term health complications (Achoki et al., 2018; Yamada, 2015).

1.2.Research Goal & Objectives

The goal of this study is to explore which factors impact equitable access to water in three rural neighborhoods within a Maasai community in Kenya.

The research objectives that will be explored to meet this research goal are to:

- investigate the relationship between travel time and waterpoint choice;
- investigate the relationship between demographic and socio-economic factors and waterpoint choice; and
- investigate the relationship between self-reported health (diarrhoea) and waterpoint choice.

1.3.Rationale

This study highlights methodological advancements to study access by comparing different approaches to measure it in a topographically heterogenous and low-infrastructure environment. This is achieved by comparing Euclidean paths, also known as the straight-line path, and the least-resistance paths that incorporate changes in slope and landcover into path calculations. This study is important as there is limited research on measuring access in topographically heterogenous and low-infrastructure environments (Blanford et al., 2012; Paez et al., 2019).

Second, this study develops a statistical model to explain waterpoint choice based on available household-specific demographic, socio-economic and health factors and attributes of waterpoints. This methodological tool can also be used to study factors that impact decision-making when multiple waterpoint alternatives are present. Very few studies have previously explored physical (time to collect water and water quality), demographic (family size) and socio-economic (income and education) determinants of waterpoint choice, but none of these studies have examined all variables together (Irianti & Sasimartoyo, 2016; Mu et al., 1990; Nyong & Kanaroglou, 1999; Rauf et al., 2015). Moreover, none of these studies have explored the health variable either. Therefore, this study will fill current gaps in the field of determinants of waterpoint choice and will be of great importance in aiding future research and policy. As such, the key findings from this study may be later used to inform evidence-based decision-making regarding locations of a new waterpoints within this community.

1.4.Scope

This thesis was prepared according to the regulations provided by McMaster University. Chapter 1 of this thesis includes a brief background, the research goal and objectives, the rationale, and the scope of this thesis. Chapter 2 consists of a comprehensive literature review to provide adequate background to the reader. Chapter 3 describes the methods used to achieve the research goal. Chapter 4 elaborates on the results and discussion of the findings. Chapter 5 provides conclusions and future recommendations for research.

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Chapter 2. Literature Review

2.1. Water and Health

Water is essential to human health, and both are connected through the water-health nexus (Schuster-Wallace & Watt, 2015). Both water quantity and quality can affect human health. The quantity of water is dependent on the physical amount of water available and the ability to access it; whereas, the quality of water is determined by the presence of chemical, biological, and radiological contaminants (WWAP, UNESCO, & Azoulay, 2019). The accessibility or ability to access water depends on various physical, demographic, and socio-economic factors (**Figure 1**) (Schuster-Wallace & Watt, 2015).

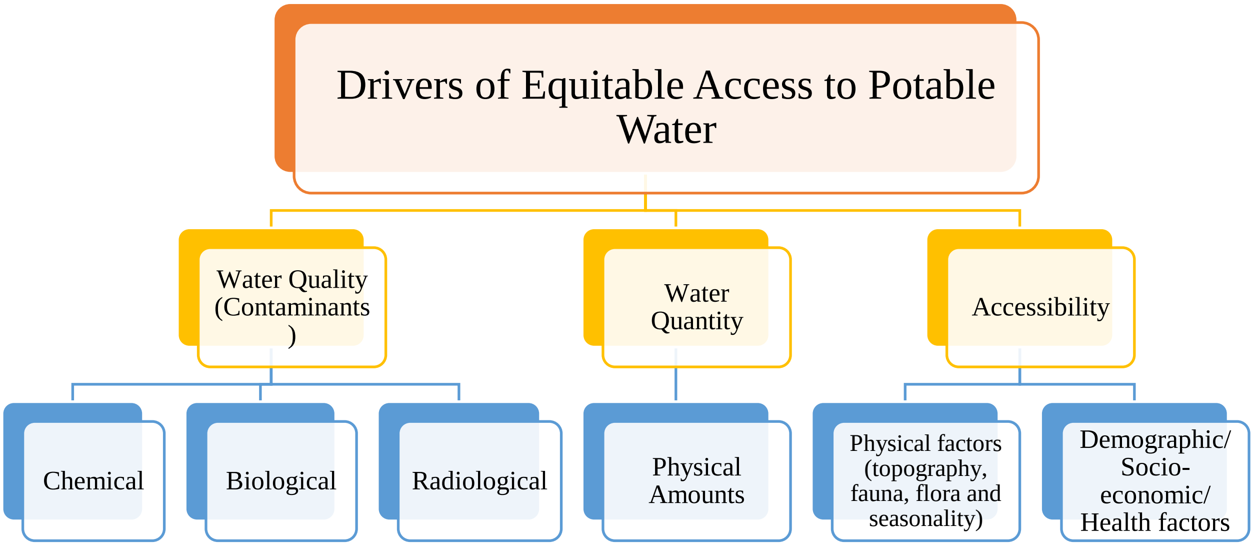


Figure 1: Drivers of access to potable water

2.1.1. Water Quantity and Health

Water quantity is characterized by physical amounts of, and ability to access water (WWAP et al., 2019). Today, challenges related to water quantity affect four of every 10 individuals and are expected to impact approximately 700 million individuals worldwide by 2030 Growing population, climate change, industrialization, poverty and poor infrastructure are some factors that affect physical amounts of and ability to access water (WWAP et al., 2019).

Variation exists in the extent of water access. According to the Joint Monitoring Programme (JMP) ladder for the drinking water service, an improved water source is structurally designed to provide safe water (World Health Organization & UNICEF, 2017). If an improved water source takes less than 30 minutes of roundtrip including wait time, it is considered a basic water source (World Health Organization & UNICEF, 2017). In 2017, approximately 1.4 billion individuals fetched water from at least a basic water source (World Health Organization & UNICEF, 2019). Within sub-Saharan Africa, only 61 % of the population had access to at least a basic water source in 2017 (World Health Organization & UNICEF, 2019). Furthermore, in Kenya, 59 % of the population had access to at least a basic water source in 2017, marginally higher than sub-Saharan Africa (World Health Organization & UNICEF, 2019).

Quantifying Water Access

Previously, access to water has been quantified by measuring distance or travel time to a waterpoint (Paez et al., 2019; Tanser, Gijsbertsen, & Herbst, 2006). Of the two, travel time is a preferred scale of measurement as it accounts for pedestrian-unfriendly landmarks such as steep hills and dense vegetation (UN-Habitat, 2006). Recently Paez et al. described use of energy expenditure to measure access to water, as the energy required to fetch water from a waterpoint has implications for vulnerable populations such as children and pregnant women (2019) .Spatial access to water and healthcare facilities has been explored using GIS in numerous studies (Blanford, Kumar, Luo, & MacEachren, 2012; Huerta Munoz & Källestål, 2012; Ntozini et al., 2015; Pearson, 2016; Tanser et al., 2006). GIS can be used to represent individual networks, villages and/or facilities and the relationships between spatial objects (Nelson, 2000). The distance and travel time between two spatial objects can be measured using a variety of methods. Network path, based on street networks, is a favorable approach in urban areas (Nesbitt et al., 2014; UN-Habitat, 2006). Euclidean or straight-line path, which is the path as the crow flies, is considered a poor proxy for spatial access as it does not recognize the presence of barriers, both human-made or topographical (UN-Habitat, 2006). The least-resistance path, which accounts for topographical features and landcover, has been used to illustrate spatial access, particularly in infrastructure-poor areas, and is proven to generate more realistic distance and travel time estimates than Euclidean path in lower- and middle-income countries (LMIC) (Noor et al., 2010; Okwaraji, Cousens, Berhane, Mulholland, & Edmond, 2012; Paez et al., 2019).

Access to Water and Equity considerations

It is important to note that access to water is not only an issue in the lower- and middle-income countries (LMICs). Certain rural, remote, and marginalized communities in high-income countries also face challenges related to access to water that is available when needed and is free from contaminants. For example, Indigenous populations in

Canada are ninety times more likely than the rest of the Canadian population to lack piped water within the household premises (Hanrahan, 2017). Furthermore, many Indigenous people in Australia have been deprived of their rights to water throughout their history of evolving water law and policy (S. Graham et al., 2017). A recent example of lack of access to potable water among the marginalized communities is from Flint, Michigan (Day, O'Shay-Wallace, Seeger, & McElmurry, 2019). This area is resided by a relatively low-income African-American population and has been facing the issue of lead contamination in their drinking water since 2014 (Day et al., 2019). This shows that though it is a fundamental human right, access to potable water is a challenge around the globe and can have many health implications.

Equitable access to water refers to provision of adequate water, both in terms of quality and quantity, to all individuals in a population, but especially those who are poor, vulnerable, or excluded (United Nations Economic Commission for Europe & World Health Organization Regional Office for Europe, 2013). There can be many barriers to the provision of equitable access to potable water, and these barriers can be divided into macro-level barriers, such as region- and population-wide barriers, or micro-level barriers which are more household- and/or individual-specific barriers. Some notable examples of these barriers are shown in **Figure 2**.

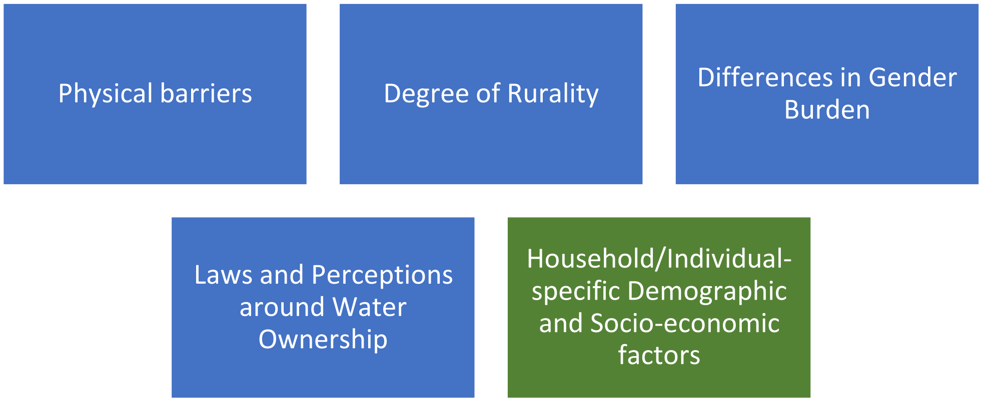


Figure 2: Macro- and micro-level barriers to equitable access to potable water, where blue boxes represent macro barriers, while green boxes represent micro-barriers

Physical factors, contributing to the macro-level barriers, may affect one's ability to fetch water from a source. Examples of physical factors include variations in topography, landcover and infrastructure and seasonality (Blanford et al., 2012). For instance, seasonality may manifest as wet or dry seasons in some areas, where excess rain can lead to flooding or a lack of rain can lead to droughts (Blanford et al., 2012). The former may result in creation of new waterpoints or contamination of existing waterpoints due to surface runoff, while the latter may worsen water scarcity and affect access through diminishing existing waterpoints and/or modifying the landcover in the area Similarly, some individuals may reside in naturally water-scarce areas, which has implications for their ability to access water.

A macro-level barrier to equitable access to potable water stems from differences in water-related services in rural and urban areas. Based on recent global reports, 50 % and 85 % of the population in the rural and urban areas had access to a basic water source (World Health Organization & UNICEF, 2019). Another level of the JMP drinking water service ladder is safely-managed drinking water. To be considered a safely-managed drinking water service, an improved water service (structurally designed to provide safe water) must be accessible on premises, available when needed and the water supply must be free from all types of contaminants (World Health Organization & UNICEF, 2017). When access to a safely-managed water service was compared between rural and urban settings, it was shown that a lower proportion of the rural population had access to a safely-managed water source (World Health Organization & UNICEF, 2017). This evidence highlights that access to water is a greater challenge in rural areas than urban areas, perhaps due to differences in population growth and size, infrastructure, or political nuances (Gomez, Perdiguero, & Sanz, 2019; WWAP et al., 2019).

Another macro-level factor affecting access to water is the gender burden. Women and girls, in particular, are disproportionately more affected by poor access to potable water (Roche, Bain, & Cumming, 2017; Schuster-Wallace & Watt, 2015; Smiley, 2016). In areas where piped water is not available in the house, women and girls bear the burden of fetching water (Roche et al., 2017; Schuster-Wallace & Watt, 2015; Smiley, 2016). An analysis on gender burden and water access in sub-Saharan countries has shown that approximately 3.36 million children and 13.54 million adult women were responsible for fetching water where collection times exceeded 30 minutes (J. Graham & Hirai, 2016). Travelling to a waterpoint may compromise their safety by exposing adolescent girls and women to instances of sexual violence or attacks by wild animals (Pommells, Schuster-Wallace, Watt, & Mulawa, 2018). Furthermore, pre-adolescent girls may be unable to attend school if they spend too much time fetching water, and this has a serious impact on their access to education and thus, adoption of public health and safety procedures in their own households (Kitamura et al., 2014; Schuster-Wallace & Watt, 2015).

Legislation and perceptions around water control and management also contribute to equitable access to water on a macro-level. Laws and regulations surrounding water vary between and within countries. Water may be considered a commodity, a human right, a private source, a public source, or a combination thereof in various regions based on the legislation (Noga & Wolbring, 2013). Additionally, different individuals may have contrasting perceptions surrounding water due to local level of water ownership among other factors (Noga & Wolbring, 2013). Such variations in legislation and perceived ownership are important as they shape the actions an individual takes in consumption, conservation, control, and management (collectively referred to as stewardship) of water (Noga & Wolbring, 2013). According to the Kenya 2016 Water Act, access to clean water is now a basic human right embedded in the national legislation, where provision of water and water-related services are considered a shared responsibility between the national and county governments (World Resource Group, 2016). The new law adopted a pro-poor and pro-rural approach to ensure water for all in the country (Avidar, 2018). Despite the introduction of the act, it has been shown that the law might be failing in some areas such as the Siaya county due to lack of leadership and poor governance on all levels (Avidar, 2018). To overcome these barriers, a strong commitment to pro-poor policies, innovative financial models and monitoring of water service providers is essential (Bisung et al., 2016).

Socio-economic status of a household or an individual is a micro-level challenge to equitable access to water. Factors such as income and education may play a pivotal role in determining access to a water point (Mahama, Anaman, & Osei-Akoto, 2014; World Health Organization & UNICEF, 2019). According to recent reports, approximately 36.8 % of Kenyans lived below the poverty line (USD $1.90) in 2017 and the literacy rate was approximately 78.73 % in 2014 (UNESCO, 2016; World Bank, 2015). Income has been shown to affect access to potable water previously as wealthier individuals may be in a better position to pay for water (Mahama et al., 2014). Education, on the other hand, did not affect potable water access (Angoua, Dongo, Templeton, Zinsstag, & Bonfoh, 2018; Mahama et al., 2014). Although a higher level of education among women affects adoption of public health measures in their households (Alemu, Kumie, Medhin, Gebre, & Godfrey, 2017).

Waterpoint Choice

As mentioned previously, many physical, demographic and socio-economic factors can drive or impede ability to access water (Schuster-Wallace & Watt, 2015). These factors also affect the choice of waterpoint in presence of multiple alternatives. Physical factors such as changes in slope and landcover affects walking and travel time to the waterpoint, where steep downhill slope may decrease travel time and presence of dense vegetation such as shrubs may increase travel time (Bartholomé & Belward, 2005) . Travel time or walking distance to the waterpoint has previously been established as a determinant of waterpoint choice (Fotue, 2012; Rauf, Bakhsh, Hassan, Nadeem, & Kamran, 2015). Socio-economic drivers of access, in comparison, focus on demographic and socio-economic factors that influence an individual's ability to access water (Schuster-Wallace & Watt, 2015). Examples of such factors are age, sex, and health status of the individual fetching water, as well as income and education level of individuals in the household (Adams, Boateng, & Amoyaw, 2016; Schuster-Wallace & Watt, 2015). For instance, children and adolescent girls who are sick may find it difficult to walk longer distances and carry water due to their young age and poor health (Kher, Aggarwal, & Punhani, 2016; World Health Organization & UNICEF, 2019). Other studies have shown importance of household population and socio-economic status in determining waterpoint choice (Fotue, 2012; Irianti & Sasimartoyo, 2016; Rauf et al., 2015). Together, physical, demographic, health and socio-economic drivers of access may influence which waterpoint an individual chooses to fetch water from when multiple alternatives are present (Kanyoka, Farolfi, & Morardet, 2008; Mu, Whittington, & Briscoe, 1990).

Health Implications of Access

Inadequate access to potable water has implications for health. In Kenya, lack of access to WaSH has remained the number one risk factor to human health between 1990 and 2016 (Achoki et al., 2018). Inadequate access to water may also affect psychological health, as poor access to water has been associated with increased anxiety and depression (Workman & Ureksoy, 2017). Furthermore, a study conducted in Ethiopia demonstrated effects of inadequate water access on psychosocial distress, which involves effects on both interpersonal relationships and the community (Stevenson et al., 2012). Another study, conducted with eight Indigenous communities in Saskatchewan, Canada, demonstrated that water-related health outcomes encompass psychological health challenges due to poor water quality and inadequate water quantity (Bharadwaj & Bradford, 2018). A systematic review of 42 studies showed that excessive water carriage is associated with pain, fatigue and perinatal health problems (Geere, Cortobius, Geere, Hammer, & Hunter, 2018). Furthermore, violence against vulnerable groups was also associated with water carriage (Geere et al., 2018).

2.1.2. Water Quality and Health

Like water quantity, water quality also affects health, and is becoming a major concern in many parts of the world (Yongsi, 2010). Growing human population contributing to improperly managed domestic waste and sewage, intensification of industrial and agricultural activities and climate change are some of the factors involved (UNDESCA, 2014).

The 2019 JMP report by the WHO stated that only 5.3 billion people globally had access to safely-managed drinking water in 2017, while the rest of the population consumes water with poor quality or access (World Health Organization & UNICEF, 2019). As a consequence of consumption of poor quality water, many individuals are exposed to contaminants that have a negative impact upon their health (Workman & Ureksoy, 2017). The impact of such contaminants can be acute – sudden and short-term – or chronic – gradual and long-term.

Pathogens in Water – Exposure Pathways

Pathogens, comprising of bacteria, viruses and protozoa, are microorganisms that are harmful to human health, and are present in the environment, including in water. Water can become contaminated with pathogens when it comes into contact with human or animal excreta (World Health Organization, 2017). An individual may then be exposed to waterborne pathogens through consumption of contaminated water, inhalation of water droplets, or direct skin contact, and each transmission pathway has its own associated health implications (World Health Organization, 2017). Waterborne pathogens may lead to different types of infections including water-washed (e.g., skin and eye infections) and waterborne (e.g., cholera, dysentery) diseases (Annenberg Foundation, 2017; Yamada, 2015).

Pathogens in Water – Symptoms and Long-Term Effects

Waterborne diseases may manifest through mild symptoms such as fever or gastrointestinal symptoms such as diarrhoea (World Health Organization, 2017). They may also lead to severe outcomes, such as haemolytic uraemic syndrome and toxic shock syndrome, which are rare, or death secondary to diarrhoea and dehydration, which is more common (World Health Organization, 2017). The haemolytic uraemic syndrome and toxic shock syndrome may be caused by exposure to more virulent pathogens such as the O157: H7 strain of *E. coli* (World Health Organization, 2017).

Diarrhoea is described as passing three or more loose stools in a 24-hour period (Troeger, Forouzanfar, Rao, & Mokdad, 2017). Diarrhoea depletes the human body of water and other important micronutrients (e.g., vitamins and minerals) that are critical for its function (Yamada, 2015). Diarrhoea can be an outcome of gastrointestinal exposure to more than 27 different species of pathogens (Hodges & Gill, 2010; Yongsi, 2010). This exposure may occur through ingestion of contaminated water or food prepared with contaminated water (Hodges & Gill, 2010). In fact, many studies have shown associations between consumption of contaminated water and diarrhoeal disease (Bivins et al., 2017; Null et al., 2018; Wolf et al., 2014; Yongsi, 2010).

Under normal physiological circumstances, the gastrointestinal tract is capable of absorbing and secreting fluids to meet the body's needs and maintain a state of fluids and mineral homeostasis (Yamada, 2015). Typically, the gastrointestinal tract can absorb 8-9 liters of fluids per day, where only 100-200 millilitres is excreted in stool (Hodges & Gill, 2010). However, in the case of diarrhoea, this absorption-secretion balance is can be seriously disrupted (Troeger et al., 2017).

Acute effects of diarrhoea involve loss of water and nutrients and consequently, short-term malnutrition and wasting (Raihan et al., 2017; Schuster-Wallace & Watt, 2015; Yamada, 2015). If diarrhoea persists for a long time or consists of multiple acute episodes, permanent alteration of the gut lining can occur, thus hampering an individual's gastrointestinal functions (Schuster-Wallace & Watt, 2015; Yamada, 2015). Some other long-term effects of diarrhoeal malnutrition include stunted growth and cognitive impairment among children, and childbirth complications among women due to poor pelvic development and obstructed labour (Schuster-Wallace & Watt, 2015; Yamada, 2015). Additionally, an indirect consequence of both acute and chronic physical health outcomes is their effect on psychological health. For instance, psychological health challenges can be related to loss of dignity and human productivity due to poor physical health (Bisung & Elliott, 2017). Furthermore, psycho-emotional stress may stem from providing care to an individual who is sick (Workman & Ureksoy, 2017).

The health effects from consumption of poor-quality water are not limited to individual-level outcomes but have implications for the whole population. In fact, the long-term individual-level health effects may have an impact at the national level due to loss of human potential and productivity (Schuster-Wallace & Watt, 2015). In areas where potable water is not accessible, individual households, forming the bottom of the drinking water service ladder, may be more likely to spend additional time and energy to access potable water (Bisung & Elliott, 2018). This can lead to loss of time and productivity (Bisung & Elliott, 2018). In fact, additional time spent on water fetching reduces the time available to invest in home-making, education, income generation through work, food collection, and other productive activities (UNICEF, 2016). On a national scale, time spent on water collection may impact poverty reduction efforts negatively (Bisung & Elliott, 2018).

Diarrhoea Prevalence and the Kenyan Context

Diarrhoeal disease is highly prevalent around the world (Hodges & Gill, 2010). In 2016, approximately 829,000 diarrhoeal deaths were attributed to inadequate WaSH, accounting for 2.8 % of deaths from all causes (Prüss-Ustün et al., 2019). Despite the high global prevalence of diarrhoea, its severity has shown trends temporally as well as spatially. In Kenya, for example, there was an overall reduction in rates of communicable diseases, such as diarrhoea and lower-respiratory infections from 1990 to 2016 (**Figure 3**) (Achoki et al., 2018).

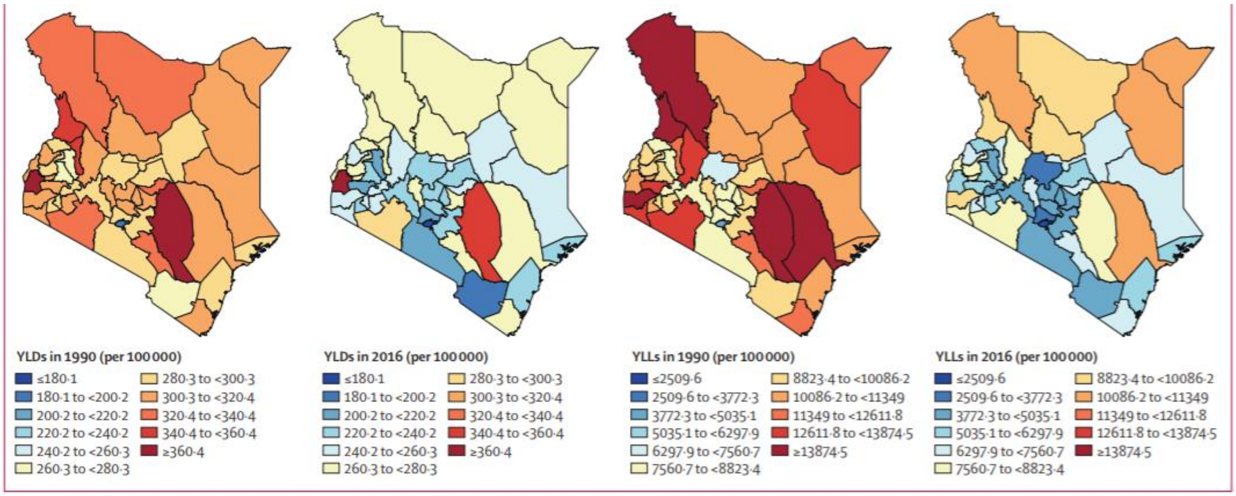


Figure 3: Age-standardized rates of diarrhoeal diseases in Kenya from 1990 to 2016 where YLD = Years Lived with Disability and YLL = Years of Life Lost (Achoki et al., 2018).

2.2. Water and Human Rights

Water and sanitation were recognized as a human right by the UN General Assembly and the Human Rights Council as a part of binding international law in 2010 (UN-WATER, 2010). Declaration of access to potable water as a fundamental right has many benefits. First, adequate access to potable water can lead to a significant decrease in the global burden of waterborne disease and provision of sufficient water enhances sanitation and hygiene practices (The PLoS Medicine Editors, 2009). Second, treating water as a commodity, rather than a basic human right, is not equitable as individuals from poor households are not able to afford water (Smiley, 2016; The PLoS Medicine Editors, 2009). Lastly, with the looming crisis of water scarcity and climate change, it is recognized that the poor and vulnerable will be affected most (The PLoS Medicine Editors, 2009). In 2012, the UN declared that water is life and equitable access to this human right requires provision of water that is safe for consumption regardless of an individual's socio-economic status (Smiley, 2016; Tortajada & Biswas, 2017). The UN Assembly also acknowledged sanitation as a separate right in 2015 (United Nations, 2015). Acting on the understanding that water is a human right is a mechanism for addressing inequities between and within countries and ensures no one is left behind in gaining access to potable water (The PLoS Medicine Editors, 2009). To this end, the SDGs provide a framework for working towards good quality water in sufficient quantity for all (WWAP et al., 2019).

Water, MDGs, and SDGs

The Millennium Development Goals (MDGs), introduced in 1990s, were a multifaceted approach to development that guided the global community and individual LMIC countries in their commitment to eradicating poverty (Kumar, Kumar, & Vivekadhish, 2016). In 2015, the SDGs were introduced to create an updated MDG-like development agenda applicable to all nation states (Kumar et al., 2016). The SDGs are a people-centered agenda which was formed to enable individual countries to grow economically and socially (Kumar et al., 2016). Consisting of 17 goals and 169 targets, the SDGs aim to build on the MDGs (Goals 1-7); promote inclusivity in infrastructure and industrialization etc. (Goals 8-10); and, ensure sustainability and improvement in urbanization (Goals 11-17) (Kumar et al., 2016). The SDGs are also heavily focused on equity and human rights (Kumar et al., 2016). The 2030 SDG Agenda further reiterates its commitment to reducing inequalities by calling for the disaggregation of SDG indicators by factors such as income, sex, age, race, and geographical location and ensure that subnational inequalities are not overlooked in the national-level SDG monitoring (World Health Organization & UNICEF, 2017).

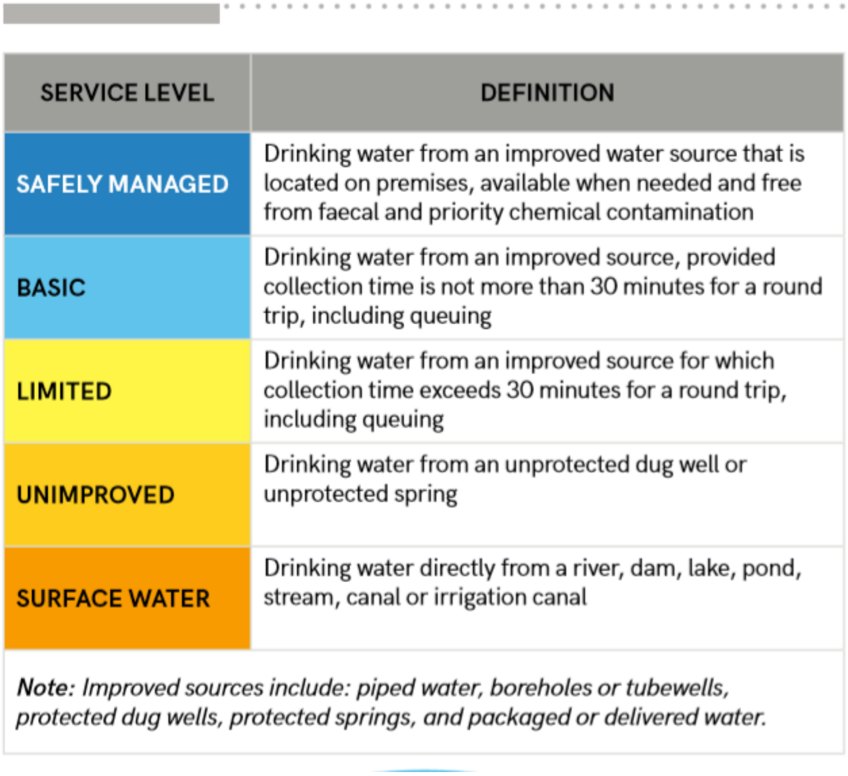
In terms of WaSH, the MDG to SDG transition was an opportunity to address limitations in monitoring access to water and sanitation moving forward (Roche et al., 2017). MDG indicator 7c was focused on access to an improved source of drinking water, which includes piped water, public taps, boreholes, wells, protected springs, and rain water (Onda, LoBuglio, & Bartram, 2012). The MDG 7c target was to halve the proportion of people without access to safe drinking water and basic sanitation by the end of the MDG era (Roche et al., 2017). The target was met for drinking water, but not for sanitation (Roche et al., 2017).

Despite the attainment of MDG 7c target for drinking water, there were some limitations associated with the framing of the target. The MDG indicator 7c for drinking water did not include water quality, which is an important attribute of the water-health nexus (Onda et al., 2012). When tested, improved water sources, considered a gold standard, were found to be contaminated with biological or chemical constituents (Bain et al., 2014; Roche et al., 2017; Weststrate, Dijkstra, Eshuis, Gianoli, & Rusca, 2018). Another major distinction between MDGs and SDGs lies in the scope of their respective targets. MDGs aimed to reduce the proportion of individuals with poor access to water and sanitation by half; whereas, the SDGs provide a more wholistic approach to access to water and sanitation by striving for universal and equitable access to both (Weststrate et al., 2018). Therefore, upon transition from MDGs to SDGs, location of source (accessibility), affordability, continuity of water supply and water quality were added for a more comprehensive approach to water access (Weststrate et al., 2018). All these factors contribute to the safely-managed drinking water service part of the revised JMP ladder

(World Health Organization & UNICEF, 2017). Additionally, following the transition into SDGs, access to water and sanitation were broken down into two main targets, 6.1 and 6.2 (Weststrate et al., 2018). SDG target 6.1 aims to achieve universal and equitable access to safe and affordable drinking water for all by 2030 (World Health Organization & UNICEF, 2017). Whereas, SDG 6.2 aims to achieve access to adequate and equitable sanitation and hygiene for all and end open defecation while paying special attention to vulnerable populations such as girls and women (World Health Organization & UNICEF, 2017). Examples of other SDG 6 targets include integrated water source management, pollution reduction and increase water use efficiency among others (Weststrate et al., 2018).

Components of access to water are linked to many SDGs. For instance, water is important to SDG 3 (Good Health and Well-being) through the water-health nexus; to SDG 7 (Affordable and Clean Energy) through the use of water as a renewable energy source; to SDG 11 (Sustainable Cities and Communities) from the perspective of economic impact of industries and water-related disasters, and SDG 15 (Life on Land) from the environmental conservation viewpoint (UNDESCA, 2015; William, 2017) . However, challenges related to drinking water access are primarily addressed through SDG 6.

For SDG 6.1, the proportion of population using safely-managed drinking water services (improved source with accessible, available and free of contaminants water supply) is used as the global indicator (World Health Organization & UNICEF, 2017). If water collection from an improved water source takes more than 30 minutes (including waiting time), then the water service is limited (World Health Organization & UNICEF, 2017). Together, the safely-managed, basic, and limited water service form the JMP ladder for drinking water services, along with unimproved (not structurally designed to provide safe water) and surface water sources (World Health Organization & UNICEF, 2017). Figure 4 shows the JMP ladder for drinking water services.



SERVICE LEVEL	DEFINITION
SAFELY MANAGED	Drinking water from an improved water source that is located on premises, available when needed and free from faecal and priority chemical contamination
BASIC	Drinking water from an improved source, provided collection time is not more than 30 minutes for a round trip, including queuing
LIMITED	Drinking water from an improved source for which collection time exceeds 30 minutes for a round trip, including queuing
UNIMPROVED	Drinking water from an unprotected dug well or unprotected spring
SURFACE WATER	Drinking water directly from a river, dam, lake, pond, stream, canal or irrigation canal

Note: *Improved sources include: piped water, boreholes or tubewells, protected dug wells, protected springs, and packaged or delivered water.*

Figure 4: JMP ladder for drinking water service (World Health Organization & UNICEF, 2017)

2.3. Summary

Water, a fundamental human right, impacts health through both quality and quantity. Equitable access to potable water can be affected by macro-factors, such as differences in drinking water service in rural versus urban areas, disproportionate gender burden, legislation, and perceptions surrounding water, or by micro-factors such as demographic, health, and socio-economic factors related to the individuals. Poor water quality and inadequate access to water may negatively influence health through diarrhoea, physical and cognitive impairment, and psychological health impacts. Previous research studies have identified water quality, physical access to waterpoint, as well as age, sex, health, income, household population, and education level as some of the factors affecting equitable access to potable water. These factors may also impact decision-making in terms of which waterpoint to use in the presence of multiple alternatives. Based on this literature review, a limited number of studies have previously examined the physical (time to collect water and water quality), demographic (family size) and socio-economic (income and education) determinants of waterpoint choice, but none of the studies have examined all variables together (Irianti & Sasimartoyo, 2016; Mu et al., 1990; Nyong & Kanaroglou, 1999; Rauf et al., 2015). Therefore, this study will fill current gaps in the field of determinants of waterpoint choice for this particular community.

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Chapter 3. Methods

This study involved analysis of a secondary dataset collected in 2011-12 from a rural Maasai community in Kenya (Barber, Dickson-Anderson S.E., Schuster-Wallace C.J., Elliot S.J., & Tema S., 2017).

3.1. Study Population

In Kenya, the Il Ngwesi Group Ranch (IGR) is located on the east end of the Rift Valley province and is colonized by a traditionally nomadic and pastoralist Maasai population (Barber, 2013). Consisting of eight distinct neighborhoods, IGR is situated in the Laikipia district (Barber et al., 2017). Three of these neighborhoods (Ethi, Chumvi and Nadungoro) have been part of a mixed-methods coupled systems study that explored implications of WaSH and diarrhoeal outcomes in the area previously (Barber et al., 2017). The biological quality testing of water sources showed that microbial levels in most waterpoints in the three neighborhoods were above the Kenyan drinking water standards (Barber et al., 2017). Thus, lack of access to potable water in these neighborhoods might expose individuals to waterborne diseases, typically manifested as diarrhoea.

Geography

Chumvi, the neighborhood where the data collection method was piloted in 2011-12, is located approximately 20 kilometres southwest of IGR, covering around 75 square kilometres of land. Chumvi has diverse topographical features including gradual slopes in the south and hills in the north. Distinct dry (March – May) and wet (mid-November – mid-December) seasons exist in this region with an annual rainfall of 580 mm. Chumvi has a population of 2,000 people with a population density of 27 individuals per square kilometres of land (Barber, 2013). Ethi, the neighborhood located east of Chumvi, is a relatively smaller neighborhood of about 23 square kilometres of land with a mostly hilly landscape (Barber, 2013). It has a population of 750 individuals and a population density of 37 individuals per square kilometres (Barber, 2013). Of the three, Nadungoro is the smallest neighborhood with 8 square kilometres of land (Barber, 2013). Unlike Chumvi and Ethi, the landscape consists of open plain with foothills and a gradual southward slope (Barber, 2013). It has a population of 375 people and population density of 49 individuals per square kilometres (Barber, 2013). These neighborhoods lack electricity service and paved roads (Barber, 2013). All bomas (households) in Ethi and Nadungoro and some bomas in Chumvi lack a piped water supply as well (Barber, 2013). The bomas lacking a piped water supply obtain water from waterpoints such as open springs, single drilled wells (with hand pumps), or rain especially during the wet season (Barber, 2013).

3.3. Data Analysis

The data analyses consisted of two components: cost analysis and discrete choice analysis. Cost analysis was conducted to calculate travel time from each boma to a waterpoint. The discrete choice analysis included the calculated travel time, demographic and socioeconomic factors, diarrhoea, and microbiological water quality variables to determine which factors affect waterpoint choice. Microsoft Excel and RStudio were used for descriptive analyses and model development, respectively. The issue of missing data was overcome by omitting such data points from the analysis. Alternative methods such as replacing the missing value with the mean of the variable was considered, but not implemented due to its potential effect on the variability of the dataset.

3.2. Data Collection

Data collected included concentrations of selected microbiological contaminants, global positioning system (GPS) coordinates for bomas and waterpoints, demographics and health data of the boma members, and the female head of boma's knowledge, attitudes and practices (KAP) around WaSH.

The water samples were analyzed for total coliforms, *E. coli*, and *Salmonella* spp. using the Micrology Laboratory's ECA Check Plus® Easygel® rapid water-quality assessment technology. The presence of sulphur-reducing bacteria (e.g., *Salmonella* spp.) was detected using the hydrogen sulphide gas strips. The GPS coordinates were determined using handheld devices. The demographic, socio-economic, health and KAP data were collected using a household questionnaire. The survey was administered in English, Swahili and Maasai to provide equal opportunity to all participants to complete the survey in their desired language. To ensure appropriate coverage of the three neighborhoods, a stratified random-sampling strategy was used and the adult females representing the household in each neighborhood were invited to participate in the survey. Approximately 115 surveys were administered in Chumvi, 40 surveys in Ethi and 23 surveys in Nadungoro. This represents 10% of adult females in Chumvi and Ethi and 15% of adult females in Nadungoro, which was sufficient to reach data saturation. More details can be found in Barber et al., 2017.

All procedures involving human participants were performed according to the standards set by the McMaster Research Ethics Board (MREB) and the 1964 Helsinki declaration (Original certificate # 2011-148). An ethics approval was received to complete the secondary data analysis (2011-148, Amendment 3). An informed consent was obtained from all the study participants prior to initiating interviews. The questionnaires were de-identified and the coded questionnaire results were double entered into a database to ensure quality and safety. No conflicts of interest have been identified in this study so far.

Summary Statistics

Summary statistics were calculated to explore relationships among microbiological water quality score, seasonality (dry vs. wet), type of waterpoint (i.e. piped, non-piped, rainwater), and self-reported aggregate frequency of diarrhoea stratified by age cohorts (i.e. percentage of bomas with diarrhoea problem). The water quality scores were established through expert knowledge (Dickson-Anderson and Schuster-Wallace), building on White et al. (n.d.) and the WHO drinking water quality standards (**Table 1**) (World Health Organization, 2017).

Table 1: Categorization of microbiological water quality data

	Colony Forming Units (C.F.U.)/250mL				
	Coliform	***Aeromonas***	***E. Coli***	**Fecal *E. Coli***	***Salmonella***
Very Low	0	0	0	0	0
Low	≤ 2500	≤ 2500	0	0	0
Moderate	> 2500	> 2500	≤ 87.5	0	0
High	> 2500	> 2500	> 87.5	0	0
Very High	> 2500	> 2500	> 87.5	> 0	> 0

Cost Analysis

Estimated theoretical travel times were calculated using a digital elevation model as shown in a previous study (Paez et al., 2019) . In addition to the digital elevation model, the global landcover (vegetation, rivers and water bodies) data obtained from IPUMS-Terra Terraclip (GLC2000) was incorporated into the path analysis (National Science Foundation, 2018). The landcover types and their respective walking speeds which were used to calculate travel times are summarized in **Table 2** (Bartholomé & Belward, 2005). Details pertaining to projections and the exact geospatial coordinates have been masked to protect the privacy of the community.

Table 2: Landcover dataset included in the cost analysis where highlighted landcover types are found in the study area

Code	**Landcover Type**	**Travel Speed (mins/km)**
1	Tree Cover, broadleaved, evergreen	60
2	Tree Cover, broadleaved, deciduous, closed	60
3	Tree Cover, broadleaved, deciduous, open	48
4	Tree Cover, needle-leaved, evergreen	36
5	Tree Cover, needle-leaved, deciduous	36
6	Tree Cover, mixed leaf type	36
7	Tree Cover, regularly flooded, fresh water	60
8	Tree Cover, regularly flooded, saline water	60
9	Mosaic: Tree cover / Other natural vegetation	48
10	Tree Cover, burnt	48
11	Shrub Cover, closed-open, evergreen	36
12	Shrub Cover, closed-open, deciduous	36
13	Herbaceous Cover, closed-open	36
14	Sparse Herbaceous or sparse Shrub Cover	24
15	Regularly flooded Shrub and/or Herbaceous Cover	60
16	Cultivated and managed areas	36
17	Mosaic: Cropland / Tree Cover / Other natural vegetation	36
18	Mosaic: Cropland / Shrub or Grass Cover	36
19	Bare Areas	24

20	Water Bodies	0

Discrete Choice Analysis

A multinomial logit model allows for discrete choice analysis when more than two distinct alternatives are present, which is why it was used to explore factors involved in waterpoint choice (**Table 3**) (Ben-Akiva & Bierlaire, 1999; Bierlaire, 2003). The model optimization process was conducted, and the results were reported only for the dry season as the initial model runs were all insignificant for the wet season. The insignificant results could be explained by a smaller sample size for the wet season (N=55) and the statistical demands of the discrete choice modelling.

Table 3: Description of variables included in the discrete choice analysis

#	**Variable**	**Description**
1	Travel times to chosen waterpoint	"*Which source do you visit MOST OFTEN in both dry and wet season?"* Return trip travel time from boma to the chosen waterpoint obtained from least-resistance path calculations (with both slope and landcover)
2	Microbiological water quality	Categorized as Very low, Low, Moderate, High, Very High risk based on levels of selected microbiological species (**Table 1**)
3	Income	*"How much money, if any, do you personally make in a month during dry season?"* Reported as a local currency value and analysed without any manipulations
4	Education	*"What is the highest level of school you have completed, if any?"* Reported level (e.g. primary, secondary) and grade and analysed without any manipulations
5	Boma population	Number of individuals in the boma
6	Average boma age	Calculated average age for all individuals in a boma

7	Number of females between age 8-45	Calculated total number of females in the boma between the ages of 8-45 years
8	Number of children under 5 years of age	Calculated total number of children under 5 in a boma
9	Aggregate frequency of diarrhoea stratified by age cohorts	*"How often do the following family members in your boma suffer from watery stomach?"* Reported on a 5-level Likert scale (never [1], rarely [2], sometimes [3], often [4], always [5]) Recoded into a binary variable for some analyses (1-2 on Likert scale = 0 on binary scale; 3-5 on Likert scale = 1 on binary scale) Age Cohorts: Under 5 years, 5 – 12 years, 13 – 17 years Female, Above 18 Female, Grandparents *Male members not included in the discrete choice analysis as they do not bear the burden of fetching water
10	Ratio of boma population to females between 8-45 years of age	Calculated ratio of number of individuals in the boma to the number of females between 8-45 years of age

All variables were incorporated as an interaction with time to investigate their effects on time as a cost. For each interacting variable, the model generated a coefficient that represented the direction of its effect on the cost associated with time. For example, a negative coefficient indicated that the variable further increased the cost related to travel time and decreased the attractiveness of a waterpoint. A positive coefficient indicated that a given variable decreased the cost related to travel time and increased the attractiveness of a waterpoint. The p-values associated with contribution of each variable were also calculated. The equation describing the model is referred to as a utility function and is shown below:

$$V_i x = \beta_1 A_i x + \gamma_1 B\&A_i x + \delta_1 C\&A_i x + \dots \qquad (1)$$

where x is a waterpoint alternative and β is the coefficient for variable A, γ is the coefficient for the interaction of variable A with variable B and δ is the coefficient for the interaction of variable A with variable C.

The best models were selected based on two-point criteria: the p-value of variable contribution and the log likelihood value of the model. The log-likelihood value is used to determine the fit of a curve and should be maximized when optimizing the models (Groenen, 2018). Variables were added to the model one at a time and assessed using the two-point criteria each time. If a model did not meet the two-point criteria, no further variables were added to improve it. This process was continued until a model with all significant variables ($p < 0.05$) and maximum log likelihood value was developed.

Once the model was established, it was used to predict the most probable waterpoint for each boma to fetch water from. Then, for each boma, the expected travel times were compared for the most probable predicted by each model and chosen waterpoints. Both travel times were calculated using the least-resistance path analysis and performed using changes in both slope and landcover.

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Chapter 4. Results & Discussion

4.1. Summary Statistics

Waterpoints

Within the Chumvi, Ethi and Nadungoro neighborhoods, not all bomas had piped water present within the premises and thus, some bomas fetched water from identified waterpoints. In the dry season, 63.3 % of the bomas fetched water from a waterpoint; whereas in the wet season, 39.6 % of the bomas fetched water from a waterpoint, and these values include bomas with a piped water source available on premises. In the 2012 dataset, 38 of the 75 sampled bomas in Chumvi, 40 of the 40 sampled bomas in Ethi and 23 of the 23 sampled bomas in Nadungoro fetched water from a waterpoint. When the effect of seasonality on waterpoint choice was further explored, the waterpoints used by bomas also differed in the two seasons. Approximately 74 % bomas in Chumvi, 48 % bomas in Ethi and 44 % 23 bomas in Nadungoro fetched water from the same waterpoints in both dry and wet season. This difference in waterpoint choice in dry and wet season can be explained by factors such as availability of piped water in the household premises, varying travel times to a waterpoint in different seasons, health factors (physical ability to fetch water from a waterpoint in different seasons), and water quantity or water quality in different seasons (Pearson, Zwickle, Namanya, Rzotkiewicz, & Mwita, 2016).

During the wet season, approximately 40 % of bomas in Chumvi, 8 % in Ethi and none in Nadungoro harvested rainwater. Although a lower percentage of bomas opted for rainwater harvesting in these three neighborhoods, rainwater harvesting is the most common alternative water collection method (Exall & Vassos, 2012). The likelihood of an individual adopting rainwater harvesting has been associated with factors such as their age and family size among others (Staddon, Rogers, Warriner, Ward, & Powell, 2018). Other challenges associated with nation-wide rainwater harvesting practices include water quantity and quality and economic feasibility of practices adopted (Amos, Rahman, & Mwangi Gathenya, 2016).

Diarrhoea cases from each boma were traced to the waterpoint used and the results are summarized in **Table 9** in the **Appendix**.

Water Quality

The waterpoints used by the bomas were all contaminated to some extent (Barber, Dickson-Anderson S.E., Schuster-Wallace C.J., Elliot S.J., & Tema S., 2017). Approximately 5% of the waterpoints were classified as low level of contamination and 5% were classified as high level of contamination. Of the 21 waterpoints, approximately 90% of them were classified as very high level of contamination. None of the waterpoints were classified as very low level or moderate level of contamination. This shows that majority of the individuals fetching water from the waterpoints were exposed to waterborne pathogens, which has implications for health. This lack of variability in the water quality dataset has implications for statistical modelling as well.

Diarrhoea

Self-reported aggregate frequency of diarrhoea showed that bomas with piped water in Chumvi had the lowest diarrhoea score and the non-piped bomas in Ethi had the highest score associated with them (**Table 4**). When these values on the Likert scale were tested for significance, the p-value was greater than 0.05. Presence of piped waterpoints, an improved water source as defined by the JMP, eases access to water. However, it does not improve access to potable water as piped water, if not treated, can still be contaminated (Bain et al., 2014). This highlights the difference between access to water and access to potable water and its implications for human health in the form of diarrhoea.

Table 4: Self-reported aggregate frequency of diarrhoea reported on a 5-level Likert scale stratified by neighborhood, seasonality and type of water source (piped to boma or a waterpoint)

	Dry		**Wet**	
	Water Piped to Boma	**Waterpoint**	**Water Piped to Boma**	**Waterpoint**
Chumvi	2.47	2.62	2.45	2.70
Ethi	--*	3.12	--*	3.19
Nadungoro	--*	2.67	--*	2.50

*Piped water within household premises are not present in this area.

Table 5: Percentage of bomas that reported diarrhoea as a problem (Likert scale 3-5) stratified by age cohort

	Under 5	5-12	13-17 Females	13-17 Males	Above 18 Females	Above 18 Males	Grandparents
Chumvi	83.6	65.7	42.3	43.2	26.4	19.1	50

Ethi	96.3	88	93.3	84.6	76.3	71.0	99.9
Nadungoro	52.4	85	72.7	65	44.4	50.0	76.9

When the aggregate frequency of diarrhoea was stratified by age cohorts, the differences between age groups were confirmed by the one-way ANOVA test where the diarrhoea score was found to be significantly among between all age groups ($p < 0.001$). Children under 5 years of age and grandparents' cohorts seem to have diarrhoea problems in all neighborhoods (diarrhoea considered a problem by 50 % or more bomas as shown in **Table 5**). This can be explained by the underdeveloped immune system in young children and a weaker immune system among seniors (Yamada, 2015). In this community, diarrhoea was generally a worse problem among all age groups, which could be explained by different water fetching or water handling preferences (Barber et al., 2017). In Nadungoro, diarrhoea was a problem among children 5-12 years of age, females 13-17 years and grandparents, perhaps due to differential immune system status (Yamada, 2015). It is important to note that diarrhoea is a symptom that can be an outcome of infection by a variety of pathogens. As children aged 5-12 are more active outdoors and females aged 13-17 are responsible for water fetching, these two age cohorts might be more exposed to other pathogens that cause diarrhoea, such as malaria.

Demographic and socio-economic variables

When differences between demographic and socio-economic variables were explored between bomas with piped water versus those that fetch water from waterpoints, the average boma population and income were higher among those with piped water (**Table 6**). This suggests that bomas with more individuals in the household and/or a higher income may find having a piped water supply more convenient due to their household population and are also in a better position to pay to obtain a piped water supply. Importance of income in waterpoint choice has also been explored previously where an individual's income level determines access to potable water, especially in areas where water is a commodity (Mahama, Anaman, & Osei-Akoto, 2014; Van Houweling, Hall, Carzolio, & Vance, 2017). That is not the case in this community as all waterpoints are free for use, but they do not supply potable water. Another way a higher income can affect access to potable water is through increased ability to hire someone for water fetching. Interestingly, the education level of the female heads of the household was higher for non-piped households. This unexpected result cannot be explained using existing literature. To explore this unexpected result further, income and education were tested for a correlation. Typically, a higher income provides opportunities for better education. However, in IGR, higher income does not correspond to a higher education level as scholarships are provided to youth, especially girls to go to school, so the finances do not pose a barrier the pursuit of education (United Nations Development Programme, 2012). This also explains why there was a lack of correlation between the two (**Figure 5**).

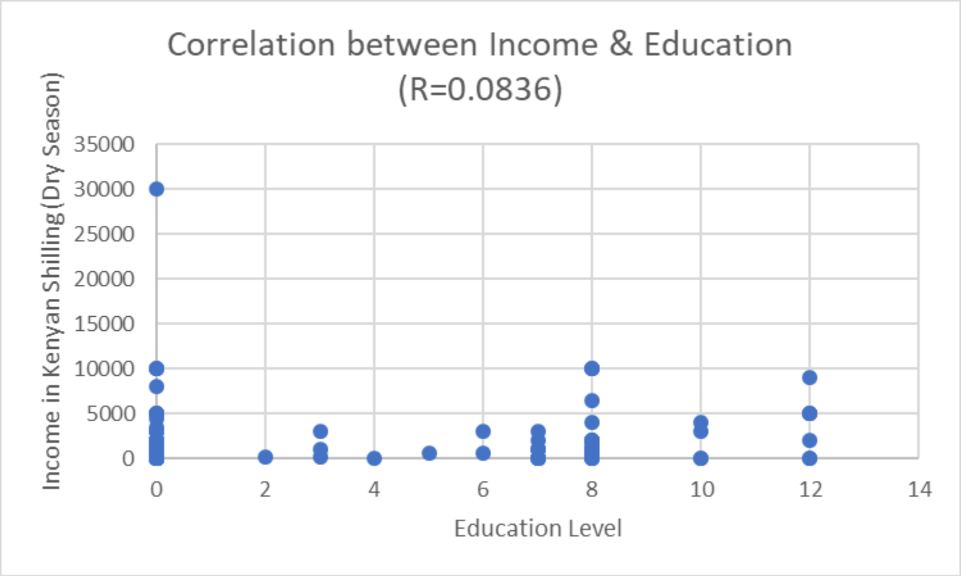

Figure 5: Correlation between Income and Education

Table 6: Differences in demographic and socio-economic variables between piped and non-piped sources

	Boma population		***Average age in the boma***		***Education level***		***Income in the dry season***	
	Piped	**Waterpoints**	**Piped**	**Waterpoints**	**Piped**	**Waterpoints**	**Piped**	**Waterpoints**
Mean	7.7	6.7	22.5	26.1	2.2	3.4	2332.7	1643.8
Standard Deviation	2.0	2.4	8.5	11.0	3.8	4.2	4617.864	2617.0
Range	9.0	11.0	49.3	60.0	12.0	12.0	30000.0	10000.0
Minimum	2.0	1.0	10.7	12.0	0	0	0	0
Maximum	11.0	12.0	60.0	72.0	12.0	12.0	30000.0	10000.0
Confidence Level (95.0%)	0.6	0.5	2.5	2.3	1.1	0.9	1340.9	551.3

4.2. Cost Analysis

As discussed earlier, straight-line path typically underestimates the cost associated with a path as it assumes a barrier-free movement on a flat surface (Noor et al., 2010; Okwaraji, Cousens, Berhane, Mulholland, & Edmond, 2012). To visually compare the different paths, the straight-line path, the least-resistance path with slope only and the least-resistance path with both slope and landcover **(Figure 6)** are illustrated below (**Figure 7**). As it can be observed from Figure 7, when changes in slope and landcover are included in the path analysis, the path differs based on the directionality of the trip. This is due to different slope changes in the to and from trip, showing that the least-resistance path calculations are a more nuanced way of measuring access. When the travel times extracted from the two least-resistance paths (with slope only and with slope and landcover both) were compared, they were highly correlated (R = 0.99) (**Figure 8**). Addition of the landcover layer increased the travel time by a factor of 0.2. Previously, Blandford et al. have conducted cost analyses to measure access to healthcare services in rural Niger and it was found that presence of vegetation reduces walking speed and increases travel time (Blanford, Kumar, Luo, & MacEachren, 2012). This change in speed can be explained by the varying plant morphology and density which can act as a barrier or even pose physical harm to individuals passing by (Bartholomé & Belward, 2005).

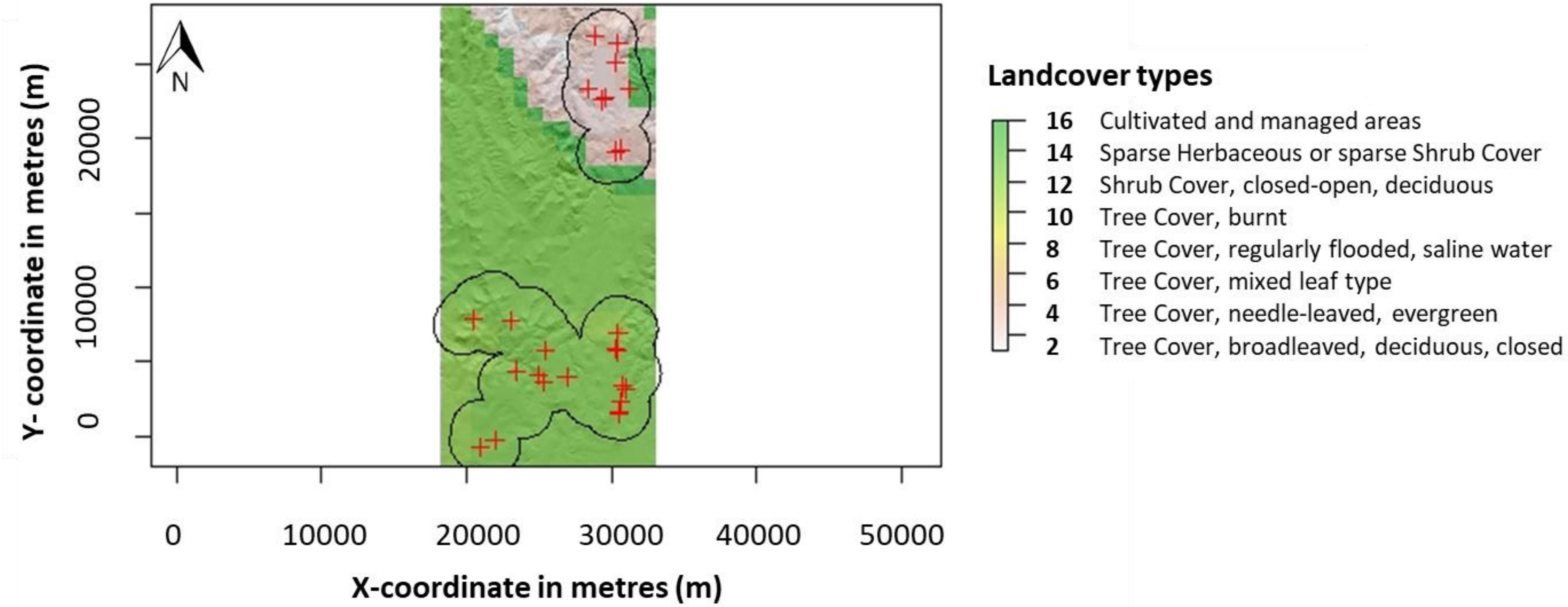

Figure 6: Landcover in the area of interest. Red crosses represent existing waterpoints.

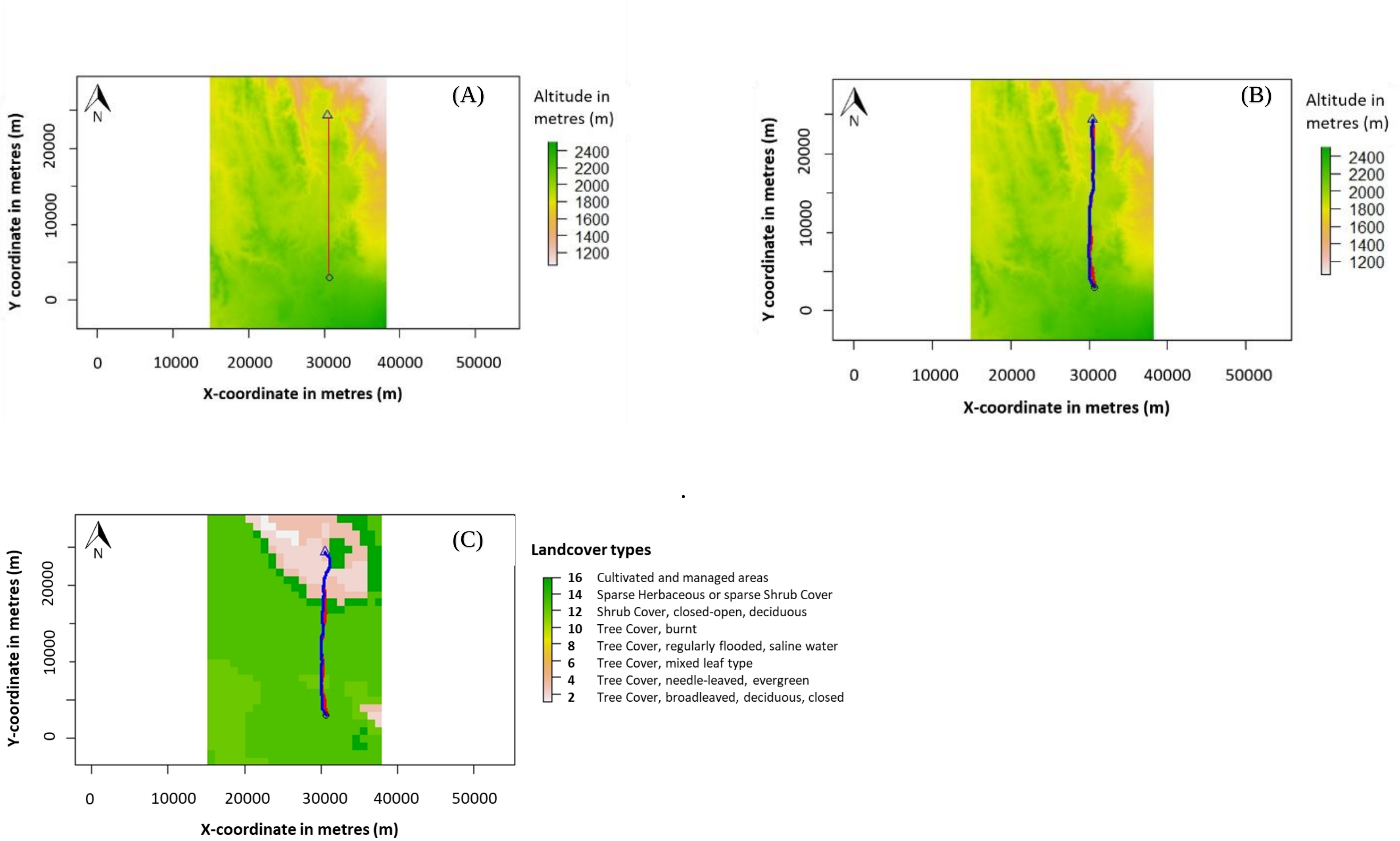

Figure 7: Comparison of different paths. (A) represents Euclidean or straight-line path. (B) represents least-resistance path using the slope only. (C) represents least-resistance path using both slope and landcover. Red denotes boma to water point trip and blue denotes

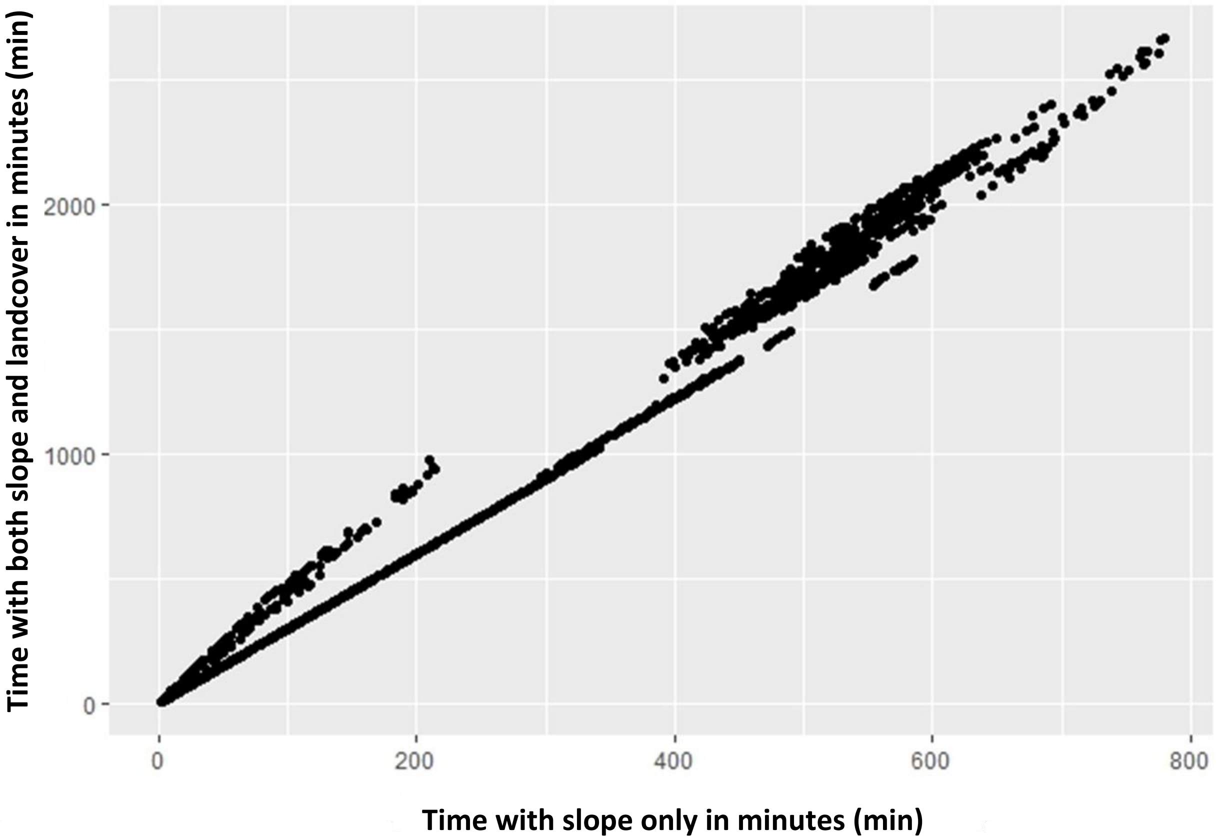

Figure 8: A scatterplot between travel time extracted from least-resistance path with slope only and with both slope and landcover. Pearson Correlation Coefficient, R= 0.99

4.3. Discrete Choice Analysis

Many physical, demographic and socio-economic factors were tested while developing the discrete choice model. The model optimization runs were completed only for the dry season as many bomas (40 % of bomas in Chumvi, 8 % in Ethi and 0% in Nadungoro) opted for rainwater harvesting in the wet season which was not a common water source in the dry season due to lack of rain in the dry season. Due to this, the number of bomas fetching water from waterpoints decreased (N=55) in the wet season and the sample size was not sufficient to conduct a discrete choice analysis. The justification for inclusion of each variable is shown in **Table 7**.

Table 7: Variables used in discrete choice analysis and rationale behind selection

#	**Variable**	**Rationale**
1	Travel times	Time spent on water fetching is the time lost from other productive activities. Individuals may choose to fetch water from a nearby waterpoint to save time and to avoid carrying water over large distances.
2	Microbiological water quality	Consumption of contaminated water has implications for human health; therefore, water quality may determine choice of water point in presence of multiple alternatives.
3	Income	A higher income may indicate a better access to resources (i.e., mode of transport to waterpoint or money to purchase water) and/or assistance (hiring someone else to fetch water for the individual).
4	Education	Higher education may correspond to a better understanding of water and its impact on health. It may also affect adoption of public health measures in the household. This may affect waterpoint choice.
5	Boma population	The number of household members determines the quantity of water that must be carried from the waterpoint. A boma with a larger number of individuals may choose to fetch water from a nearby waterpoint to avoid carrying water over large distances.
6	Average boma age	Average boma age can be used to determine the boma structure where a lower average age may indicate a younger population (including children) in the household or a smaller elderly population. This may have implications for childcare or responsibility to care for the elderly may also pose a barrier.
7	Number of females between age 8-45	This value indicates the number of individuals who are available to fetch water in the household.
8	Number of children under 5 years of age	A higher number of children under 5 years of age indicates additional maternal responsibilities, which has implications for waterpoint choice made by the women.

9	Aggregate frequency of diarrhoea stratified by age cohorts	The impact of poor water quality can be assessed through health outcomes and severity of diarrhoea can be used as a proxy for exposure to pathogens.
10	Ratio of boma population to females between 8-45 years of age	Number of individuals in the household per female can be used to determine the impact of boma population and number of females available to fetch water on waterpoint choice.

Among the variables tested, water quality, diarrhoea among children under the age of 5, diarrhoea among children age 5-12, diarrhoea among females age 13-17, diarrhoea among grandparents, number of children under 5, and ratio of number of household members to number of women between 8-45 did not contribute significantly to any of the tested models. Intuitively, the quality of water may affect choice, where an individual may choose to fetch water from a farther but better quality waterpoint, if an individual is aware of the effects of poor water quality on health. However, there is insufficient evidence to support contribution of water quality to waterpoint choice model. This is likely due to a lack of variation in the water quality data, that is, almost all waterpoint samples were highly contaminated (95% were classified as either high or very high level of microbial contamination). Diarrhoea among children (under 5 and 5-12 years) may be another important factor in determining waterpoint choice, as women with sick children may choose to fetch water from a closer waterpoint to accommodate the additional childcare, or they may be willing to travel farther distances to fetch safer water for their children. Based on our results, it is not possible to determine if/how diarrhoea among children impacts waterpoint choice.

Similarly, females between ages 13-17 years are usually responsible for fetching water, so their health would seem to be an important variable in water choice model. However, we do not have enough evidence to support its contribution to the waterpoint choice model. Diarrhoea among grandparents, which may be important from provision of childcare and elderly care viewpoint was another insignificant variable. An explanation to this could be that we did not have sufficient datapoints to lead to significant results or perhaps this variable is not important in this particular context. The number of children under 5 was included to explore whether increased childcare responsibilities contributed to waterpoint choice, but based on the model testing, this variable did not affect waterpoint choice. To investigate whether water collection burden stemming from a large household population (higher quantity of water needed) contributes to waterpoint choice, the ratio of number of household members to females between 8-45 years of age was explored but was also found to be insignificant.

4.3. Emergent Models

Travel time, income, education, average boma age, diarrhoea among women above 18, and number of women between ages 8 and 45 contributed significantly to the models. Exploration of different combinations of these variables led to development of the three best models (**Table 8**). In these models, the contributions from all individual variables were statistically significant and the log likelihood values were maximized.

Model 1 (Time, diarrhoea among adult women and boma average age) (**Equation 2)** predicts that (i) as the travel time to a waterpoint increases, its utility or attractiveness decreases (Coefficient estimate = -2.1e-02; p-value = 7.4e-09). It is interpreted as individuals being less likely to fetch water from a waterpoint located far away to minimize cost. Previous studies have also shown impact of travel time on waterpoint choice (Fotue, 2012; Rauf, Bakhsh, Hassan, Nadeem, & Kamran, 2015). (ii) The model also predicts that as the boma average age increases, the utility or attractiveness associated with farther waterpoint further increases (Coefficient estimate = 3.0e-04; p-value = 4.2e-05). If a lower boma average age is interpreted as a larger number of children in the boma, then having to provide childcare puts an additional strain on women as water-collectors, thus limiting their ability to travel farther distances. However, when the number of children under 5 was used a variable, it was found to be insignificant. If a lower boma average age is interpreted as fewer number of adults in the boma, then lack of support for women who fetch water or fewer number of individuals available to fetch water may pose additional strain on water-collectors. Although unclear, the results show that differences in the boma structure may affect women's ability to fetch water from farther waterpoints and therefore their choice of waterpoints. (iii) Lastly, the model also predicts that increased diarrhoea frequency in adult women further decreases the utility or attractiveness of a waterpoint with a long travel time (Coefficient Estimate = -6.7e-03; p-value = 0.049). As adult women are usually responsible to fetch water, their poor health (indicated here by increased frequency of diarrhoea) may affect their ability to walk far and/or carry water.

$$V_i x = \beta_1 \mathrm{Time}_i x + \gamma_1 \, \mathrm{Diarrhoea} \,\&\, \mathrm{Time}_i x + \delta_1 \, \mathrm{AverageAge} \,\&\, \mathrm{Time}_i x \qquad (2)$$

Similar to Model 1, Model 2 (Time, income and boma average age) (**Equation 3**) also predicts that (i) as the travel time to a waterpoint increases, its utility or attractiveness decreases (Coefficient estimate = -2.6e-02; p-value = 7.1e-10). (ii) The contribution of average age to Model 2 is also the same as Model 1 (Coefficient estimate = 3.1e-04; p-value = 0.0001). (iii) Model 2 is slightly different from Model 1 as it predicts that higher income further increases the utility or attractiveness of a waterpoint with a long travel time (Coefficient Estimate = 1.1e-06; p-value = 0.01). This can be explained by the ability of individuals with a higher income to pay someone else to fetch water for them (Mahama et al., 2014).

$$V_i x = \beta_1 \text{Time}_i x + \gamma_1 \text{ Income \& Time}_i x + \delta_1 \text{ AverageAge \& Time}_i x \qquad (3)$$

In Model 3 (Time, income, education and number of females between 8-45 years), the contribution of time and income was similar to those of Model 1 and 2 (**Equation 4**). (i) It predicts that as the travel time to a waterpoint increases, its utility or attractiveness decreases (Coefficient estimate = -7.9e-03; p-value = 0.004) and (ii) higher income further increases the utility or attractiveness of a waterpoint with a long travel time (Coefficient estimate = 9.5e-07; p-value = 0.03). (iii) Model 3 also predicts that as the education level of the female head of boma decreases, the utility or attractiveness associated with a farther waterpoint further increases (Coefficient estimate = -1.2e-03; p-value = 0.04). This means that female heads with a lower education status are more willing to travel farther to fetch water. Previously, higher education has been found to increase awareness surrounding water behaviours and led to individuals walking further for better water or adopting water-related public health safety measures in the household (Kitamura et al., 2014). However, from these results, it is unknown whether less educated individuals go farther in search for relatively better quality, better water quantity or another reason. (iv) Lastly, the model also p redicts that a higher number of females between 8-45 years of age in a boma further decreases the utility or attractiveness of a waterpoint with a long travel time (Coefficient Estimate = -6.7e-03; p-value = 0.049). If a higher number of females between 8-45 years of age means a larger boma population, then these results can be interpreted as women choosing a closer waterpoint to avoid carrying a large quantity of water over a long distance. However, when the boma population was tested as a variable in the model, the model did not meet the two-point criteria.

$$V_i x = \beta_1 \text{Time}_i x + \gamma_1 \text{ Income \& Time}_i x + \delta_1 \text{ Education \& Time}_i x + \varepsilon_1 \text{ Number of Women 8-45 \& Time}_i x \qquad (4)$$

Table 8: Best models based on significance of contribution of each variable to the model and log likelihood value

	Estimate	**Standard Error**	**Z-value**	**P-value**	**Log Likelihood**
Model 1					
Time	-2.1e-02	3.6e-03	-5.8	7.4e-09	-116.98
Diarrhoea (Adult Women)	-6.7e-03	3.4e-03	-2.0	0.049	
Average age	3.0e-04	7.2e-05	4.1	4.2e-05	
Model 2					
Time	-2.6e-02	4.3e-03	-6.2	7.1e-10	-116.98
Income	1.1e-06	4.5e-07	2.5280	0.01	
Average age	3.1e-04	8.1e-05	3.8398	0.0001	
Model 3					
Time	-7.9e-03	2.8e-03	-2.8	0.004	-117.45

Income	9.5e-07	4.3e-07	2.2	0.03	
Education	-1.2e-03	5.8e-04	-2.1	0.036	
Number of females in the boma between 8-45 years	-3.2e-03	1.5e-03	-2.2	0.03	

Different combinations of the six variables that contributed to the best three models were explored. However, the addition of variables beyond the third variable for Models 1 and 2, and the fourth for Model 3 resulted in one of the variables becoming insignificant. This can be explained by the relative explanatory power of each variable and how the addition of each subsequent variable affects the contribution of other variables to the model. Therefore, when another variable is added, the contribution by all variables is affected, which may lead to some variables becoming insignificant. **Figure 11** in the **Appendix** shows some of the models explored during the optimization process.

The models were used to predict the most probable waterpoint for each boma and then the travel times to the most probable waterpoint were calculated using the least-resistance path analysis described above. When the travel times from the three models were plotted, they overlaid on each other due to their similar predictive powers. The actual travel time to the waterpoint was calculated using the least-resistance path (with slope and landcover) to a boma’s chosen waterpoint. A comparison of the distribution of the calculated travel time based on the most probable waterpoint (extracted from each model) and the actual travel time to the chosen waterpoint was conducted. This comparison showed that all three models fit the actual travel time distribution well (**Figure 9**). However, all models overestimate the number of bomas that may choose to fetch water from a closer waterpoint. There were a few outliers where some bomas fetched water from farther waterpoints due to factors not explored in this study (i.e., to avoid waiting times, overcrowding, conflict or safety).

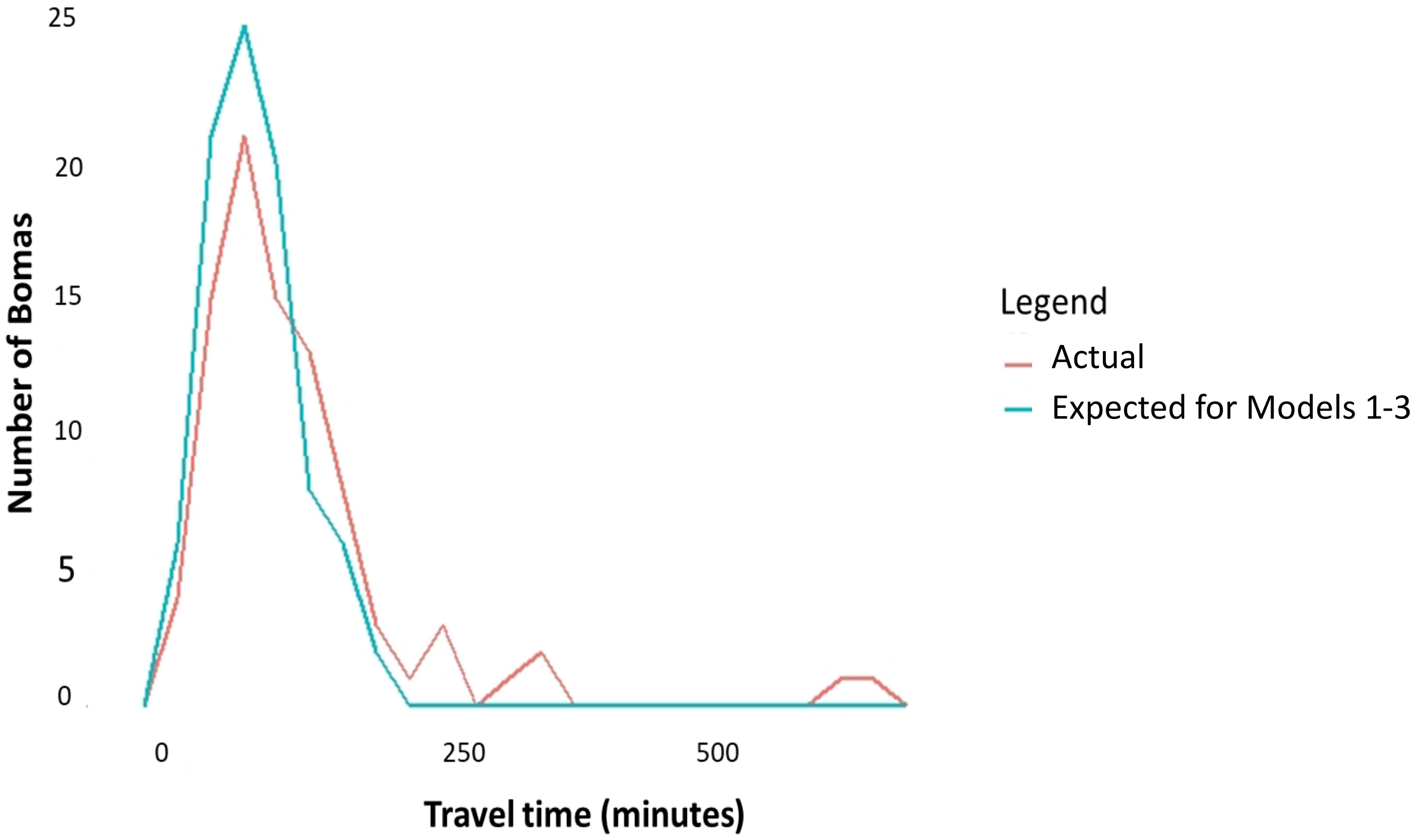

Figure 9: Comparison of the distribution of travel times originating from the multinomial logit models (Expected) with the actual distribution of travel times (Actual).

4.4. Public Health & Policy Implications

Equitable access to potable water is a public health concern in this Maasai community. Most of the bomas lack a piped water source on the household premises, and women and adolescent girls bear the burden of fetching water as a result. From the results, travel time to waterpoints emerged as an important variable in waterpoint choice decision-making. This highlights physical barriers to potable water in this community due to the heterogenous landscape. Furthermore, the majority of waterpoints in this community are contaminated with pathogens, which results in a higher diarrhoeal burden in the community. High diarrhoeal burden, in turn, affects the quality of life and an individual's ability to be productive member of the society. The models also show that diarrhoea among adult women and number of females between eight and 45 years of age are important factors in the waterpoint choice matrix among others. This is intuitive as there is a disproportionate water collection burden on women, so the number of females available to fetch water and their health impacts access to water. Access to potable water is a fundamental human right, yet many individuals lack access to this necessity and this highlights the importance of research on factors that impact waterpoint choice.

This study also highlights certain social determinants of health (i.e., income and education) as determinants of waterpoint choice. Socio-economic factors such as income and education contributed to the models, showing that individuals with a higher income and lower education were willing to go farther to fetch water. When a safely-managed drinking water service is not readily accessible, an individual's income level may determine the additional services they can access (e.g., purchasing water from water vendors and hiring someone to fetch water), and provides an advantage to some members of the population. This has implications for equity and SDG's mandate for leaving no one behind (WWAP, UNESCO, & Azoulay, 2019) where individuals and communities are denied their right to access to potable water and suffer from poor health consequences. Moreover, an individual's education level impacts the water-education nexus, awareness around water-safety behaviours and public health measures in their homes (Kitamura et al., 2014).

Issues related to access to potable water are typically worse in rural areas. However, following the implementation of the Kenya 2016 Water Act, a policy based on a pro-poor and pro-rural strategy to tackle water issues, it is possible that access to potable water in this community may improve in the years to come, even though not much progress has been made since the introduction of the act (Bisung et al., 2016; World Resource Group, 2016). A policy recommendation stemming from these results includes provision of piped water into the boma premises from waterpoints to minimize the burden of water collection and to improve health outcomes for women. Another policy recommendation is introduction of equitable, accessible and potable waterpoints in these communities as the already-existing waterpoints are not geographically well-spread. This can be done by introducing waterpoints that supply potable water at no cost and are located within 30 minutes travel time (SDG 6.1) for all bomas. Introduction of new accessible waterpoints also provides an opportunity to ensure they are also potable by implementing source water protection measures and introducing treatment systems. A policy to improve the potability of the waterpoints in this community by subsidizing the cost associated with water treatment (e.g., filters to purify and fuel to boil water) can also be enforced (Cohen & Colford, 2017).

Many public health recommendations can also be drawn from this study. For example, accessibility can be improved by offering alternative methods to ease the water collection burden (e.g., provision of animals and/or bicycles to women to travel to/carry water). Although, in many cultures, women are not allowed to ride bicycles; therefore, a culturally-appropriate alternative, perhaps providing backpacks to carry water, could be adopted (Asaba, Fagan, Kabonesa, & Mugumya, 2013; Markham, 2012). Public health professionals can also ensure the sustainability of waterpoint potability through monitoring and reporting. Regardless of the type of intervention introduced in this community to improve equitable access to potable water, it is critical to involve the community in the decision-making process to ensure appropriateness, sustainability and positive health impact of an intervention (O’Mara-Eves et al., 2015).

4.5. Limitations

Important challenges with secondary data analysis include limitations associated with repurposing the dataset, interpretation of variables and lack of control over the methodology used and variables collected. For this study, variables such as self-reported travel time and waiting time at the waterpoint might have been important factors to consider in waterpoint choice modelling. However, these data were not collected. Furthermore, the framing of the question about diarrhoeal disease also made it difficult to determine whether the variable was incidence or prevalence. This challenge was overcome by classifying it as a self-reported aggregate frequency of diarrhoea stratified by age cohorts.

Although the model explains waterpoint choice behaviour well, caution must be taken when interpreting the results of this study. The results show that certain variables (e.g. water quality) do not contribute waterpoint choice, but this does not mean that the importance of water quality in choice should be disregarded. Rather, this is likely an artifact due to the lack of variability in the water quality parameter (i.e., state 90 % of waterpoints were either at high or very high level of contamination) suggesting that the evidence is insufficient to support the impact of water quality on source choice based on this dataset.

Another limitation associated with this study is the absence of water quality and aggregate frequency of diarrhoea variables stratified by seasonality. Although, the focus of the analysis was on the dry season, this lack of data may impact the results as the data are not specific to the dry season. This can mask the impact of seasonal changes in water quality and aggregate frequency of diarrhoea on waterpoint choice.

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Chapter 5. Conclusions and Future Directions

5.1. Conclusions

The goal of this study was to explore which factors effect equitable access to water in a rural Maasai community in Kenya. The goal was achieved through investigation of relationships between travel time and waterpoint choice, demographic and socio-economic factors and waterpoint choice and self-reported health (diarrhoea) and waterpoint choice. The following conclusions can be drawn from the results of this study.

The addition of landcover (vegetation and water bodies) into cost analysis reduced walking speed and increased travel time. Travel time calculated by incorporating landcover variables in addition to the slope provides more realistic estimates of travel time between two points. For example, presence of broadleaved evergreen trees and water bodies may slow down the walking speed significantly or pose a barrier in the path. Presence of low shrubs, however, may not have a huge impact on walking speed.

Based on the findings of this study, travel time, income and average age of the household; travel time, diarrhoea among adult females and average age of the household; and travel time, income, education and number of females between ages 8-45 years form the three best models that explain waterpoint choice in this community. All models suggest that travel time is a very important variable in waterpoint choice from the perspective of water-collectors. In the presence of a waterpoint where financial cost does not pose a barrier, travel time can be a cost associated with fetching water from different waterpoints. This finding also has implications for the SDG 6.1 target of universal access to potable water within 30 minutes of roundtrip including queuing time.

The SDG 6.1 target is to provide equitable access to potable water to everyone around the world. From this study, physical barriers (travel time), health (diarrhoea), disproportionate gender burden, rurality and micro-level socio-economic factors (income and education) emerged as potential barriers to equitable access to potable water. However, the pro-rural and pro-poor approaches under the 2016 Kenya Water Act, may target these barriers to water access in the upcoming years.

5.2. Future Directions

Factors such as water quality, which may have implications for waterpoint choice, were found to be insignificant within the limitations previously identified. To explore how contributions of variables change with different methodological approaches, other statistical methods and regression models could be explored.

In this study, travel time was used as a cost. Other ways to measure cost associated with accessing a waterpoint are walking distance and energy expenditure and should be explored in future studies. The latter of which has implications for adolescent girls and pregnant women.

To investigate whether this model can be further improved in its predictive power, data should be collected on other variables such as self-reported travel time to chosen waterpoint, prevalence of diarrhoea for each household member, water quantity and waiting times associated with each waterpoint.

Once a model with a high predictive power is built, it can be used to propose policy recommendations and to inform evidence-based decision-making for water-related developmental work. A time savings map provides an opportunity to identify the most equitable locations for new points that will reduce travel time for all bomas in the community. Furthermore, such new water interventions will be implemented by keeping physical and socio-economic accessibility and demographic factors in mind.

Appendix

*Table 9: This table shows aggregated reported boma diarrhoeal frequencies by age group linked with each waterpoint in the dry season. Here 0 = diarrhoea is not a problem; 1 = diarrhoea is a problem; * = data not available*

Waterpoint	**Under 5**	**5-11**	**13-17 Females**	**13-17 Males**	**Above 18 Females**	**Above 18 Males**	**Grandparents**
1	1	1	1	1	1	1	1
2	1	1	1	*	1	1	*
3	1	1	*	1	0	0	*
4	1	1	1	1	1	1	1
5	*	1	*	1	0	0	*
6	1	*	1	*	1	1	*
7	1	1	1	1	1	1	1
8	1	0	0	0	0	0	1
9	*	1	1	0	0	0	*
10	1	1	1	1	1	1	*
11	1	1		1	1	1	1
12	0	1	1	1	0	1	1
13	1	1	1	1	1	1	*
14	1	0	*	0	0	0	*
15	1	1	*	*	1	1	1
16	1	1	1	1	1	1	1
17	1	1	0	1	1	1	1
18	*	*	1	*	*	*	*
19	0	1	*	1	1	0	1
20	1	1	1	0	0	0	1
21	1	1	0	1	1	1	1
22	1	1	1	1	0	0	1
23	1	1	0	1	1	1	1
24	1	1	1	1	1	1	0
25	1	1	1	1	1	0	*
26	0	0	0	0	0	0	*
27	0	1	1	1	0	1	1
28	1	1	1	1	1	1	1

		Time		Income		Average age		Education		Diarrhoea Females Above 18		Number of children 5 and under		Number of women in household between 8-45		Ratio of total household size to women between the ages of 8 and 45		Household Size	
Model #	Log-likelihood Value	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value	Estimate	P-value
1	-123.8	-0.0139337	<0.05																
2	-122.87	-0.0097476	<0.05													-0.00147	>0.05		
3	-122.72	-0.0111882	<0.05									0.003206	>0.05						
4	-122.02	-0.0089678	<0.05											-0.0026937	>0.05				
5	-121.74	-1.38E-02	<0.05	6.8141E-07	>0.05					-4.10E-03	>0.05								
6	-121.74	-1.38E-02	<0.05	6.8141E-07	>0.05					-4.10E-03	>0.05								
7	-121.68	-9.49E-03	<0.05							-0.0050905	>0.05	-0.0028506	>0.05						
8	-121.68	-0.0075265	<0.05							-0.0053875	>0.05					-0.0015006	>0.05		
9	-121.5	-5.25E-03	>0.05															-0.0014551	<0.05
10	-121.35	-0.00471929	>0.05													-0.00060715	>0.05	-0.00125372	>0.05
11	-121.2	-5.09E-03	>0.05									-0.00185313	>0.05					-0.0012159	>0.05
12	-121.17	-0.01175576	<0.05					-0.0012149	<0.05										
13	-121.14	-1.10E-02	<0.05	9.61E-07	<0.05											-1.75E-03	>0.05		
14	-120.95	-1.30E-02	<0.05	1.00E-06	<0.05							-3.55E-03	>0.05						
15	-120.48	-1.05E-02	<0.05	9.10E-07	<0.05									-2.88E-03	>0.05				
16	-120.37	-0.00824601	<0.05					-0.001205	<0.05							-0.00123474	>0.05		
17	-120.36	-0.0060928	<0.05							-0.0062187	>0.05			-0.0029758	<0.05				
18	-120.2	-0.00286672	>0.05							-0.00553209	>0.05							-0.00149841	<0.05
19	-120.19	-7.43E-03	>0.05	8.95E-07	>0.05													-1.39E-03	<0.05
20	-120.18	-0.01002135	<0.05					-0.0011567	>0.05	-0.00472959	>0.05								
21	-120.18	-0.01002135	<0.05					-0.0011567	>0.05	-0.00472959	>0.05								
22	-120.03	-0.00915051	<0.05					-0.001223	<0.05			-0.00297513	>0.05						
23	-119.91	-1.35E-02	<0.05	7.4908E-07	>0.05			-1.15E-03	>0.05										
24	-119.91	-1.35E-02	<0.05	7.4908E-07	>0.05			-1.15E-03	>0.05										
25	-119.17	-0.00686188	<0.05					-0.0012299	<0.05					-0.0026666	<0.05				
26	-119.09	-2.28E-02	<0.05			2.74E-04	<0.05												
27	-118.22	-2.83E-03	>0.05					-1.32E-03	<0.05									-0.00146421	<0.05
28	-117.45	-7.94E-03	<0.05	9.54E-07	<0.05			-1.21E-03	<0.05					-3.19E-03	<0.05				
29	-117.23	-1.98E-02	<0.05			2.41E-04	<0.05	-1.05E-03	>0.05										
30	-117.23	-1.98E-02	<0.05			2.41E-04	<0.05	-1.05E-03	>0.05										
31	-116.98	-2.09E-02	<0.05			2.97E-04	<0.05			-6.72E-03	>0.05								
32	-116.77	-6.23E-03	<0.05	1.06E-06	<0.05			-1.17E-03	<0.05					-2.79E-03	<0.05	-9.21E-04	>0.05		
33	-116.32	-6.43E-03	<0.05	1.13E-06	<0.05			-1.15E-03	>0.05			-2.80E-03	>0.05	-2.89E-03	<0.05				
34	-116.29	-6.17E-03	<0.05	1.13E-06	<0.05			-1.14E-03	>0.05			-2.43E-03	>0.05	-2.81E-03	<0.05	-2.56E-04	>0.05		
35	-115.61	-2.44E-02	<0.05	9.073E-07	>0.05	3.28E-04	<0.05			-5.62E-03	>0.05								
36	-115.61	-2.44E-02	<0.05	9.073E-07	>0.05	3.28E-04	<0.05			-5.62E-03	>0.05								
37	-115.59	-4.15E-03	>0.05	9.30E-07	>0.05			-1.07E-03	>0.05	-4.08E-03	>0.05	-2.32E-03	>0.05	-2.95E-03	<0.05	-2.59E-04	>0.05		
38	-115.58	-2.30E-02	<0.05	9.5388E-07	<0.05	2.71E-04	<0.05	-9.25E-04	>0.05										
39	-115.54	-1.82E-02	<0.05			2.58E-04	<0.05	-9.42E-04	>0.05	-5.86E-03	>0.05								
40	-115.49	-3.39E-03	>0.05	9.42E-07	>0.05			-1.12E-03	>0.05	-3.76E-03	>0.05	-1.83E-03	>0.05	-2.40E-03	>0.05	-1.16E-04	>0.05	-4.45E-04	>0.05

Figure 10: List of models tested