UNDERSTANDING WHAT SANITATION USERS VALUE – EXAMINING PREFERENCES AND BEHAVIORS FOR SANITATION SYSTEMS

A Dissertation
Presented to
The Academic Faculty

by

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In Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy in Environmental Engineering in the
School of Civil and Environmental Engineering

Georgia Institute of Technology
August 2013

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To my host of angels in heaven above…
Great-grandfather Curry Hall and Great-grandmother Rosa Bell
Grandmother Olivia, Grandmother Lula, and Grandfather Oliver
Great-uncle David, Great-aunt Daisy, Great-aunt Sarah, and Great-great-aunt Blanche
Uncle Ardell, Uncle DeeDee, Uncle Bobby,
Uncle Kenny, Uncle Ricky, and Aunt Anne Mae
Cousin Dominion and my dear friend Melissa

And to those here on earth …

Ubuntu
I am because you are because we are

ACKNOWLEDGEMENTS

I would like to take this opportunity to thank my advisor Dr. Joseph Hughes for his continued support throughout my tenure at Georgia Tech. I remember when we started on this journey so many years ago. Your encouragement has always allowed me to dream big. Thank you for your guidance and always reminding me to "tell the right story."

I would also like to thank members of my doctoral committee – Drs. Yongsheng Chen, Eugene Cloete, John Crittenden, Susan Cozzens, and Jaehong Kim – for your critical review and constant guidance throughout my doctoral process. A personal heartfelt thanks goes to my mentor Dr. Reginald Desroches for, simply, everything he has done. I also wish to thank:

> The Brook Byers Institute for Sustainable Systems at Georgia Tech and the Water Institute at Stellenbosch University for their support of my research.
>
> The National Science Foundation and the Georgia Tech FACES Program for funding my academic career.
>
> The Georgia Tech community that I have grown to love and will miss dearly, including the Civil and Environmental Engineering staff, the Engineering Education Outreach staff of the College of Engineering, and my fellow members of the BGSA.
>
> The countless friends I have met over the years – including Akibi, Akil, Christian, Denise, Diran, Ellenor, Fei, Nathanial, Jazz, Johana, and Sachiyo – for making my years at Georgia Tech memorable.

My friends who have been here from the beginning to the end – including Cassandra, Tammy, Lydia, and Benecia – for being such true friends.

My parents – Cornell and Shirley Seymour – for their unconditional love and support, my siblings – Oni, Uri, and Chris – for being my loudest and proudest cheerleaders, my Grandmother Cynthia for always being there for me, my nephew Kayin for constantly reminding me that life is a bundle of joy, and my host of uncles, aunts, and cousins for the abundant love I receive from them.

And to the Creator, the Most High, My Provider, My Refuge and My Fortress who knew me in the womb and planned this very precise moment in my life: I give thanks.

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SUMMARY

Over the last two decades, sanitation policy and development has undergone a paradigm shift away from heavily-subsidized, supply-driven approaches towards behavioral-based demand-driven approaches. These current approaches to increase sanitation demand are multi-faceted, requiring multiple stakeholders with varying degrees of interest, knowledge, and capacity. Although efforts exist to increase sanitation access by incorporating engineering design principles with implementation planning approaches, these groups generally work independently without strong connections, thus reducing the potential of their impact. As a result, the design of appropriate sanitation technology is disengaged from the implementation of acceptable technology into communities, disconnecting user preference integration from sanitation technology design and resulting in fewer sanitation technologies being adopted and used. To address these challenges in developing successful interventions, this research examined how user preferences for specific attributes of appropriate sanitation technologies and their respective implementation arrangements influence their adoption and usage. Data for the study included interviews of 1002 sanitation users living in a peri-urban area of South Africa; the surveyed respondents were asked about their existing sanitation technology, their preferences for various sanitation technology design attributes, as well as their perspectives on current and preferred sanitation implementation arrangements. The data revealed that user acceptability of appropriate sanitation technology is influenced by the adoption classification of the users. Through the identification of motives and barriers to sanitation usage that were statistically significant, it exhibited the need to differentiate users who share private sanitation from those use communal sanitation facilities. Results also indicated that user acceptability of appropriate sanitation systems is dependent on the technical design attributes of sanitation. The development of utility functions detailed the significance of seven technical design attributes and determined their respective priorities. An agent-based simulation examined how user preferences for sanitation technology design and implementation influence its adoption and usage. Findings suggest that user acceptability of sanitation technology is dependent on both the technology design and the implementation arrangement being preferred.

CHAPTER 1

INTRODUCTION

1.1 Background and Justification

The term "sanitation" refers to the hygienic management of human excreta through collection, disposal, or reuse methods (Ujang and Henze 2006). As human excretion is a primary mode of disease transmission, "improved" sanitation technologies attempt to minimize human contact with excreta, and therefore, reduce the risk of transmission of potential pathogens (Wagner and Lanoix 1958, Kawata 1978, UNICEF & WHO 2012). The overwhelming majority of the estimated 2.6 billion people who do not have access to improved sanitation lives in the developing regions of Asia, Africa, and Latin America (UNICEF & WHO 2012). Little progress has been made over the last two decades to reduce the percentage of the world's population without access to improved sanitation. As shown in Table 1.1, the additional 1.3 billion people who obtained access to improved sanitation between the years of 1990 and 2008 represent a mere 7% increase in sanitation coverage for the world population.

Table 1.1. Access to Improved Sanitation 1990-2008

Year	1990	2008	Differential
World total population (#)	5.3 billion	6.7 billion	1.4 billion
Percentage of world total population with access to improved sanitation (%)	54%	61%	7%
Total population of the world with access to improved sanitation (#)	2.8 billion	4.1 billion	1.3 billion

(Joint Monitoring Programme 2010)

Figures 1.1 and 1.2 illustrate the global disparity within sanitation access at the regional level. As of 2008, developing regions with the largest portion of their population using improved sanitation facilities include Northern Africa, Western Asia, Latin America and the Caribbean; in contrast, regions with the least amount of sanitation coverage are Sub-Saharan Africa and Southern Asia. The most significant changes in improved sanitation usage are in South-Eastern Asia and Northern Africa. The Sub-Saharan region of Africa lags behind; coverage rose slightly from 27% in 1990 to 31% in 2010 (Joint Monitoring Programme 2010).

Notwithstanding the fact that "water and sanitation" are often coupled as a policy approach, sanitation investments are, by and large, dwarfed by those supporting water initiatives. From 1990-2000, investments in sanitation represented one-fifth of the total invested amount made by developing countries for water and sanitation initiatives; this disparity equated to US$12.6 billion (year 2000) in water investments and only US$3.1 billion (year 2000) in sanitation (UNICEF & WHO 2000). Whereas the relationship between clean water, adequate sanitation, and proper hygiene is well established, recent research has shown that investments in sanitation provide higher returns. Improving water supplies can lead to a 25% reduction of diarrheal disease among children under five, compared to a 32% reduction for similar investments in sanitation systems (Fewtrell et al. 2005). Out of the estimated 2.2 million people that die annually from diarrheal diseases due to the lack of clean water supplies, inadequate sanitation, and poor hygiene practices; approximately 68% of those deaths represent 1.5 million children under five whose deaths result just from the lack of basic sanitation and poor hygiene habits (Green and Ho 2005, UNICEF & WHO 2006).

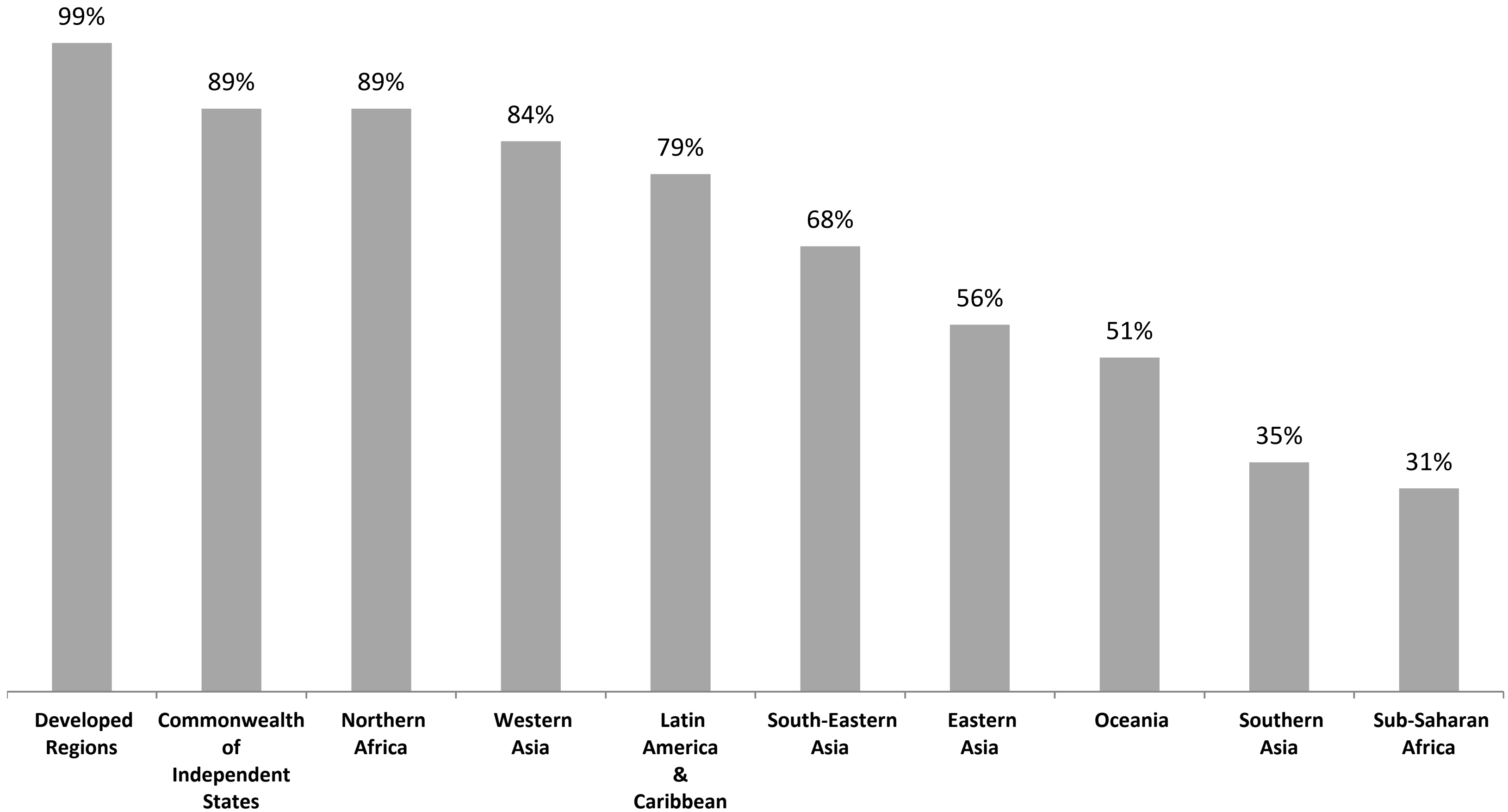

Figure 1.1. Usage of improved sanitation by region in 2010 (Joint Monitoring Programme 2010)

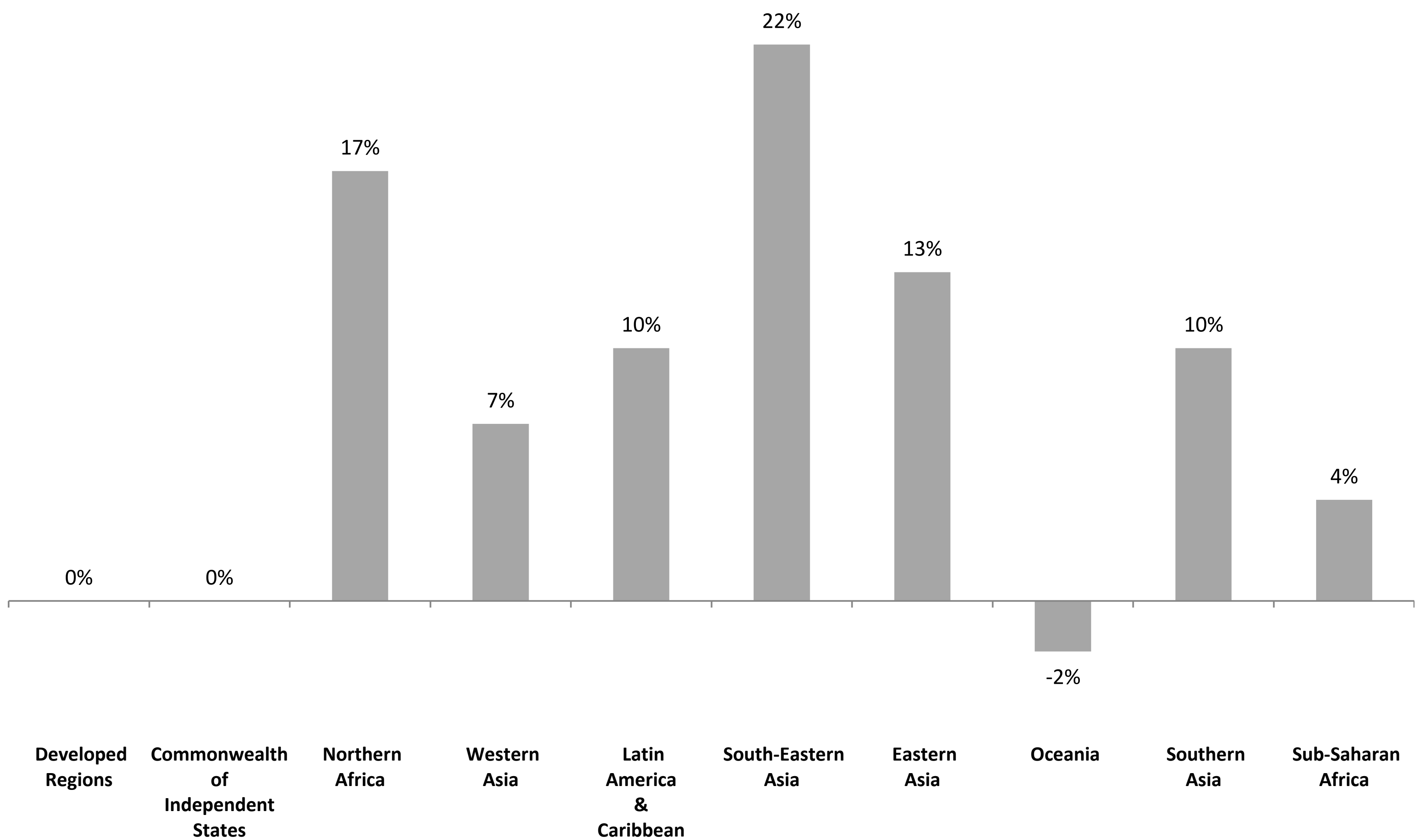

Figure 1.2. Usage percentage-point change in improved sanitation by region, from 1990 – 2008
(Joint Monitoring Programme 2010)

As global attempts to increase sanitation coverage continue, it is evident that supply-driven, health-endorsed approaches are not enough to encourage the use of sanitation technology. Specifically, the disconnect between sanitation user preferences and past interventions to install sanitation reveals the inadequacy of these systems to stimulate household sanitation demand, develop reproducible solutions, or extend sanitation products and services beyond subsidized mechanisms (Jenkins 2004). Furthermore, recent studies suggest that health may not be the primary motivating factor for households to install sanitation technology (Jenkins 1999, Jenkins 2004, Jenkins and Curtis 2005).

1.2 Historical Perspective

Improving sanitation access in the developing world has been a key policy mandate for the last three decades beginning with the United Nations' declaration of the 1980s as the International Drinking Water Supply and Sanitation Decade. The primary goal of this declaration was to provide access to safe drinking water and adequate sanitation systems to all by the end of the decade. One of the challenges with this approach was its focus on the construction of sanitation facilities, thereby creating a supply-driven approach to reducing the underserved population. With this intervention approach, many implementations were installed without regard to user preferences or operational and maintenance costs (Wright 1997). In the final analysis, a projected 1.2 billion people obtained access to safe drinking water and 770 million people received adequate sanitation during this decade; however, this outcome was far below the desired goals, primarily as a result of population growth and rapid urbanization (Black and Fawcett 2008).

The WHO, United Nations, and Water and Sanitation Program all began to promote demand-response approaches to sanitation implementation in the 1990s. Demand-response approaches differed from supply-driven approaches because operational and maintenance components were also considered in the construction of facilities (Wright 1997). Although these demand-response approaches were promoted as an investment- and incentive-driven, the consideration of water as a "right" versus an "economic good" impeded the development of an accurate and unambiguous definition of "demand" by stakeholders (Wright 1997, Wedgwood 2005).

In 2000, the United Nations developed the Millennium Development Goals (MDGs) as an aggressive catalyst to attack the challenges of improving the well-being for the world's poorest citizens; the goals include developmental targets to eradicate world hunger, reduce child immortality, and tackle global health epidemics. The seventh goal, which targets environmental sustainability, was expanded in 2002 to include increasing global sanitation coverage; this objective is an attempt to halve the underserved sanitation population by 2015 (Black and Fawcett 2008, United Nations 2010). With little to no progress having been made over the last two decades, it appears that this objective will not be met by its target year; if fact, if the current trend continues, it is estimated that the underserved sanitation population will grow to 2.7 billion by 2015 (United Nations 2010). Recent approaches to increase sanitation access have redefined demand-driven approaches to from being "investment-driven" to "user-driven." Current sanitation interventions programs now include community health clubs, community-led total sanitation, and social marketing; all of these methods focus on incentivizing sanitation users to want improves sanitation (Mara et al. 2010).

1.3 Problem Statement

The inability of target-based, health-driven sanitation initiatives to provide significant sustainable sanitation coverage in developing regions indicates that substantial changes must be made to design and implementation approaches. The approaches executed in the developed world over the last century are often unsustainable in developing nations. These "conventional" methods are designed as water-based collection systems where human excreta are collected at points of generation, aggregated with additional wastes (including other human, industrial, and commercial wastes) in complex piping systems, and then transferred to a central treatment and disposal location. Established institutional structures, stringent water quality requirements, and prescriptive treatment technologies frame these approaches to design and implement sanitation systems that are highly regulatory-based. Political instability, water scarcity, unreliable energy supply, and capital constraints challenge the development of regulatory-based sanitation systems in developing regions. Population growth and rapid urbanization, specifically in peri-urban areas, exacerbate the challenges of providing sanitation access in these regions (Black and Fawcett 2008). When regulatory-based systems can be established, governing agencies must supplement these approaches if access is to be provided across a wide range of socioeconomic levels. Typically, individuals in higher socioeconomic classes benefit from having relatively adequate, conventional sanitation service delivery; however, informal growth, population density, and challenging topography often exclude the extension of this service delivery into peri-urban areas (Paterson et al. 2007).

Little social acceptance is needed when conventional approaches are designed and implemented; thus, there is no need for higher socioeconomic classes to be active participants in their sanitation decision-making process (Paterson et al. 2007). Nevertheless, the need to consider user perspectives in sanitation approaches that serve the impoverished has been established, as the minimal or lack of user participation has been identified as a key barrier towards increasing access (Paul 1958, McPherson and McGarry 1987, UN 2010). Little motivation exists for disadvantaged sanitation users to pay, operate, and maintain systems properly if they are not provided with opportunities to engage in the decision-making process (Paterson et al. 2007).

Previous studies have attempted to gather user perspectives on sanitation technology using contingent valuation techniques (Whittington et al. 1993a; Whittington et al. 1993b, Altaf 1994, Altaf & Hughes 1994, Fujita et al. 2005). These studies determine the maximum amount individuals are willing to pay for sanitation technologies. While these studies engage sanitation users in the decision-making process, they constrain users to choose options based upon their ability to pay, not necessarily their preferences for the chosen sanitation technology.

The need to develop sanitation products specifically for the peri-urban users was highlighted recently by Paterson and her colleagues (2007); in coining the phrase "pro-poor sanitation technologies," they presented simplified sewage as an affordable, appropriate sanitation solution designed for users located in high-density areas.

Furthermore, Paterson et al. expressed the need for engineers to design user-centered sanitation solutions, engage with implementing communities, and collaborate with social scientists to provide lasting sanitation technology solutions (2007).

The absence of user preference integration into sanitation systems represent a true disconnect between the development of appropriate sanitation technology and the deployment of acceptable and affordable technology. As engineers begin to design and develop a new generation of sanitation products and services, we must look for innovative approaches to articulate user preferences within the design process if sanitation implementations are to be a means increasing access to sanitation. To date, research that develops an understanding of how user preferences for sanitation impact technology design and implementation has not been published. Furthermore, no comparable research has been published that develops an approach to determine user acceptability for attributes relating to sanitation technology design and implementation.

1.4 Research Questions

Based on the background and problem statement, the following questions are then raised:

- What are the motives and barriers, as viewed by the users, to sanitation technology use?
- Are preferences for sanitation technology dependent on socioeconomic and/or demographic characteristics of the users?

- Are preferences for sanitation technologies dependent on their respective attributes?
- Does the incorporation of user preferences into sanitation system design impact the use of the system?

1.5 Objective and Research Aims

The objective of this study is to examine the impact that individual preferences and behaviors have on the use of sanitation systems in peri-urban communities in Sub-Saharan Africa. Specifically, this study identifies influential attributes of sanitation systems by investigating user perspectives and behavioral patterns in one particular community, as well as to determine the preferred options, for sanitation alternatives. For the purposes of this study, user preferences for sanitation are measured for technical (design) attributes and arrangement (implementation) attributes. Sanitation technical attributes refer to the various design specifications that detail operation modes of the sanitation technology, including attributes for water reuse, disposal of excreta, and excreta resource recovery. Sanitation arrangement refers to implementation attributes, including aspects for placement, quantity, and ownership. The former attributes have direct design implications on developing appropriate sanitation technology. The latter attributes have direct policy implications on determining access and coverage to sanitation. Collectively, the technical and arrangement attributes describe sanitation systems. It is theorized that coupling user preferences with sanitation technology design and implementation arrangement will increase the usage of improved sanitation systems. The exploration of this goal is broken into three aims:

Aim I – Investigate factors that influence sanitation usage

Approach: Develop a questionnaire to measure stated user preferences and behavioral patterns. This questionnaire served as the script for the structured interviews that were designed to collect data regarding sanitation topics, including information regarding existing sanitation technology, preferences for various sanitation technical design attributes, as well as perspectives on current and preferred sanitation implementation arrangements. It was categorized by the following themes:

> Demographic and Socioeconomic Characteristics These questions were used to determine respondent characteristics, including gender, age, health, education, and employment.
>
> Descriptors This portion gathered information regarding municipal service delivery on water, sanitation, and solid waste systems.
>
> Preferences This section solicited respondents to state their preference regarding various technology design attributes and their respective operation modes.
>
> Behavioral Analysis This segment examined the use of sanitation systems under various implementation arrangements, including ownership, placement, quantity, cost and accessibility.

Aim II – Develop a utility-based model to determine user-preferred sanitation technology

Approach: Based upon data collected in Aim I, evaluate the desired user preferences for sanitation technology design. Taking into consideration the technical design attributes investigated in Aim I, the relative priorities sanitation users placed on these attributes were calculated using multinominal logistic regression. Parameter estimates and preferences for operation modes of the design attributes aided in the development of individual utility functions; these functions were used to examine which sanitation technology designs and determine which technology would be provided that maximum utility.

Aim III – Design an agent-based simulation to illustrate sanitation system use in various scenarios

Approach: Using the results from Aim I and Aim II as inputs, develop an agent-based simulation to examine micro-level individual behavior and the macro-level patterns that emerge from sanitation system use. Agents represent as individual respondents surveyed during Aim I and modeled in a heterogeneous manner, having varying levels of satisfaction for sanitation alternatives. Behavioral rules are based on the influence of preferences and beliefs identified for sanitation technology and arrangement, as calculated in Aim II.

1.6 Organization of Dissertation

Subsequent chapters are written as a collection of stand-alone journal articles with each having their respective references provided at the end of each chapter. Chapter 2 reviews existing perspectives and recent progress on collecting sanitation user preferences; it also address current knowledge gaps in the field. Chapter 3 summarizes the theoretical framework for the dissertation. Knowledge gaps detailed in Chapter 2 are addressed in Chapters 4, 5, and 6. Chapter 4 focuses on Aim I and addresses the first research question examining motives and barriers of sanitation use. It also develops the classification groups of user adoption mentioned throughout the rest of the dissertation. Chapter 5 targets Aim II and addresses the second and third research questions that analyze technology design preferences. Chapter 6 builds on the knowledge gained in Aims I and II to investigate the fourth research question. To provide further context, each chapter focusing on an aim begins with "Chapter Focus" to reiterate the purpose for each chapter and concludes with "Correlation to Body of Work" to show the relationship of each chapter to the dissertation. Chapter 7 concludes the dissertation and provides future research directions. The appendices follow Chapter 7 and include a brief summary of the sampling area (Appendix A).

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CHAPTER 2

SANITATION IN DEVELOPING COUNTRIES – A SYSTEMATIC REVIEW OF USER PREFERENCES AND MOTIVATIONS

A paper to be submitted to

The Journal of Water, Sanitation, and Hygiene for Development

2.1 Introduction

Although improving sanitation access in the developing world has been a global target of the United Nations Millennium Development Goals (MDG) for the last two decades, little progress has been made towards reducing the percentage of the world's underserved population. Expanding the definition of "improved sanitation" to include sewage treatment prior to disposal suggests that 4.1 billion people – nearly twice the previous estimate of 2.6 billion people – are now identified as lacking access to improved sanitation. The overwhelming majority of these individuals live in the developing regions of Asia, Africa, and Latin America (UNICEF & WHO 2012, Baum et al. 2013).

Providing the inhabitants of developing regions with sanitation access has several challenges, including political instability, water scarcity, unreliable energy supplies, and capital constraints. From a policy perspective, multiple approaches are implemented to provide sanitation access across a wide range of socioeconomic levels. Individuals of a higher socioeconomic class typically benefit from having relatively adequate, sewerage-based sanitation designed to provide central collection, treatment, and disposal. These conventional approaches – proven and well established in industrialized nations – require minimal social acceptance from the users; thus, individuals that are provided with this type of service delivery typically do not participate in making decisions about their sanitation needs. Alternatively, the need to involve individuals in lower socioeconomic classes when selecting their sanitation delivery options has been well established; the lack of participation from this user subset continues to be identified as a barrier preventing increased access and use of sanitation technology (Paul 1958; McPherson & McGarry 1987; United Nations 2010).

Informal growth, population density, and challenging topography often exclude the extension of conventional service delivery in developing regions and as such, there is a need to develop sanitation technologies for lower socioeconomic classes. As sanitation technologies are designed with the intended operation permitting the hygienic removal of pathogens, users are required to interact with sanitation technologies based upon design guidelines. Proper user interaction with sanitation technology is essential for it to operate at its anticipated capacity or for its expected lifetime. Thus, sanitation technology designed and implemented for users of a lower socioeconomic class must be technically-feasible, economically-appropriate, and user-accepted (Paterson et al. 2007).

As sanitation practices are user-specific, sanitation interventions are challenged by the need to incorporate user preferences. Moreover, the specificity of previous relevant literature work often makes it difficult to generalize the results to a broader community. Previous work examining various user perceptions for sanitation systems often focus on a specific geographical region, type of sanitation technology, or user adoption classification. The objective of this paper is to systematically review user experiences and the impact that various contextual variables - including geographical setting, technology type, and adoption mode - have on sanitation preferences and perception. Given the shift in sanitation research towards behavioral change, this work will explore reported evidence regarding attitudes and the beliefs that structure user perceptions for sanitation service delivery. User experiences are explored to examine overall user satisfaction with various sanitation systems, analyze commonalties and variances throughout sanitation user preference studies, and investigate perceived drivers and deterrents of sanitation adoption. For the purpose of this study, the user adoption classification, as identified by Jenkins (1999) is used; households that possess an improved sanitation technology, regardless of its location relative to the dwelling, are considered adopter households. Non-adopter households represent those individuals who, regardless of stated preferences or intent, have yet to make an observable choice towards installing an improved sanitation technology. This review focuses on sanitation behavioral change and serves as the holistic approach to analyze the relationship between user perceptions and sanitation technology. It concludes with an outlook of future work in the field.

2.2 Methods

Decision roles assisted in determining which case studies should be included in the systematic review. In order for a case study to be included in the analysis, sanitation must have been referred to as the collection, removal, and/or disposal of human excreta, not refuse. Furthermore, at least one sanitation technology had to be examined and studies that investigated other infrastructure systems, such as solid wastes or water services, in addition to sanitation were included if appropriate data was available. Selected case studies were geographically restricted to areas that were deemed as lower or middle income countries – as classified by the World Bank country income-criterion classification (World Bank 2012).

The investigation of sanitation preferences, perceptions, and measured outcomes was a major selection criterion. Each case study had to include one or more of the following: measures of overall satisfaction or dissatisfaction, reasons for satisfaction or dissatisfaction levels, views of drivers or deterrents on sanitation facility usage, perceptions on preferences between sanitation technologies, or insights on user adoption of sanitation technology. Case studies also had to include a rigorous data analysis that detailed pertinent statistical information, such as sample sizes and percentages, for comparison.

Various combinations of the following key words were used to select case studies: sanitation, toilet, wastewater, latrine, user, preference, behavior, attitude, and belief. Case studies published in English on or before August 2011 were obtained from Web of Science, JSTOR, Google Scholar, and ProQuest. A manual bibliographical cross-search was also conducted.

The collected case studies were reviewed and divided into four groups: descriptive studies about sanitation user satisfaction; comparative work analyzing preferences for sanitation technologies; perspectives on sanitation usage and ownership; and importance of factors driving household sanitation installation. The following information was determined from each case study: the sampling characteristics, including the mean household size, total sample size and proportion that were female respondents;

characteristics of the investigation, including country of origin, the sanitation technology investigated, geographical setting (urban, peri-urban, rural), designation (household, community/shared); and respective outcomes sampled sanitation users.

2.3 Results

2.3.1 User Satisfaction with Existing Sanitation Options

Case studies exploring the acceptability of sanitation systems in developing countries have examined general satisfaction levels with existing technology. Measuring satisfaction levels is a subjective, survey-based method of determining user contentment. Various bipolar (measuring relating to the degree of satisfaction) psychometric measures were used, including the Likert scale and the semantic differential scale. Measurements of user satisfaction were examined to understand how users perceived various sanitation options; for sanitation users to be considered "satisfied," they must indicate their satisfaction with their existing sanitation as "good," "somewhat satisfied," or "very satisfied." The lack of expressed dissatisfaction by the users was not interpreted as satisfaction and vice versa. A summary of the case studies included in the analysis is shown in Table 2.1.

Table 2.1. Summary of Satisfaction Levels with Existing Sanitation Technologies

Study Year (Location – Area Type)	Data collection method N – number of responses	Existing technologies examined (adoption – % of sample population)	Key results
Whittington et al. 1993a (Ghana - urban)	Household survey; two-stage stratifying sampling N = 1,224 households Refusal rate: 4%	Pit latrine (adopter - 7%) Pit latrine (non-adopter ~ 40%), Water closet (shared ~ 25%), Bucket latrine (25%) Open defection (5%)	- 38% of the water closet users ranked their overall satisfaction as "good" in comparison to 1% of the communal pit latrines users with the same ranking for their existing sanitation. - 6% of household pit latrine users ranked their sanitation level "good."
Altaf and Hughes 1994 (Burkina Faso – rural)	Household survey; two-stage stratifying sampling N = 593 households Refusal rate: 1%	Simple pit latrine (adopter - 57.2%) Lined pit latrine (adopter - 24.1%) Water closet (adopter - 12.5%) No pit latrine (adopter - 6.5%)	- 57% of the respondents indicated their overall dissatisfaction with use of household pit latrines. The major contributions to dissatisfaction were smells (13%) and inconvenience in use (11%).
Jenkins and Scott 2007 (Ghana – rural and peri-urban)	Household survey; N = 536 households	Pit latrine (adopter - 11%) Pit latrine (shared - 14.6%) Pit latrine (non-adopter - 58.2%) Open defection (14%)	- The majority of communal sanitation users (65.3%) were dissatisfied with their existing option, stating lack of cleanliness as the least preferred feature.
Oswald and Hoffman 2007 (Peru – peri-urban)	Household survey; N = 52 households	Ecological sanitation (adopter - 100%)	- 65% of the surveyed respondents with ecological sanitation latrines indicated it was a "very useful" technology.

Table 2.1. Summary of Satisfaction Levels with Existing Sanitation Technologies

Study Year (Location – Area Type)	Data collection method N – number of responses	Existing technologies examined (adoption – % of sample population)	Key results
Davis et al. 2008 (India – urban)	Household survey; N = 919 households	Toilet with sewer connection (adopter - 58%) Toilet with sewer connection (shared - 3%) Open defecation (39%)	- Approximately half (47%) of the respondents indicated to be at least somewhat dissatisfied with their existing defecation practices. Reasons listed for dissatisfaction included inconvenience, embarrassment, and unhygienic conditions.
Walker 2011 (Ghana – rural)	Household survey N = 31 respondents	Pit latrine (adopter - 35%) Open defection (93%) (multiple responses were allowed)	- Twelve respondents using no facilities were "somewhat" or "very" satisfied with current defecation practices. - Highest dissatisfaction levels were associated with high installation costs (stated by ~80% of respondents) and lack of deterrent (smells, flies) mechanisms (mentioned by ~30% of respondents).
Roma et al. 2010 (South Africa – peri-urban)	Household semi-structured interviews N = 86 households	Ablution blocks (adopter - 100%)	- 52.3% of the respondents reported being overall satisfied with existing sanitation. - While user satisfaction of sanitation option was correlated to cleanliness, the ability to pay for daily use of sanitation does not correlate to higher satisfaction.
Schouten and. Mathenge 2010 (Kenya – peri-urban)	Household semi-structured interviews N = 76 respondents	Seven communal sanitation facilities were examined; technologies included biogas toilets, VIP latrines, pour flush toilets, and water closets.	- On a scale of 1 to 10, all tested facilities averaged a satisfaction ranking of 7.1 from the surveyed respondents.

Table 2.1. Summary of Satisfaction Levels with Existing Sanitation Technologies

Study Year (Location – Area Type)	Data collection method N – number of responses	Existing technologies examined (adoption – % of sample population)	Key results
Bolaane and Ikgopoleng 2011 (Botswana)	Household survey plus contingent valuation; N = 405 households	Flush toilets (adopter - 55.6%) VIP latrine (adopter - 26.5%) Simple pit latrine (non-adopter - 17.6%) Open defection (0.3%)	- 44% of the respondents are satisfied with using pit latrines and plan on continual usage. Reasons for satisfaction include the ability to user cheaper anal cleaning methods.
Roma and Jeffrey 2011 (Indonesia – peri-urban)	Household survey and qualitative interviews N = 122 respondents	Flush toilets (non-adopter - 100%)	- 66.3% of the respondents reported being overall satisfied with existing sanitation. - 81.7% of the respondents indicated that their existing sanitation fulfilled their defecation needs.

Stated user satisfaction levels are dependent on sanitation technology and user adoption classification. In general, improved sanitation technologies had higher percentages of satisfied users than unimproved sanitation technologies. Specifically, technologies that utilized water as a conveyance operation mode, such as cistern flush toilets and ablution blocks, consistently had higher numbers of satisfied users than dry pit-based technologies. Ecological sanitation latrines, communal ablution blocks using cistern flush toilets, and cistern flush toilets indicated satisfaction levels of 88%, 69%, and 53% , respectively (Oswald & Hoffman 2007, Roma & Jeffery 2011, Roma et al. 2010). One study indicated that a high percentage of surveyed users (83%) were generally satisfied with open defecation (Walker 2011).

Six articles analyzed shared and/or communal sanitation facilities; the rest were non-communal or privately-owned facilities. Satisfaction with shared facilities was found to be dependent on sanitation technology type. Cistern flush toilets and ablution blocks with shared access to the community had higher percentages of satisfied users than shared pit latrines (Roma et al 2010, Roma & Jeffery 2011, Bolaane & Ikgopoleng 2011).

Regardless of geographical region, designation approach, or respondent sample size, pit latrines consistently have lower percentages of satisfied sanitation users. Lack of cleanliness of pit latrines was a reported concern at both the household and communal level. Whittington et al. (1993a) reported 90% of communal pit latrine users and 56% of household pit latrine users rated their overall satisfaction of cleanliness as “poor” or “fair.” Furthermore, privacy and convenience were additional factors for communal sanitation users with each reporting a poor ranking of 54% and 70%, respectively (Whittington et al. 1993a). Jenkins and Scott (2007) stated that the foremost reasons for dissatisfaction with communal pit latrines were malodorous air (mentioned by 27.1% of communal users) and uncleanliness (mentioned by 26.6% of communal users).

2.3.2 Preferences among Sanitation Technologies

Few studies have been developed to examine preferences for sanitation systems (Whittington et al. 1993a; Whittington et al. 1993b, Altaf 1994, Altaf & Hughes 1994, Fujita et al. 2005). In these studies, user perspectives for sanitation systems were gathered via assessing the willingness to pay for various technology or implementation alternatives. Using this methodology, the price point that users were willing to pay for improved sanitation was established based upon the selection of a bid price in a hypothetical market. All studies were conducted in urban areas and with a sample population size that ranged from approximately 600 households (Altaf & Hughes 1994) to 1,200 households (Whittington et al. 1993a, 1993b).

Whittington and colleagues (1993a; 1993b) examined user willingness to pay for water and sanitation services delivery options in Kumasi, Ghana. This study sampled 1,224 households and focused on ventilated improved pit (VIP) latrines and sewer connections for water closets. The study was conducted in a manner that allowed respondents to state their willingness to pay based on a choice set of sanitation alternatives that included improvements to their individual existing sanitation situation. Respondents indicated that they were willing to pay equal proportions of the household income on improved sanitation, regardless of the technology (Whittington et al. 1993b). Operational costs being equal, water closets were slightly preferred (54%) over VIP latrines by users who did not have current access to water closets (Whittington et al.

1993a). Socioeconomic characteristics, including income status and education level, did not predict preference likelihood for water closets. Of the respondents preferring VIP latrines, 47% indicated that their preference was a result of the ability to access sanitation technologies independent of a water source (Whittington et al. 1993a).

Altaf (1994) probed approximately 1,000 respondents to determine the priority preference among infrastructure services (water, sanitation, or solid waste) in Gujranwala, Pakistan. This study assumed that the municipality could provide all services free to citizens, but only in a phased introduction as a result of budgetary constraints. Although respondents recognized the interdependency between water and sanitation services, they prioritized sanitation the highest; respondents also indicated that they were more willing to pay for sanitation services than water services (Altaf 1994).

Altaf and Hughes (1994) conducted a study to determine willingness to pay for sanitation for 593 households located in Ouagadougou, Burkina Faso. The researchers attempted to decouple past experiences with sanitation from current perspectives by asking respondents about the sanitation attributes for their tested technologies as they considered their sample population's unfamiliarity with them. The technologies tested included simple off-site wastewater disposal, pour flush toilets, and VIP latrines. The study revealed that user preferences for sanitation systems depended on the technology attributes, not simply having access to sanitation. In general, 64% of the respondents preferred pour flush toilets in comparison to 30% of the respondents preferring VIP latrines. While 42.9% of respondents stated preference towards VIP latrines was a result of their water efficiency, pour flush toilets were perceived as being more "hygienic and modern" by 58.1% of respondents that preferred that technology (Altaf & Hughes 1994).

Fujita et al. (2005) examined the desire of 1000 households in Iquitos City, Peru to pay for their wastewater to be treated prior to river disposal. Existing sanitation services in the sample area included households without any connection to sewerage or access to pre-treatment effluent disposal, households with sewerage connection but no protection against rain overflows, and households with both sewerage connection and protection against rain overflows, representing 38.3%, 27.4% and 34.3% of the sample population, respectively (Fujita et al. 2005). The study concluded that female respondents and younger respondents were willing to pay higher costs for pre-treatment effluent disposal; it also correlated a higher willingness to pay with individuals without indoor sanitation facilities (Fujita et al. 2005).

2.3.3 Perspectives on Sanitation Usage/Ownership

Several studies examined perceived benefits and constraints to sanitation usage in various geographical settings or different designation approaches. Although perspectives examined are similar throughout several of the studies, the number of surveyed respondents that consider the benefits and constraints varied significantly. Table 2.2 details the perceived advantages of sanitation usage and/or ownership. For studies that included adopter and non-adopter households, the frequency and percentage of the subpopulation that mentioned the advantage is provided accordingly.

Table 2.2. Reported Advantages of Sanitation Use/Ownership

Study Year (Location – Area Type)	Technology examined	Number of Respondents	Driver	Frequency of response (%)		
				Total	Adopters	Non-Adopters
Jenkins and Curtis 2005 (Benin – rural)	Pit latrine (household)	N = 40 total 25 adopters 15 non-adopters	Affiliate with urban elite	12 (30)	8 (20)	4 (10)
			New experience/lifestyle	13 (33)	8 (20)	5 (13)
			Intergenerational status	4 (10)	2 (5)	2 (5)
			Aspire to royalty	3 (8)	3 (8)	–
			Family health/safety	13 (33)	8 (20)	5 (13)
			Convenience/ comfort	12 (20)	8 (20)	4 (10)
			Protection	8 (20)	6 (15)	2 (5)
			Cleanliness	5 (13)	5 (13)	–
			Privacy	4 (10)	4 (10)	–
			Restricted mobility	5 (13)	5 (13)	–
			Increase rental incomes	5 (13)	5 (13)	–
O'Loughlin et al. 2006 (Ethiopia – rural and urban)	Pit latrine (household)	N = 116 total 81 adopters 35 non-adopters	Cleanliness	56 (48)	39 (48)	17 (49)
			Health benefits	49(42)	33 (41)	16 (46)
			Privacy	28(24)	24 (30)	4 (11)
			Reduced Flies	25(21)	19 (23)	6 (17)
			Convenience	21(18)	19 (23)	2 (6)
			Reduced Smell	15(13)	9 (11)	6 (17)
USAID 2009 (Uganda – rural)	Pit latrine (household)	N = 30 total 16 adopters 14 non-adopters	Health benefits	25 (83)	15 (94)	10 (71)
			Visitors' convenience	17 (57)	11 (96)	6 (43)
			Self esteem	14 (47)	7 (44)	7 (50)
			Proper feces disposal	11 (37)	7 (44)	4 (29)
			Privacy	10 (33)	6 (38)	4 (29)
			Reduced Smell	10 (33)	4 (25)	6 (43)
			Comfort/convenience	8 (27)	5 (31)	3 (21)
			Reduced Flies	8 (27)	3 (19)	5 (36)

Table 2.2. Reported Advantages of Sanitation Use/Ownership

Study Year (Location – Area Type)	Technology examined	Number of Respondents	Driver	Frequency of response (%)		
				Total	Adopters	Non-Adopters
			Avoid conflicts with neighbors	3 (10)	1 (6)	2 (14)
			Lack of other alternative	2 (7)	2 (13)	–
Hernandez et al. 2009 (Ethiopia – rural)	Pit latrine	N = 2000 total	Status	43 (4)		
			Comfort	85 (12)		
			Convenience	200 (27)		
			Privacy	19 (3)		
			Security	93 (13)		
			Health benefits	93 (13)		
			Ownership	21(3)		
			Proper feces disposal	297(41)		
Fu 2010 (Uganda – rural)	Ecological Sanitation	N = 57 total 36 adopters 21 non-adopters	Permanent structure		18 (32)	
			Less smell		6 (11)	
			Cannot fill with water		5 (9)	
			Get manure		8 (14)	
			Cheaper		4 (7)	
			Visitors' convenience		3 (5)	
			Less flies		2 (4)	
			Cleanliness		2 (4)	
			Durability		2 (4)	
			Reliability		1 (2)	
			Ease of cleanliness /maintenance		1 (2)	
			Convenience		1 (2)	

Table 2.2. Reported Advantages of Sanitation Use/Ownership

Study Year (Location – Area Type)	Technology examined	Number of Respondents	Driver	Frequency of response (%)		
				Total	Adopters	Non-Adopters
Roma et al. 2010 (South Africa – peri-urban)	Ablution blocks (communal)	N = 86 total	Comfort Cleanliness	43 (50) 40 (46)		
Roma and Jeffrey 2011 (Indonesia – peri-urban)	Flush toilets (communal)	N = 122 total	Health Benefits	102 (84)		

2.3.3.1 Comfort, Cleanliness and Convenience

The desire of sanitation users to utilize sanitation facilities that are comfortable, clean and convenient was mentioned throughout the case studies. When installed at the household level, pit latrines were considered more convenient and comfortable to adopter households than to non-adopter households (Jenkins & Curtis 2005, O'Loughlin 2006, USAID 2009). These desires were seen in both rural and urban sanitation users; approximately half of the households in both urban and rural areas examined in Ethiopia mentioned convenience as a major benefit to using sanitation (O'Loughlin 2006).

2.3.3.2 Prestige

The sense of prestige given to users was also mentioned as an advantage for rural sanitation users. It was measured by the ability to have a preferred sanitation option for guests to use (USAID 2009, Fu 2010), the association of sanitation with elite status (Jenkins & Curtis 2005), and increased amounts of self esteem (USAID 2009).

2.3.3.3 Health Benefits

The frequency of sanitation users stating disease prevention as an advantage of sanitation usage appears to be dependent on household adoption status. While adopter households were more likely to mention the health benefits of sanitation, non-adopter households still recognized sanitation interventions as mechanisms to prevent diseases and improve family health (Jenkins & Curtis 2005, O'Loughlin 2006, USAID 2009).

Two studies also reported some constraints relating to sanitation ownership; the perceived disadvantages of sanitation ownership are detailed in Table 2.3. The most frequently mentioned disadvantages related to land conditions, including poor terrain and lack of space, financial constraints of construction, as well as lack of knowledgeable and experienced artisans to build the sanitation facility appropriately (Hernandez et al. 2009, USAID 2009).

2.3.4 Importance of Drivers on Household Sanitation Installation

Several studies have analyzed the importance of factors motivating a household's decision to install private sanitation (Jenkins 1999; Jenkins & Curtis 2005; Jenkins & Scott 2007; Hernandez et al. 2009; Santos et al. 2011). Although the studies included different geographical settings and investigated various sanitation technologies, the use of similar rating scales allowed for proportional comparisons to be inferred. In the aforementioned studies by Jenkins (1999), Hernandez et al. (2009), and Santos et al. (2011), respondents were asked to indicate the relative importance of drivers and barriers toward sanitation use based upon a four-point importance scale, ranging from 1 = not important to 4 = very important. Additionally, these surveys stratified respondent households similarly such that households with previously-installed private sanitation were classified as adopters, whereas those households without private sanitation were considered non-adopters. The statistical significance (p-value) of responses between the adopters and non-adopters was also determined.

Table 2.3. Reported Disadvantages of Sanitation Use/Ownership

Study Year (Location – Area Type)	Technology examined	Number of Respondents	Constraints	Frequency of response (%)		
				Total	Adopters	Non-Adopters
Hernandez et al. 2009 (Ethiopia – rural)	Pit latrine	N = 2000 total	Land ownership	155 (12)		
			Shortage of available land	144 (11)		
			Poor soil conditions	53 (4)		
			Lack of construction materials	64 (5)		
			Lack of technical expertise	54 (4)		
			Lack of experienced artisans	221 (18)		
			High cost of materials	53 (4)		
USAID 2009 (Uganda – rural)	Pit latrine	N = 30 total 16 adopters 14 non-adopters	Low income	16 (53)	8 (50)	8 (57)
			Rocky soils	16 (53)	8 (50)	8 (57)
			Heavy rains	11(37)	8 (50)	3 (21)
			Weak construction materials	8 (27)	7 (44)	1 (7)
			Termites	10 (33)	5 (31)	5(36)
			Lack of construction materials	11 (37)	4 (25)	7 (50)
			Laziness	5(17)	3 (19)	2 (14)
			High cost of materials	4 (13)	3 (19)	1 (7)

The pioneering work conducted by Jenkins and others (Jenkins 1999; Jenkins & Curtis 2005; Jenkins & Scott 2007) conveyed the importance in understanding drivers and barriers to predict the likelihood that households would install private sanitation. Jenkins (1999) detailed a behavior-decision model that conceptualized the decision-making process of installing private sanitation into three stages, namely: the preference towards improving existing sanitation practices, the intention to change sanitation practices, and the choice to improve sanitation conditions based upon capacity. Successful adopters were defined as those households in the final stage of the decision-making process whose desire for an improved sanitation condition represented new demand for sanitation. The model further characterized drivers to install private sanitation based upon three motivating factors: the ability to provide prestige to its owners, the capacity to mitigate health and safety concerns, and household-specific factors (Jenkins 1999).

Using the behavior-decision model developed by Jenkins (1999), Jenkins and Curtis (2005) examined household desire to install private sanitation in rural Benin. Using in-depth probing interviews, 40 household heads, including 25 heads with private household latrines (adopters), were questioned to determine the drivers and barriers toward their ownership of private sanitation (Jenkins & Curtis 2005). While sanitation users' desire for prestige and well-being were listed as motivating factors for sanitation adoption, the prevalence of those drivers were dependent on demographic and socioeconomic factors (Jenkins 1999; Jenkins & Curtis 2005). Jenkins and Curtis (2005) also reported that health benefits were not a statistically significant driver towards motivating adopters to install private sanitation.

Jenkins and Scott (2007) re-examined the behavior-decision model and considered the impact of targeted social-marketing approaches towards persuading households to install private sanitation. Through the examination of 536 latrines installed in Ghanaian rural and peri-urban households, the authors categorized respondents based upon their adoptive or non-adoptive practices. An analysis of the non-adopter households indicated that health benefits, convenience, and ease of maintenance were the primary motivating factors involved in the decision-making process to install a latrine (Jenkins & Scott 2007).

Hernandez et al. (2009) compared similar drivers for sanitation adoption as Jenkins (1999) did and investigated household motivations to build a pit latrine in rural Ethiopia. Focusing on females with children, 745 respondents in 22 villages were interviewed to determine their perspective on sanitation ownership. Both user adoption classifications groups, regardless of private sanitation ownership, indicated that the ease of maintenance, privacy, and health benefits were their motivating factors. Furthermore, the sanitation adopters also designated prestige, modernity, and popularity as significant drivers (Hernandez et al. 2009).

Santos et al. (2011) sought to expand the framework described by Jenkins and Scott (2007) by examining the impact that socioeconomic, demographic, and socio-psychological variants had on household sanitation adoption. The study evaluated the purchasing decisions of 721 households to install household toilets connected to sewer systems in peri-urban Brazil. Prestige, modernity, and popularity were examined as well; yet, the difference between household adopters and non-adopters was not significant for the factors tested (Santos et al. 2011).

2.3.4.1 Relative Importance of Prestige

Review of the literature indicated inclusiveness regarding the significance of the prestige driver among adopter and non-adopter households. Using the importance scale ranking scale with 4 being "most important," gaining prestige is ranked consistently between 3.39 and 4.00, regardless of household adoption status. However, the significance of this driver varied among the three studies. In Jenkins (1999), the average importance (indicated as "M") of the driver "gain prestige from visitors" indicated that all adopter households surveyed considered this driver to be "very important." A *t*-test revealed a statistical significance between the relative importance of this driver for adopter households (n = 22 users, M = 4.0) and non-adopter households (n = 298 users, M = 3.96), p-value < 0.05. Prestige was also a significant driver in the Hernandez et al. (2009); the mean of adopter households (M = 3.98) was statistically significantly different than non-adopter households (M = 3.91), p-value < 0.001. In Santos et al. (2011), a *t*-test failed to show statistical significance with the same the need to expand social status; adopter households (n = 647 users) have a mean ranking for "gain prestige" as M = 3.43, while non-adopter households (n = 71 users) indicate a ranking of M = 3.53, p-value = 0.512.

2.3.4.2 Relative Importance of Health Benefits

The ability for improved sanitation to provide health benefits has inconclusive results for being a driver. Jenkins (1999) reported spontaneous mentions of health benefits as being the third most frequently mentioned driver ranked most important by heads of households overall. When broken into household adoption groups, none of the 22 adopter households considered health benefits as their most important driver; 7.3% of the non-adopters mentioned it as their most important factor, ranking it third most important for this adoption class as well (Jenkins 1999). Adopter households ranked the average importance of health benefits (M=1.05) lower than of non-adoption households (M=1.29), $p < 0.005$, indicating that health, even though one of the most frequently mentioned drivers, was not an actual driver to persuade adoption of technology (Jenkins 1999). On average, non-adopter households placed a higher importance on health than adopter households. Conversely, households questioned in Hernandez et al. (2009) placed a higher importance on health, with adopter households ranking the ability for improved sanitation adoption to prevent disease (M=3.92) higher than non-adopter households (M=3.89), $p = 0.10$. Santos reported the lack of statistical significance among adopter households (M=3.70) and non-adopter households (M=3.71), $p = 0.274$.

2.4 Summary and Outlook

Noteworthy contributions from the examined case studies address the challenges of increasing sanitation coverage suggest that individuals see benefits to using sanitation, and that they are willing to pay higher premium for those services relative to certain other infrastructure services. Prior research has also acknowledged the differences between households who choose to install private sanitation than those who use shared and/or communal sanitation facilities.

Despite these gains, challenges still exist in understanding user perceptions of their sanitation needs. Current knowledge gaps include:

- Current adoption classification of sanitation users does not identify individuals who share improved household-level sanitation among several households and/or individuals. This distinction in classifications has vast implications on the United Nations MDG indicator metrics tracking improved sanitation progress. Currently, these individuals are grouped with those who use communal sanitation facilities. *It is unknown if the adoption practices for those individuals who share private sanitation are more similar to those who choose to purchase household sanitation or those who use communal sanitation*.
- While it has also been shown that drivers can motivate individuals to adopt improved sanitation technologies, *it remains unclear if there are specific design attributes of sanitation technologies that are preferred over others.* Although the willingness to pay studies did compare preferences for several sanitation technologies; they did not capture user insight regarding the technical characteristics of these various sanitation technologies. Instead, opinions were gathered regarding cost considerations for pre-fabricated sanitation designs, leaving the user unable to express their satisfaction (or dissatisfaction) for specific design and/or implementation components related to sanitation technology. Furthermore, the priorities and tradeoffs sanitation users make when determining their preferences of certain sanitation technologies over others remain unknown.
- *An understanding of how user preferences for various sanitation design and implementation attributes impact overall user adoption and usage is unknown*.

The previous studies analyzing the desire to adopt sanitation systems individually focused on one type of sanitation technology. Based on those studies, it is unclear if those types of sanitation technologies were installed because they were the preferred sanitation alterative or if other alternative were unknown. Furthermore, for sanitation users who are unable to install private household sanitation, it is unclear if the sanitation design and implementation characteristic impact overall desire to use shared and/or communal sanitation on a continual basis.

With recent trends in sanitation access moving towards increasing user demand, understanding these further perspectives will help to provide additional insight.

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CHAPTER 3

THEORETICAL FRAMEWORK

The underpinning theoretical framework of the research entails the integration of social science theories with engineering principles. Insights from the fields of economics, cognitive psychology, and sociology guided the development of optimization and simulation models. The theoretical framework informed the research process, providing the basis for data collection and analysis. The theories central to the examination of user preferences and behaviors for sanitation systems are: random utility theory, behavioral decision theory, and the theory of reasoned action/planned behavior. This section summarizes those doctrines that assisted in developing the conceptual framework for examining user preferences. Theories are discussed in detail in the appropriate chapters.

3.1 Random Utility Theory

Utility theory is an economic concept that attempts to explain preference of individuals (Fishburn 1970, Beach 1997). One of the fundamental concepts within utility theory is rationality (Giocoli 2003). In a purely economical sense, rationality is confirmed through axiomatic preferences (also known as axioms of choice and Von Neumann–Morgenstern axioms) imposed on the individual's behavior. In considering the following axioms, the preference relation $\gtrsim$ implies preference (symbolized as $>$) or indifference (symbolized as ~). For M alternatives (indexed $j = 1,2,\ldots,M$) listed as A_1, $A_2,\ldots,A_m$, the fundamental preference axioms are:

Axiom 1: Reflexivity For any alternative, $A_j \gtrsim A_j$. Each alternative is as good as itself.

Axiom 2: Completeness For any two alternatives in the choice set A_1 and A_2, either $A_1 \gtrsim A_2$ or $A_2 \gtrsim A_1$. Out of the given options, ranking is developed based upon preference or indifference.

Axiom 3: Transitivity or Consistency If $A_1 \gtrsim A_2$ and $A_2 \gtrsim A_3$, then $A_1 \gtrsim A_3$. One option preference over another can infer its preferences to other options as well.

Axiom 4: Continuity For any alternative A_1, when $X(A_1)$ is defined as the "at least as good as A_1 set" and $Y(A_1)$ is defined as the "no better than A_1 set," then $X(A_1) = \{A_j | A_j \gtrsim A_1\}, Y(A_1) = \{A_j | A_1 \gtrsim A_j\}$. $X(A_1)$ and $Y(A_1)$ are considered closed set, containing their respective boundary points (as detailed in von Neumann & Morgenstern 1947).

With the satisfaction of all the axioms, an individual is considered rational and able to choose, based upon subjective preferences, the most preferred alternative in a logical and consistent manner (Giocoli 2003). The selection of the alternative that maximizes their satisfaction or profits (utility) and minimizes their losses is identified as utility maximization (Keeney & Raiffa 1976, Hanley et al. 2007). In this notion, utility is expressed as a measurement in a value-based environment where individual preference dictates the selection of the best alternative. When an individual analyzes his/her preferred alternatives, s/he determines the expected value of the proposed alternatives.

Random utility theory posits that the utility U_{ij} that individual *i* receives from alternative j is described by a deterministic component V_{ij}, which accounts for observable characteristics of the individual, as well as a stochastic component ε_{ij}, which is unobservable such that:

$$U_{ij} = V_{ij} + \varepsilon_{ij}$$

In an individual's attempt to maximize personal utility, an individual will select *j* = *m* if and only if s/he will receive the highest utility of all of the available alternatives. The probability that individual *i* selects option *m* is:

$$P_{im}(S) = P(U_{im} \geq U_{ij}) \ \forall j \in S, j \neq m$$

with $P_{im}(S)$ equating to the probability of option m having the highest utility of all the alternatives represented in the subset of alternatives S. Therefore, the decision making process to maximize utility is represented as:

$$P_{im}(S) = P(U_{im} \geq U_{ij}) \ \forall j \in S, j \neq m$$

$$P_{im}(S) = P(\mathrm{V}_{im} + \ \varepsilon_{im} \geq \mathrm{V}_{ij} + \ \varepsilon_{ij}) \ \forall j \in S, j \neq m$$

$$P_{im}(S) = P(\mathrm{V}_{im} - \ \mathrm{V}_{ij} \geq \varepsilon_{im} - \ \varepsilon_{ij}) \ \forall j \in S, j \neq m$$

(as detailed in Train 2009)

When considering choices regarding sanitation options, $P_{im}(S)$ represents the probability of selecting a discrete value. Assuming that the alternatives are mutually exclusive and collectively exhaustive,

$$\sum_{j=1}^{M} P_{ij}(S) = 1.$$

The deterministic component of utility V_{ij} is represented by vectors (attributes) X_{ij}that describe the alternative *j* such that:

$$U_{ij} = V_{ij} + \varepsilon_{ij} = X_{ij}\beta_j + \varepsilon_{ij}$$

The estimation of parameter vectors $\hat{\beta}_j$ for multinomial logit models is given by determining the likelihood $L(\beta_j)$ of observing the i^{th} individual choosing alternative j. Mathematically,

$$L(\beta_j) = \prod_{i=1}^{N}\prod_{j=1}^{M} P_i(j)^{y_{ij}} \Rightarrow \log L(\beta_j) \sum_{i=1}^{N}\sum_{j=1}^{M} y_{ij}P_i(j)$$

where y_{ij} is a dummy variable; $y_{ij} = \begin{cases} 1 \text{ if } i^{th} \text{ individual selects alternative } j \\ 0 \text{ otherwise} \end{cases}$

The parameter vectors $\hat{\beta}_j$ are selected to maximize the above likelihood function such that β_{jr} chosen is most likely to generate the pattern of observed samples. Parameter vectors $\hat{\beta}_j$ exist if the following conditions are satisfied:

$$\frac{\partial \log L}{\partial \hat{\beta}_j} = \sum_{i=1}^{N}\sum_{j=1}^{M} y_{ij} \frac{\frac{\partial (P_i(j))}{\partial \hat{\beta}_j}}{(P_i(j))} = 0 \; for \; r = 1,2,\ldots,R$$

(as detailed in Ben-Akiva & Lerman 1985)

As ε_{ij} is a random variable, the appropriate choice model is predicated on assumptions made regarding its probability distribution. Assuming that unobserved random preferences have equal variance and are uncorrelated regardless of the choice set S given to the individual, the disturbances ε_{ij} can be presumed to be independent and identically distributed, providing a extreme value type 1 (Gumbel) distribution (Ben-Akiva & Lerman 1985). Therefore, as the i^{th} individual attempts to maximize payoff, the choice model for alternative $j = 1$ and $j = m$ is derived as multinomial logit regression model (McFadden 1981) , stating

$$for\ j = m = 1: P_i(j) = \frac{1}{1+\sum_{j=2}^{M} \exp(v_{ij})}$$

$$for\ j = m = 2, \dots M:\ P_i(m) = \frac{\exp\,(v_{im})}{1+\sum_{j=2}^{M} \exp\,(v_{ij})}$$

Thus, through the estimation of parameter vectors $\hat{\beta}_j$, estimates of the observable deterministic components v_{ij} can be solved. Upon obtaining V_{ij}, the probability $P_i(j)$ of selecting jth alternative can be computed.

3.2 Behavior Decision Theory

Although rational individuals strive to maximize their utility, decisions can only be made based upon information known. Without complete knowledge, the ability to choose alternatives with the highest utility is limited, "bounding" the ability for individuals to act rational (Simon 1972). With the premise of bounded rationality, behavioral decision theory examines the psychological aspects of the decision process (Beach 1997). As detailed by Simon (1978), bounded rationality extends the limit of rational choice in three manners:

- *Incorporating risk and uncertainty.* Whereas rationality describes the probabilities of expected outcomes, risk and uncertainty can be incorporated by changing the parameter vectors to known distributions of random variables. In this manner, an individual's complete knowledge regarding an alternative's probability is replaced with the complete knowledge regarding the distribution of the probability's occurrence.
- *Recognizing incomplete alternative choice sets.* Whereas rationality assumes perfect knowledge, an individual may, in fact, be ignorant, possessing partial

knowledge for alternatives or not aware of all alternatives available within the choice set. However, probability distributions can be introduced to examine the impact of knowledge deficiency.

- *Selecting through "satisficing."* Due to the complexity of selecting an alternative, an individual may select one that satisfies his/her preferences, rather than determining the optimal solution (Beach 1997). Thus, due to the desire to choose an alternative, an individual makes tradeoffs, pursuing an option that provides "satisfaction at some specified level of all of its needs" (Simon 1957).

In essence, behavioral decision theory expands rationality by considering the cognitive limitations of the individual and reconciling knowledge known and knowledge unknown. This incorporation of uncertainty into the decision-making process occurs though the inclusion of unobservable random characteristics, as indicated by ε_{ij}, into random utility theory (McFadden 1981).

3.3 Theory of Reasoned Action / Theory of Planned Behavior

General decision theory focuses on selection among alternatives with multiple, and possibility conflicting, criteria. It can be broadly categorized in two manners: normative decision theory, which prescribes how individuals should behave when making decisions, and descriptive decision theory, which describes how individuals actually behave when making decisions (Simon 1978). The theory of reasoned action, as developed by Fishbein and Ajzen (1975), is a descriptive-based approach designed to analyze the influence preferences have on behaviors. The theory captures the relationship between preferences for alternatives and actual behavior towards those alternatives. As it is generally accepted that preferences for alternatives are based upon beliefs about them (Ajzen 1991), the theory is based on the construct that intention of action will lead to actual behavior. It is anticipated that intentional behavior will lead to definite behavior patterns. Intention is described by the decision made to participate in a certain behavior (Fishbein & Ajzen 1975, Ajzen & Fishbein 1980). An individual's intent is, in turn, influenced by his/her preferences, representing favorable or unfavorable opinions placed upon beliefs (Eagly & Chaiken 1993), and subjective norms, his/her perceptions of social pressure towards the behavior (Azjen 1996). The more favorable these perceptions are regarding a behavior or its outcome, the more likely the behavior is to occur. The theory of planned behavior extends upon the theory of reasoned action by incorporating the influence of perceived behavioral control, examining the individual's thoughts regarding difficulty on performing the behavior (Azjen 1996). Mathematically,

$$B \approx BI = w_1 A_B + w_2 SN + w_3 PBC$$

$$such\ that\ A_B \propto \sum_{f=1}^{F} b_f e_f\ ; SN \propto \sum_{g=1}^{G} nb_g mc_g\ ;\ PBC \propto \sum_{h=1}^{H} cb_h pf_h$$

where variables w_1, w_2, and $w_3$represent empirically determined weights, b_f represents the f^{th} behavioral belief, e_f represents the f^{th} outcome evaluation, nb_g represents the g^{th} normative belief, mc_g represents the g^{th} motivation to comply, cb_h represents the h^{th} control belief, pf_h represents the h^{th} perceived facilitation.

3.4 Application of Theory in Body of Work

Two primary individual decision-making processes frame the research: 1) the determination of preferred sanitation options (based on preferences), and 2) the choice to adopt a certain sanitation behavior (based on beliefs). Incorporating random utility and behavioral decision theories, the preference-based decision-making process will determine the preferences users have for technical attributes as well as determine the tradeoffs among them. Their application is seen in *Chapter 5 – User Preferences for Sanitation Technology Attributes*.

The theory of planned behavior is used to examine an individual's behavior to use various sanitation technologies. Its application is seen in *Chapter 6 – Analyzing Usage of Sanitation Technology: An Agent-Based Analysis.*

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CHAPTER 4

MOTIVES AND BARRIERS OF USER ACCEPTANCE OF SANITATION SYSTEMS IN INFORMAL SETTLEMENTS

A paper to be submitted to

The Journal of Water, Sanitation, and Hygiene for Development

4.1 Chapter Focus

This chapter characterizes sanitation users included in this study. It addresses the first knowledge gap identified in *Chapter 2 Sanitation in Developing Countries – A Systematic Review of User Preferences and Motivations*. It suggests the need to differentiate between individuals who share private improved sanitation with other households, allowing for a sense of controlled access, versus individuals who use publically available communal facilities. In general, users who share private sanitation technology with other households place a higher importance on drivers motivating sanitation usage than other classification groups.

4.2 Introduction

Indicator metrics used to evaluate the Millennium Development Goal (MDG) targeted towards increasing sanitation access do not currently distinguish between private sanitation shared among households and communal public sanitation. Instead, these non-individual household facilities are labeled as “shared sanitation” and considered unimproved – regardless of the type of technology installed – as a result of possible unhygienic conditions from unkemptness as well as concerns regarding accessibility

(UNICEF & WHO 2012). With shared sanitation accounting for an estimated one-third of the global population who use unimproved sanitation (UNICEF & WHO 2010a), the decision to exclude these facilities that have technologies otherwise deemed appropriate from being considered improved has recently been reexamined (UNICEF & WHO 2010b). The lack of distinction between various shared sanitation facilities has led to an oversimplification of the term and the need to examine the potential impacts of private sanitation shared among households (Cairncross &Valdmanis 2006; Montgomery et al. 2010, Wolf et al. 2013).

It has been postulated that sanitation facilities shared among households with appropriate hygienic technology may be analogous to sanitation facilities privately used by an individual household (UNICEF & WHO 2010b). Installation of private sanitation is not a feasible option for all households, as some must rely on shared and/or public sanitation facilities (Norman 2011). It is recognized that sharing private sanitation with a few households may be an acceptable approach (UNICEF & WHO 2010b), as the lack of available resources and other constraints can impede private installation at the household level (Saywell & Shaw 1999, Jenkins & Scott 2007). While the desire to differentiate sanitation users who share improved sanitation facilities among several households has been established, it remains unclear if differentiating users of shared household-level sanitation from those who primarily use private or public sanitation facilities will provide further insight into shared sanitation users. Moreover, factors influencing the potential benefits of shared facilities are largely unknown, thereby preventing an accurate description of the characteristics of these users.

Recognizing the need to accurately describe and differentiate various sanitation user adoption groups, this study reclassifies sanitation into three groups: individual household private sanitation, shared private sanitation, and public sanitation. The study explores the motivations of users in these groups and examines if similar motivating factors exist between them. It expands on other comparative studies examining users of private sanitation and non-private (including shared and public) sanitation facilities (Jenkins 1999; Jenkins & Curtis 2005; Jenkins & Scott 2007; Hernandez et al. 2009; Santos et al. 2011). These previous studies established the framework for understanding the factors driving sanitation users to install and finance, if necessary, their private household sanitation. With the focus of the previous studies on private sanitation ownership, the study will investigate whether the previously-tested motivating factors to install private household sanitation will also motivate the continual usage of shared and public sanitation facilities.

4.3 Methods

4.3.1 Sampling Site

The Republic of South Africa is located on the southernmost tip of the continent of Africa. In 1994, it was estimated that just over half of the population (52%) had access to sanitation (South Africa Department of Water Affairs 2012). Three years later, the South African government recognized access to water and sanitation as a basic human right under the Water Services Act of 1997 and decreed that access cannot be denied to anyone, regardless of socioeconomic status (Republic of South Africa 1997). Since then, South Africa has been striving to provide these services and has increased sanitation access to 82.8% of the population as of 2012 (South Africa Department of Water Affairs 2012). The majority of the population who does not have access lives in peri-urban settlements throughout the country (World Bank 2012).

This work focuses on sanitation users located in Kayamandi, a peri-urban settlement under the jurisdiction of the City of Stellenbosch, South Africa. Stellenbosch is separated into 19 wards; three of the wards are exclusive to Kayamandi, while another ward includes other surrounding areas (Stellenbosch Municipality 2007). Over the last ten years, Stellenbosch has experienced a dramatic increase in population, doubling to approximately 222,000 inhabitants in 2010 (South Africa Statistics 2010). This population boom has intensified demand for municipality service delivery, including water and sanitation services.

4.3.2 Survey Design

Data for the study investigated the motives and barriers for the use of private, shared, and public communal sanitation facilities. Using structured in-person interviews, respondents were questioned on (i) existing sanitation practices and their respective level of satisfaction; (ii) stated motives and barriers to sanitation system usage; and (iii) their socioeconomic and demographic characteristics. A previous approach of classifying adoptive or non-adoptive practices (Jenkins & Curtis 2005; Jenkins & Scott 2007; Hernandez et al. 2009; Santos et al. 2011) was modified to differentiate between the types of sanitation facilities used. This modification was needed to classify sanitation users who use private household sanitation that share sanitation facilities with others (i.e. the landlord, other family members, etc.) For this study, private sanitation users – individuals who do not share sanitation facilities with anyone outside their household – are considered adopters. Shared sanitation users – individuals who share sanitation facilities with others but the accessibility of these facilities are exclusive to a particular group of individuals – are considered partakers. Public sanitation users – individuals who use communal sanitation facilities available to anyone in the community – are considered non-adopters.

The combination of open-ended and close-ended questions allowed for probing and informative answers regarding specific motives and barriers. Open-ended questions were asked first, followed by closed –ended questions; in some instances, sanitation users mentioned determinants in the open-ended section that were also addressed in the closed-ended section. Similar determinants illustrated in Jenkins (1999), Hernandez et al. (2009), and Santos et al. (2011) are investigated in this study to determine the impact of these factors on sanitation user acceptability. The four-point relative importance measurement scale, used previously by Jenkins (1999) Hernandez et al. (2009), and Santos et al. (2011) was also used in this study.

4.3.3 Sampling Procedures

A total of 1002 sanitation users were interviewed over a four month period from August 2012 to December 2012. For sanitation users to participate in the study, they had to be at least eighteen years old and stay at the surveyed dwelling at least four nights a week. To assist with the data collection, four enumerators (two males and two females) were trained in the administration of the questionnaire. Enumerators were fluent in both questionnaire languages: isiXhosa and English.

Ethical approval prior to commencing any field testing was provided by both the Institutional Review Board (IRB) at the Georgia Institute of Technology as well as the Committee for Human Research at Stellenbosch University.

4.3.4 Data Analysis

Descriptive statistics were calculated. The chi-square test of independence was used to analyze the statistical independence of frequencies in the open-ended responses given by each adoption group. Non-parametric one-way analysis of variances was used to determine the statistical significance of differences in the mean responses given for the closed-ended questions. Assuming a confidence interval of 95% ($\alpha = 0.05$), p-values < 0.05 would indicate that responses were independent of each other. P-values > 0.05 would indicate no statistical significance.

4.4 Results

Descriptive characteristics of the sample population are shown in Table 4.1. Approximately 48.5% of the respondents are female and 54.8% are heads of households. The sample median age was 25-34 with 73.2% of the population having completed at least secondary education and/or trade school training. As 44.3% of the respondents reported being employed in the last three months, the majority took on jobs as laborers, domestic workers, and shop attendants, having an estimated monthly income in the range of R2000 to R2999 (1 US$ = 8.6 ZAR year 2012) . When examining health aspects, 52.3% of the respondents indicated that they felt they were in very good or excellent health, while only 8.5% reported having any serious and/or chronic illness. 5.1% of the respondents indicated having some gastro-internal illness that impacted their livelihood over the last two weeks. The median household size of sample population is four, with 53.2% of the respondents living in an informal dwelling.

4.4.1 Existing Sanitation Facilities

Sanitation users were asked specific questions about the type of sanitation technology they used the most when at home; the identified technology was considered to be their main sanitation technology. The overwhelming majority (97.8%) used cistern flush toilets as their main sanitation technology. The high access to cistern flush toilets as a main sanitation technology is consistent with the South African 2011 Census Survey estimates of 93.9% within the same sampling area (Statistics South Africa 2012).

Approximately one-third of the sample population (35.9%) were adopters, using private household sanitation and not sharing with anyone living outside the dwelling; only 35.8% of the adopters have their main sanitation technology installed within the dwelling. Additionally, 84.3% of the adopters reported that their main sanitation was working properly at the time of the interview. 38.3% of the sample population were partakers, having reported sharing their main sanitation technology with at least another household; 16.1% of those partakers owned their own sanitation technology. Partakers stated sharing sanitation facilities with several different users, including:

- Neighbors (59.1%)

- Family living in other households (48.0%)
- Tenants (12.7%)
- Landlords (6.8%)

The rest of the sampling population was non-adopters (25.8%), using sanitation technology that was available for communal use. Among users using shared private sanitation and/or public facilities, 44.4% reported being fairly or very dissatisfied with their main sanitation technology.

4.4.2 Advantages and Motives for Sanitation Usage

Sanitation users were asked to provide their perspective on advantages to use their main sanitation technology (Figure 4.1). 338 of the 360 adopters mentioned at least one advantage to having sanitation, with adopters stating an average and median of 3.3 and 4.0 advantages, respectively. 337 of the 384 partakers and 178 of the 258 non-adopters mentioned a minimum of one advantage. Both partakers and non-adopters stated an average of 2.7 advantages. When asked open-ended questions, the most frequently cited reasons partakers saw that their sanitation option was advantageous were:

- Cleanliness (23.8%)
- Ability to use sanitation that flushes (13.5%)
- Ability to use in a safe environment (10.6%)
- Placement of sanitation nearby the dwelling (8.4%)
- Ability to lock the facility (4.8%)

Table 4.1. Demographic and Socioeconomic Characteristics of Sample Population

Characteristic (N= 1002)	Sample description
Sex of respondent	
Male	51.5%
Female	48.5%
Age of respondent (in years)	
18-24	24.0%
25-34	39.4%
35-44	23.8%
45-54	9.3%
55-64	2.8%
over 65	0.7%
Highest level of education completed	
Primary	26.7%
Secondary	61.3%
Trade School	3.3%
College/University	8.7%
Ethnicity	
African/Black	98.0%
Coloured	1.9%
Indian/Asian	0.1%
Employment	
Paid employment within the last three months	44.3%
Type of dwelling	
Formal	46.8%
Informal	53.2%
Head of household	
Yes	54.8%
Household size	
Average	4.4
Median	4
Occupancy	
Owned and fully paid off	8.3%
Owned but not yet paid off	1.0%
Rented	7.4%
Occupied rent-free	82.2%
Other	1.1%
Water Source	
Piped water inside the dwelling	40.2%
Piped water inside the yard	4.9%
Piped water from access point outside the yard/communal pipe	54.9%

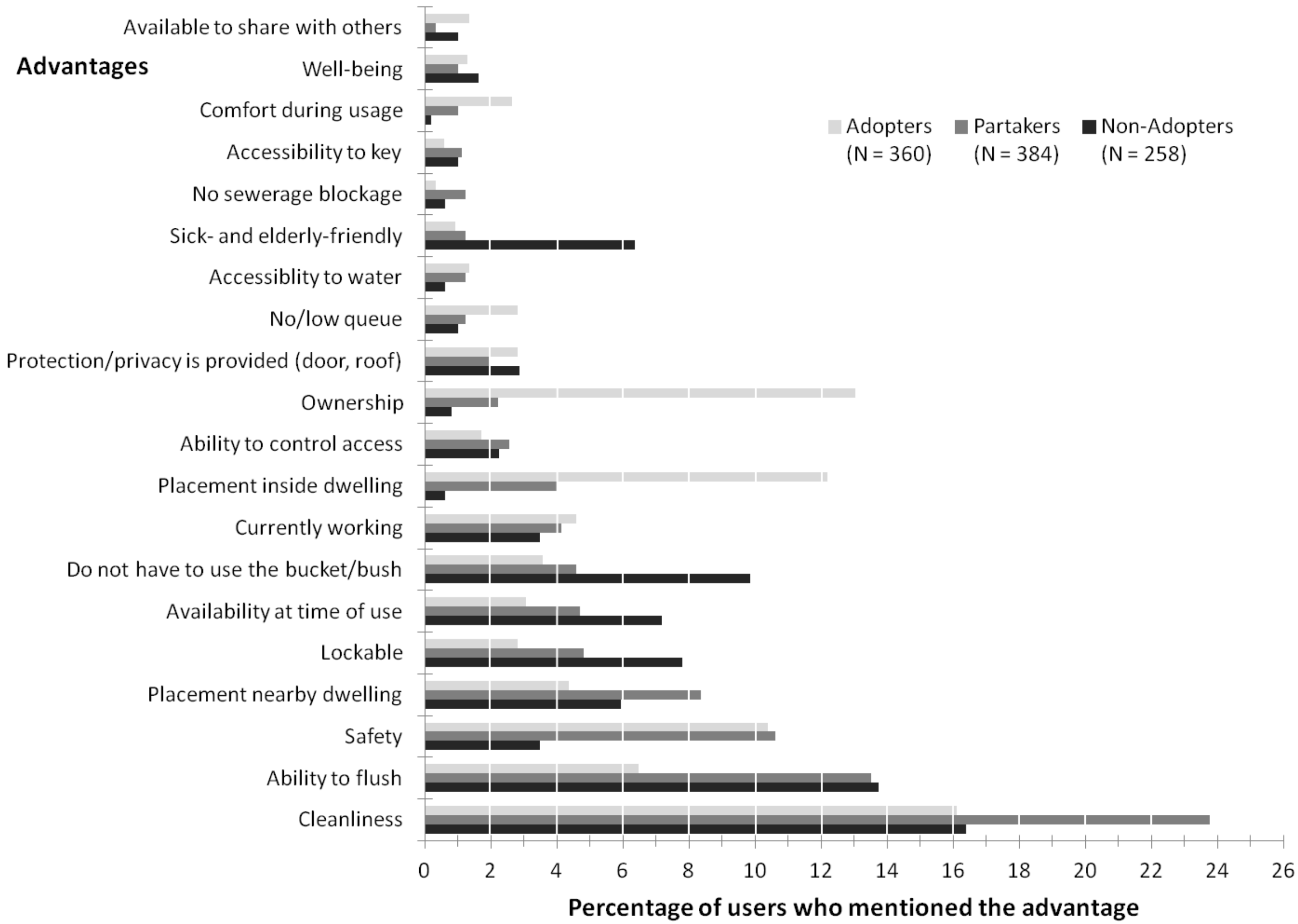

Figure 4.1. Frequency of Open-Ended Advantage Questions by Classification Group

Regardless of the type of adoption classification, using toilets that are clean was the most frequently mentioned advantage. Being able to use sanitation technology that flushes was also a clear advantage to partakers (13.5%) and non-adopters (13.7%), as it was the second most mentioned advantage by both of these groups. Adopters more frequently mentioned the lack of queues and comfort during using as advantages. Unlike the partakers or non-adopters, adopters were more likely to associate the use of sanitation with hygiene. Although frequently mentioned by all groups, the ability to use sanitation that flushes was most frequently mentioned by partakers. Non-adopters were more likely to identify the ability to share accessibility with others as well as use the sanitation facility without pay as advantageous reasons to use their sanitation facility.

The importance of specific motives was also asked to adopters, partakers, and non-adopters. Respondents were questioned on the average importance of these motives and their p-values were compared to previous studies in Table 4.2. All motives asked in previous studies were also considered to be statistically significant among the adoption groups. Partakers consistently ranked the importance of the motives higher than both adopters and non-adopters. While a previous study also examining flush toilet connections to a sewerage system did show the average importance of non-adopters being higher than of non-adopters (Santos 2011), the result of this study indicates the means of those two classification groups to be of statistical significance.

Table 4.2. Average Importance of Motives of Sanitation Usage Based upon Adoption Classification

Adoption vs. Non-Adoption	Jenkins (1999) Pit Latrine Rural Benin			Hernandez et al. (2009) Pit Latrine Rural Ethiopia			Santos et al. (2011) Toilets + Sewerage Peri-Urban Brazil			Seymour et. al (2013) Toilets + Sewerage Peri-Urban South Africa			
Total Sample Size	N = 320			N = 2000			N = 718			N = 1002			
Driver Importance Rating (1 to 4) (Sample Size)	Adopters (N=22)	Non-Adopters (N=298)	p-value[a]	Adopters	Non-Adopters	p-value[a]	Adopters (N=647)	Non-Adopters (N=71)	p-value[a]	Adopters (N=360)	Partakers (N=384)	Non-Adopters (N=258)	p-value[a]
Gain prestige from visitors	4.00	3.96	**	3.98	3.91	****	3.39	3.53	NSS	3.03	3.35	3.09	****
Feel royal	2.74	2.75	NSS				3.95	3.90	NSS				
Make my life more modern	3.48	2.93	**	3.94	3.86	****	3.48	3.71	NSS	3.15	3.40	3.24	****
Health Benefits	1.05[b]	1.29[b]	***	3.92	3.89	*	3.7	3.71	NSS	3.34	3.54	3.46	****
Make it easier to defecate due to age/sickness	3.05	2.58	*	3.94	3.90	**	3.64	3.71	NSS	3.19	3.40	3.32	****
Have more privacy to defecate	3.89	3.65	***	3.91	3.90		3.62	3.71	NSS	3.26	3.57	3.53	****
Keep my house/property clean	3.83	3.57	**	3.97	3.93	**							
Make my house more comfortable	3.82	3.47	***				3.58	3.71	NSS	3.26	3.56	3.50	****
Avoid risk of smelling/seeing feces in bush	3.94	3.77	**										

[a]: p-value representations - NSS: Not Statistically Significant; *: $p<0.1$; **: $p<0.05$; ***: $p<0.005$; ****: $p<0.0005$

[b]: Jenkins (1999) reported spontaneous mention of health benefits.

4.4.3 Disadvantages and Barriers for Sanitation Usage

Similar to the advantages, sanitation users were also provided open-ended responses to questions regarding disadvantages to sanitation usage. 237 of the 360 adopters mentioned at least one disadvantage; an average of 3.1 disadvantages was mentioned per adopter. 242 of the 384 partakers mentioned a minimum of one advantage. On average, partakers mentioned 2.7 disadvantages. The most frequently listed partaker disadvantages were:

- Sharing with too many other users (14.9 %)
- Lack of cleanliness (13.0%)
- Lack of ability to use at night (9.4%)
- Long queues (8.3%)
- Sanitation is in an unsafe environment (8.1%)

Only eleven non-adopters did not state a disadvantage. Non-adopters averaged 3.6 disadvantages, stating more disadvantages than advantages to usage. Similar to the adopters, sharing with too many users as well as the lack of cleanliness and security of the sanitation environments were also concerns for partakers and non-adopters. Additionally, partakers and adopters mentioned the lack of accessibility at night and long queues to be disadvantageous to using their sanitation options (Figure 4.2).

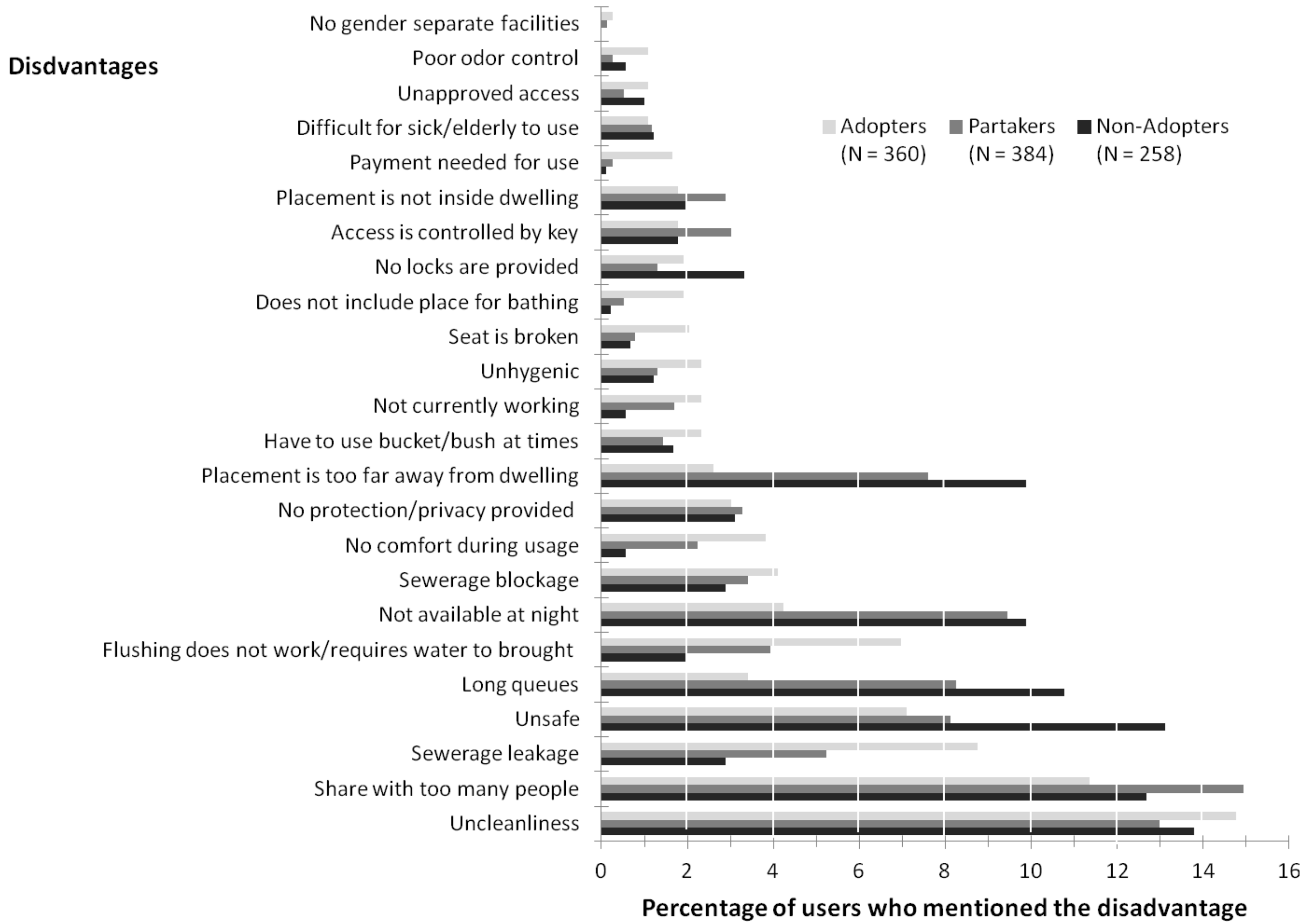

Figure 4.2. Frequency of Open-Ended Disadvantage Questions by Classification Group

4.4.4 Impacts of Demographic and Socioeconomic Characteristics

In addition to the open-ended questions, specific factors were investigated to determine the impact of demographic and socioeconomic characteristics. The calculated p-values analyzing the different factors and differences between the reported responses for particular subgroups are presented in Table 4.3. The differences between the adoption classifications were statistically significant for all motivating factors analyzed. The desire for privacy was statistically dependent for all demographic and socioeconomic characteristics, except for the location of their existing sanitation. Having sanitation available for visitors to use was statistically dependent on location and adoption classification, but not on the head of household status of the type of housing.

Adopters, partakers, and non-adopters were also asked about their specific barriers to sanitation use. While there was no statistical significance among the adoption groups for the disadvantages of walking too far, fear of safety was a clear disadvantage amongst them. Similar demographic and socioeconomic characteristics were examined. The placement of sanitation inside the dwelling, type of dwelling, or head of household status did not affect how often fear of safety was mentioned as a disadvantage.

Table 4.3. Statistical Significance of Motives and Barriers of Sanitation Usage Based upon Demographic and Socioeconomic Characteristics

	Adoption Classification	Location of Sanitation Option	Household Dwelling Classification	User Sanitation Satisfaction	Head of Household Classification
Subgroups	*Adopters, Partakers, Non-Adopters*	*Inside of Dwelling, Outside of Dwelling*	*Informal Dwelling, Formal Dwelling*	*"Fairly" or "Very" Satisfied vs. Not*	*Head of Household vs. Not*
Motives					
Available for visitors	<0.0001	0.0063	0.2029	0.0759	0.8470
Modern lifestyle	<0.0001	0.0374	0.6664	0.0385	0.8537
Hygienic	<0.0001	0.0108	0.3612	0.1019	0.0117
Comfort during usage	<0.0001	0.0462	0.1658	0.0163	0.0282
Privacy is provided	<0.0001	0.0612	0.0052	0.0296	0.0457
Safety is provided	<0.0001	0.4665	0.3509	0.1915	0.0599
Sick- and elderly-friendly	<0.0001	0.0355	0.0545	0.0952	0.8209
Barriers					
Lack of control	0.0021	<0.0001	0.0013	0.0224	<0.0001
Difficulty in use	0.0007	<0.0001	0.0002	0.2524	<0.0001
Payment needed for use	0.0004	<0.0001	0.0063	0.9320	<0.0001
Fear of safety	<0.0001	0.5043	0.8603	<0.0001	0.5224
Walking too far	0.1474	<0.0001	0.1741	0.0261	<0.0001
Having no place to sit	0.0073	<0.0001	0.0252	0.0001	<0.0001
Waiting too long for queues	0.0216	<0.0001	0.3566	0.0222	0.0186

4.4.5 Indentifying Partakers as a New User Adoption Classification

The calculated p-values comparing the open-ended responses for partakers and non-adopters are presented in Table 4.4. Partaker and non-adopter responses are statistically different on the majority of motives and barriers of sanitation usage. Factors of safety, cleanliness, close placement, and accessibility are mentioned as advantages for partakers; subsequently, the lack of these factors acts as barriers to usage for non–adopters.

Table 4.4. Comparison of Open-Ended Responses for Partakers and Non-Adopters

Advantages	**p-Value ($f \leq 5$)**	**Disadvantages**	**p-Value ($f \leq 5$)**
Cleanliness	<0.0001	Unsafe	<0.0001
Safety	<0.0001	No locks are provided	0.0016
Placement inside dwelling	<0.0001	Long queues	0.0072
Placement nearby dwelling	<0.0001	No comfort during usage	0.0105
Ability to flush	0.0001	Placement is too far away from dwelling	0.0106
Accessibility without a key	0.0001	Difficult for children to use	0.0209
Ownership	0.0011	Not currently working	0.0593
Available to share with others	0.0020	No gender separation	0.0736
Currently working	0.0046	Flushing mechanism does not work / requires water to brought	0.0833
Free to use	0.0105	Sewerage leakage	0.0848
Availability to use at night	0.0114	Lack of cleanliness	0.0941
Comfort during usage	0.0114	Unapproved access	0.1655
Accessibility to water	0.0325	Not Available at Night	0.1803
No sewerage blockage	0.0325	No controlled access	0.2623
Ability to control access	0.0396	Have to use bucket/bush at times	0.4328
No/low queue	0.1336	Placement is not inside dwelling	0.5271
Accessibility to key	0.1967	Difficult for sick/elderly to use	0.6547

Table 4.4. Comparison of Open-Ended Responses for Partakers and Non-Adopters

Advantages	**p-Value ($f \leq 5$)**	**Disadvantages**	**p-Value ($f \leq 5$)**
Ease of use	0.2059	No protection/privacy is provided (door, roof)	0.6803
Availability at time of use	0.4250	Unhygienic	0.8273
Do not have to use the bucket/bush	0.4581	Share with too many people	1.0000
Protection / privacy is provided (door, roof)	0.4795	Sewerage blockage	1.0000
Lockable	0.5785	Seat is broken	1.0000

4.5 Discussion

This study investigates motivating and discouraging determinants of sanitation usage. The results, summarized in Table 4.5, support a need to consider motives and barriers of sanitation usage of partakers separately than adopters and non-adopters. As an adoption group, partakers have the option of using a sanitation facility that is shared among several households as well as one that is publicly open to the community. When openly asked about their motives for usage, the statistical differences in the advantages between the adoption groups suggests that partakers value the placement of their shared sanitation nearby their homes as well as the ability to use sanitation that flushes. When compared to the adopters, both groups valued environments where sanitation access is controlled, a clear motive differencing the use of sanitation for non-adopters. In contrast, when compared to the non-adopters separately, partakers viewed their sanitation facilities as advantages due to their cleanliness and ability to use them at night. All adoption groups, regardless of classification, view sanitation as beneficial to their well-being. The groups valued not having to use bucket latrines or the bush, the ability to use sanitation that is lockable, as well as the availability of the facility when it is needed by the user. Barriers to sanitation usage indicate that unsafe environments, long queues, and facilities considered too far away continue to deter usage. Although partakers view controlled access as benefit to their current sanitation practices, they still feel that they share with too many individuals – a sentiment also felt by non-adopters. Partakers view their sanitation as safe as adopters do, and the fear of an unsafe environment suggests their desire to not use shared communal sanitation. With the overwhelming majority of respondents in the sample population having access to cistern flush toilets, the study was able to focus on the difference between user adoption classes.

Table 4.5 Motives and Barriers of Sanitation Usage by Adoption Classification

Adoption Classification	Motives	Barriers
Adopters	Ownership Placement Safety Privacy/Protection No/no queue Cleanliness	Sewerage leakage Broken flushing mechanism Lack of comfort
Partakers	Cleanliness Ability to control access Ability to flush Placement	Lack of cleanliness Share with too many people
Non-Adopters	Ability to share with others Free to use Accessibility without a key	Lack of cleanliness Share with too many people Unsafe Long queues Placement

Shared sanitation may be a viable way to increased access to improved sanitation, specifically in regions that individual household ownership may not be possible for all dwellings. Determining the appropriate number of households and well as which households should share the facilities can be difficult. In this study, partaker households were able to determine who was given access to the sanitation facility. In most cases, partakers shared with neighbors and family members. In broad implementation schemes where municipalities or agencies want to increase access through shared sanitation, the inability for households to choose their fellow partakers may deter usage of the sanitation system. Involving the households in the decision-making process for shared sanitation is needed if it is to be considered a feasible option to improve sanitation coverage.

4.6 Correlation to Body of Work

The chapter addresses Aim I. While the majority of the sanitation users characterized used cistern flush toilets as their main sanitation technology, only 60% of the sample population stated that they were "fairly satisfied" or "very satisfied" with their main sanitation technology. From this characterization, it remains unclear if changes to the installed type of technology or changes to the implementation approach would increase user satisfaction with sanitation.

The next chapter, *Chapter 5 – User Preferences for Sanitation Technology Attributes*¸ presents the paper analyzing the impact changing sanitation technology would have on user satisfaction. In total, eight sanitation technologies are investigated, each having multiple operation modes that were tested. It examines how changing operation features (including placement and waste flow stream attributes) of a sanitation technology can impact how individuals perceive that technology. User satisfaction will be measured using random utility theory. Assuming that sanitation users act rationally, they will prefer a sanitation alternative that provides them with the highest amount of satisfaction (utility).

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CHAPTER 5

USER PREFERENCES FOR SANITATION TECHNOLOGY ATTRIBUTES

A paper to be submitted to

The Journal of Environmental Science & Technology

5.1 Chapter Focus

This chapter investigates user preferences for technical attributes of sanitation and their impact on user satisfaction with their sanitation technology. It explores the second knowledge gap identified in *Chapter 2 Sanitation in Developing Countries – A Systematic Review of User Preferences and Motivations*. As users were asked about technical attributes instead of pre-fabricated sanitation technologies, specific user insight was captured regarding the priorities given to the operational modes of various sanitation technologies.

5.2 Introduction

As sanitation practices are embedded into cultural values and behaviors, the selection of sanitation systems must consider the user preferences to ensure the selection of appropriate technology. Historically, approaches to select sanitation technologies for communities do not place emphasis on user acceptability; instead, decision-based criteria to determine technology appropriateness have included location profiles, regulatory frameworks, pollution control methods, construction feasibility, and operation and maintenance considerations (Kalbermatten et al. 1982, Franceys et al. 1992, Loetscher & Keller 2002, Mara et al. 2007). Furthermore, decisions determining what sanitation technologies to install are based on pre-determined sanitation technologies instead of general attributes of sanitation technology. Historical approaches to determining which sanitation technology was appropriate contended that since it takes considerably more time and analysis to implement the treatment technology in developing countries, it is best to use elimination algorithms to determine unsuitable sanitation technology (Kalbermatten et al. 1982). Other decision-support systems caution to consider possible social implications of sanitation technology, as it relates to regulatory framework and cultural beliefs (Franceys et al. 1992, Mara et al. 2007).

Previous attempts to gather user perspectives on sanitation systems assessed willingness to pay for various technology and/or implementation alternatives. In this methodology, the price point users are willing to pay for improved sanitation is established upon the selection of a bid price in a hypothetical market. Previous contingent valuation studies that examine sanitation technology have gathered user perspectives for pre-fabricated sanitation designs (Whittington et al. 1993, Altaf & Hughes 1994, Fujita et al. 2005), not capturing user insight for specific technical attributes of these various sanitation technologies. These previous approaches left sanitation users unable to express their preferences for specific design and/or implementation attributes. The need to examine attributes of technology design and implementation, not just specific technologies, in contingent valuation studies has been recognized (Altaf & Hughes 1994).

Herein, this study attempts to determine the appropriateness of sanitation technology for a community by examining the community's user preferences for specific technical attributes. The study examines user preferences for sanitation technology among peri-urban households in South Africa. It also analyzes the priorities individuals place on various attributes of sanitation technology. Finally, the study presents a model to determine which sanitation technology alternatives would be more favored by users based upon their stated preferences. An established discrete choice model, maximum difference scaling (MaxDiff), is used to investigate priorities and tradeoffs made for specific criteria of the sanitation technology as well as develop a utility function to analyze the sanitation technology alternatives.

5.3 Methods

5.3.1 Maximum Difference Scaling

The MaxDiff model was developed by Louviere (1990) as a quantitative approach to determine relative priorities (preferences) among a set of items. MaxDiff has been used widely to elicit preferences throughout a variety of fields, including health care, consumer ethnics, buyer spending habits, and food quality (Finn & Louviere 1992, Louviere et al. 1994, Flynn et al. 2007, Hein et al. 2008, Flynn 2010). To assist with determining relative priorities, MaxDiff relies on comparisons provided within a given set of choices. The model is an extension of the comparative judgment approach of pairwise comparisons (Thurstone 1927). In traditional approaches to pairwise comparisons, comparative judgments are made between two mutually exclusive items, such that an individual can express preference of one item over the other or indifference between the two items. The number of pairwise comparisons needed to consider all possible item pairs is contingent upon the number of items, n, such that the required number of pairwise comparisons is equal to $n(n - 1)/2$. When there are a considerable number of items, the number of pairwise comparisons needed to provide a complete analysis can add to response burden.

MaxDiff reduces the number of pairwise comparisons (and thereby potential response burden) by increasing the number of items in a given comparison (to at least more than two items) and asking individuals to determine the best and worst items (or most important and least important items, respectively) in a given comparison. By analyzing all possible pairs in a given comparison, an individual then selects the pair that provides the maximum difference based upon his/her preference (or importance). Through this sequential analysis, called best-worst scaling, an evaluation of the majority of possible pairs provided in the comparison can be inferred, resulting in an implied ranking of the items. For example, consider the analysis of five ($n = 5$) alternatives: A, B, C, D, and E. Using the traditional method of pairwise comparisons, ten pairwise comparisons are required to examine all possible arrangements. Using the MaxDiff method of best-worst scaling, if an individual considers A the best item and E the worst item, the 7 of the 10 pairwise comparisons are also inferred

$$A > B, A > C, A > D, A > E, B > E, C > E, D > E$$

By asking an individual to determine the maximum difference pairs given in subset choice sets that provide four of the comparable items (i.e., ABCD, ABCE, ABDE, ACDE, and BCDE), all 10 pairwise comparison relationships can be inferred.

Depending on desired comparison, items are framed either as objects, attributes, or alternative profiles (Flynn 2010). As objects, items are used in determining preferences, concepts, or opinions without any descriptive attributes being considered (Finn & Louviere 1992). As attributes, items are used to examine the impact of attributes and their subsequent levels based on a common scale, allowing for direct attribute level comparison of alternatives (Louviere et al. 1994). As alternative profiles, items are developed in similar fashion as discrete choice experiments; in this comparison, individuals are asked to select the most appealing and least appealing options (Flynn 2010).

5.3.2 Random Utility Theory Framework

The theoretical framework of MaxDiff is based upon random utility theory (McFadden 1973), which posits that the satisfaction (utility) that individual i can obtain from item j in choice set s can be decomposed into a deterministic, V_{isj}, and random error ε_{isj} components:

$$U_{isj} = V_{isj} + \varepsilon_{isj}$$

Assuming a linearly additive indirect utility function gives the following:

$$U_{isj} = V_{isj} + \varepsilon_{isj} = X_{isj}^{'}\beta_j + \varepsilon_{isj}$$

where $X_{isj}^{'}$ is the vector of attributes of the *jth* good as viewed by the *ith* individual in the *sth* choice set, and β_j is the coefficient vector to be estimated.

5.3.3 Model and Analysis

An orthogonal balanced incomplete block design (BIBD) model is employed to develop the experimental design that details the subset choice sets for the comparable items. BIBDs ensure that the choice sets are statistically designed so that the items being compared appear the same number of times throughout the experiment and that each item does not appear in the same position in another choice set. The experimental design is based upon the following equations:

$$bk = nr$$

$$\lambda(n-1) = r(k-1)$$

where b is the number of subset choice sets to appear in the experiment (the blocks), k is the number of items provided in each subset choice set, n is the previously described total number of items to be compared in the overall choice set s, r is the number of subset choice sets with a given item, and λ is the count frequency that a pair of items appear in the subset choice sets. Using these design conditions, the preceding equations must equal integers for statistical accuracy of the experimental design.

5.3.4 Probability of Selection

When considering items within the choice set, $P_{is}(j)$ represents the probability of i^{th} individual choosing the discrete item j, assuming that the items in choice set s are mutually exclusive and collectively exhaustive. The probability that i^{th} individual will select $j = m$ from choice set s is represented as:

$$P_{is}(j = m) = P(U_{ism} \geq U_{isj}) = P(v_{ism} - v_{isj} \geq \varepsilon_{ism} - \varepsilon_{isj})\ \forall j \in s, j \neq m$$

As ε_{isj} is a random variable, the appropriate choice model, as indicated in the structure of probability $P_{is}(j)$, is predicated on assumptions made regarding its probability distribution. Assuming that unobserved random preferences have equal variance and are uncorrelated regardless of the choice set *s* given to the individual, the disturbances ε_{isj} can be presumed to be independent and identically distributed, providing an extreme value type 1 (Gumbel) distribution (Ben-Akiva & Lerman 1985). Given these assumptions, the choice model of i^{th} individual selecting $j = m$ is expressed as the multinomial logit regression (McFadden 1973), commonly referred to for discrete choice model analysis and given as:

$$P_i(j = m) = \frac{e^{Vism}}{\sum_{j=1}^{J} e^{Visj}}\,.$$

5.3.5 Alternative Comparison with Utility Maximization

The utility function U_{isj} determines the value that individual *i* places on alternative *j* from the choice set *s*. Assuming that individuals are acting rationally, they will examine all available alternatives and select the option that maximizes their utility and minimizes their losses (Hanley et al. 2007). In this notion, utility maximization indicates an individual's selection of the option with the highest anticipated expected value; this option represents the alternative that would be most preferred by the individual.

5.4 User Preferences for Sanitation Technology Attributes

Complete sanitation systems include methods to collect, treat, reuse and/or dispose of human wastes. Technology designed for sanitation systems can include any of these methods or all of them. For sanitation technologies to function properly, users of the system are required to interact with it in a certain manner. Without correct user interaction, the technology will not efficiently work as it was designed and could potentially impact other downstream components in the treatment train. For example, urine diverting toilets require users to divert their waste stream flows and dispose of their excreta wastes separately. If excreta wastes are routinely combined, urine fecal cross-contamination can limit urine reuse capability and pose a major health risk if the urine is used without efficient pathogen removal (Schonning & Stenstrom 2004).

5.4.1 Experimental Design

Attributes for sanitation technology requiring direct user interaction were gathered from the literature (WASTE 2005, WSSCC & WHO 2005, Netherlands Water Partnership 2006, Tilley et al. 2006). Table 5.1 details the eight general sanitation technology types, including their various operation modes of design and implementation that were identified. These technologies are classified based upon their technical design and implementation attributes that had a component of user interaction. Seven user-associated technical attributes are identified: *posture, excreta flow, conveyance, anal cleansing, location, odor control, and waste storage. Posture* reflects to the position the user assumes to use the technology. *Excreta flow* examines if urine and feces waste flows can be combined or if they must be diverted for the technology to function correctly. *Conveyance* evaluates the mechanism used to transfer excreta flows from the defecation location. Technologies can be water-based, requiring water for transport excreta, or dry-based, not needing water. *Anal cleansing* indicates the means to cleanse the anus after defecation. Cleansing methods include water and/or wiping materials, such as natural materials, paper, or newspaper. *Location* specifies the placement of the sanitation technology as being inside or outside the household dwelling. *Odor control* evaluates the need to use odor adsorption techniques for proper functioning. *Waste storage* identifies the ability to reuse waste containers. Some technologies allow the waste container to be emptied and reused again while others are only useable until filled.

Structured interviews were designed to elicit preference levels from respondents. Preference information was gathered to determine the preferable mode of operation at the attribute level as well as the values placed upon each attribute. Scripted questions described each technical attribute, discussed the various options for the attribute, and then asked the residents which option they preferred. If a resident did not have a preference towards one option or was not sure which option was preferred, that answer was also recorded. Additionally, residents were informed that they could skip any question that they did not want to answer.

After preferences for each technical attribute were determined, a MaxDiff model was designed to determine the priorities placed on the sanitation technical attributes. Respondents were asked to evaluate seven subset choice sets with four attributes per subset. With each subset, respondents were asked which attribute was most important and least important among the provided options. Each attribute appeared four times throughout the MaxDiff model design. Respondents who skipped one or more of the seven subsets were not included in the data analysis.

Table 5.1. List of Sanitation Technologies and Their Respective Attribute Operation Modes

List of Sanitation Technologies	Attribute Operation Modes													
	Posture		Excreta Flow		Conveyance		Anal Cleansing		Location		Odor Control		Waste Storage	
	Raised Seat	*Squat*	*Combine*	*Divert*	*Water-Based*	*Dry-Based*	*Water*	*Material*	*Inside*	*Outside*	*Needed*	*Not Needed*	*Reused at Site*	*Not Reused at Site*
Chemical Toilet	X		X			X	X	X		X		X	X	
Cistern Flush Toilet	X	X	X		X		X	X	X	X		X		X
Dry Toilet/Fossa Alterna	X	X	X			X	X	X		X	X	X	X	X
PeePoo	X	X	X			X		X	X			X		X
Pour Flush Toilet	X	X	X		X		X	X		X		X	X	X
Urine Diverting Dry Toilet / Composting Toilet	X	X		X		X	X	X		X	X	X	X	
Urine Diverting Flush Toilet	X			X	X		X	X	X	X		X	X	X
Ventilated Improved Pit (VIP) Latrine	X	X	X			X	X	X		X		X	X	X

Data analysis was conducted using SAS software, Version 9.2 of the SAS System for Microsoft; the software was used to generate the BIBD experimental design and determine parameter estimates for the utility function using multinomial logit regression.

5.5 Data Collection

5.5.1 Sampling Procedures

To be eligible to participate in the sample population, residents had to be at least 18 years old and stay in the surveyed household at least four nights a week. Written consent was obtained by the resident prior to participating in the survey. Enumerators (two males and two females) were recruited from the local community and trained on the research study objectives, ethical conduct, the interviewing script for the data collection, and the method of capturing data on mobile devices. All enumerators were fluent in the survey languages: English and isiXhosa (the primary local language in the sampling area). Enumerators were instructed to vary the days and times they conducted interviews to provide a representative sampling population. Residents were interviewed in private by same sex enumerators.

5.5.2 Study Site

This study focused on Kayamandi, a peri-urban area outside of the Stellenbosch, South Africa. Kayamandi has an estimated population of 26,200, with approximately 14% of the population being children under the age of five (Statistics South Africa 2008). Areas within Kayamandi can be loosely broken into two categories that include: formal developed areas which have electrification, paved roads, waterborne sewerage, piped household and water connections, as well as informal squatter areas that included substandard housing, community sanitation facilities, and communal water taps. Census estimates include assess to sanitation, via cistern flush toilets or pit latrines with ventilation, to 94.1% of the residents (Statistics South Africa 2012).

5.5.3 Ethics Statement

Ethical approval was provided by the Human Research (Humanities) Ethics Committee of Stellenbosch University, South Africa as well as the Institutional Review Board at the Georgia Institute of Technology, United States prior to the commencement of any data collecting.

5.6 Results

Over a five month period (August 2012 to December 2012), 1002 Kayamandi residents were surveyed to determine their preferences toward sanitation technology design and implementation attributes. Table 5.2 shows the descriptive characteristics of the sample respondents. The median household size of sampled residents is 4 residents. Approximately half (53.2%) of people surveyed lived in informal dwellings. The majority of the population (97.8%) used flush toilets with pedestals as their sanitation technology. 19% of the population owned their own private sanitation technology installed in their dwelling. Some of those individuals shared access to their flush toilets to surrounding neighbors and/or family members living in the same community. 25.8%

of the population used public sanitation facilities provided by the municipality as their sanitation technology.

Table 5.2. Sample Population Descriptive Characteristics

Characteristic (N= 1002)	Sample Description
Sex of respondent	
Male	51.5%
Female	48.5%
Age of respondent (in years)	
18-34	63.4%
35 to 65+	36.6%
Median age group (% of population)	25-34 (39.4%)
Highest level of education completed	
Primary	26.7%
Secondary/Trade School/College/University	73.3%
Employment	
Paid employment within the last three months	44.3%
Type of dwelling	
Formal	46.8%
Informal	53.2%
Head of household	
Yes	54.8%
Household size	
Average	4.4
Median	4
Households with at least 4 residents	57.4 %
Occupancy	
Owned and fully paid off	8.3%
Owned but not yet paid off	1.0%
Rented	7.4%
Occupied rent-free	82.2%
Other	1.1%
Water Source	
Private source (piped water inside the dwelling/yard)	45.1%
Public source (piped water from communal pipe)	54.9%
Current Sanitation Technology	
Cistern flush toilet	97.8 %

5.6.1 Preferences for Sanitation Technology Attribute Operation Modes

Figure 5.1 presents the percentage of times a specific option for a sanitation technical attribute was preferred by the residents of Kayamandi. The light gray bar represents the percentage of the sample population that prefers operation modes typically seen in conventional implementation of cistern flush toilets, while the black bar highlights the percentage of the sample population that does not have any preference towards an option. Based upon the results, 90% of the residents preferred sanitation technology that allowed them to sit (they have a raised seat) as well as used water as a conveyance mechanism.

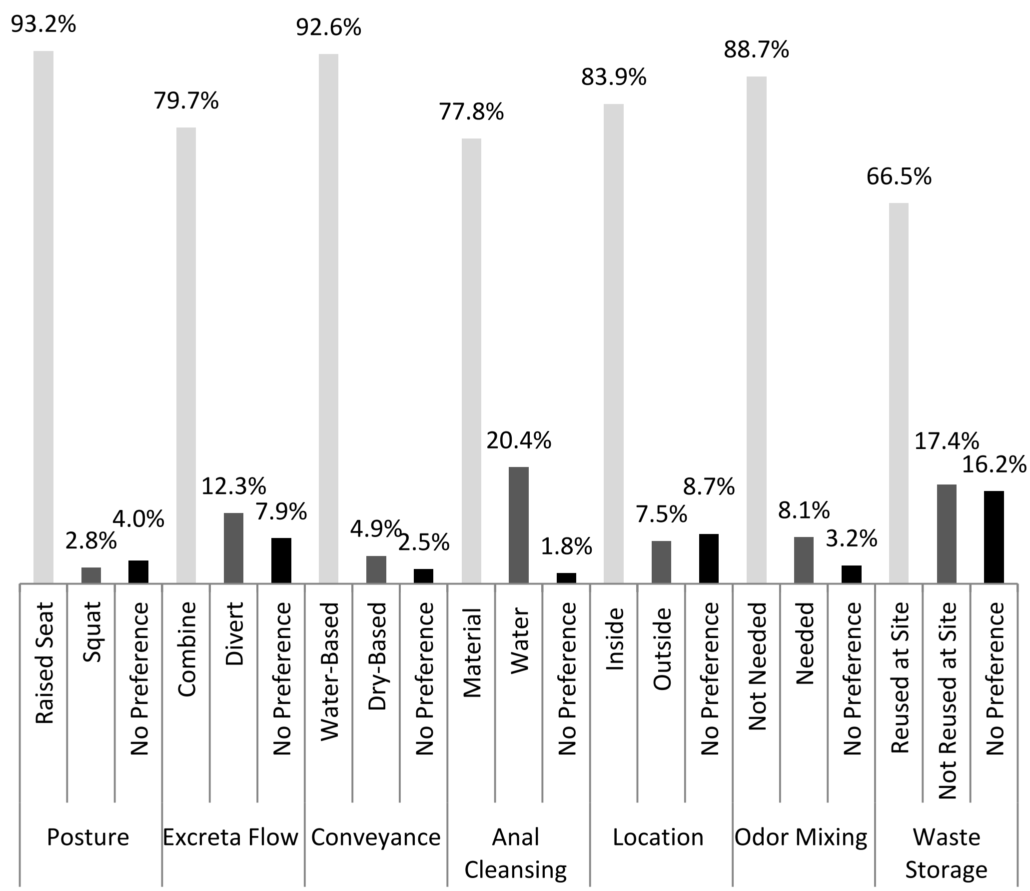

Figure 5.1. Attribute Operation Modes Preferred by Sample Population

5.6.2 Relative Priorities among Sanitation Technology Attributes

The utility model that individual i derives from selecting a specific sanitation technical attribute from a subset choice set s is represented as

$$U_{isj} = X_{isj}^{'}\beta_j + \varepsilon_{isj}$$

where X denotes the four of seven technical attributes selected for that choice set. Results of the MaxDiff model estimate the coefficient vectors for each respective attribute. As the vectors of the coefficient are estimated on a relative scale, one of the attributes serves as the reference level. Table 5.3 presents the coefficient estimates of the technical attributes aggregated for the sample population. With the attribute excreta flow as the reference level, the attribute conveyance has the largest impact compared to the other attributes. The attribute with the least impact is the anal cleansing method. Each attribute is considered to be statistically significant, having p-values less than 0.001.

Table 5.3. Coefficient Estimates of Sanitation Technical Attributes

Technical Attribute	Parameter estimate	Standard error	p-value	Centered Parameter Estimate	Probability Scaled Parameter Estimate
Posture	0.34244	0.04230	<.0001	0.09593	0.1515
Excreta Flow	.	.	.	-0.24650	0.1076
Conveyance	0.63221	0.04360	<.0001	0.38570	0.2024
Anal Cleansing	-0.30529	0.04209	<.0001	-0.55180	0.0793
Location	0.33698	0.04624	<.0001	0.09047	0.1507
Odor Control	0.40768	0.04559	<.0001	0.16117	0.1617
Waste Storage	0.31154	0.04537	<.0001	0.06503	0.1469

To determine if the impacts of the attributes were homogenous across the demographic and socioeconomic characteristics of the sample population, further analyses were conducted to investigate the differences between various subgroups of the population. The residents were broken into several subgroups based upon their descriptive characteristics: gender, age, education, head of household, employment status within the last three months, household size, home ownership, and their existing sanitation practices. If the resident used a private sanitation technology and did not share the facilities on a regular basis with anyone living outside the dwelling, the person was considered an adopter. Residents whose current sanitation practices included regular use of a sanitation technology that belonged to a private dwelling but was shared among other residents (family members, tenants, landlords) but did not necessarily live at the particular dwelling were considered partakers. Residents who used public communal sanitation facilities were considered non-adopters.

The chi-square test of independence was used to analyze the statistical independence of frequencies between the residents who indicated a preference towards one technical attribute operation mode. Residents who were indifferent to an operation mode for a specific attribute were excluded from the analysis. detail

Table 5.4 presents the percentage of individuals with certain preferences for technical attributes based upon their descriptive characteristic subgroups. In addition to these preferences, the table also describes the percentage of subgroups that indicated a lack of preference for the respective operational mode. The p-values presented in the table detail the statistical significance among the descriptive characteristic subgroups for each technical attribute. Some respondent characteristic subgroups, such as age and employment status within the last three months, had minimal impact on significance of the various attribute levels. Between the age subgroups, there was only a statistical significance in the selection of preferred operation modes of waste storage. Younger respondents preferred to reuse the waste containers while higher percentages of older respondents preferred to not reuse the containers or indicated no preference between the operational modes. The statistical significance of employment status of the respondent was dependent on the impact of the preferred location of the sanitation technology. Individuals employed in the last three months indicated a higher preference towards have their sanitation facility located outside than those who were not employed.

Other respondent characteristics had a statistically significant influence on the preferred operation levels of the attribute operation modes. When considering the technical attributes, the gender of the respondent and the head of household status influenced the preferred operation mode. Gender preferences were found throughout all technical attributes. While women preferred to combine their excreta flow and to use material for their anal cleansing method, men preferred to have their sanitation technology be located inside their household and to reuse the waste storage containers. Men also indicated higher lack of preferences than women for several of the technical attributes, including posture and excreta flow.

Head of household status was a determinant characteristic for the majority of the technical attributes. Individuals considered heads of their respective households indicated higher preferences to divert their waste flow streams and to not reuse their waste storage containers. Heads of households also indicated a higher lack of preference of location of sanitation technology.

Table 5.4. Preferences and Statistical Significance of Technical Attributes for Select User Characteristics

	Age (years)		Education Level		Employed ≤ 3 months		Gender		Type of User		
	18-34	*35-65+*	*Primary*	*Secondary*	*Yes*	*No*	*Female*	*Male*	*Private*	*Shared*	*Public*
Posture											
Sit	93.17	93.11	95.31	92.32	92.04	94.41	98.00	88.45	91.29	93.36	94.75
Stand	3.17	2.20	2.53	2.93	3.52	2.10	1.24	4.31	3.37	3.13	2.10
Indifferent	3.66	4.69	2.16	4.75	4.44	3.49	0.76	7.24	5.34	3.51	3.15
p-value	0.3876		0.6824		0.1810		0.0020		0.5210		
Excreta Flow											
Combined	79.46	80.22	86.69	77.05	82.13	77.82	91.51	68.68	70.87	79.3	88.28
Diverted	12.32	12.36	7.91	14.05	12.30	12.01	4.76	19.46	18.49	11.33	7.29
Indifferent	8.22	7.42	5.40	8.90	5.57	10.17	3.73	11.86	10.64	9.37	4.43
p-value	0.9754		0.0046		0.8769		<0.0001		<0.0001		
Conveyance											
Water	92.65	92.46	95.22	91.57	92.71	92.51	94.3	90.98	92.16	92.94	92.74
Dry	4.63	5.31	3.68	5.34	4.47	5.06	3.16	6.47	5.60	5.10	4.03
Indifferent	2.72	2.23	1.10	3.09	2.82	2.43	2.54	2.55	2.24	1.96	3.23
p-value	0.6485		0.2535		0.6832		0.0160		0.6254		
Anal Cleansing											
Material	77.92	77.65	83.82	75.53	80.94	75.8	84.13	71.71	67.13	81.96	85.22
Water	20.16	20.67	13.60	22.93	17.88	21.76	13.08	27.11	30.62	17.25	12.63
Indifferent	1.92	1.68	2.58	1.54	1.18	2.44	2.79	1.18	2.25	0.79	2.15
p-value	0.8629		0.0014		0.1112		<0.0001		<0.0001		
Location											
Inside	84.59	82.63	76.75	86.6	84.91	83.27	75.95	91.3	84.46	83.14	83.83
Outside	7.87	6.72	9.59	8.63	5.66	8.65	10.13	4.94	6.21	9.02	7.55
Indifferent	7.54	10.65	13.66	4.77	9.43	8.08	13.92	3.76	9.33	7.84	8.62
p-value	0.6067		0.0547		0.0882		0.0003		0.4569		
Odor Mixing											
Not Needed	88.33	89.29	92.81	87.08	88.01	90.49	88.41	88.93	86.83	87.94	90.89
Needed	8.52	7.42	5.04	9.31	8.67	6.73	9.73	6.60	8.40	8.56	7.55
Indifferent	3.15	3.29	2.15	3.61	3.32	2.78	1.86	4.47	4.77	3.5	1.56
p-value	0.5440		0.0230		0.2509		0.0921		0.8140		
Waste Storage											
Reused at Site	68.72	62.64	61.87	68.29	70.23	64.76	56.31	76.07	55.46	66.42	76.82
Not Reused at Site	15.64	20.33	23.74	14.88	16.51	16.79	25.05	10.12	26.33	17.19	9.11
Indifferent	15.64	17.03	14.39	16.83	13.26	18.45	18.64	13.81	18.21	16.39	14.07
p-value	0.0409		0.0015		0.5798		<0.0001		<0.0001		

Table 5.4. Preferences and Statistical Significance of Technical Attributes for Select User Characteristics

	Type of Water Source		Household Size		Home Ownership		Head of Household	
	Private	*Public*	*≤ 4 members*	*> 4 members*	*Yes*	*No*	*Yes*	*No*
Posture								
Sit	93.76	92.41	95.01	91.78	90.57	93.46	93.88	92.35
Stand	2.75	2.90	1.90	3.50	4.72	2.59	3.40	2.43
Indifferent	3.49	4.69	3.09	4.72	4.71	3.95	2.72	5.22
p-value	0.8609		0.1222		0.2053		0.4011	
Excreta Flow								
Combined	80.69	78.57	81.8	78.22	81.14	67.92	74.86	85.36
Diverted	12.39	12.28	11.35	13.07	10.77	25.47	16.01	7.88
Indifferent	6.92	9.15	6.85	8.71	8.09	6.61	9.13	6.76
p-value	0.9274		0.3483		<0.0001		<0.0001	
Conveyance								
Water	93.73	91.18	94.99	90.8	94.34	92.37	91.87	93.17
Dry	4.80	4.98	2.39	6.73	4.72	4.90	4.54	5.47
Indifferent	1.47	3.84	2.62	2.47	0.94	2.73	3.59	1.36
p-value	0.8282		0.0018		0.9036		0.5601	
Anal Cleansing								
Material	75.28	80.95	79.24	76.77	53.77	80.73	75.76	80.87
Water	22.88	17.23	19.81	20.74	42.45	17.67	22.35	17.31
Indifferent	1.84	1.82	0.95	2.49	3.78	1.6	1.89	1.82
p-value	0.0282		0.6292		<0.0001		0.0503	
Location								
Inside	88.35	78.36	84.65	83.30	86.79	83.52	78.29	90.21
Outside	4.62	10.93	6.00	8.53	4.72	7.78	8.95	5.92
Indifferent	7.03	10.71	9.35	8.17	8.49	8.70	12.76	3.87
p-value	<0.0001		0.1494		0.2527		0.0276	
Odor Mixing								
Not Needed	89.25	87.97	86.76	91.27	85.85	89.01	86.94	89.96
Needed	7.83	8.46	10.28	5.19	7.96	9.43	10.81	6.13
Indifferent	2.92	3.57	2.96	3.54	6.19	1.56	2.25	3.91
p-value	0.6928		0.0039		0.5613		0.0101	
Waste Storage								
Reused at Site	67.94	64.73	71.23	63.00	62.26	67.00	65.24	68.17
Not Reused at Site	16.39	18.53	13.68	20.07	19.87	17.17	20.63	13.32
Indifferent	15.67	16.74	15.09	16.93	17.87	15.83	14.13	18.51
p-value	0.3182		0.0044		0.5358		0.0069	

5.6.3 Preferred Sanitation Technology Alternatives

Information residents provided about their preferred attribute operation mode and their relative priorities between the attributes was used to calculate individual utility functions for the various sanitation technologies. To assist with determining the utility function for each technology, the parameter estimates of the utility function are adjusted to consider the total number of attributes and then rescaled so that all seven attributes are included in the utility function. The utility function for the seven attributes is

$$U_{ij} = \sum_{r=1}^{R} X_{ir}\, \beta_{jr} + \varepsilon_{ij}$$

$$\begin{aligned} U_{ij} = {} & X_{i_{posture}} \beta_{j_{posture}} \\ & + X_{i_{excreta\ flow}} \beta_{j_{excreta\ flow}} + X_{i_{conveyance}} \beta_{j_{conveyance}} \\ & + X_{i_{anal\ cleansing}} \beta_{j_{anal\ cleansing}} + X_{i_{location}} \beta_{j_{location}} \\ & + X_{i_{odor\ control}} \beta_{j_{odor\ control}} + X_{i_{waste\ storage}} \beta_{j_{waste\ storage}} + \varepsilon_{ij} \end{aligned}$$

where X_{ir} is individual *i's* preferred operation mode of attribute *r*, β_{jr} is the estimated parameter coefficient of the respective attribute. In total, 59 sanitation technology alternatives were examined. When the preferred operation mode of individual *i* matches the operation mode of the sanitation technology being examined, X_{ir}= 1; when they do not match, X_{ir}= 0. Thus, if sanitation alternative *j* matches all of the preferred operation modes of individual *i*, the utility that individual *i* would receive from alterative *j* would be $U_{ij} = 1$ and the individual would be considered perfectly satisfied with the alternative. Using the principles of utility maximization, sanitation technology alternatives with the higher levels of utility would represent the alternatives that would be most preferred by the individual. Depending on an individual's preferred operation mode and relative priorities for technical attributes, multiple sanitation technologies could have the same utility and be considered the most preferred.

Considering that a small number of sanitation technologies would be able to provide maximum utilization $U_{ij} = 1$, various amounts of minimum utilities were calculated, from $U_{ij} > 0.0$ (a minimum of one preferred operation mode of individual *i* matches with one of operation modes the sanitation technology *j*) to $U_{ij} = 1.0$ (all preferred operation modes of individual *i* match with the operation modes of sanitation technology *j*).

Figures 5.2 to 5.9 compare the number of sanitation users that would be satisfied based upon various minimum utility levels required, ranging from $0.0 < U_{ij} \leq 1.0$. The eight general sanitation technology types previously identified were compared to determine which sanitation technologies would be most accepted based upon the user preferred interactions with the technology. The analysis also considers the previous tradeoffs between the technical attributes calculated previously. Each utility level compares all of the various operation modes of its respective sanitation technology. Several data points are revealed at each utility level, including the minimum, median, and maximum number of satisfied users for all possible attribute operation mode combinations. The entire range of satisfied users is represented by the end lines.

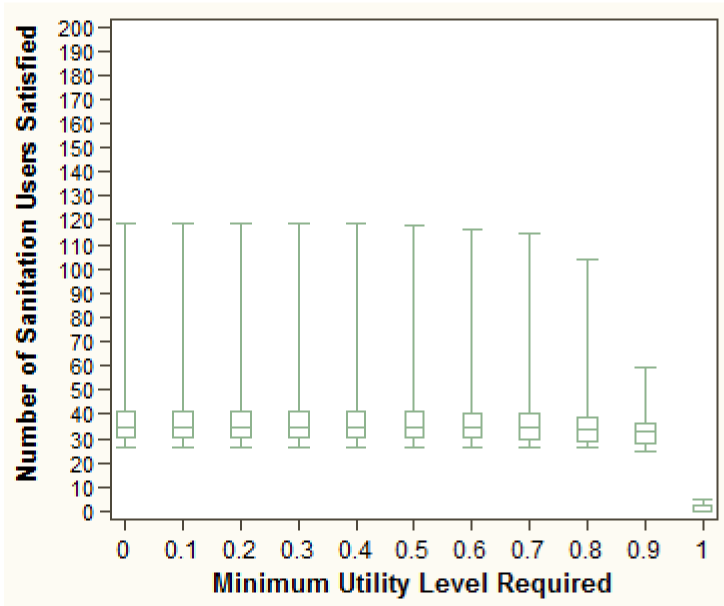

Figure 5.2. Dry Toilet - number of sanitation users satisfied for various design and implementation modes

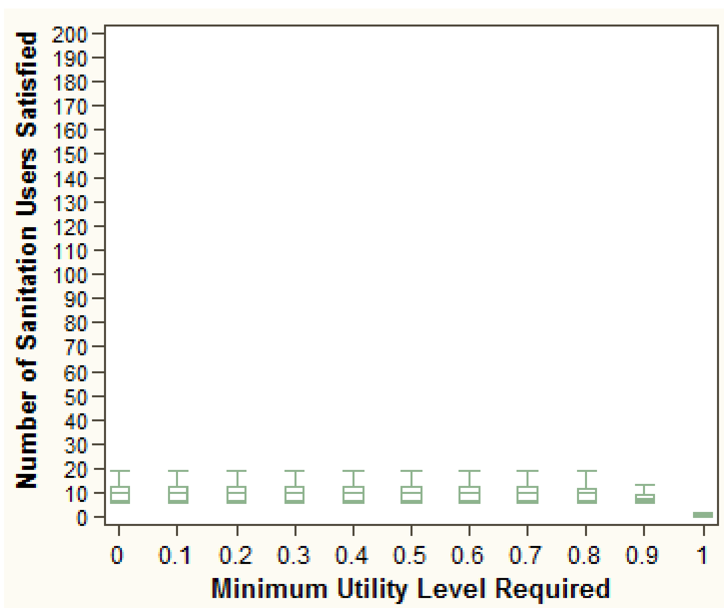

Figure 5.3. Urine Diverting Dry Toilet - number of sanitation users satisfied for various design and implementation modes

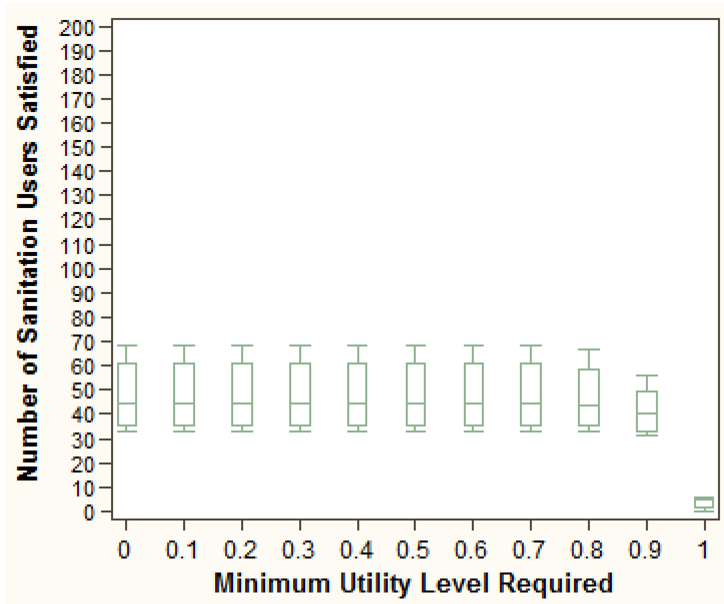

Figure 5.4. Pour Flush Toilet - number of sanitation users satisfied for various design and implementation modes

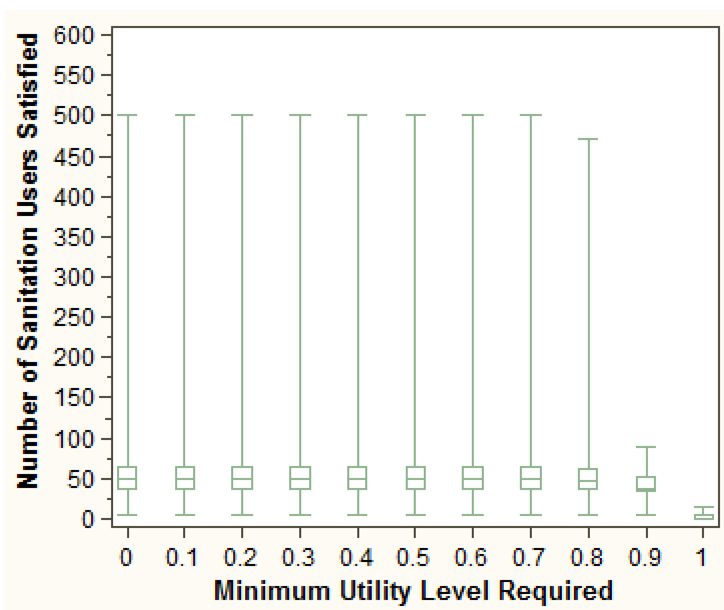

Figure 5.5. Cistern Flush Toilet - number of sanitation users satisfied for various design and implementation modes

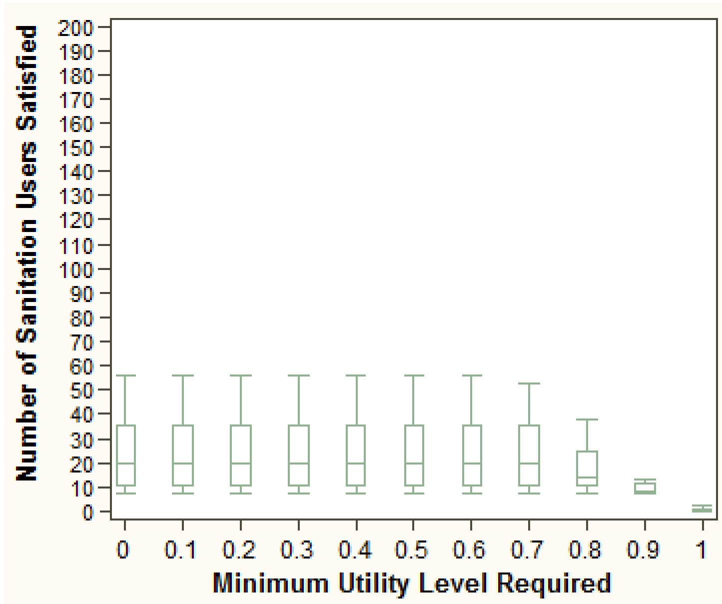

Figure 5.6. Urine Diverting Flush Toilet - number of sanitation users satisfied for various design and implementation modes

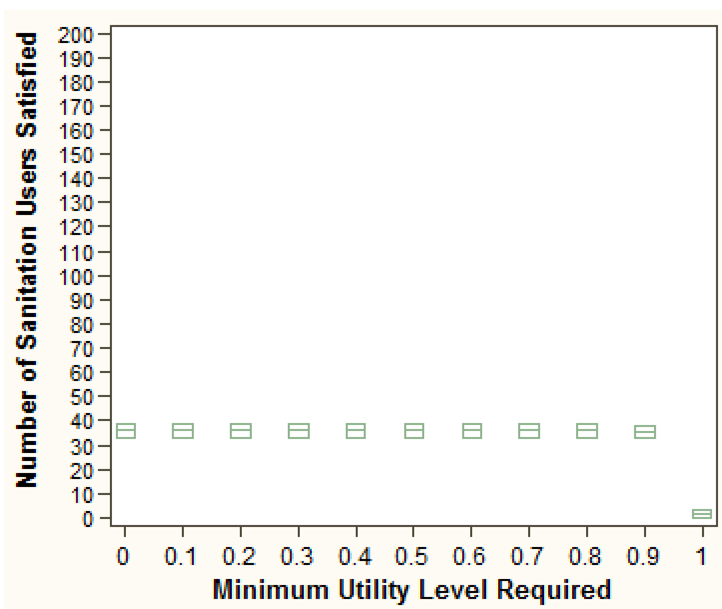

Figure 5.7. Chemical Toilet - number of sanitation users satisfied for various design and implementation modes

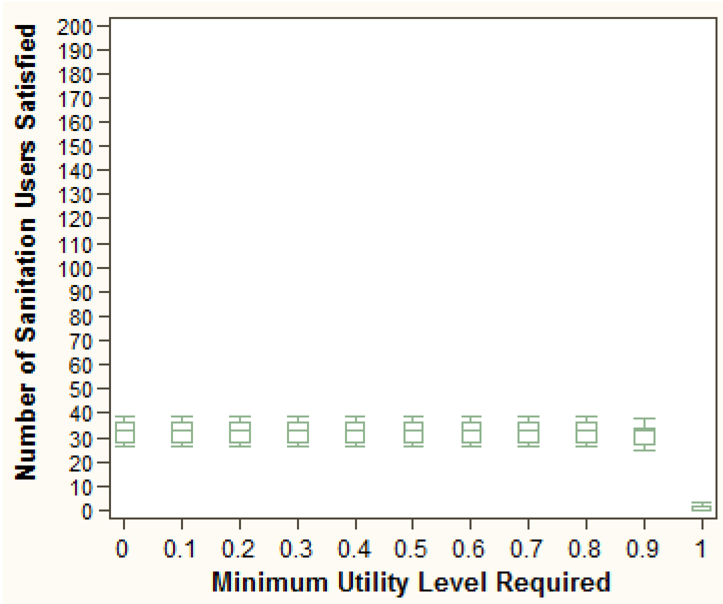

Figure 5.8. Ventilated Improved Pit Latrine - number of sanitation users satisfied for various design and implementation modes

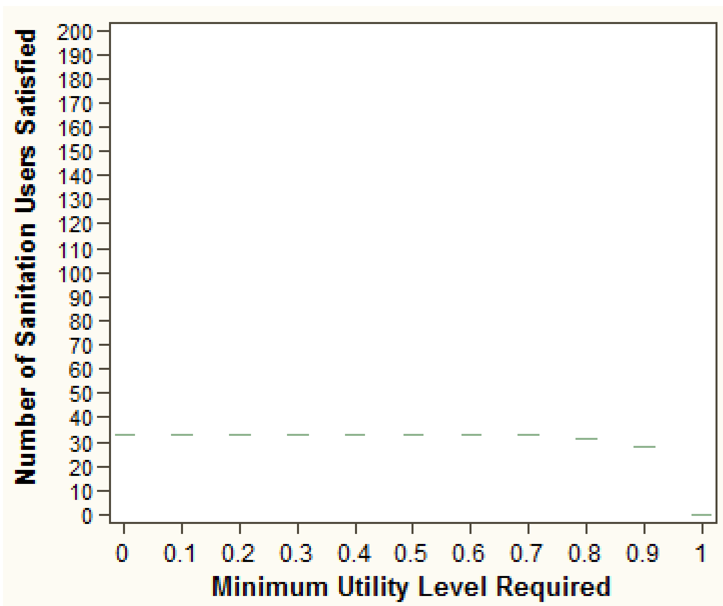

Figure 5.9. PeePoo - number of sanitation users satisfied for various design and implementation modes

Across all sanitation technologies, fewer sanitation users are satisfied as the minimum utility level required increases; in most cases, the number of satisfied sanitation users decreases significantly at $U_{ij} \geq 0.9$. Some sanitation technologies – including dry toilets, cistern flush toilets, and urine diverting flush toilets – have a high variance in the number of satisfied sanitation users, indicating that user satisfaction is dependent on the sanitation technologies begin designed and implemented in manners that are preferred by the proposed sanitation users. Cistern flush toilets designed and installed with the most preferred attribute operation modes have the potential to be the most acceptable of the sanitation users, having a maximum of 502 users satisfied at $U_{ij} \geq 0.7$. At $U_{ij} \geq 0.8$, the number of users satisfied with cistern flush toilets decreases to 470 users. Simple changes to the operation mode greatly impacts the number of users satisfied with the technology. For example, a simple operation mode change from material-based anal cleansing to water-based anal cleansing decreases the number of users who view the sanitation technology as most preferred from 470 to 156 users. The least preferred sanitation technologies are urine diverting dry toilets, with an average of eight users indicate that sanitation technology their most preferred, regardless of the operation modes selected. Table 5.5 summarizes the most preferred sanitation technologies based upon their preferred operation mode at $U_{ij} \geq 0.8$.

Table 5.5 Ranking of Preferred Sanitation Technology by Operation Mode

List of Sanitation Technologies	Attribute Operation Modes														Users with $U_{ij} \geq 0.8$
	Posture		Excreta Flow		Conveyance		Anal Cleansing		Location		Odor Control		Waste Storage		
	Raised Seat	*Squat*	*Combine*	*Divert*	*Water-Based*	*Dry-Based*	*Water*	*Material*	*Inside*	*Outside*	*Needed*	*Not Needed*	*Reused at Site*	*Not Reused at Site*	
Cistern Flush Toilet	X		X		X			X	X			X	X		470
Cistern Flush Toilet	X		X		X		X		X			X	X		156
Dry Toilet	X		X			X		X		X	X		X		104
Pour Flush Toilet	X		X		X			X		X		X	X		67
Cistern Flush Toilet	X		X		X			X		X		X	X		67
Pour Flush Toilet	X		X		X			X		X		X		X	61
Dry Toilet	X		X			X		X		X	X			X	60
Pour Flush Toilet	X		X		X		X			X		X	X		56
Cistern Flush Toilet	X		X		X		X			X		X	X		56
Dry Toilet	X		X			X	X			X	X		X		54
Pour Flush Toilet	X		X		X		X			X		X		X	50
Cistern Flush Toilet		X	X		X			X	X			X	X		49
Cistern Flush Toilet		X	X		X		X		X			X	X		43
Dry Toilet	X		X			X		X		X		X	X		39

Table 5.5 Ranking of Preferred Sanitation Technology by Operation Mode

List of Sanitation Technologies	Attribute Operation Modes														Users with $U_{ij} \geq 0.8$
	Posture		Excreta Flow		Conveyance		Anal Cleansing		Location		Odor Control		Waste Storage		
	Raised Seat	*Squat*	*Combine*	*Divert*	*Water-Based*	*Dry-Based*	*Water*	*Material*	*Inside*	*Outside*	*Needed*	*Not Needed*	*Reused at Site*	*Not Reused at Site*	
Chemical Toilet	X		X			X		X		X		X	X		39
VIP Latrine	X		X			X		X		X		X	X		39
Dry Toilet		X	X			X		X		X	X		X		38
Urine Diverting Flush Toilet	X			X	X		X		X			X	X		38
Dry Toilet	X		X			X		X		X		X		X	37
Pour Flush Toilet		X	X		X		X			X		X	X		37
Cistern Flush Toilet		X	X		X		X			X		X	X		37
VIP Latrine	X		X			X		X		X		X		X	37
Dry Toilet	X		X			X	X			X		X		X	36
Pour Flush Toilet		X	X		X			X		X		X	X		36
Cistern Flush Toilet		X	X		X			X		X		X	X		36
VIP Latrine	X		X			X	X			X		X		X	36
Pour Flush Toilet		X	X		X			X		X		X		X	35
Dry Toilet	X		X			X	X			X	X			X	34

Table 5.5 Ranking of Preferred Sanitation Technology by Operation Mode

List of Sanitation Technologies	Attribute Operation Modes: Posture		Excreta Flow		Conveyance		Anal Cleansing		Location		Odor Control		Waste Storage		Users with $U_{ij} \geq 0.8$
	Raised Seat	*Squat*	*Combine*	*Divert*	*Water-Based*	*Dry-Based*	*Water*	*Material*	*Inside*	*Outside*	*Needed*	*Not Needed*	*Reused at Site*	*Not Reused at Site*	
Dry Toilet	X		X			X	X			X		X	X		33
Pour Flush Toilet		X	X		X		X			X		X		X	33
Chemical Toilet	X		X			X	X			X		X	X		33
VIP Latrine	X		X			X	X			X		X	X		33
Dry Toilet		X	X			X		X		X		X	X		32
VIP Latrine		X	X			X		X		X		X	X		32
PeePoo		X	X			X		X	X			X		X	31
Dry Toilet		X	X			X		X		X	X			X	30
Dry Toilet		X	X			X		X		X		X		X	29
Dry Toilet		X	X			X	X			X	X		X		29
VIP Latrine		X	X			X		X		X		X		X	29
Urine Diverting Flush Toilet	X			X	X			X	X			X	X		28
Dry Toilet		X	X			X	X			X		X	X		27
VIP Latrine		X	X			X	X			X		X	X		27
Dry Toilet		X	X			X	X			X		X		X	26
Dry Toilet		X	X			X	X			X	X			X	26
VIP Latrine		X	X			X	X			X		X		X	26

Table 5.5 Ranking of Preferred Sanitation Technology by Operation Mode

List of Sanitation Technologies	Attribute Operation Modes															Users with $U_{ij} \geq 0.8$
	Posture		Excreta Flow		Conveyance		Anal Cleansing		Location		Odor Control		Waste Storage		
	Raised Seat	*Squat*	*Combine*	*Divert*	*Water-Based*	*Dry-Based*	*Water*	*Material*	*Inside*	*Outside*	*Needed*	*Not Needed*	*Reused at Site*	*Not Reused at Site*	
Urine Diverting Flush Toilet	X			X	X			X	X			X		X	21
Urine Diverting Dry Toilet	X			X		X		X		X	X		X		19
Urine Diverting Flush Toilet	X			X	X			X		X		X		X	14
Urine Diverting Flush Toilet	X			X	X		X		X			X		X	14
Urine Diverting Flush Toilet	X			X	X		X			X		X		X	14
Urine Diverting Dry Toilet	X			X		X	X			X	X		X		12
Urine Diverting Dry Toilet		X		X		X	X			X	X		X		11
Urine Diverting Dry Toilet		X		X		X		X		X	X		X		10

Table 5.5 Ranking of Preferred Sanitation Technology by Operation Mode

List of Sanitation Technologies	Attribute Operation Modes: Posture		Excreta Flow		Conveyance		Anal Cleansing		Location		Odor Control		Waste Storage		Users with $U_{ij} \geq 0.8$
	Raised Seat	*Squat*	*Combine*	*Divert*	*Water-Based*	*Dry-Based*	*Water*	*Material*	*Inside*	*Outside*	*Needed*	*Not Needed*	*Reused at Site*	*Not Reused at Site*	
Urine Diverting Dry Toilet		X		X		X		X		X		X	X		9
Urine Diverting Flush Toilet	X			X	X		X			X		X	X		8
Urine Diverting Dry Toilet		X		X		X	X			X		X	X		7
Urine Diverting Flush Toilet	X			X	X			X		X		X	X		7
Urine Diverting Dry Toilet	X			X		X	X			X		X	X		6
Urine Diverting Dry Toilet	X			X		X		X		X		X	X		6

5.7 Discussion

Current perceptions and past experiences with a certain sanitation technology can influence a user's preferences for that sanitation technology. Rather than eliciting preferences about the sanitation technology in general, MaxDiff scaling is a novel approach to compare the attributes of various sanitation technologies. MaxDiff scaling has several advantages over the approach of conducting contingent valuation experiments. Further user choice information is provided with MaxDiff scaling than from traditional discrete choice experiments, allowing a further understanding of what attributes about a particular sanitation technology is preferred over others. Additionally, MaxDiff can assist with examining the influence user characteristics have on preferences toward sanitation technology. Having a better understanding about user preferences can assist in informing the decision making process regarding sanitation technology design and implementation.

The research suggests that sanitation users have preferences that can influence their acceptance of the design and implementation of sanitation technologies. The application of the MaxDiff model demonstrates the ability to examine the impact sanitation technical attributes have on user acceptance as well as the relative priorities users place on various technical attributes. Furthermore, the study illustrates that sanitation users place higher importance on their preferred operation mode to convey their excreta wastes. With over 90% of the population preferring sanitation technology that is water-based, technologies with this conveyance approach are more likely to be accepted by the community. However, conveyance is only one attribute that impacts user acceptance, as evident in approximately half of the sample population being no more than 80% satisfied with a cistern flush toilet installed in a certain manner.

Decisions around sanitation technology design and implementation are complex. Sanitation technologies must be efficient in minimizing human contact with excreta as well as removing harmful pathogens from fecal matter. As decision makers are determining the appropriate sanitation technologies, the study suggest that clear consideration must be given to how the user will ultimately be asked to interact with the sanitation technology. Ultimately, sanitation technology design and implementation must occur with user preferences in mind. Sanitation technologies must be designed and installed in manners that allow the user to interact with the technology in the preferred operation mode.

5.8 Correlation to Body of Work

This chapter addresses Aim II. By incorporating the theories of rational choice and behavioral decision into random utility theory, seven operation modes of sanitation systems were analyzed. Parameter estimates determined using multinomial logit regressions indicate that, in general, users place a higher value on using sanitation technology that is suitable with their preferred conveyance operation mode. Conversely, users place low value on sanitation technology matching their anal cleansing operation mode.

User satisfaction (utility) levels were also estimated for eight sanitation technologies. Out of the sanitation technologies tested, cistern flush toilets have the potential to provide the sample population with the high level of satisfaction; urine diverting dry toilets were the least preferred sanitation technology. It is important to note that cistern flush toilets were not the preferred sanitation alternative for the entire sample population. It was estimated that the maximum percentage of the community satisfied with cistern flush toilets would be 50.5% (at $U_{ij} \geq 0.7$).

Understanding what sanitation technologies are preferred, it remains unclear whether or not sanitation users will use their preferred technology if it is also implemented in a manner that is also preferred.

The next chapter, *Chapter 6 – Analyzing Usage of Sanitation Technology: An Agent-Based Analysis*, will examine the impact of implementation approaches on user satisfaction. Several implementation options (including ownership and placement attributes) will be considered. Using the theory of planned behavior, it investigates if various implementation options impact the decision of sanitation users to use sanitation technology. The intention to use a specific sanitation technology will be measured by considering behavioral belief, normative beliefs, and perceived control beliefs regarding sanitation usage.

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CHAPTER 6

ANALYZING USAGE OF SANITATION TECHNOLOGY: AN AGENT-BASED ANALYSIS

6.1 Chapter Focus

This chapter examines the impact of implementation approaches on user satisfaction. It investigates the third knowledge gap identified in *Chapter 2 Sanitation in Developing Countries – A Systematic Review of User Preferences and Motivations*. Several implementation options (including ownership and placement attributes) will be considered. Using the theory of planned behavior, it investigates if various implementation options impact the decision of sanitation users to use sanitation technology. The intention to use a specific sanitation technology will be measured by considering behavioral belief, normative beliefs, and perceived control beliefs regarding sanitation usage.

6.2 Introduction

Over the last two decades, sanitation policy and development has undergone a paradigm shift away from heavily-subsidized, supply-driven approaches towards behavioral-based demand-driven approaches (UNICEF 1997). These new approaches were required as a result of the inability of supply-driven approaches to stimulate household sanitation demand, develop reproducible solutions, or extend sanitation beyond subsidized mechanisms (Jenkins 2004). By focusing on desired sanitation access, demand-driven approaches incorporate the intended beneficiaries of sanitation into the decision-making process. Interest in demand-driven approaches began in the late 1990s with the Participatory Hygiene and Sanitation Transformation (PHAST), an interactive, participatory methodology developed to advocate and promote health awareness in communities while suggesting beneficial hygiene and sanitation improvements (Lionde 2000). The community health club (CHC) approach was derived from PHAST and incorporated measures of behavioral change as indicators of health improvements (Waterkeyn 1999, Waterkeyn & Cairncross 2005). Community-led total sanitation (CLTS) emphasized establishing entire communities that are "open defecation free", through collaborative interactions with the community (Kar & Chambers 2008). The aforementioned approaches to increase sanitation demand are multi-faceted, requiring multiple stakeholders with varying degrees of interest, knowledge, and capacity. Regardless of the demand-driven approach used, the decisions made by three entities – the designer of the sanitation technology (the engineer), the implementers of the sanitation technology (the planner) and the beneficiaries (the users) – impact the successful adoption of the sanitation intervention. Beneficiaries are typically the least knowledgeable about appropriate sanitation technology and may not have requisite skills to install sanitation technology that hygienically minimize human contact with excreta (Salter 2008). Conversely, engineers are the entity most informed about the development of hygienic sanitation technologies, but they oftentimes lack an appropriate understanding of socio-cultural norms for the intended community (Kalbermatten et al. 1982, Paterson et al. 2007). Planners focus on implementing acceptable technology for the community; however, they are usually unaware of the full spectrum of available sanitation interventions (Mara et al. 2007). Although efforts exist to increase sanitation access by incorporating engineering design principles with planning approaches, entities generally work independently without strong connections, thus reducing their impact. As a result, the design of appropriate sanitation technology is disconnected from the implementation of acceptable technology into communities, which includes an absence of user preference integration into sanitation technology design and results in a lower adoption rate.

To address the challenges of developing successful interventions, we present an agent-based modeling approach designed to collectively simulate the impact of sanitation technology attributes has on utilization rates. Agent-based models are social simulation techniques that explore the intricacy of individual behavior and the collective impact on communities. This model examines how design choices and implementation choices alter the desire for individuals to use the sanitation technology. It also addresses the need to collectively consider both the appropriateness and acceptability of sanitation technology during interventions. An application is included to simulate the sanitation usage behavior of a peri-urban community in South Africa.

6.3 Methods

6.3.1 Modeling Human Behavior

Two decision-based theories, also classified as utility methods, are employed to model sanitation usage behavior: random utility theory and theory of planned behavior. Both approaches are based on the premise of utility, which is defined as an arbitrary measurement of satisfaction that a user derives from an item. Utility levels describe the amount of gratification given when choosing an item, behavior, or activity. A utility function represents the combined preferences and perceptions that frame the user's value system and allow the most preferred option to be revealed (Hanley et al. 2007). User's valuation approaches are variable; therefore component weighting within the utility function will vary as well.

The decision-making process of selecting an alternative is framed by fundamental preference axioms regarding completeness and transitivity. Completeness indicates that out of the given options, ranking can be developed based upon preference or indifference, while transitivity details that the preference of one option over another can infer its preferences to other options as well (Hanley et al. 2007). Whereas random utility theory is focused on external components of the decision-making process, such as attributes of sanitation technology, the theory of planned behavior focuses on internal components of the decision-making process, such as motivating factors to use sanitation (Andrews et al. 2011).

6.3.1.1 Random Utility Theory

Random utility theory is a socioeconomic framework used to analyze the decision making processes of individuals. The theory is based on the underlying premise that rational individuals select options based upon their preferences in an attempt to provide the highest amount of personal satisfaction, thus maximizing their individual utility (Hanley et al. 2007). Rationality relates to the fact that individuals consistently know their desires and needs, and preferences are chosen options of alternatives that can be ordered in a logical manner (Hanley et al. 2007). However, because individuals are limited to evaluating only those alternatives known to them, their rationality is bounded, and the limits represented by these bounds are modeled as a stochastic unobservable component of the overall rationality. Formally, random utility theory is expressed as

$$U_{ij} = V_{ij} + \varepsilon_{ij}$$

where

U_{ij} is utility that individual i can obtain from item j;

V_{ij} is deterministic measurable utility obtained by individual i from item j;

ε_{ij} is stochastic unobservable utility obtained by individual i from item j;

6.3.1.2 Theory of Planned Behavior

The theory of planned behavior, developed by Ajzen (1991), is a psychological approach analyzing the influence that beliefs and attitudes have on behaviors. It is generally accepted that preferences for alternatives are based upon beliefs about them (Ajzen 1991), and this theory is based on the construct that the mere intention of action will lead to actual behavior. In this definition, intention is described as the decision to participate in a certain behavior before actually engaging in that behavior (Fishbein and Ajzen 1975, Ajzen and Fishbein 1980). An individual's intent is, in turn, influenced by his/her preferences, which represent favorable or unfavorable opinions placed upon beliefs (Eagly and Chaiken 1993), subjective norms, and his/her perceptions of social pressure towards the behavior (Azjen 1996). The more favorable these perceptions are regarding a behavior or its outcome, the more likely the behavior is to occur. The theory of planned behavior extends upon the theory of reasoned action by incorporating the influence of perceived behavioral control, examining the individual's thoughts regarding difficulty on performing the behavior (Azjen 1996). Formally, the theory of planned behavior is expressed as

$$B \approx BI = w_1 A_B + w_2 SN + w_3 PBC$$

$$A_B = \sum_{f=1}^{F} b_f e_f$$

$$SN = \sum_{g=1}^{G} nb_g mc_g$$

$$PBC = \sum_{h=1}^{H} cb_h pf_h$$

where

B is behavior;

BI is intentional behavior;

A_B is attitudinal beliefs towards this behavior;

SN is subjective norms for this behavior;

PBC is perceived behavioral control over this behavior;

w_1, w_2, w_3 are empirically determined weights applied to A_B, SN, and PBC;

b_f is impact of the f^{th} behavioral belief;

e_f is outcome evaluation of f^{th} behavioral belief;

nb_g is impact of the g^{th} normative belief;

mc_g is motivation to comply with the g^{th} normative belief;

cb_h is impact of the h^{th} control belief;

pf_h is perceived facilitation to influence h^{th} control belief;

6.3.2 Simulating Human Behavior

Simulations are applied computational approaches designed to examine real world phenomena. When applied to social behavior, social simulations replicate complex, adaptive behaviors of individuals and illustrate the impact individual interactions have on the overall outcome (Gilbert & Troitzsch 1999). Social simulation theory can be classified into three modeling techniques: system dynamics, discrete events, and agent-based (Gilbert &Troitzsch 1999). System dynamics techniques are system-centric simulations that attempt a holistic replication of organizational and industrial environments. While this mathematically-based method incorporates feedback loops, flow accumulation, and time delays into model development, it disregards human behavior and peer interactions at the individual level, and is better suited toward macro-analysis. Discrete events techniques are process-centric simulations focusing on the impact that macro-level policies have on individuals. Each of these individual “units” are modeled based on a criteria set of attributes, preferences, and behaviors. Using differential calculus, social interactions of the units are analyzed during their participation in a hierarchical sequence of events.

Agent-based techniques, which constitute the simulation method of analysis for this study, expand on the previous simulation approaches by providing a micro-level understanding to social phenomena. Agents represent individual decision-making entities that are modeled based upon their characteristics and behaviors (Twomey & Cadman 2002). Agent-based simulations are developed with the following key assumptions: autonomy, interdependency, simplicity, and adaptability (Macy & Miller 2001). Agents are self-organized, requiring little to no governing direction (autonomy), and can have the ability to influence each other in direct or indirect manners (interdependency). Although agents make complex decisions, the behavioral patterns and preferences are based on simple rules (simplicity); yet, the ability to analyze and reflect on past behaviors makes the agents adaptable (adaptability). This simulation approach builds upon the previous system-centric and process-centric approaches. As the behaviors of individual agents are modeled collectively to determine their overall impact on the system, the impact the system has on individual agents is also examined. Rather than focusing on predicting accuracy of the outcome, agent-based simulations are concerned with examining interactions between agents; thus, the simulations are developed as a manner to explain emerging social development (Gilbert & Troitzsch 1999, Railsback & Grimm 2005).

6.3.3 Application to Sanitation Usage Behavior

Using the theoretical framework, each individual will consider using a given sanitation technology depending on the satisfaction level (utility) derived from using it. Utility for sanitation usage is measured for both the technical (design) attributes and arrangement (implementation) attributes. Sanitation technical attributes refer to the various operation modes that specify the design of sanitation technology. Specific technical attributes considered in this simulation include: posture, excreta flow, conveyance, anal cleansing, location, odor control, and waste storage. Random utility theory is used to develop individual utility functions relating to the design components of sanitation. Detailed descriptions of the technical attributes as well as calculations of the utility functions are found in Seymour (2013a).

The theory of planned behavior guides the development of behavioral rules regarding the implementation attributes of sanitation technology. The incorporation of behavioral beliefs facilitates the determination of the extent to which an individual's intent on usage is influenced by implementation arrangements, including ownership, cost, placement, and availability. Consideration of normative beliefs allows for the measurement of the degree to which an individual's family and friends, neighbors, community and/or government influence his/her behavioral practices. Moreovoer, looking at the control beliefs provides insight into the influence that privacy, safety and cleanliness have on sanitation usage. Beliefs are measured on a five-point Likert "strongly agree" to "strongly disagree" scale, and the aggregation of these beliefs will serve as behavioral rules for individuals in the agent-based simulation.

6.3.4 Simulation Details

The individual decision-making process of agents in determining whether they will use a sanitation technology is illustrated in Figure 6.1. There are two components of the agent-based model framework: initialization of the simulation and simulation execution. During initialization, the environment characteristics and the agents are established and subsequently, during execution, the agents undertake the decision to determine what, if any, sanitation to use.

6.3.4.1 Initialization

Agents are modeled as heterogeneous individuals, each having varying levels of satisfaction for sanitation alternatives. The core characteristics of each agent are age group, gender, education level, respective house location, and head of household status. Agents are also characterized based upon their sanitation adoption classification as adopters, partakers, or non-adopters. Adopters are individuals who use private sanitation facilities that are not shared with anyone living outside the household. Partakers have access to private sanitation with other households, having controlled access, as well as communal sanitation, having public access. Non-adopters only use communal sanitation facilities with open access to the community. In addition to the core characteristics, the walking threshold – defined as the maximum amount of time that the agent is willing to spend in transit to the sanitation facility – and the waiting threshold – defined as the maximum amount of time that the agent is willing to wait at the sanitation facility – are also established. The initial environment determines placement of the agent's houses as well as the sanitation facilities. The core characteristics of each house include its location, water source, household size, ownership status, and whether or not the house is made of substandard housing materials. The core characteristics of each sanitation facility are the type of technology; its associated operation modes, location, and the type of users – identified by their sanitation adoption classification – that use the facility.

6.3.4.2 Execution

With each simulation run, agents determine which sanitation alternative within their preferred walking threshold is most closely linked to their preferences. This analysis is done by establishing the sanitation technology that provides the highest satisfaction when considering its design attributes and implementation arrangements. When the agents determine their respective preferred sanitation alternative, the agents travel to their preference as needed. If there are no sanitation technology or arrangement that meets the minimum design utility level or the minimum implementation utility level, respectively, the agent is considered unsatisfied. If there is a queue at the preferred sanitation alternative, the agents will stay in line based upon their waiting threshold. If the agents' wait in line has reached their respective waiting thresholds, the agents leave the queue and then they are labeled as unsatisfied users. The simulation output includes the number and adoption classification of users who have used their modeled sanitation alternative (i.e. satisfied users) versus those who have not.

6.3.4.3 Simulation Settings

The agent-based model was built using NetLogo 5.0.4. The graphical user interface allows the observer – the individual executing the simulations – to choose options for several variables to determine what type of simulation to perform. The *environment* variable has two settings: surveyed and user input. If the surveyed option is selected, agents and the house dwellings are instantiated as a replica of the sample population and the preferences and behavioral patterns are indicative of the individuals surveyed. Alternately, if the user input option is selected, the observer must input the number of agents based upon their sanitation adoption classification.

The *time of day* allows for global temporal control and modifies the walking and waiting thresholds of the agents. The *design scenario* variable indicates the type of sanitation technology and has three modeling options: surveyed, optimized, and user input. The surveyed option models the surveyed respondents' current sanitation scenario. The sanitation technology simulated has the same technical design attributes as surveyed. The optimized option selects the most preferred sanitation technology based upon the maximization of each agent's utility function. The user input allows the observer to select the type(s) of sanitation technology to model, the quantity of each chosen technology, as well as the percentage of agents that will use the technology based upon their adoption classification.

The *implementation scenario* variable details the type of implementation arrangement to model and includes three options: surveyed, preferred, and user input. The surveyed option details the implementation arrangements as surveyed. The walking and waiting thresholds of the agents are set at the current walking and waiting times, respectively. The preferred option determines how close the surveyed option is to the preferred option of the agents. This option analyzes preference for behavioral beliefs indicated previously, including privacy, security, and ownership. The user input option permits the observer to determine which behavioral beliefs to consider in calculating the utility functions.

Several variables also exist to modify the minimum utility levels needed for the agents to be considered satisfied. The *minimum design utility* variable allows the observer to select the lower limit of satisfaction that must be met for the sanitation technology design. If an agent has a utility level for the sanitation technology selected to be modeled less than the lower limit of satisfaction, the agent will be considered unsatisfied. The *minimum implementation utility* variable permits the observer to determine the lower satisfaction limit for the sanitation technology implementation arrangement. Variables can be switched "on" or "off" to be considered in the calculation of the implementation utility function: *ownership*, *payment*, *security*, *walking*, *waiting*, and *subjective norms* (described collectively as the implementation variable switches). When the *ownership*, *payment*, and *security* variables are switched on, the observer can change the attributes of these respective variables for the modeled sanitation technology. For example, when the *payment* variable is switched on, a percentage (to be determined by the observer) of the model technology will require payment. When both the *walking* and *waiting* variables are switched on, agents choose their respective thresholds based upon their preferred times. When those variables are switched off, the agents are modeled after their actual walking and waiting times. The *subjective norms* variable determines whether societal influences are included in the implementation utility function.

6.3.4.4 Model Development

To develop the agent-based model for this work, data for this study investigated attributes of sanitation technologies that influenced user perspectives and experiences for sanitation alternatives. 1002 sanitation users living in a peri-urban area of South Africa were asked about their existing sanitation system, their preferences for various sanitation technology design attributes, as well as their perspectives on current and preferred sanitation implementation arrangements. Descriptive characteristics of the sample population and overall satisfaction levels with existing sanitation technology by user adoption classification are found in Tables 6.1 and Table 6.2, respectively.

Table 6.1. Descriptive Characteristics of Sample Population

Characteristic (N= 1002)	Sample Description
Sex of respondent	
Male	51.5%
Female	48.5%
Age of respondent (in years)	
18-24	24.0%
25-34	39.4%
35-44	23.8%
45-54	9.3%
55-64	2.8%
over 65	0.7%
Highest level of education completed	
Primary	26.7%
Secondary	61.3%
Trade School	3.3%
College/University	8.7%
Employment	
Paid employment within the last three months	44.3%
Type of dwelling	
Formal	46.8%
Informal	53.2%
Head of household	
Yes	54.8%
Household size	
Average	4.4
Median	4
Households with at least 4 residents	57.4 %
Occupancy	
Owned and fully paid off	8.3%
Owned but not yet paid off	1.0%
Rented	7.4%
Occupied rent-free	82.2%
Other	1.1%
Water Source	
Private source (piped water inside the dwelling/yard)	45.1%
Public source (piped water from communal pipe)	54.9%
Current Sanitation Technology	
Cistern flush toilet	97.8 %

Table 6.2. Overall Satisfaction Levels with Existing Sanitation Technology by User Adoption Classification

Overall Satisfaction Scale	Total (N = 1002)	Adopters (N = 360)	Partakers (N = 384)	Non-Adopters (N = 258)
Very Satisfied	36.4	56.4	40.9	7.1
Fairly Satisfied	23.6	22.5	25.9	21.8
Neither Satisfied/Dissatisfied	4.4	3.8	4.6	4.8
Fairly Dissatisfied	12.5	8.0	10.5	20.6
Very Dissatisfied	23.1	9.3	18.2	45.6

Sanitation users ranking their satisfaction level as "fairly satisfied' or "very satisfied" on a five-point satisfaction scale were considered satisfied with their existing sanitation. Detailed classification data for the sample population based upon adoption classification can be found in Seymour (2013b).

6.3.4.5 Model Calibration and Validation

The calibration and validation of agent-based models are particularly complex, as these simulations are concerned with examining interactions between agents; thus, the simulations are developed as a manner to explain emerging social development (Gilbert & Troitzsch 1999, Grimm & Railsback 2005). Considerable debate in the field of agent-based modeling exists with regards to which techniques are appropriate (Windrum et al. 2007, Marks 2007, Klügl 2008).

The "surveyed" scenario – choosing the surveyed option for *environment*, *design scenario*, and *implementation scenario* variables – simulates sanitation usage based upon the sample population and was used to calibrate and validate the model based upon user satisfaction with existing sanitation technology. Sanitation users were modeled to use their existing sanitation option as indicated during the data collection process. In this scenario, the minimum utility levels for design and implementation are set to 0.0 and all switches are placed in the off mode.

An 80%-20% split-sample model calibration technique was used; 800 individuals in the sample population were used to calibrate the model. This split-sample technique has utilized in other social simulations (Andrews 2001, Zurell et al. 2012, Choi et al. 2013, Santos et al. 2013).

The *environment*, *design scenario*, and *implementation scenario* variables were selected as surveyed for both model calibration and validation. The model calibration adjustments included the reduction of sanitation users who did not indicate satisfaction levels during the data collection process. Twenty percent of the sample population indentified as adopter did not indicate any user satisfaction levels for their existing sanitation technology; thus, those missing data points had no analysis for replication. In comparison, 8% of the partaker sample population and 2% of the non-adopter sample populations had user satisfaction levels missing as well. Providing for the adjustment of the adopter sample population during the model calibration assisted with the validation of the model.

Replicative validation, one of the three main approaches to validate simulations (Ziegler 2000), was used to validate the model. In this approach, the ability of the model to replicate actual behavior is examined. The percentage of satisfied users reported by the calibration simulation, validation simulation, as well as the actual surveyed satisfaction levels are provided in Table 6.3. The largest percent difference between the calibration results and actual results are for the adopters. This differential is to be expected due to the considerable amount of respondents who did not provide their existing satisfaction levels. The percent difference between the calibrated results and actual results partakers and non-adopters are 4.7% and 3.6%, respectively. Considering that the model calculated user satisfaction based upon utility functions with stochastic variables, the range is acceptable.

During calibration and validation, the simulation was executed until the percentage change in the average of the results did not change more than 0.5%; this results in approximately 20 simulation runs. The subsequent scenarios are executed 20 times as well.

Table 6.3. Comparison of Calibration and Validation Results to Actual Satisfaction Levels - Percentage of Satisfied Users

User Adoption Classification	Calibration (80% of population)	Validation (100% of population)	Actual Surveyed Responses
Adopters	71.7	78.8	78.9
Partakers	62.1	70.9	66.8
Non-Adopters	25.4	27.5	29.0

6.3.4.6 Simulation Runs

In addition to the "surveyed" scenario, three other simulation scenarios were developed to investigate the impact of changing sanitation technology design and implementation has on the usage behavior of sanitation users. Each additional scenario and the associated parameters are summarized in Table 6.4.

Table 6.4. Description and Parameters of Simulation Scenarios

Simulation Scenario	Description	Variables & Selected Option	
Surveyed	Specifications used to calibrate and validate model	*Environment* *Design* *Implementation*	Surveyed Surveyed Surveyed
Most Preferred Sanitation	Sanitation technology selected for individual agent utility maximization	*Environment* *Design* *Implementation*	Surveyed Optimized Surveyed
Analysis of Implementation	Comparison between existing and preferred implementation arrangements	*Environment* *Design* *Implementation*	Surveyed Surveyed Preferred
Most Preferred Sanitation + Analysis of Implementation	Combination of previous scenarios	*Environment* *Design* *Implementation*	Surveyed Optimized Preferred

6.4 Results & Discussion

Based upon the calibration and validation techniques, several other scenarios were simulated. Figures 6.1 to 6.4 detail the ranges of satisfied sanitation users for each simulation scenario. The plots indicate the minimum, median, and maximum number of users by adoption classification. As a classification group, the adopters have the least amount of variability among the simulation scenarios.

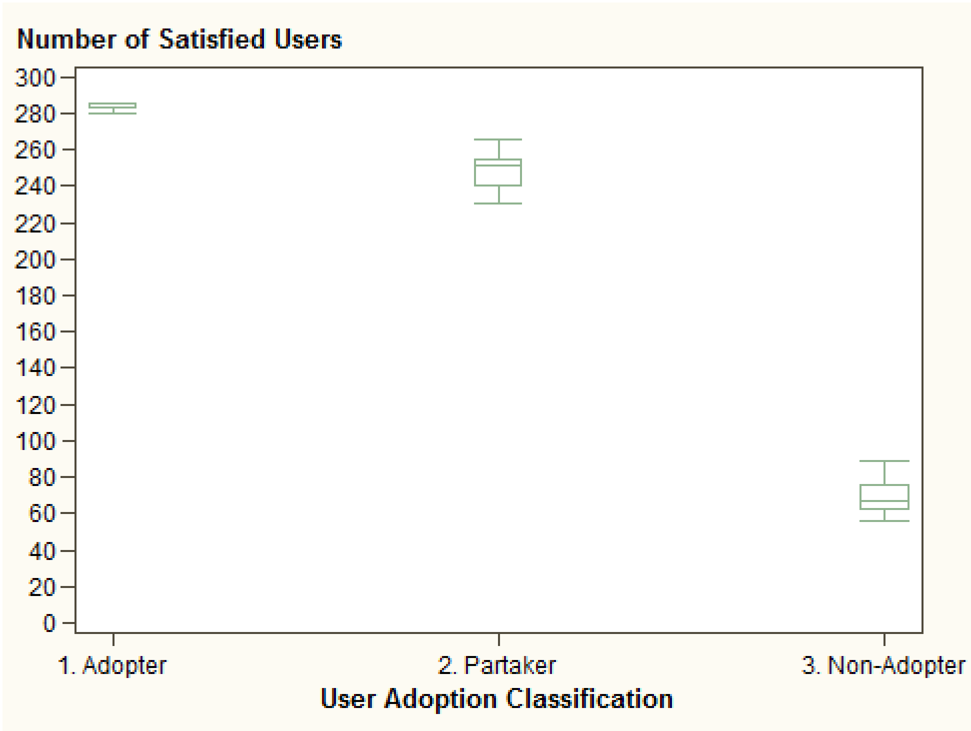

Figure 6.1. Satisfaction Levels in the Simulation: Surveyed

In the surveyed scenario (Figure 6.1), the adopters are the most satisfied with their existing sanitation, reporting a median of 283 satisfied users of 360 individuals what were surveyed. It appears that the partakers are as satisfied as adopters; however, their responses have more variability. It is important to note that while partakers have access to using a restricted sanitation facility, they also may use communal sanitation facilities as times. While partakers and adopters have more variability in their satisfactions levels, partakers, in general, are more satisfied with their sanitation. The spread of partakers and non-adopters are also similar, indicating the amount of satisfaction variability when using sanitation facilities that are not owned by the user.

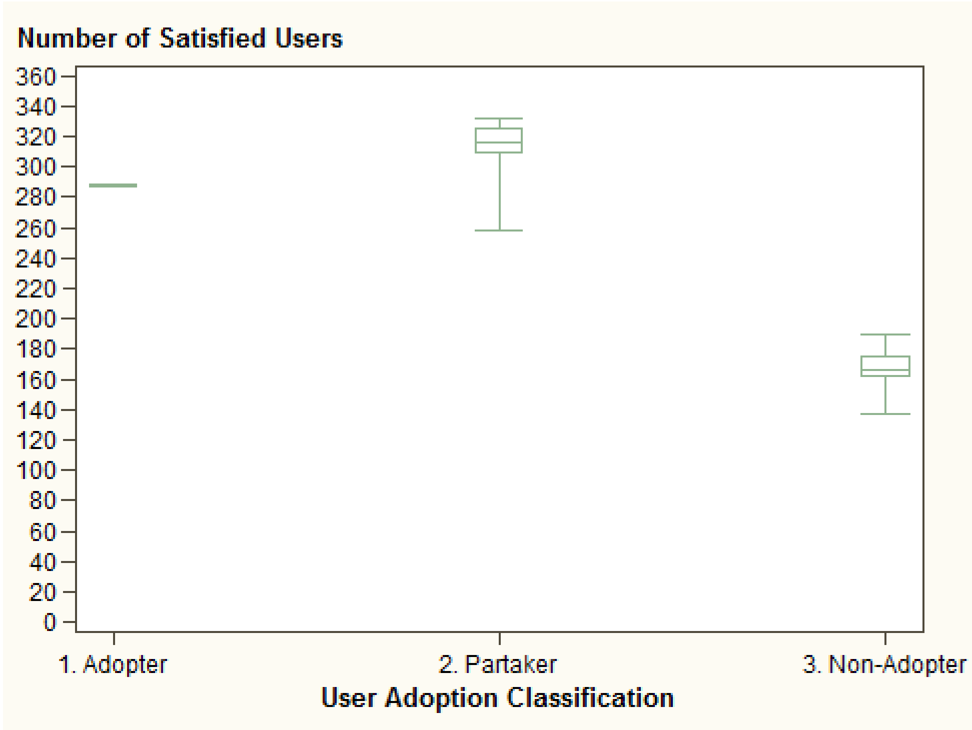

Figure 6.2. Satisfaction Levels in the Simulation: Most Preferred Sanitation

Figure 6.2 shows the results when the most preferred sanitation technology is installed for the user. As this simulation maximizes individual utility design levels, multiple sanitation technology types are implemented. Comparing Figure 6.1 and Figure 6.2, there is not a significant increase in the satisfaction levels of adopters, indicating that adopters actually have access to their most preferred sanitation technology. Satisfaction levels increase when the most preferred sanitation alternatives are implemented for the partakers and non-adopters. The number of satisfied partakers increased 26.1% from an average of 248.9 (surveyed) to 313.9 (most preferred alternative) users. The average non-adopter satisfaction nearly doubled, increasing from an average of 69.4 (surveyed) to 167.3 (most preferred alternative) users.

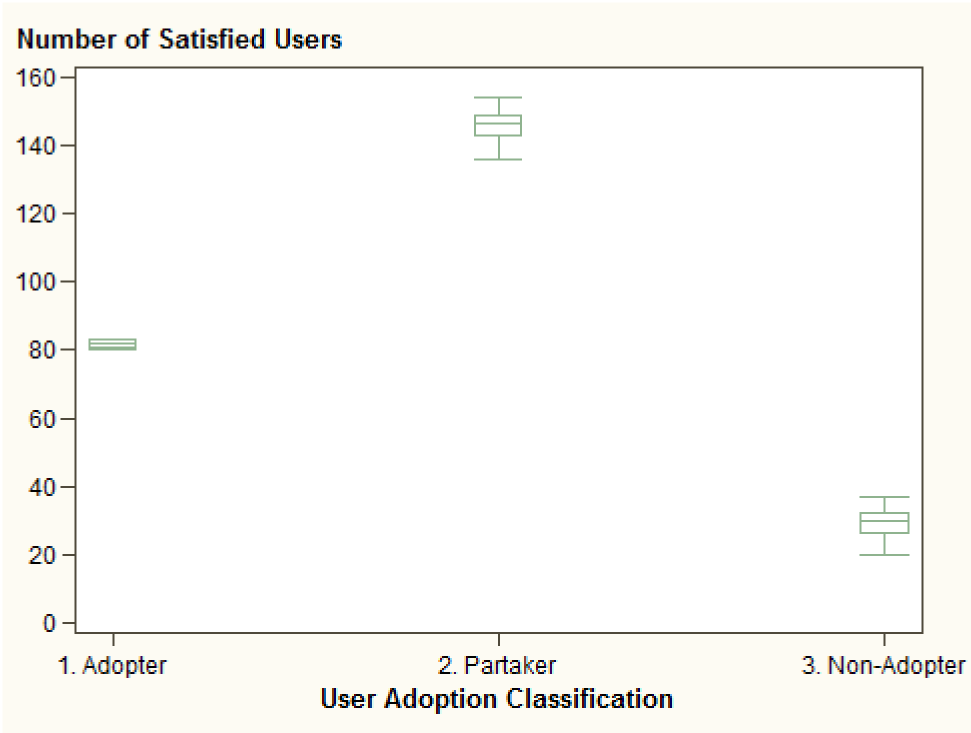

Figure 6.3. Satisfaction Levels in the Simulation: Analysis of Implementation

Figure 6.3 shows the analysis of the implementation scenario and reveals how close the existing sanitation implementation arrangements are to the preferred arrangements of the users. While partakers are the most satisfied with their existing implementation, satisfaction levels are less than half of the sample population, averaging 145.6 users. As anticipated, non-adopters prefer their existing implementation arrangement the least.

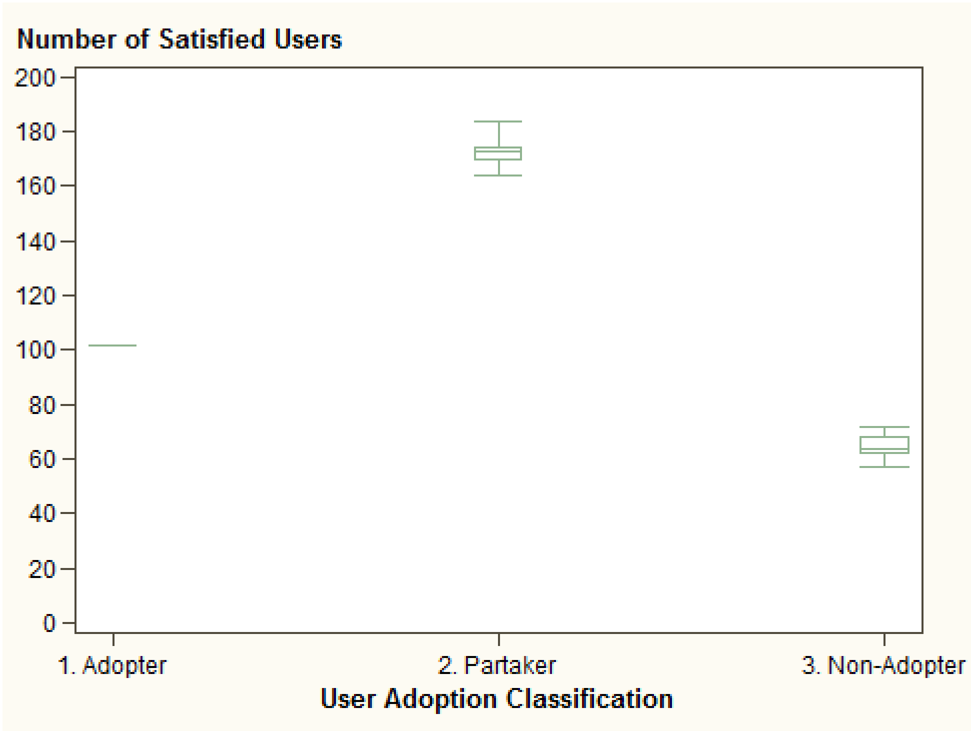

Figure 6.4. Satisfaction Levels in the Simulation:
Most Preferred Sanitation + Analysis of Implementation

The last simulation combines the preceding two simulations by analyzing the impact of providing preferred sanitation technology in an implementation arrangement that is not preferred by the user, as shown in Figure 6.4. While overall satisfaction levels do increase from simply having a providing preferred technology, the lack of satisfaction in the implementation arrangement decreases the potential satisfaction levels. In comparison to the "analysis of implementation" scenario, the number of satisfied partakers and non-adopters increase 18.4% and 19.3%, respectively.

6.5 Conclusion

This analysis is an attempt to understand social behavior regarding sanitation adoption and usage. This work produces a multi-agent simulation on sanitation behavior to investigate the impact of technology appropriateness and acceptability on sanitation use. Through a series of simulation scenarios, it provides insight regarding the connection in sanitation interventions between technology design and implementation arrangements.

The applied case study of residents in a peri-urban area of South Africa places context to the simulation. The majority of the sanitation technology utilized by the sample population was cistern flush toilets, regardless of the sanitation adoption classification. Having similar technology throughout the area coupled with varying levels of user satisfaction indicate the need to consider the impact of implementation arrangement of technology during sanitation interventions. Adopters, as anticipated, are the most satisfied adoption classification as most of them already have their preferred sanitation technology already installed. On the other hand, user satisfaction increased when their sanitation technology is modified to one more preferred.

In general, the sample population simulation does not prefer its current implementation arrangements. The adopter and partakers were most impacted by changes in implementation arrangements. As a result of the number of adopters who did not report initial satisfaction levels during the data collection process, further research should be conducted to determine if there are implementation variables which were not tested for that impact this group more so than the other user adoption classes. For instance, adopter may be more concerned with the operation and maintenance components on privation sanitation ownership; this issue would not be addressed in the other groups.

This analysis also addresses the need to different the preferences of partakers from non-adopters. As a whole, this classification group is 37.7% more satisfied with their existing sanitation than non-adopters.

Deciding which sanitation technologies would be suitable is an important step during sanitation interventions. The results of this analysis suggest that when design and implementation choices are in sync with the preferences of the intended community, the overall satisfaction with the sanitation alternative may be higher than if those decisions are made separately. Through considering the preferences of sanitation users throughout the planning process, different choices may be made about sanitation technology appropriateness and acceptability.

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CHAPTER 7

CONCLUSIONS AND RESEARCH DIRECTIONS

7.1 Conclusions

The research presented in this dissertation clearly illustrates that the incorporation of user preferences in the technology design, implementation, and policy framework for sanitation systems deployed in resource-challenged areas is of paramount importance. Leveraging prior work in the field to provide the relevant contextual background, the key conclusions in this work address current knowledge gaps and prescribe appropriate short- and long-term research goals toward delivering adequate sanitation access to underserved populations. The primary findings of this effort include:

Identification of Shared Sanitation Users as a Separate Sanitation Adoption Classification

This research is the first to describe individuals who share sanitation with other households as a new classification of sanitation adoption in order to more accurately model aggregate user behavior. Consensus in the literature before this work has typically grouped these individuals as a subset of non-adopters – individuals who use communal sanitation facilities. ***Using an alternative approach, this work identified several motives and barriers of these users to sanitation usage to be statistically significant from non-adopters.*** Identifying this new class of users as partakers this research proved that they value the ability to use sanitation that flushes as well as have shorter walking distances to use their sanitation facility. Furthermore, partakers value the cleanliness of their sanitation facility as well as the ability to use them at night.

Shared sanitation continues to advance as an implementation approach to providing access. Understanding this group of users provides a foundation in furthering sanitation interventions, specifically those being implemented in informal settlements and other resource-challenged areas. Using the current United Nation's definition of improved sanitation, global use to unimproved sanitation has decreased over the last two decades from 20% to 11%; during the same time, access to shared sanitation has nearly doubled, going from 6% to 11% (UNICEF & WHO 2010a). Using the reclassification of these users identified in this work assists in developing new user-specific intervention approaches.

Furthermore, this reclassification of shared sanitation users clarifies the linkage between sanitation definitions and user adoption classifications. Current definitions of sanitation access identify shared sanitation as a type of sanitation classification, without differentiating shared sanitation facilities that provide for controlled access from those that are communal. With this reclassification, shared sanitation facilities can be indentified on the basis of implementation arrangements.

Specification of Sanitation Technology Design Attributes Preferred Over Others

This work presents evidence that design attributes can be ranked using a generalized multinomial logit valuation metric for a given sanitation user. Applied to this research using maximum difference scaling, this metric accurately predicted value preferences for seven technical attributes of sanitation technology. This is a significant improvement over the prior work in the field which investigated preferences for sanitation technology while neglecting what attributes of the technology were influencing those preferences. Conversely, this work demonstrates that the attributes of sanitation technology do not have equal importance to the sanitation user. Parameter estimations detailed the significance of technical attributes and determined their respective priorities. Specifically, the application of the maximum difference scaling reveals the higher priority sanitation users place on using water-based conveyance in sanitation technologies and the lower priority placed on anal cleansing approaches.

Furthermore, this research developed and implemented utility functions, based upon stated preferences on the technical attributes, to determine which sanitation technologies would be more preferred. A case study examining the various operation modes of eight sanitation technologies revealed that while cistern flush toilets were, in general, the most preferred sanitation technology, this option provided the highest amount of utility for only half of the community. ***This finding indicates the need to develop sanitation interventions that incorporate multiple sanitation alternatives that are user-preferred.***

Results from this work also provide an understanding of which operation modes of sanitation technologies are preferred. It details that changing operation modes of sanitation technology can have a devastating impact on the satisfaction an individual receives from its usage, providing further insight to why the implementation of sanitation technology can fail in communities.

Model Simulation of User Preferences Integration into Sanitation Technology Design and Implementation

This work presents a novel approach for examining how user preferences for sanitation technology design and implementation influence its adoption and usage. Through the development of multi-agent simulation, sanitation behavior was modeled to determine satisfaction with various sanitation technology and implementation arrangements. ***This analysis is the first approach in the field to model sanitation usage behavior to examine the relationship between appropriate technology and acceptable technology***. Previous approaches in determining the appropriateness of a technology considered the functionality to reduce pathogens and the feasibility of implementation. While user acceptability of sanitation technology was a concern, there was no methodology to assess how acceptable a technology would be to a community.

This simulation presents an approach to access user acceptability. It incorporates engineering design principles with planning approaches to determine the impact of sanitation interventions. ***It provides a framework to make better decisions to determine what sanitation technology to implement and which implementation arrangement would work best with the indented community***. As the model details several sanitation technologies with all their possible operation modes, it expands the planner's knowledge base for comparison between sanitation technologies, promoting to make better, more informative decisions. Additionally, the model assists engineers with determining what sanitation technology design are being preferred in the field, furthering the developing of user-centric sanitation technologies.

7.2 Research Directions

This work sought to advance the understanding of the value preferences of sanitation users in hopes of developing new approaches to increase global sanitation coverage. It details a new classification methodology as well as optimization and simulation techniques to examine sanitation users and their preferences. While it addresses the impact of those preferences on sanitation technology design and implementation practices, further work is needed towards using these findings to influence policy.

Focusing on partakers as a new class of sanitation users, future research is needed to develop sanitation intervention schemes directed towards shared controlled usage of sanitation as a mechanism to improve sanitation coverage. Specifically, determination of the optimal number of preferred households to share sanitation must be determined to ensure that access has a sense of controllability. Additionally, it needs to be determined how to allocate ownership and accountability responsibilities for partakers shared sanitation facilities.

Furthermore, more research is needed to replicate the approaches used in this work in other sanitation settings. The specificity of the data collection process was limited to sanitation users in a peri-urban context. To determine the prevalence the characteristics of sanitation users that served as a basis of the work, similar studies should be performed in the rural and urban settings. Sanitation users in these environments can have different socio-cultural and socioeconomic constraints than those living in peri-urban areas. Gathering additional data from different settings will assist in understanding those settings.

Further modifications to the agent-based simulation will provide a more holistic model of the interactions between public health, sanitation, and the environment. The incorporation of hydrologic data can detail the anthropogenic threats to water resources if contamination due to poor sanitation occurs. The integration of epidemiologic data can explore the health impacts of user sanitation preferences. Encompassing these interactions will further assist in understanding the implications of sanitation choices.

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APPENDIX A

SUMMARY OF THE SAMPLING AREA

A.1 Historical Perspective

Being among the first countries to recognize water and sanitation as basic human needs, South Africa passed the Water Services Act in 1997 (South Africa Department of Water and Forestry 1997); this legislation decreed that access to water and sanitation cannot be denied to anyone, regardless of ethnicity or socioeconomic status. Yet, almost two decades after Apartheid's end in 1994, 17.2% of the country's population remains without access to improved sanitation facilities (South Africa Department of Water Affairs 2012); many of those that do not have access live in the country's peri-urban areas called townships. Unlike many peri-urban settlement areas throughout Sub-Saharan Africa, townships were formally institutionalized under Apartheid rule. With the establishment of the Group Areas Act of 1950, all non-whites were forced out of city limits and concentrated in areas based upon ethnicity (South Africa 1950). For the next 45 years, townships were plagued with gross overpopulation, inadequate housing, and poor water and sanitation facilities.

After Apartheid's abolishment, the South African government began increasing public service delivery in impoverished townships. Providing services has not been without challenges. With many of these areas now serving as urbanization and migration centers for the economically disenfranchised, service delivery is exacerbated.

Governments are now challenged with determining the appropriate schemes to deliver water and sanitation facilities. Often, providing individual households in these densely-populated areas with non-communal services is not a feasible option because of economic, spatial, and logistical constraints; yet, establishing water and sanitation access as basic human rights has indebted the country to develop programs that are engaged in planning, providing, and monitoring the service delivery processes.

A.2 Existing Country Sanitation Estimates

Data estimates on access to improved sanitation services within South Africa are conflicting. At the national level, data is presented from four sources: the Joint Monitoring Programme (JMP) for Water Supply and Sanitation, UNICEF, the South Africa General Household Survey (SA GHS) as well as the South Africa Department of Water Affairs and Forestry (SA DWAF). The data provided by SA DWAF is extrapolated from the 2001 South African Census.

With 2006 serving as the base year, Table A.1 details the percentage of the country's population with access to improved sanitation. It appears that discrepancies between the compared data sources may be due to:

Consideration of geographical density While the JMP and the UNICEF surveys attempt to show the disparity between urban and rural land areas; it is not clear how each land mass is defined.

Definition of improved sanitation facilities With the development of the Millennium Development Goals as a catalyst to improve the well-being for the world's poorest citizens, the JMP and UNICEF settled on which sanitation systems would be considered to be “improved,” namely, sewer connections, septic tank connections, pour-flush latrine, pit latrine with slab and/or ventilation. However, South African statistics also includes chemical toilet and simple pit latrine as acceptable sanitation systems. Including these extensions of systems synthetically increases access.

Design of sampling procedure To ensure that sampling populations would not by impacted by the size of the strata, probability proportional to size sampling was utilized by the SA GHS. Additionally, institutions such as schools, worker quarters, and hospitals are not included. However, the census data did include coverage into these institutions.

Table A.1. 2006 Estimates for South Africa Access to Improved Sanitation

Source	Percentage of Total Population		
	Total	Urban	Rural
Joint Monitoring Programme (JMP)	*	93.2	75.5
United Nations Children’s Fund (UNICEF)	59	66	49
General Household Survey (SA GHS)	91.4	*	*
Department of Water Affairs& Forestry (SA DWAF)	68.6	*	*

* Data not provided at this level.

(JMP 2010, UNICEF 2010, South Africa Statistics 2008,
South Africa Department of Water Affairs 2012)

A.3 Description of Sampling Area and Size

The study area focuses on sanitation users in a peri-urban area in the Sub-Sahara South Africa. The Republic of South Africa is located on the southernmost tip of the continent of Africa. The population of South Africa, approximately 50 million people in 2010, lives across the country’s nine governing provinces (South Africa Statistics 2010). The study was performed in the Western Cape Province of South Africa. While this province is one of the most prosperous in South Africa, it also has significant socioeconomic gaps as it is home to large peri-urban areas in the country, including Khayelitsha. Furthermore, political power struggles within the province also have led to contentious approaches to social and economic development. Additionally, perceived economic opportunities have led to complex migrations patterns into the Western Cape from other provinces, increasing the demands for sanitation throughout the region. Outside of the premier province of Gauteng, the Western Cape is the only province with an increase in net migration over that last five years; an estimated 94,000 people have migrated into this province from others throughout South Africa (South Africa Statistics 2010).

The sampling area focuses on sanitation users located in a peri-urban area called Kayamandi. This settlements falls under the jurisdiction of the City of Stellenbosch, located within the Western Cape. Stellenbosch is separated into 19 wards; three of them are located in Kayamandi (Stellenbosch Municipality 2007). Over the last ten years, Stellenbosch has experienced a dramatic increase in population; the population of the city has doubled to approximately 222,000 inhabitants (South Africa Statistics 2010). This upsurge in population has lead to intensified demand for municipality service delivery, including sanitation.

The study utilizes stratified random sampling as its sampling method. This probabilistic method was selected to ensure representative subsets (strata) of population. It assists in the removal of unrepresentative sampling bias.

Kayamandi is broken into census wards. The three wards located in Kayamandi served as the enumeration areas. These demarcations were used to determine which households to interview.

The strata will be based upon household type as well as type of sanitation system. For the purposes of this study, the definition of a household will coincide with the explanation provided in the 2007 South Africa Community Survey, stating,

> A household is a group of persons who live together and provide themselves jointly with food and/or other essentials for living, or a single person who lives alone…Multiple households occur when (1) there is more than one household at one address, or (2) there is more than one household at one dwelling unit. Multiple households can be found, for example, in polygamous or extended family situations. (South Africa Statistics 2007)

Households are characterized as "formal dwellings" or "informal dwellings." Table A.2 illustrates the types of dwellings that will be included in each strata based on the categories provided by 2007 South Africa Community Survey.

Table A.2. Strata Classification Based on Household Dwelling

Formal Dwellings	Informal Dwellings
- House or brick structure on a separate stand or yard - Flat in block of flats - Town/ cluster/ semi-detached house (simplex, duplex, triplex)	- Traditional dwelling/ hut/ structure made of traditional material - House/flat/room in backyard - Informal dwelling/ shack in backyard - Informal dwelling/ shack NOT in backyard, e.g. in an informal/ squatter settlement - Room/ flatlet NOT in backyard but on a shared property - Caravan or tent - Other

(South Africa Statistics 2007)

Squatter areas within the community are differentiated from the established areas due to their dense populations, informal houses, gravel/dirt roads and lack of electricity. Figures A.1 details various house dwelling seen throughout Kayamandi.

Figure A.1 House Dwellings Located in Kayamandi, South Africa
(personal photos)

Data for the population sampling frame comes from the 2011 South Africa Census Survey. Table A.3 details the population sampling frame and estimated sample population size for each stratum.

Table A.3 Sample Population Frame

Type of main dwelling	Ward 13	Ward 14	Ward 15	Total	Formal	Informal
House or brick/concrete block structure on a separate stand or yard or on a farm	1,632	1,752	1,816	5,200	5,200	
Traditional dwelling/hut/structure made of traditional materials	5	2	25	32	32	
Flat or apartment in a block of flats	126	11	201	338	338	
Cluster house in complex	-	24	24	48	48	
Townhouse (semi-detached house in a complex)	-	7	15	23	23	
Semi-detached house	77	159	993	1,228		1,228
House/flat/room in backyard	50	11	33	95		95
Informal dwelling (shack; in backyard)	101	689	761	1,551		1,551
Informal dwelling (shack; not in backyard)	141	2,421	5,700	8,262		8,262
Room/flatlet on a property or larger dwelling/servants quarters/granny flat	14	13	198	226		226
Caravan/tent	8	8	-	16		16
Other	41	10	241	292		292
Unspecified	39	27	91	157		157
Not applicable	248	147	304	699		699
Total	2,483	5,279	10,402	18,164	5,641	12,526
Sample Size (e = 0.05)					374	388

The target sample size for each stratum was calculated using the Yamane's formula (1967); it is shown as:

$$n = \frac{N}{1 + Ne^2}$$

where n is the estimated sample size, N is the total population, and e is the level of precision (confidence level) desired in the calculated estimates. Assuming a level of precision of 0.05 (confidence interval of 95%), a total of a least 762 individuals was needed to have a statistically significant sample population size.

A.4 Comparison to Other Peri-Urban Areas

While the sampling area Kayamandi is similar to other peri-urban settlements that serve as densely populated urban growth areas, there are unique legislation and policy approaches in South Africa. Unlike peri-urban areas found in other countries, South African townships were formally established under Apartheid rule and are recognized by governing authorities. Additionally, municipalities are under legislative rule to attempt to provide infrastructure services, including water and sanitation service delivery, in peri-urban areas. Figure A.2 further details the institution, legislation, and policy approaches taken in South Africa since 1994. Duty bearers represent governing authorities responsible for service delivery; right holders represent individuals receiving the service.

Figure A.2 South African Experience in Water and Sanitation Service Delivery

A.5 References

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