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WATER ACCESS AND MAINTENANCE IN KARONGA, MALAWI

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WATER ACCESS AND MAINTENANCE IN KARONGA, MALAWI

By

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A REPORT

Submitted in partial fulfillment of the requirements for the degree of

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This report has been approved in partial fulfillment of the requirements for the Degree of MASTER OF SCIENCE in Mechanical Engineering.

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Acknowledgments

I would like to thank the staff of Lufilya Community Day Secondary School who took me into their community and made it home. Dr. Rochelle Holm and Jim McGill of Mzuzu University also deserve many thanks for their generosity and guidance throughout my numerous attempted research ideas. Thanks to my Peace Corps bosses in Malawi; Paul Miamba, Helen Katimba, and Michael Kumwenda, who supported my research efforts in any way they could. Thanks to my advisers, Dr. Michele Miller and Dr. John Gershenson who were flexible and supportive throughout my 26 months in Malawi. Lastly, a big thanks to my parents, family, and friends who sent me letters and care packages to give me little tastes of home.

Abstract

This report is a case study of how Mwangalala community accesses water and how that access is maintained. Mwangalala community is located in the northern tip of Karonga district in Malawi, Africa. The case study evaluates how close the community is to meeting target 10 of the Millennium Development Goals, sustainable access to safe drinking water, and evaluates the current water system through Human Centered Design's criteria of desirability, feasibility, and viability. It also makes recommendations to improve water security in Mwangalala community.

Data was collected through two years of immersive observation, interviews with 30 families, and observing two wells on three separate occasions. The 30 interviews provided a sample size of over 10% of the community's population. Participants were initially self-selected and then invited to participate in the research. I walked along community pathways and accepted invitations to join casual conversations in family compounds. After conversing I asked the family members if they would be willing to participate in my research by talking with me about water. Data collected from the interviews and the observations of two wells were compared and analyzed for common themes.

Shallow wells or open wells represented the primary water source for 93% of interview participants. Boreholes were also present in the community, but produced unpalatable water due to high concentrations of dissolved iron and were not used as primary water sources. During observations 75% of community members who used the shallow well, primarily used for consumptive uses like cooking or dinking, were females. Boreholes were primarily used for non-consumptive uses such as watering crops or bathing and 77% of the users were male.

Shallow wells could remain in disrepair for two months because the repairman was a volunteer, who was not compensated for the skilled labor required to repair the wells. Community members thought the maintenance fee went towards his salary, so did not compensate the repairman when he performed work. This miscommunication provided no incentive for the repairman to make well repairs a priority, and left community members frustrated with untimely repairs. Shallow wells with functional pumps failed to provide water when the water table levels drop during dry season,

forcing community members to seek secondary or tertiary water sources. Open wells, converted from shallow wells after community members did not pay for repairs to the pump, represented 44% of the wells originally installed with Mark V hand pumps. These wells whose pumps were not repaired were located in fields and one beside a church. The functional wells were all located on school grounds or in family compounds, where responsibility for the well's maintenance is clearly defined.

Mwangalala community fails to meet Millennium Development goals because the wells used by the community do not provide sustainable access to safe drinking water. Open wells, used by half the participants in the study, lack a top covering to prevent contamination from debris and wildlife. Shallow well repair times are unsustainable, taking longer than two weeks to be repaired, primarily because the repair persons are expected to provide skilled labor to repair the wells without compensation.

Improving water security for Mwangalala can be achieved by improving repair times on shallow wells and making water from boreholes palatable. There are no incentives for a volunteer repair person to fix wells in a timely manner. Repair times can be improved by reducing the number of wells a repair person is responsible for and compensating the person for the skilled labor provided. Water security would be further improved by removing iron particulates from borehole water, thus rendering it palatable. This is possible through point of use filtration utilizing ceramic candles; this would make pumped water available year-round.

1. Introduction

How is water accessed and how is that water access maintained? This report seeks to tell the story of how Mwangalala community interacts with their water sources and evaluate their water security. United Nations Millennium Development project Target 10 seeks to “Halve, by 2015, the proportion of people without sustainable access to safe drinking water [...]” (United Nations 2006). The purpose of the Millennium Development Goals is to improve the lives of people all around the world by accomplishing the ambitious targets set through the actions of governments and non-governmental organizations (NGO). Target 10 specifically seeks to provide sustainable access to drinking water, meaning a source that reliably provides water throughout the year and can be maintained by the community, otherwise known as village level operation and maintenance (VLOM). Many governments and Non-Governmental Organizations use wells dug/drilled as their indicator for this target. Although this indicator does not evaluate sustainability, it is commonly used due to the difficulty and cost of putting monitoring and evaluation programs in place. As the deadline for this goal draws to a close, this report studies the progress of one community in the Northern region of Malawi towards water security. Progress will be evaluated through Human Centered Design’s criteria of desirability, feasibility, and viability.

2. Area of study

Malawi is a land locked country in south eastern Africa bordered by Tanzania in the north, Mozambique on the east and south, and Zambia on the west.

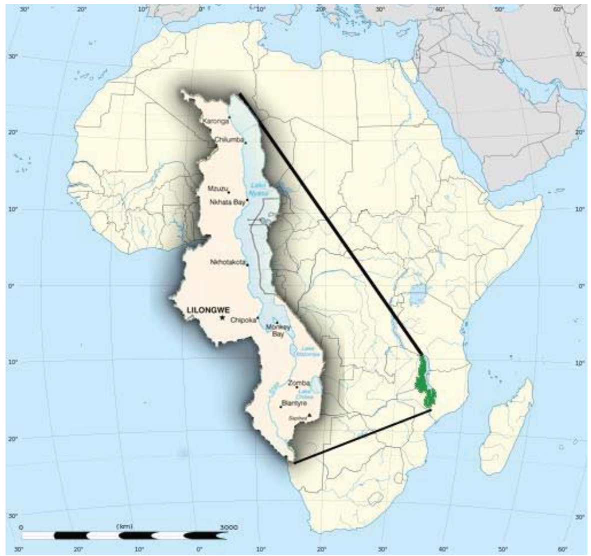


Figure 1: Malawi's location in African Continent

Africa political map by Eric Gaba

Malawi had a population of 14.8 million people in 2008 according to the World Health Organization. With Malawi's annual population growth rate of 3%, in 2014 it has a population of approximately 17 million people. Of the approximate population in 2014, 74% or 12.5 million people live on less than $1 per day (World Health Organization 2010). Malawi is split into three regions: South, Central, and North. The official language of Malawi is English, due to their history as a colony of England until 1961. Many people can understand and speak some English, and this incidence of English comprehension is higher in the Northern region. In addition to English, Malawi has many Bantu languages and dialects; the two most widely spoken Bantu languages are Chichewa and Chitumbuka. The South and Central regions predominantly speak Chichewa. The Northern region predominantly speaks Chitumbuka.

Mwangalala village is located in the far north of Malawi in Karonga district along the lakeshore, only 15 kilometers south of the Tanzanian border (although it is 40 kilometers from the nearest Tanzania border crossing). The nearest trading center is Mwenitete, which is 15 kilometers north of Karonga Boma. This study encompasses a 2.4 square kilometer area, with 15 wells observed, in Mwangalala village. Figure 2 shows the location of the wells in relation to each other.

Figure 2: Map of well sites

This area of study was chosen for its proximity to Lufilya Community Day Secondary School (Lufilya CDSS), where I was based for two years of Peace Corps service. The scope is limited to wells within easy walking distance, primarily within Mwangalala village. A few wells are within the boundaries Msomba village, where the Lufilya school campus lies. Although Mwangalala village is in the Northern region, within Karonga district, the community primarily speaks Chingonde. I learned Chitumbuka during my Peace Corps training, and with community members' understanding of English, it allowed me to communicate with the local community members. Occasionally an interpreter who spoke Chingonde was used in interviews with community members who were not comfortable conducting the conversation in Chitumbuka or English.

The Northern region has 13% of the population of Malawi and is least densely populated (National Statistical Office 2008). In addition to having the smallest population density of the three regions, it has the highest primary student retention rate, highest secondary school enrollment, and lowest student to teacher ratio. People in the Northern region place an emphasis on pursuing education, which was the first region in the nation to receive formal western education from missionaries. The value placed on education combined with favorable teacher/student ratios has produced quality secondary schools (Nellemann 2004). The prevalence of education in Northern Malawi has helped the populace understand some of the risks of untreated drinking water and the sources of water-borne diseases. Community members knew that debris in open wells increased risk of illness. They referenced using “water guard”, a chlorine solution produced by Population Services International and subsidized by USAID, to treat water from an open well known to cause sickness.

Mwangalala village is located in an alluvial aquifer which has a water table between 10 to 30 meters beneath the ground (Hooydonck 2001). This depth of ground water is ideal for siting shallow wells, and as a result nearly any spot on the Malawi lakeshore will produce water when a well is dug. The water table does drop below the depth at which some shallow wells are capable of pumping water. When a pump goes dry, water can sometimes still be reached by removing the pump and using buckets and rope to draw water. Illustrating the high water table along the lakeshore, Figure 3 shows ground water reached at a depth of 1 meter during the middle of July, which is approximately two months after the end of rainy season.

Figure 3: Water access pit dug for brick making

2.1. Wells

Mwangalala community has three types of wells: borehole, shallow well, and open well. Boreholes were drilled by a machine to be 40 meters deep, cased with polyvinyl-chloride pipe (PVC), and sealed with an Afridev hand pump and concrete lid. Shallow wells in Mwangalala were hand dug to a depth of 4 to 7 meters and then sealed with a concrete lid and a Mark V hand pump. Open wells are essentially shallow wells without the concrete lid and hand pump. They varied the most in construction, some were previously sealed with lids and hand pumps, and others were constructed as open wells.

2.1.1. Borehole

Boreholes have great depth, 40 meters, which results in a larger and heavier column of water that needs to be lifted to the surface. The pumping mechanism for Afridev wells were designed with this in mind, and offers a variable mechanical advantage, allowing large columns of water to be pumped with little effort on the part of the user (see Figure 4). The water is pumped to the surface using two valves, a foot valve and a plunger valve. The plunger valve closes when it is being drawn upwards and the foot valve opens, allowing water to be drawn upwards as well. This is like pulling the plunger back on a syringe, using a vacuum to pull water inside. Then as the plunger valve moves down it opens, as the foot valve closes. This keeps the water moved upwards by the previous stroke in the water column and resets the mechanism to draw water upwards again. Repetitions of vertical movement pumps water to the surface.

Figure 4: Borehole with Afridev hand pump

The Afridev hand pump uses a lever to reduce the effort needed to raise the water column. The handle, as seen in Figure 4, can be lengthened as necessary to reduce pumping effort. According to the Karonga District Water Board Director it costs approximately $7500 (2.4 million kwacha) to install an Afridev hand pump. The community is expected to provide 5% of this cost through labor and raw materials, such as sand bricks. The Malawi government and UNICEF provide the rest of the necessary funds.

2.1.2. Shallow well

Shallow wells are hand dug wells with a depth of 4 to 7 meters. They have a direct action pump mechanism, there is no mechanical advantage like in the Afridev; the user is lifting the column of water directly. Mark V hand pumps use a mechanism similar to Afridev hand pumps to draw water upwards, a foot valve and a plunger valve. These pumps can only be used in shallow wells because the water column must be small enough to be lifted by a user without too much difficulty. Direct action pumps are chosen because they are easier and cheaper to repair. They are designed to be village level operation and maintenance (VLOM). This means the pump can be repaired with few tools and locally available parts. Shallow wells in Mwangalala village all have Mark V hand pumps and were constructed with the aid of Marion Medical Mission between 2001 and 2004. These shallow wells have a donor cost of $400 USD. (Mission n.d.)

Figure 5: Shallow well with Mark V hand pump

2.1.3. Open well

Open wells in Mwangalala village vary in construction and condition. There are six open wells. Four of those six wells used to be topped with a Mark V hand pump. Figure 6 shows an open well in Mwangalala village. It used to have a Mark V hand pump as evidenced by the concrete lid that is still next to the opening and the concrete apron which is the style of Marion Medical Mission.

Figure 6: Open well XII

Open wells are the simplest form of well, there is no maintenance of the pump required. As long as a community member is able to find string or rope and a pail (or borrow from a neighbor), they can draw water from the well. Figure 7 shows a community member drawing water from an open well using a 5 liter pail. The drawbacks of open wells are easy contamination from debris and animals and the danger of small children falling in the well.

Figure 7: Drawing water from open well XIV

2.2.Previous work

Water is accessed in rural Malawian villages through the use of boreholes or shallow wells. The former is typically drilled by a machine to depths of 40 meters and the latter is hand dug to depths of 10 to 20 meters. Both wells use a hand pump to draw water from the ground to a spigot and an awaiting bucket. The World Health Organization defines sustainable water access where hand pumps "are functional if they operate at 70% of the time with a lag between break down and repair of not more than two weeks." (WHO, UNICEF 2000) This standard for hand pumps covers solely the functionality of the pump; another aspect of sustainable water access is the quality of water expelled by the pump.

Water quality of a well must be perceived as good by a community for the well to be used. The Malawi Standard Board defined quality standards for water access:

- Organoleptic Characteristics: pleasant (typical) characteristic, palatable, fresh flavor
- Freedom from the following defects: dust, fibrous particles, sediments, other foreign matter
  (Malawi Standard Board 2005)

This is a subjective standard, which makes sense. Water sustainability is defined by the people who depend on that water. If a water source is deemed unsuitable by the community it will be abandoned. A water quality defect present in Mwangalala village as well as other parts of Malawi is the presence of iron concentrations in groundwater. Specifically, water at a depth of at least 40 meters below ground surface is contaminated by excess iron in Mwangalala. Shallow wells drawing water from a depth of 4 to 7 meters are not affected by iron contaminants. Boreholes in other parts of Karonga district do not have iron contaminants and produce palatable water. The quantity of dissolved iron in the water drawn from boreholes in Mwangalala is greater than the limits recommended by the World Health Organization. Community members disdain water sources containing these high concentrations of iron due to the discoloration and taste (Bath 1980).

The high iron content of borehole water issue was prominent in Mwangalala village, and has yet to be resolved for the general population of afflicted rural Malawians. Boreholes in Mwangalala were used primarily for non-consumptive use; bathing, farming, washing non-stainable items, etc. I was warned immediately upon arrival at Lufilya CDSS not to use the borehole for drinking or cooking water. Participants in the interviews detailed later in this report preferred distant surface water sources rather than using water from a much closer borehole, if the primary water source shallow well was not producing water. Figure 8 shows iron stains on the concrete below the spigot of a borehole installed one year prior to the date the photograph was taken. While communities surrounding Lufilya CDSS were unable to use borehole water for consumption, other communities in Karonga district used boreholes without encountering high concentrations of dissolved iron. As a result, in areas without high iron concentrations boreholes were more prevalent than shallow wells possibly due to the year-round water availability associated with boreholes.

Figure 8: Iron-stained borehole

Water pump breakage is a well-known issue, and as a result several different aspects of water well failures have been studied in Malawi. WaterAid found that 66% of MALDA hand pumps installed in Malawi were either partially functional or non-functional after one year of use. (Shaw and Manda 2013) Mark V hand pumps in Mwangalala village were installed from 2001 to 2004, and have a non-functionality/failure rate of 44%. People have sought the reason for the poor functionality rates of these hand pumps, exploring the supply chain and the mechanical design of the hand pumps installed. In my interview with the district water board director for Karonga, he suggested a working water pump committee was necessary for a functional well. A study found that a water source having an active water committee, responsible for the maintenance of the pump, did not guarantee the pump would be functional. This suggests other factors affect functionality (Shaw and Manda 2013).

The factors causing non-functional wells to remain in disrepair can be complex and varied; dysfunctional wells are not all broken due to a singular cause, even in a limited geographical area. What factors can cause a well to remain in a state of disrepair? Lack of funds, lack of action on the community's part, lack of action on repairman's part, lack of replacement parts, or undesirable water can all contribute to a state of continued disrepair.

In the case of Mwangalala village, spare parts were not an issue. Another researcher, Duncan McNicholl, studied the spare parts supply network in Karonga. He found that parts were accessed by communities regardless of distance to the parts source, but that fund raising for the parts themselves was the most cited challenge in his survey. Communities that raised funds only when the well was broken were able to repair 36% of the break-downs within a week, whereas communities that raised funds on a monthly basis were able to repair 66% of the break-downs within a week.

A study was conducted investigating the causes for Mark V pump failures installed by Marion Medical Mission. Dr. Boyd identified two overarching causes for wells to remain in disrepair, “Pumps fail to be repaired because either (1) the maintenance system fails to supply the needed repair services or (2) the community fails to demand the repairs (i.e. to request and pay for them)” (Boyd 2011). This agrees with the conclusions of McNicholl, the failures of hand pumps while mechanical in nature, do not remain broken because of technical issues; rather the fault lies with human inaction.

Cost was eliminated as a critical issue, as Marion Medical Mission (MMM) constructed a maintenance program analogous to insurance; the water committee for each well pays a flat yearly fee which guarantees that all repairs for that year are covered. The fee is equivalent to sending a child to a secondary school for one semester. This system works well for communities, who have a known annual cost to budget for, and MMM will provide as many repairs as is necessary. Payments from the water committees go to a small group of volunteers called the Zone Management Team (ZMT) whose purpose is to collect fees and stock replacement parts for the Mark V pump, providing the repairman with parts on demand. (Boyd 2011) For some wells, the water committee responsible is composed of the teachers at the school, or a family whose household is the site for the well. Payment is generally collected from the surrounding families who use the well on a monthly basis in the form of a 100 kwacha fee. This monthly fee is less than $0.25, or less than the cost of a coke in Malawi. When the pumps fail, the responsible parties then contact the repairman who first inspects the well to identify the point of failure and then returns with replacement parts.

Previous research, in addition to exploring the causes of pump failures, looked at the mechanical characteristics of the water pump. Dr. John Chato led an effort to improve the design of the Mark V pump to improve its lifetime between repairs with simple mechanisms that can be retrofitted onto existing pumps. Instead of using a rubber foot valve at the bottom of the pipe, which is a consumable component, the redesigned pump has a large marble which would seat in the pipe to seal water in the pipe on the down stroke of the handle. The steel handle to PVC pipe riser connection has been redesigned with improved horizontal stability; to reduce costs, it uses pins to connect the pipes rather than a threaded connector (Chato 2002). These retrofits did not appear to be present in the Mark V pumps in Mwangalala village.

The previous works discussed above have looked at many technical aspects of water pumps and the support systems in place to facilitate maintenance. This report offers an evaluation of how the current water system works for Mwangalala village and a deep understanding of the issues faced by a small community in the far north of Malawi.

3. Methodology

How is water accessed and how is that water access maintained?
This question drives the research of this report and was instrumental in designing the interview questions and observations used to gather data. Village Headwoman Mwangalala gave me a tour of the wells within Mwangalala village. GPS coordinates and photographs were taken of each of the wells. I sought interviews through a culturally appropriate method of accepting invitations to join conversations in family compounds. Life in Mwangalala village is very communal, with most socialization occurring through visits to neighbors or friends household compounds. Conversations are held outside under trees or on porches. I interviewed participants through casual socialization in household compounds, sometimes being invited as I walked by the household on a path, or I was introduced to a family through neighbors, students, or newly made friends from previous interviews. A total of 30 interviews took place with families which represent a sample size greater than 10% of the population of Mwangalala.

Interviews were conducted at households in the vicinity of each well in order to gather user data about each of the sites. For example, if I did not have any interviews referencing Well IX then I would walk along paths that passed the well or paths that were closer to Well IX than a neighboring water source. Interviewees were initially self-selected, those who invited me to join them in conversation as I walked by the family compound on village paths. After initial self-selection the community members were invited to participate in my research. Interviews were conducted at family compounds for two reasons, cultural appropriateness, and to comply with human subject research regulations. Most community members drawing water from wells are below the age of 18, and interviews can only be conducted with minors with parental/ guardian consent in addition to minors' assent. It is not culturally appropriate to seek consent by asking parents to sign a form, which may be viewed with suspicion. Thus interviews were conducted at family compounds with parents/ guardians as well as children present to contribute to the discussion. Interview groups were randomly determined by which family members happened to be present. Some groups were only women, some were women and girls, some were only men, some were men and women, some were women and boys, and some were men and boys. My primary assignment as a teacher at Lufilya CDSS made me a respected member of the community and participants were generally enthused to participate in the research. I conducted interviews on different days of the week and at different hours to reduce the risk of biasing the sample population. A disadvantage of interviewing participants using this method was that the participants were not always the water providers. Men who did not collect water reported the number of buckets of water drawn each day; most would consult their wives or daughters on the quantity of water drawn but some did not. This may have introduced inaccurate data among the responses.

3.1. Interview question design

I iterated several interview questionnaires which I then translated into Chitumbuka. All iterations were tested with the aid of Malawian teachers at Lufilya Community Day Secondary school. Teachers also helped correct translations of the questions in Chitumbuka to ensure the correct meaning was relayed. Questions were designed to find out community members' primary water sources, the quantity of water obtained per day, uses of water that day, and how water sources were repaired when broken and what alternative water sources were used. Additionally, a Malawian perspective on water drawing was sought through a question asking the participant to draw each step they take when fetching water. A full list of the questions asked in the final interview may be found in Appendix A.

The questions require quantitative and qualitative answers to assess the user's experiences with water on a daily basis. The number of buckets fetched per day, with the bucket size (20 liters) gives a typical volume of water used in a day; combined with the number of people in the family, the volume of water used per person is calculated. Another question asks the participant how water has been used that day, to determine the purpose for the water from the primary source. Follow up questions were asked to clarify answers and to learn what users do when their primary water source is not currently producing water. These questions reflect the behavior of the participants and seek desirable well qualities. The feasibility and the viability of current water points are also discussed through data gathered from community answers.

A water point's desirability from the perspective of a community member is found through questions about why they choose to use a particular water source and why, what they use that water for, and if they have any daily concerns about drawing water. Asking the users to draw the steps they take to fetch water helps see the community's perception of water gathering. The feasibility of the current solution to water need is ascertained through questions about how many buckets are drawn daily by a family, the distance they walk to gather water, where they get water from if the primary water source is broken, and how the well is repaired. Viability of the current repair costs for water pumps are determined by asking how much families are required to contribute and how much a repair typically costs.

3.2. Interview process

Participants were initially self-selecting through invitations to join family conversations for the majority of interviews. Community members were then invited to participate in the research during the conversation. Some participants were selected through community members who I interviewed and then wished for me to interview family or friends. I walked along village paths, and would accept calls to join conversations in family courtyards. Malawians are very social, often visiting neighbors and friends to chat. I sought out participants by utilizing this cultural behavior. If a well was not yet referenced by an interview I would walk in the general area of the well to find participants likely to use the water source. Other households were interviewed with no clear primary source to determine their preference of water sources. After the traditional greetings were exchanged, and my introduction of myself and the research, community members were asked the questions in Appendix A with follow up questions if the answer needed clarification or if it opened another line of inquiry. After the interview I walked to the water source at a pace typical of carrying water to find how far the source was from the home. I made additional notes regarding any interesting comments or observations made during the interview. Interviews with women were important to find because they are the primary water providers for families. In social gatherings in Malawi men usually talk to men, and women talk to women. Interviews with participants of both sexes were generally male led with input from women only when a male participant asked for input. Interviews with only female participants helped ensure that women's perspectives were also included in the research.

3.3. Borehole and shallow well observations

I observed two wells simultaneously on three separate occasions. These wells were located 60 meters apart. Well II is a shallow well with a Mark V hand pump. Well III is a borehole with an Afridev hand pump. Two observations were made on Saturdays and one on Sunday. Observations were made for an hour long period, beginning at 5:30, 15:00, and 17:00. Wells II and III were observed due to their close proximity to one another, allowing for comparison of activities at both wells simultaneously. The wells were on Lufilya CDSS grounds, where I would not be out of place, to reduce the chance of modifying community member behavior due to my presence. Data recorded included the number of unique water users, and their sex and estimated age group. Repeat visits by the same user were noted, but not included in the overall count. Sex was recorded to identify community behavior trends and assess the validity of professed gender roles in the community, i.e. women and girls are responsible for drawing water. Estimated age groups used were children 7-12 , teens 13-18, young adults 19-24, and adults 24+. Notable behaviors were also recorded.

3.4. Data analysis

Quantitative data, such as quantity of water drawn per day, time required to walk to water source, number of people in household, and the number of wells referenced as water sources were compared to find trends and correlations. Qualitative data is compared for behavioral tendencies and water source preferences through coding and categorization. The sample size is not large enough to offer any accurate generalizations of the population in Malawi, but provides a case study on attitudes towards water sources in Mwangalala village. Responses to one interview question involved illustrating the procedure for drawing water from a water source, further revealing community perspectives. Community attitudes towards water sources are assessed through the combination of quantitative and qualitative data.

The quantity of water consumed per person per day was compared to the distance of the water source to the household and also to the number of family members living in the household. The correlations were measured using Pearson product-moment correlation coefficients to determine if either the number of people in the household or the distance to the water source affected how much water was used per person. Excel was used to calculate the correlation coefficient which was then used to find a two tailed student T distribution. The water quantity versus distance distribution was calculated from 21 data points collected in the interviews, using Equation 1 to calculate the T value. Water quantity versus household inhabitants was calculated from 25 data points collected in the interviews. The correlation coefficient was represented by r, and df was the degrees of freedom (two less the quantity of data pairs).

$$\frac{\boldsymbol{r}}{\sqrt{\frac{\boldsymbol{1 - r^2}}{\boldsymbol{df}}}}$$

Equation 1: T-value

4. Data and results

Thirty interviews were conducted among the community members of Mwangalala village, which is 12% of the sample population. In addition to interviews, a shallow well and borehole were observed, as well as immersive experience from living with the water sources for two years. Of the 30 households interviewed, 16 households referenced 1 primary well, 9 households referenced 2 primary wells, and 3 households referenced using 3 primary wells. Most households have at least two options for water points nearby but tend to prefer one over the others.

4.1. Observations of two wells

A total of 50 community members were documented drawing water from two wells, either the shallow well, well II, or the borehole, well III, on three different occasions. The purpose of these observations was to verify the responses community members gave during interviews about their behaviors. Figure 9 shows the location of the two wells, denoted by II for the shallow well and III for the borehole. Buildings located west of the wells are classrooms for Lufilya CDSS. Buildings in a row south of well IV are teachers' housing including my house, which is third from the left.

Figure 9: Shallow well and Borehole observed

Distinct water drawers are recorded by approximate age, sex, and which well is used during the observation periods. Males and females used wells nearly equally, at 48% and 52% respectively, if the type of well is not taken into account. When the water drawer population is split by the type of well used a majority of females used well II which is a shallow well, while a majority of males used well III which is a borehole as seen in Table 1. Women drawing water from shallow wells typically used the water for consumptive uses, such as cooking, washing dishes, and for drinking. Men typically used boreholes for non-consumptive uses such as watering crops or bathing. Males collected water in large metal pots to heat up bath water over a three stone fire. Some boys used the borehole to rinse their hands and feet off, rather than carrying a bucket home or to a field. Another method employed by young boys to carry water was strapping buckets to the back of a bicycle on the rear carrying rack. Water for brick making was collected by digging a shallow pit approximately 1 or 2 meters deep at the clay digging site. This method worked during rainy season or cold season when the water table was high.

Table 1: Use of wells by sex

Shallow well		Borehole	
male	25%	male	77%
female	75%	female	23%

Males using the boreholes tend to carrying buckets of water by hand rather than on top of their heads, which is the method preferred by women. I carried buckets of water both on my head and by hand. Carrying water on one's head is certainly easier than carrying by hand. My interpretation of males' tendency to carry water by hand was that they did not want to be associated with the feminine act of carrying the water on top of the head.

Women are observed carrying 20 liter buckets of water from the shallow well on their heads, and sometimes carrying an additional bucket in hand. Most women use repurposed cooking oil buckets to carry water which they rinse out with their hands prior to filling with water. Dust and dirt tend to get in buckets, which needs washing out before holding water, although rinsing by hand may introduce biological contaminants to the water.

Another common trend among water providers is age. Malawian families often rely on young family members, particularly young females, to provide water and complete a host of other daily chores. Table 2 shows 82% of the water providers observed using the wells were under the age of 18. The ages of these water users are estimated and may not be entirely accurate, but the vast majority of community members using the wells are below the age of 18.

Table 2: Use of wells by age and sex

Water drawers by Age and Sex			
	Male	Female	Total
7 to 12	22%	18%	40%
13 to 18	20%	22%	42%
19 to 24	0%	2%	2%
24+	6%	10%	16%

As Table 1 showed, the majority of people using the shallow well are female, and Table 2 shows the majority of well users are below the age of 18. Table 3 gives the distribution of who uses the shallow well by age and sex. Females 18 and younger represent 61% of the community members using the shallow well and males 18 and younger represent 21% of those using the well. Youths are charged with providing most of the water for household use, especially young females.

Table 3: Shallow well use by age and sex

Water drawers at shallow well			
	Male	Female	Total
7 to 12	7%	25%	32%
13 to 18	14%	36%	50%
19 to 24	0%	0%	0%
24+	4%	14%	18%
Total	25%	75%	

4.2. Interviews

Interviews were conducted with 30 families, including men, women, and children. Participant groups included only men, only women, men and women, and variations including children with the aforementioned groups. There were a few constants in most interview responses. Questions about what water was used for that day, payment for water, and who provided water for the family all had nearly identical answers. Water providers were said to be female, although in five of thirty interviews males were included in addition to females. Males were never exclusively water providers, and it should be noted there were no participants that lived in a solely male household. Water use was said to be exclusively domestic in nature, washing, drinking, cooking, bathing, etc. No participants mentioned watering crops, providing water for livestock, or brick making. This could also be attributed to interviews being held in family compounds, the answers may have changed had participants been working in a field when questioned.

Well repairs were done through a contract with the NGO that originally built the wells, Marion Medical Mission. The contract requires 2,500 kwacha per well which provides unlimited repairs for one year, an equivalent amount to sending a child to secondary school for one term. Community water committees are responsible for collecting fees to pay for the water repairs. Each well has a different water committee. MMM's zone management team collect the funds paid by water committees and pool all contributions to purchase spare parts. When a well breaks, the community contacts their designated repairman who inspects the well and makes any necessary repairs. In the case of Mwangalala village, a local man repairs the wells and collects the fees to pay for spare parts which he purchases in Mzuzu City. The man repairs the wells without charging for labor, as per a volunteer agreement with MMM. The NGO trained him to repair wells and Mark V hand pumps in Mzimba, Malawi in 1998.

Marion Medical Mission stated in a report that volunteer repair persons were not given gifts by communities to thank them for repairing the wells. This expectation to give the repairman a gift was not understood by Mwangalala community. During interviews, I asked those responsible for maintaining the wells what was the cost to fix a well and how did they go about getting it fixed. All parties responded that they raised the yearly sum and paid the repairman who then would repair the wells when the pump failed. No participant interviewed ever mentioned being expected to give a gift or compensation to the repairman. I assumed the fee paid to repair the wells also went towards paying the repairman from the interviews with community members. However, the repairman is unpaid and volunteers his skilled labor to ensure the 156 wells in his area are in good repair.

4.2.1. Shallow wells

Shallow wells are preferred by the community for consumptive uses, such as drinking, cooking, washing dishes. Shallow wells are preferred over boreholes because the water produced is clear and free of particulates. Shallow wells are also preferred for washing light clothing over boreholes because the water from boreholes contains dissolved iron particulates which will stain clothing over time. I asked community members where they drew water from; 53% responded that they used a shallow well and 40% responded they used an open well. No participants said they used a borehole for their primary water source, and only one participant said they used a borehole as an alternate water source. One other participant used boreholes in the event that all shallow and open wells in the area dried up, but complained the water was oily and had a bad taste.

Community members choose water sources that meet a personal minimum quality standard, and will walk further to ensure that standard is met. A participant in interview 11 reported walking to shallow well II, near Lufilya CDSS, which was over twice as far from her household as open well X. The open well, in Figure 10, is breaking apart and has turbid water from soil and debris leaking in which did not meet the participant's water quality expectations. This water is undesirable, so even if it has water all year round, it will likely be unused.

Figure 10: Deteriorating open well X

Forty percent of participants use open wells as their primary source of water, such as the open well X in Figure 10, which often has debris from the surrounding environment. Other open wells are in better condition than open well X, with an intact concrete apron and a lid that can be used to cover it at night. Participants commented that debris was undesirable, but the quality of the water was acceptable enough that the proximity of the well makes it a more desirable choice than walking to a shallow well that is further away. Participants also use Lake Malawi when shallow and open wells are dry, preferring to walk further to a surface water source than to use boreholes.

A common problem that participants reported was shallow wells drying up. Given that 97% of participants reported shallow wells as their primary water source, this is a serious issue for the community. One participant said his well (open well VII) was once covered and they paid 100 kwacha each month towards maintenance, but the cover was removed when the well was broken and they no longer pay a maintenance fee. Village Headwoman Mwangalala, during a tour of the village wells, commented that the pump on well XIV was unable to reach water which prompted the removal of the pump and cover. Water was still reachable at the bottom of the well by using buckets attached to rope. During my two years living near Mwangalala village, no well, once the cover had been removed, was repaired. It is difficult to convince people to pay for a resource they are getting for free.

Community members knew open wells were often sources of disease. Participants commented in interview 21 that the water from open well VII often made people sick. When questioned about the use of chlorination to purify water, using Water Guard which is widely available in Malawi, the participant responded that it was too expensive for villagers. “They don’t boil, they don’t chlorinate, they just trust in God.” Community members knew the dangers and consequences of using open wells without treating the water. The inconvenience of boiling water or cost of chlorinating water outweighed the risk of illness. They continued to use the water source because it was nearby and the water did not taste bad. The pump was not repaired after the shallow well was converted into an open well because an open well does not require maintenance.

Shallow and open wells dried up faster during times of water stress because more people became dependent on the remaining wells with water. The recharge rate of the water in the wells decreases as the water table drops during the dry season. Wells were unable to meet the water needs of community members due to the lower recharge rate and greater water demands placed on a well was when the water table was low. Figure 11 shows an illustration from a participant explaining the difficulties of getting water during times of water stress. The participant described the panels as follows;
Frame 1- Sister takes bucket to the well
Frame 2- There are so many women at the well waiting to draw water
Frame 3- Women are drawing water
Frame 4- Another woman is drawing water
Frame 5- Some women are still waiting to draw water
Frame 6- “The first woman has water. The second woman has some water. The last woman goes home crying”

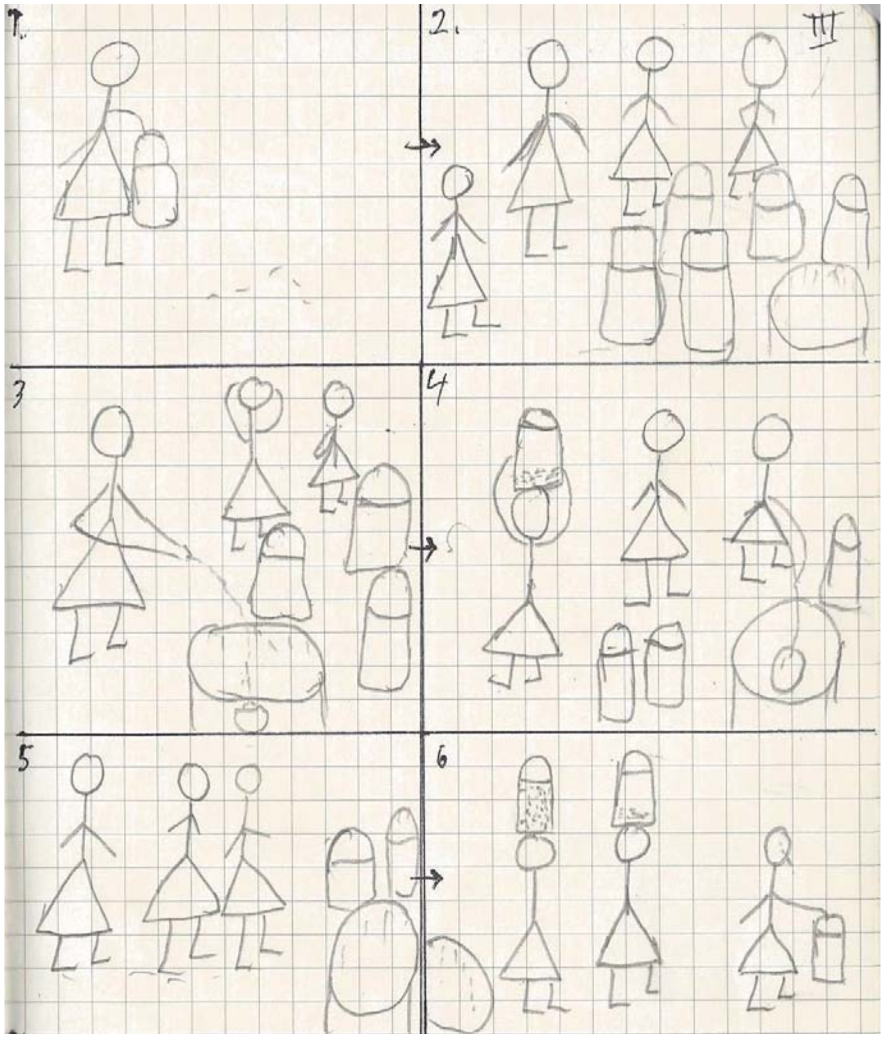


Figure 11: Women collecting water from an open well

While the last panel exaggerates how quickly the well is emptied, it serves as a good anecdote. Women who are towards the end of the queue may not be able to fill their buckets with water. Figure 12 shows the 6th panel of the drawing in Figure 11. As the participant said, "The last woman goes home crying."

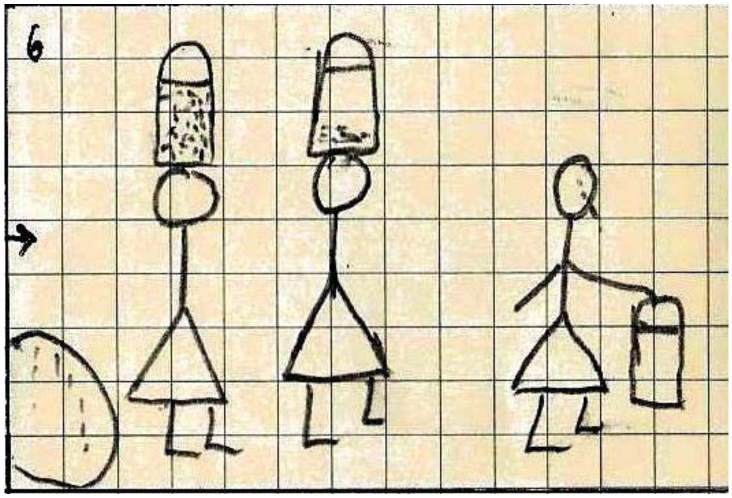


Figure 12: Panel 6 of Figure 2

Without water, family life can grind to a halt. Baths cannot be taken, breakfast is not cooked, dishes from the night before cannot be washed, and the daily mopping of the house is not possible. When the primary water source is not functional, community members must seek their secondary source.

4.2.2. Alternate water sources

Half of all participants said they sought water in the next closest shallow or open well if their primary water source was not functional or was dry. Three participants mentioned using Afridev boreholes for a secondary water source, usually as a last resort if all the shallow wells in the area were dry. Twenty percent of participants used Lake Malawi as their secondary water source. The lake also serves as the tertiary water source for many people, as well as a good spot to do laundry as the participant from interview 25 stated. The problem with secondary water sources is that they are usually much farther from a family's household than the primary water source. This vastly increases the time children and women must spend getting water for the family, as well as increasing the workload. Carrying 20 kilograms of water on one's head is not easy.

4.2.3. Water consumption in relation to distance and family size

Although carrying water is arduous, there was no correlation between the Liters of water used per Person per Day (L/P/D) and the distance to the primary water source. I measured the distance to the primary water source by timing how long it took me to walk from the participant's household to the water source at a water-carrying pace, and compared it to the quantity of water fetched each day by the participant's family divided by the number of family members in the household. I removed outliers, participants who drew 80 liters per person or more a day, and graphed the results in a scatter plot in Figure 13. I added a trend line to illustrate the best fit linear relationship between water used and distance to the water source. The coefficient of determination, R^2, is formed by a Pearson correlation.

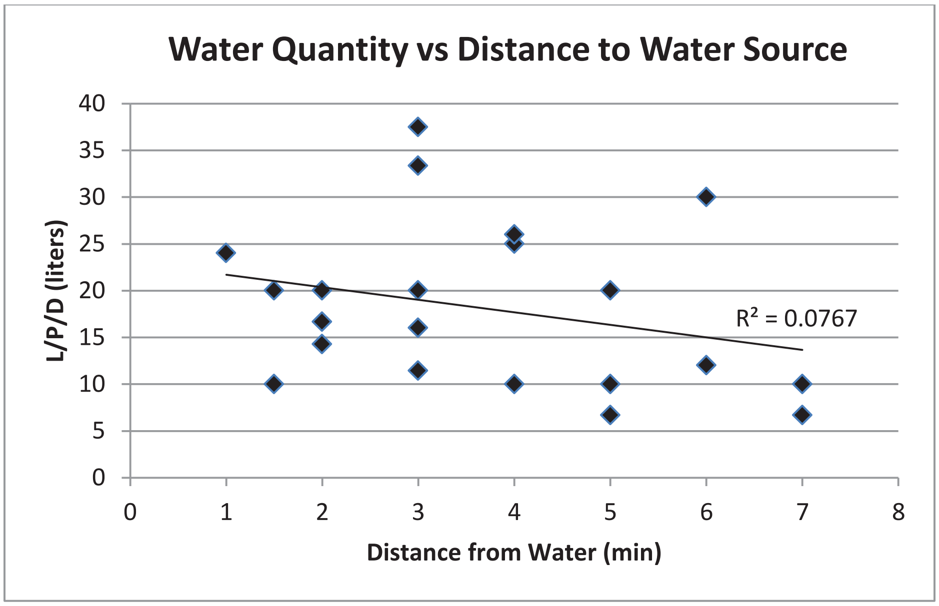


Figure 13: Graph of water quantity used versus distance from well

The distance from the water source does not determine how much water a participant uses in a day. None of the participants lived further than seven minutes from a primary water source, although behavior may differ from these results if community members live a significant distance from a water source. Within a seven minute distance, however, the probability value was 0.22 which indicates a lack of correlation between the quantity of water used per person in a day and the distance from the household to the water source. A statistically significant correlation will return a result of 0.05 or less.

I also compared the L/P/D against the number of family members staying in the household. Figure 14 shows a graph of the water quantity used on a daily basis as the independent variable against the family members in a household as the dependent variable. There is no correlation between how much water per person a family uses and how many people are using the water. The probability value for the variables was 0.22 which is far bigger than the minimum probability value for statistical correlation significance of 0.05. Larger families do not use less water per person than smaller families.

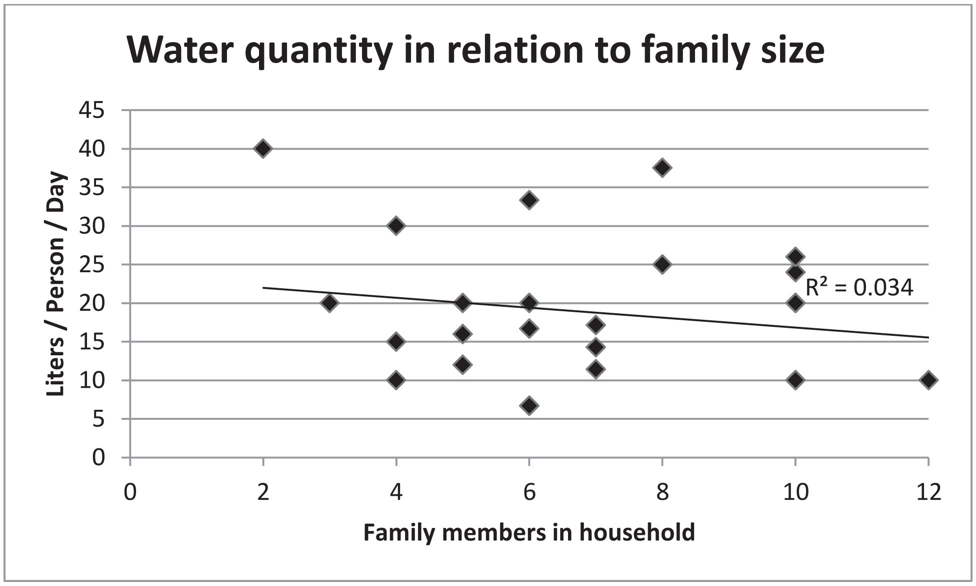


Figure 14: Water quantity in relation to family size

4.2.4. Shallow wells run dry

Limited water becomes an issue between hot season and rainy cold season. The three seasons in Malawi are hot season, rainy season, and cold season which correspond approximately to the months of September – December, January – April, and May – August, respectively. Community members identified months from September through December as months when finding water in shallow wells can be difficult.

The water table is likely to be at its lowest level at the start of rainy season, January, but consistent rainfall lets community members collect water runoff from their roofs. I did not observe any houses with rainwater collection systems, but did observe people placing buckets under the edge of the roof. A 20 liter bucket can be filled with the rainfall from a single night when placed under a roof without any gutter system. During my first year living in the village, shallow well II broke and was not repaired for two months. I was able to collect enough water from rainfall coming off the roof for all my consumptive uses during those two months, as shown in Figure 15. Bathing and clothes washing water was still collected using a borehole.

Figure 15: Collecting rainwater

So even if shallow wells are still dry during the start of rainy season, finding water is not as much of an issue for the participants if they are collecting rainwater. No participant listed this as a secondary water source, likely because it is not an option year-round. However, rainwater collection was a common practice from my observation among my village and the surrounding communities.

4.2.5. Long repair times

Shallow well repair times could take as long as two months. I observed this twice at Lufilya Community Day Secondary School. Repair funds and water committee inactivity was not an issue in this case. The yearly funds were paid out of the school's budget and the headmaster was very proactive in contacting the repairman. The teachers lived on school grounds with their families; they depended on the functionality of the school's wells. The surrounding community also depended on the school's wells. The repairman would not show up to diagnose the mechanical issue of the well for several days after being contacted, and would take several weeks to return with parts to repair the well.

I interviewed the local repairman about any issues in repairing wells in a timely manner. He reported no issues with obtaining spare parts, which were plentiful in

Mzuzu. This was also corroborated by Duncan McNichol's report on spare parts availability in Karonga District. The repairman reported no obstructions preventing him from repairing wells, and said wells were repaired in a timely fashion. When pressed about any problems encountered in trying to repair wells, he said "We are people. Sometimes we have problems." Upon finding that the repairman is not paid for his work in repairing wells, the situation became apparent; the repair work does not provide any income. In addition to being a volunteer, he is responsible for maintaining 156 wells in the area. So while he seeks to earn a living, the repair of wells in Mwangalala and surrounding villages is an additional responsibility with lower priority than everyday work.

When asked about the shallow wells in Mwangalala that used to have Mark V hand pumps and have become open wells, he reported that the maintenance fees for those wells were not paid. Since fees were not collected or available to provide repairs, the concrete lids and pumps were removed by the community to access the water in the well. Once accessed in this manner, fees are not collected again and the system is never repaired and replaced.

5. Discussion

IDEO's Human Centered Design Process provides a framework to evaluate how well a system works for the people it serves. Human Centered Design, HCD, has three phases, Hear, Create and Deliver (IDEO n.d.). I designed this case study using principles found in the first phase in Human Centered Design, Hear. The hearing phase focuses on the community's story; their experiences, tribulations, and triumphs in water access and consumption. This case study recommends further study to continue the process into the Create and Deliver phases in chapter 6.

Desirability, feasibility, and viability are the three lenses through which Human Centered Design views a system in relation to a community. These factors affect the sustainability of the water system in place, and what improvements could be made to increase water security. Desirability represents the qualities of water points that community members find pleasing. These traits include perceived water quality, distance from the water source to the household, ease of operation for the hand pump, and reliability. Feasibility covers the technical aspects of the wells and maintenance system. This includes the availability of repair parts, trained repair persons, and how well these systems function within the social context. Viability looks at the financial sustainability of the system, and how much value is delivered by different well types. Mwangalala's water system will be sustainable if it is desirable, functional, and viable within the community.

5.1. Desirability

Desirability is an essential quality for any system; the users must appreciate its qualities for its continued use. Primary water sources are a choice, balancing several criteria. These criteria include perceived water quality, water source reliability, and proximity. The strength of these qualities affects how fervently community members maintain the water source. For example, I appreciated that borehole IV was located close by my house and provided water throughout the year. I did not like the dissolved iron or odor of the water, so its use was limited to bathing water, and washing clothes. Shallow well II was appreciated for the quality of water it produced and fairly close proximity to my house. It was used for all my cooking, dishes, and drinking needs. However, the reliability of well II was not very good; it was frequently dry or had a broken pump.

5.1.1. Perceived water quality

Paramount in a well's desirability was the quality of water it produced. Many participants mentioned walking past a well with undesirable water, a deteriorating open well or a borehole with iron particulated water, to reach water they considered to be better. Interview participants preferred shallow wells for the quality of the water they produced. Community members who said open wells were their primary water source commented that covered wells were preferred due to the contamination from debris and other environmental contaminants present in open wells. Community members noticed that people were sick more often when they used water from certain open wells and knew they could sanitize the water through chlorination or boiling. They did not use these methods of producing clean water. They preferred the risk of illness to the cost of Water Guard or hassle of boiling water.

Community members preferred open wells with risk of illness over boreholes with unpalatable water. Excess iron content is not harmful to health when consumed, but the water becomes discolored when boiled and is unpalatable. The wells provide water year-round due to their depth, but is not consumed unless absolutely necessary. Boreholes are used for non-consumptive uses like watering crops or bathing. It should be noted that boreholes with Afridev hand pumps produce very good quality water in other parts of Karonga district. The villages surrounding Thunduti CDSS, near Chilumba in southern Karonga district, depend on a couple of boreholes on the school campus which provide water year-round. The water from boreholes outside Mwangalala village does not necessarily have excessive levels of dissolved iron particulates in the groundwater. Afridev boreholes have desirable qualities in ease of operation and reliability.

5.1.2. Ease of operation

Wells have varying levels of effort required to retrieve water. Table 4 summarizes the attributes of each well; the type of pump it has, how much effort it requires to draw water, and the perceived water quality.

Table 4: Well attributes

Well Type	Shallow	Open	Borehole
Pump Type	Mark V	N/A	Afridev
Effort Required	Average	Difficult	Easy
Water Quality	Best	Average	Worst

The pump requiring the least amount of effort is the Afridev hand pump. It has a mechanical advantage through the use of a lever, which allows greater columns of water to be lifted with less effort on the part of the user. The pumps are sturdy and operate smoothly. Mark V hand pumps require more effort than the Afridev pump because the Mark V is a direct action pump. It has no mechanical advantage; the user is lifting the column of water directly. Youths are responsible for most of the water provisioning of households. It can be difficult for children to pump 20 liters of water per bucket in addition to carrying the bucket home multiple times when using Mark V pumps. The Afridev pump is easier to operate, but is not used for consumptive use. Water is drawn from open wells using a 5 liter pail tied to a rope. It is not difficult to operate, but it is more time consuming to fill a 20 liter bucket using this method in comparison to a hand pump.

5.1.3. Water source reliability

Three types of wells in Mwangalala village have different strengths and weaknesses, none are currently capable of providing access to improved water throughout the year. Shallow wells provide the perceived best water quality in the Mwangalala village, but there are issues with wells running dry between September and December with long repair times for the Mark V hand pumps. Boreholes provide water year round, though it is unpalatable. The lake is used as an alternative water source when shallow wells break or run dry, and is preferable to water from Afridev wells. Mark V hand pumps were installed in 9 of the 15 wells observed in this report; 4 of those 9 wells had the pump and concrete lid removed to be used as open wells.

Many open wells in Mwangalala were formed from shallow wells whose pumps broke and were not repaired. Lack of funds was cited for several wells as the reason why the hand pumps were not repaired. Wells whose pumps broke and were never repaired were located in fields, except one which was located next to a church. These locations lack a single person that is clearly responsible for maintenance. Wells that had functional hand pumps were located on school grounds or in a family compound. A person was clearly responsible and had a vested interest in the continued maintenance of the pump in these locations. Once a well had the concrete lid and pump removed, the water was available to access with a bucket and rope and reduced the incentive to pay for a repair for a commodity currently free.

The primary cause of Mark V pump non-functionality in the study area can be attributed to lack of incentives for the repairman. The time between a breakdown and return to functionality of a Mark V pump was often greater than a month, which does not constitute sustainable access according to the WHO. The flat fee which water point committees pay to the ZMT optimally is spent entirely on spare parts. The zone management teams are entirely staffed and run by local Malawian volunteers, including the repairmen. “Lack of repair person motivation may be a bigger problem. Mendenhall found that many repair persons believed they should be compensated for their work. Our 2007 survey found that community failure to thank the volunteer repair person with a gift was widespread.” (Boyd 2011) It is not unreasonable to wish to be compensated for skilled labor and repair work, and compensation would help motivate repair persons to place community well repairs high on their priority list.

A study conducted by Duncan McNicholl found that the community’s perceived ownership of a pump affected the duration of pump failures, “Community organization can be viewed as the degree of ownership that a community feels over its pump. Breakdown durations may rise where this level of ownership is reduced” (McNicholl 2011). Community ownership can be compared to the phenomenon of the diffusion of social responsibility. Diffusion of social responsibility postulates that in a group of three or more people feel less obligated to act towards a group goal and shift that responsibility to the group as a whole. Water point maintenance suffers if the responsibility is ambiguous and specific tasks are not clearly the duty of one person. Sustainable community ownership must mean not only are the community members cognizant that the well is their responsibility, but individuals are publically tasked with specific duties and held responsible.

The time between breakage and repair on a shallow well could sometimes be more than a month. Non-functional wells were often located where responsibility for the maintenance was not blatantly obvious; whereas functional wells were located such that they had a visibly responsible party: on school grounds or in a house compound. Many community members are likely under the impression that part of the yearly fee they pay goes towards payment for the repairman and do not expect to provide additional contributions when the repair contract is fulfilled. This leads to frustration on both the part of the repair person and the community; the repairman receives no compensation for his work and has no incentive to make a greater effort to respond quickly to the community’s requests. The community is frustrated by lack of responsiveness by a repair man who they see as shirking his job which they assume he is being paid to do.

Lengthy repair times are a result of miscommunications between the repairman and the community. The people of Mwangalala, and Malawi in general, communicate indirectly. Direct confrontation is avoided. Community members do not voice frustration about the repairman's lethargic response to him. The repairman does not inform the community that he is working without compensation, and must fit repair requests in his spare time while trying to earn a living elsewhere. The repair-request and payment procedures must change to provide compensation and incentives for the repairman to complete the repairs in less than two weeks. Alterations to the payment system must remain affordable for Mwangalala, and should provide money for both spare parts and compensation for the repairman.

Boreholes were functional in Mwangalala; however the water quality produced in Mwangalala village was undesirable for human consumption. Water Aid also found that Afridev wells were very reliable in their study, but had no mention of water quality issues. Interviewees reported walking 20 minutes to draw water from Lake Malawi if their primarily used shallow well had a non-functional pump, or was dry, rather than using an adjacent Afridev pump within a 7 minute walk. Afridev pumps were sometimes used for human consumption if all other water sources were dry, as they have an average depth of 40 meters as opposed to the 10 meter depth of shallow wells.

Shallow wells whose pumps ceased to function were either repaired by the local repairman if the yearly fee (equal to the cost of sending a child to secondary school for one semester) had been paid or the top cover and pump were removed to create an open well. Shallow wells and open wells also had the disadvantage of going dry around the month of December when hot season is nearly over with the last rains having been in the month of April or May.

5.2. Feasibility

A feasible water system works well within the context of the community it serves. This includes typical distances from households to wells, the functionality of the wells, and reparability of the well hand pumps. Distance between home and water should not limit people's water use, allowing the community to use as much water as they need. Well functionality includes the time between pump failure and repair as well as sufficient well depth to access water when the water table drops. Reparability of water pumps depends on availability of spare parts and trained repairmen to diagnose and fix the pumps. Mwangalala's water system must perform well in all these factors to be feasible.

5.2.1. Water point density

Water point distance from households did not limit community members' daily consumptive water usage. I compared the reported daily water consumption per person and compared with the distance community members walked to a primary water source, expecting that people furthest away from water sources used less water than people closest to a water source. The expected behavior was not present in Mwangalala. A Pearson correlation resulted in a probability value of 0.22 which indicates a lack of linear correlation between the two variables. A probability value less than 0.05 is necessary to show a linear correlation. Figure 13 shows the reported daily water consumption per person and the distance the participant walked to get water. The trend line represents the Pearson correlation. No community members appeared to limit the amount of water they used based on the distance from the water source they used. Participants lived within a maximum of 7 minutes from their reported primary water source. This observation only applies to the primary water sources, as secondary water sources are further away than participants walk to their primary water source. Only two participants commented that the water sources were too far away and followed this by wishing they had a well within their family compound.

Family members living within a household does not correlate with the daily water consumption per person. I expected households with a large number of inhabitants to use less water per person than a smaller household. A Pearson correlation resulted in a probability value of 0.22 which indicates a lack of correlation between household size and daily water consumption per person. Figure 14 shows the graph relating the two variables and a trend line illustrating the Pearson correlation. Neither distance nor household size was correlated with daily water consumption per person.

5.2.2. Well Functionality

Fifty-six percent of the shallow wells installed in Mwangalala village by Marion Medical Mission have functional pumps over a decade later. Mark V hand pumps were removed from the other 44% of shallow wells and turned into open wells. Marion Medical Mission claims up to 90% functionality rates with some Zone Management Teams, which does not include any wells they consider unsatisfactory. A well that has collapsed, cannot be repaired, has run dry, flooded, has bad water, or that the community no longer uses will count as being unsatisfactory (and will not be counted in their functionality rates). The NGO stopped including those four wells in their functionality count because the community no longer paid for repairs. The wells are classified as "abandoned" by Marion Medical Mission although the community continues to identify the wells as their primary water source.

The number of community members using a single water point is another factor in feasibility. According to the director of the Karonga District Water Board water points need to be sufficient in quantity that not more than 120 people are supported by a shallow well or 250 people for a borehole. When participants were asked how many families drew water from individual water points, they did not quantify beyond many people from all around the surrounding area. Most people complained that too many people used the water sources. They cited this as a reason why the wells would go dry. The village headwoman reported 250 families living in the village, and the average participant household size was 7 people. Ten wells, five open and five shallow, were identified as primary water sources by participants. Each well supports 175 people for consumptive water use on average. This is greater than the 120 people per well recommended by the director of the Karonga Water Board and confirms community member complaints of too many people using a single water source. This overuse of water points is exacerbated when some wells become dry during hot season, as water points are used by more people. The recharge rate of the wells cannot compensate for the increased usage when the water table is low.

Hand pump repair delays in Mwangalala are not caused by a lack of mechanical parts or unqualified repair persons. As noted in 4.2.5., the repairman responsible for the Mark V pumps in the village stated that parts were readily available. Repairs require simple tools: two spanners, a hacksaw, solvent, and PVC pipe cement. No special items are required which might hold up a repair. The repairman was also trained to work on Mark V hand pumps by Marion Medical Mission, the NGO that installed the hand pumps in the community. He is responsible for the maintenance of 156 wells in the area, which may contribute to delays in repairing wells if many break in a short amount of time. Mark V hand pumps are repaired slowly because a repairman is responsible for many wells and has no incentive to repair them quickly. The design of the Mark V hand pumps is feasible for Mwangalala village, but the repair system needs to be modified to provide more trained repairmen and incentives to perform repairs in less than two weeks.

5.3. Viability

The costs and characteristics of a well have several tradeoffs which affect the desirability and feasibility of a well. Initial costs are primarily covered by donors, NGOs, or government agencies. Table 5: Well costsTable 5 lists the initial costs for the three well types present in Mwangalala. The community is expected to contribute labor and raw materials such as sand and bricks. Although the initial cost appears the same to the community no matter the type of well, initial cost does impact the quantity of wells that may be installed in the community. An NGO could install 18 shallow wells for the cost of one borehole. However, boreholes require less maintenance than shallow wells and are able to provide water after shallow wells have run dry which provides additional value beyond initial cost.

Table 5: Well costs

Well Type	Shallow	Open	Borehole
Initial Cost	$400	$30	$7,500
Maintenance/ year	$6	$0	Unknown
Pump Failures / year	4 to 6	Not applicable	None observed

Shallow wells require the most maintenance in Mwangalala. The group village head woman stated that Mark V pumps failed 4 to 6 times a year. There are 5 Mark V pumps currently installed in Mwangalala. Each well has a person or a group of people responsible for collecting funds to pay for the repair of the hand pump. For some wells, the group of people responsible is the teachers at the school, or a family whose household is the site for the well. Payment is generally collected from the surrounding families who use the well on a monthly basis in the form of a 100 kwacha fee. This monthly fee is less than $0.25, or less than the cost of a coke in Malawi. The responsible parties for each well then pay the Marion Medical Mission repairman or zone management team one payment of 2500 kwacha per year, the equivalent to sending a single child to a secondary school for a semester, which covers the cost of all repairs for the well that year. Two thousand-five hundred kwacha is approximately $6, as of 2014. The community depends on MMM to pool the money for all the wells, purchase spare parts, and a volunteer repairman to fix their water source.

Open wells do not require any maintenance, and boreholes were not observed to need maintenance during my two years in Mwangalala. Open wells do not have a pump, which means there cannot be a mechanical breakdown. This is advantageous for community members as they do not have to pay a monthly fee to access water and never have to wait for a pump to be repaired. They sacrifice quality of water, as uncovered open wells become contaminated with debris. Boreholes in Mwangalala village did not breakdown during my two years of observation, and provided water year round for non-consumptive use. I was unable to collect information on cost of repairs for boreholes because none needed maintenance.

5.4. Improving water security

I drew water from borehole III during times when shallow well II broke down or ran dry. In order to use the water for consumptive use I filtered it through a ceramic water filter. The filter is designed to remove protozoa and most bacteria through the use of three ceramic candles with very small pores. These pores filtered out the iron particulates as well. Ceramic candles have a slow filter rate, which was improved by the use of multiple candles in the filter. I would suggest a filtration rate of 5 liters per hour for a family. This method worked well for me because I did not need large quantities of filtered water at a single time, but used a liter or two at different times throughout the day. Filtration rate would be a major barrier in acceptance of this technology for most families. If a family were to adopt this method to improve water security during dry season, water would have to be filtered before every morning for cooking and drinking purposes as well as in the evening for washing dishes. The water would not need to be filtered for bathing water or washing clothes.

Cost of ceramic filters may be a barrier. A single ceramic candle costs approximately $20, and a single candle would not provide a fast enough filtration rate for practical use for a family. Ceramic filters will continue to be effective until broken with cleaning as needed to remove particulate buildup on the outer surface which slows filtration rate. Another barrier may be the perception of the water from boreholes. The water is seen as unpalatable currently, but stigma against the water may remain even if a filtration method is employed to remove iron particulates.

5.5. Millennium development goals and Mwangalala

Mwangalala village is very close to meeting the water security goals set by the United Nations. The outstanding issues preventing full achievement of the goals are unprotected dug wells and long repair times for shallow wells. The unprotected dug wells are considered unprotected or unimproved if they do not have a raised casing and a cover. All open wells in Mwangalala only lack the covering for the well to be considered improved water sources. The primary factor causing the long shallow well repair times is the lack of incentives for repair persons to respond in a timely manner. Figure 16 summarizes the relationship between the three well types present in Mwangalala and the factors affecting their desirability, feasibility, and viability.

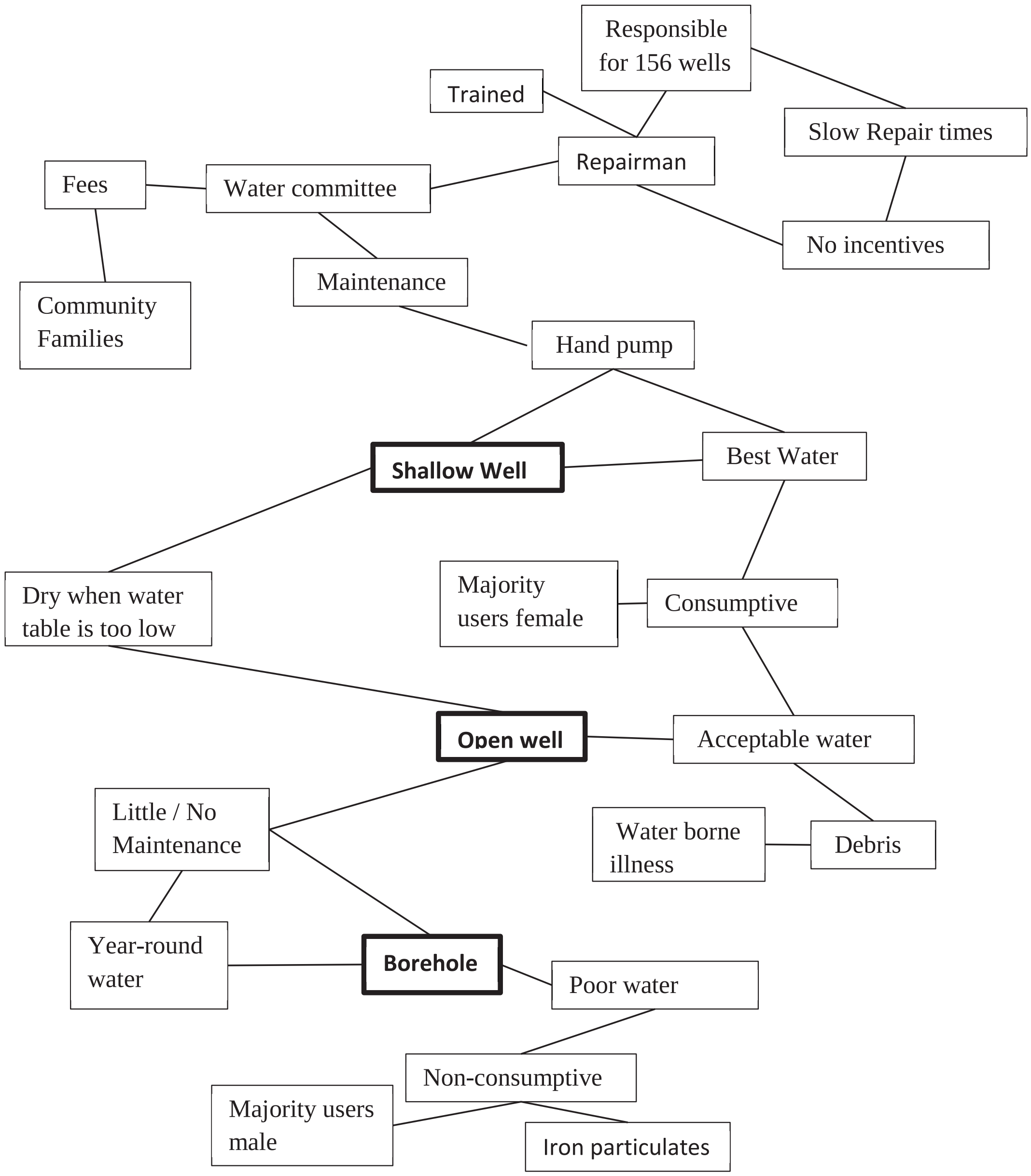


Figure 16: Well relationship map

6. Conclusion and further study

Shallow wells in Mwangalala community are the preferred water source because they produce perceived good quality water. The majority of water is provided for household consumptive use by females under the age of 18. Some male youths help provide water for the household, but this is not as regular an occurrence as female youths drawing water. Males use water sources as much as females, but they use it for non-consumptive uses such as watering crops, bathing water, or cleaning farming implements. Water scarcity occurs with shallow wells during dry season and the beginning of rainy season. Community members turn to secondary or tertiary water sources as wells dry, such as Lake Malawi or boreholes. Shallow wells are affordably repaired through the aid of Marion Medical Mission, but the time between breakdown and repair is unsustainable. The primary reason for the length of repair time is a lack of incentive for repair persons. They provide skilled labor without compensation. Functional wells tend to be located on school grounds or in family compounds, places where the responsibility for the well's functionality is clear. Other locations, such as fields or communal gathering locations allow responsibility to be dispersed among community members which increases the risk of inaction.

Shallow wells provide the best perceived water quality in Mwangalala community, but cannot produce water throughout the year. Boreholes produce water disliked because of the high iron content, but can produce water throughout the year. The easiest way to increase water security for Mwangalala community is to render the water from boreholes palatable.

The current water point system does not meet the Millennium Development Goals target 10 for sustainable water access. Half of the community members interviewed identified an unimproved open well as their primary water source, and the other half lack access to their improved water sources for extended periods of times when the pump fails. Boreholes would be able to provide sustainable access to an improved water source, except that the water they produce is unpalatable. If the water from boreholes in Mwangalala community could be rendered palatable through the removal of excess iron particulates, there would be at least three points of sustainable water access throughout the year.

Further study on the acceptance and sustainability of using ceramic filters for point of use treatment of borehole water should be investigated. A major factor in acceptance would be the filter rate of the ceramic candles. An acceptable rate would probably be 5 liters per hour. Multiple ceramic candles are needed to achieve this flow rate.

I would suggest that Marion Medical Mission revise its well repair system. The payment schedule is ideal for the communities, guaranteeing pump repairs for an affordable and predictable yearly fee, however it provides no incentive for a repairman to make a timely repair. He or she must perform repair work in his or her spare time, while still finding enough work to make a living elsewhere.

7. Appendix A

7.1. Interview questions for water users

1. How many buckets do you fetch per day?
   Muketeka ndowo zilinga za maji pa dazi?

2. Where do you draw water from? Why?
   Mukuteka maji kochi? Ndipo chifukwa uli?

3. What have you used water for today?
   Kasi maji mukugwiriska ntchito muhanyo uli?

4. Where would you draw water if the well broke?
   Mukuteka maji nkhu para mpopi ukupyoka?

5. What are your daily concerns regarding drawing water?
   Kasi muli na suzgo pa dazi na kuteka maji?

6. Why?
   Chifukwa uli?

7. Please draw each of the steps you take when fetching getting water.
   Jumbulani umo mkwendera kukateka maji.

8. Do you pay for water? How much?
   Mukulipira maji? Ndalama zilinga?

9. Do you pay for water every month, or only when a well breaks?
   Kasi mukulipira maji pa mwezi wuli wose, panji pa kunozga chiziwa cha kunangika?

10. How many are in your family?
    Mu banja linu, muli balinga?

11. Who draws water in your family?
    Mu banba binu, abo bakuteka maji mbanjani?

8. Appendix B

8.1. Water quantity data

Interview	Number of Habitants	QTY of buckets/day	Time to Well (min)	L/P/D with 20 L buckets	time (min) carrying water
1	10	13	4	26	104.0
2					
3	2	4	-	40	
4	5	5	3	20	30.0
5	6	6	-	20	
6	4	3	-	15	
7	6	10	3	33	60.0
8	10	10	5	20	100.0
9	10	so many	0	so many	n/a
10	5	3	6	12	36.0
11	6	2	7	7	28.0
12	4	2	1.5	10	6.0
13	3	3	1.5	20	9.0
14	8	so many	4	so many	n/a
15	7	5	2	14	20.0
16	3	so many	2	so many	n/a
17	10	12	1	24	24.0
18	8	10	4	25	80.0
19	6	2	5	7	20.0
20	7	6	-	17	n/a
21	7	4	3	11	24.0
22	12	6	7	10	84.0
23	10	5	5	10	50.0
24	4	6	6	30	72.0
25	10	10	2	20	40.0
26	6	5	2	17	20.0
27	10	5	4	10	40.0
28	8	15	3	38	90.0
29	5	4	3	16	24.0
30	7	30	0	86	n/a

Note: Interview 2 was conducted with the group village headwoman, which became a discussion about the Mwangalala water system as a whole and a tour of the wells rather than an interview about her household's water usage.

8.2. Wells and interview references

Well	Type	Latitude	Longitude	Interviews referenced									
I	Mark V	-9.799783	33.891823	3	8	12	13	15	16				
II	Mark V	-9.810367	33.885328	1	4	7	11	18	19	21	22	23	24
III	Afridev	-9.810485	33.884781	1	4								
IV	Afridev	-9.811344	33.885216	1	4	7							
V	Afridev	-9.798925	33.895885	26									
VI	Open well	-9.801430	33.893439	8	14	25	26						
VII	Open well	-9.812512	33.881632	5	6	21	22	23	24				
VIII	Afridev	-9.806752	33.881455										
IX	Mark V	-9.805368	33.882726	11									
X	Open well	-9.808538	33.884990	11									
XI	Open well	-9.812309	33.885307	7	19								
XII	Open well	-9.805115	33.889470	17									
XIII	Mark V	-9.803436	33.893852	9	27	28	29						
XIV	Open well	-9.805330	33.894598	2	9	10	18						
XV	Mark V	-9.802594	33.891744	30									

8.3. Number of wells referenced by households in interviews

Number of wells	Frequency
1	16
2	9
3	4

8.4. Well observations

		Ages	7 to 12	13 to 18	19 to 24	24+
15:00-16:00	Well II	Male		1		1
	Well III	Male	3	2		1
17:00-18:00	Well II	Male	2	3		
	Well III	Male	6	4		
5:30-6:30	Well II	Male				
	Well III	Male				1
15:00-16:00	Well II	Female	2	1		1
	Well III	Female	2			
17:00-18:00	Well II	Female	5	7		1
	Well III	Female		1	1	
5:30-6:30	Well II	Female		2		2
	Well III	Female				1

8.5. Water drawing procedure illustrations

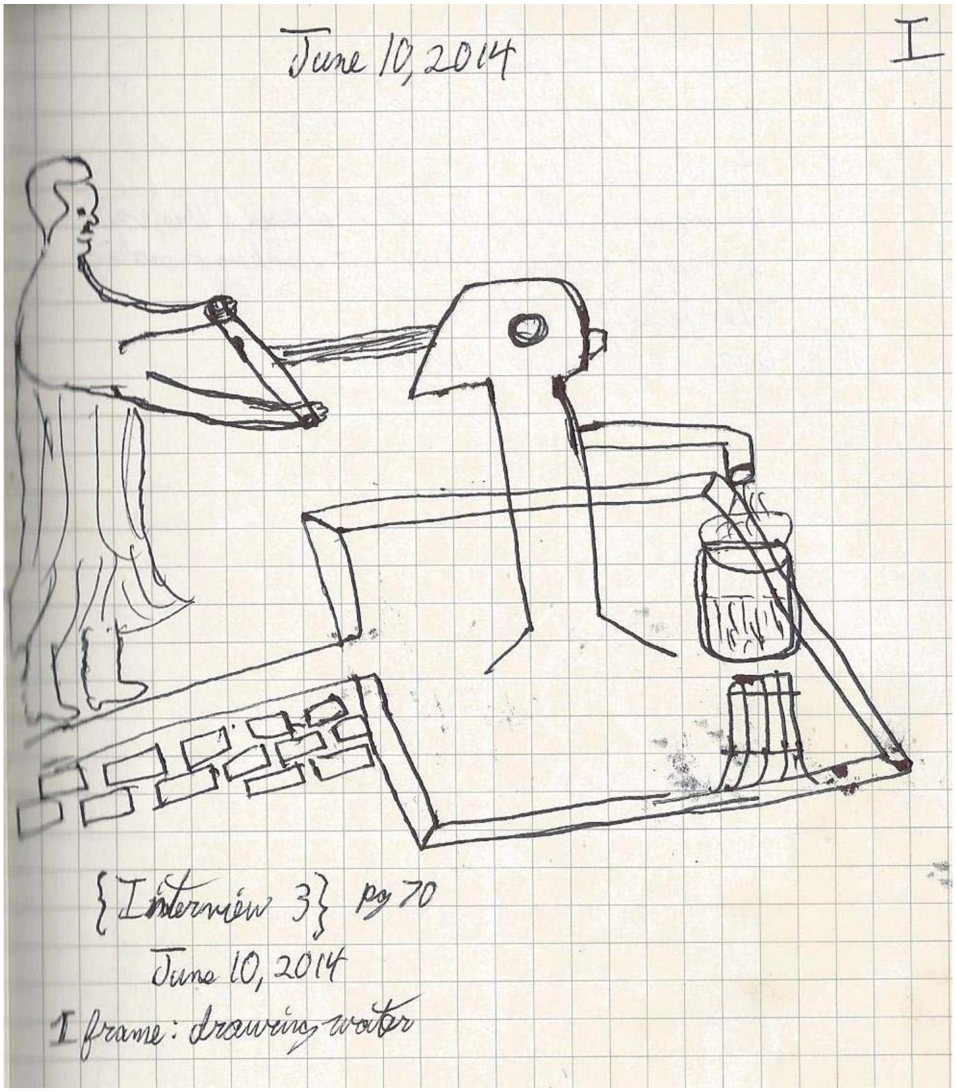
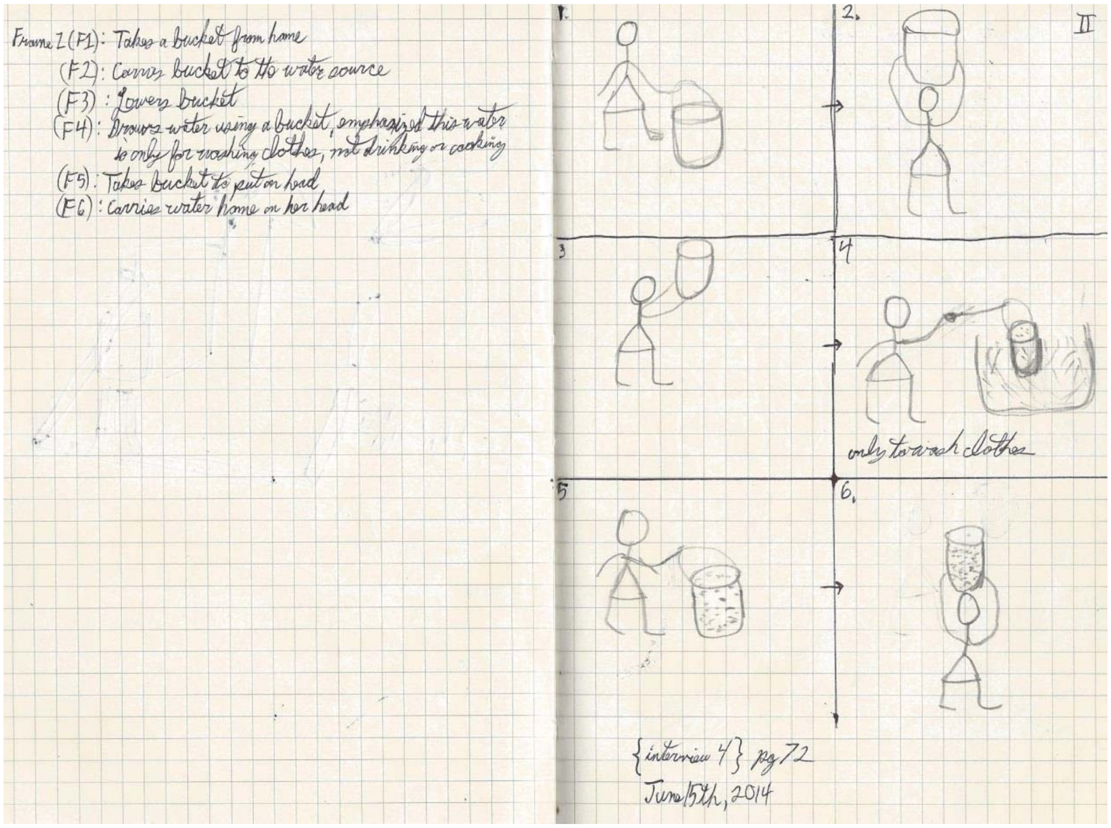
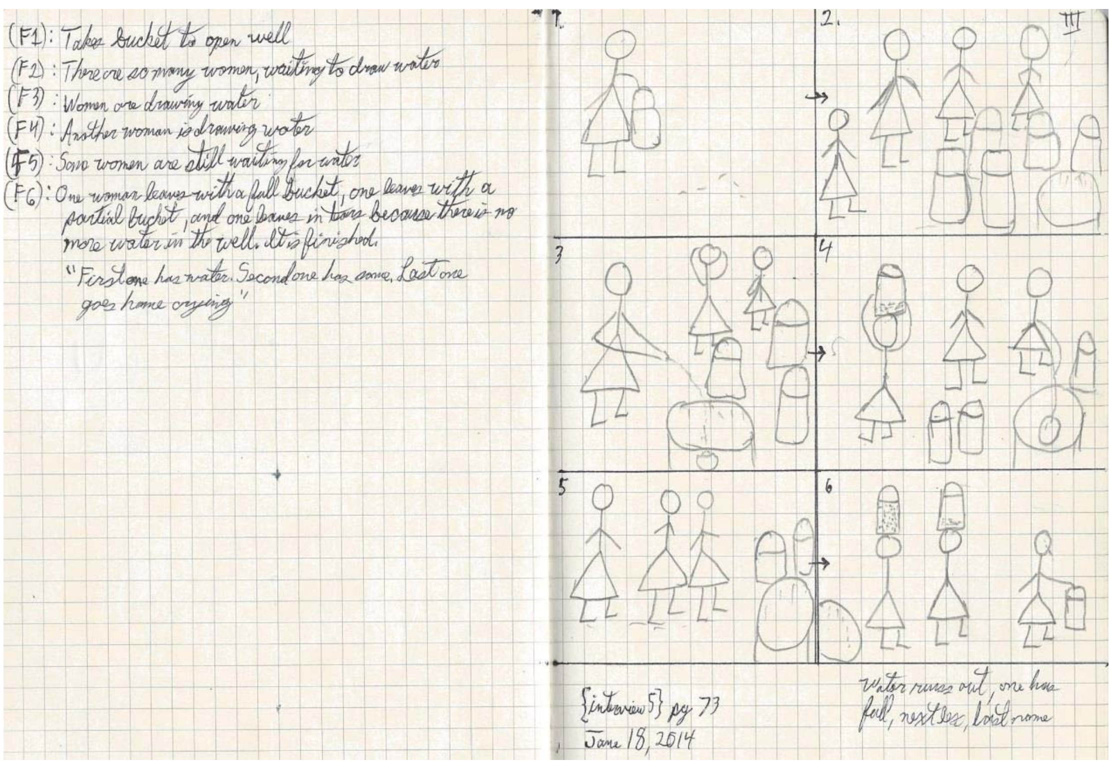


Fig. 1



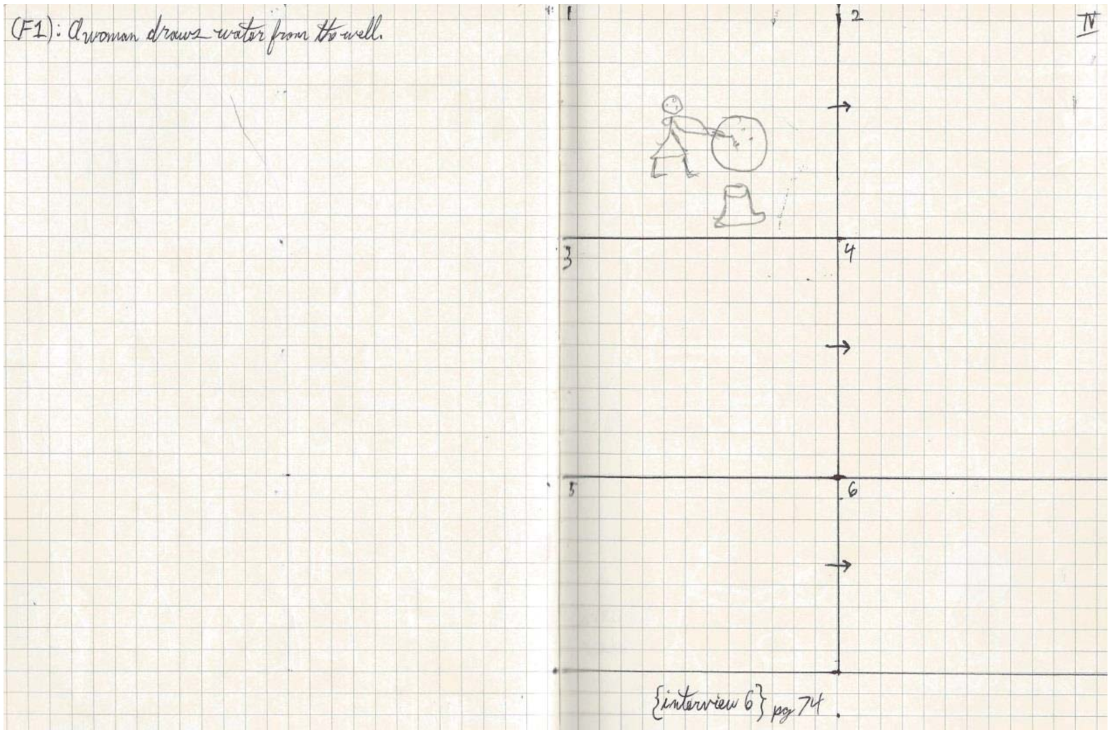
Frame I (F1): Takes a bucket from home
(F2): Carries bucket to the water source
(F3): Lowers bucket
(F4): Draws water using a bucket, emphasized this water is only for washing clothes, not drinking or cooking
(F5): Takes bucket to put on head
(F6): Carries water home on her head
1.
2.
II
3
4
only to wash clothes
5
6.
{interview 4} pg 72
June 15th, 2014

Fig. 2



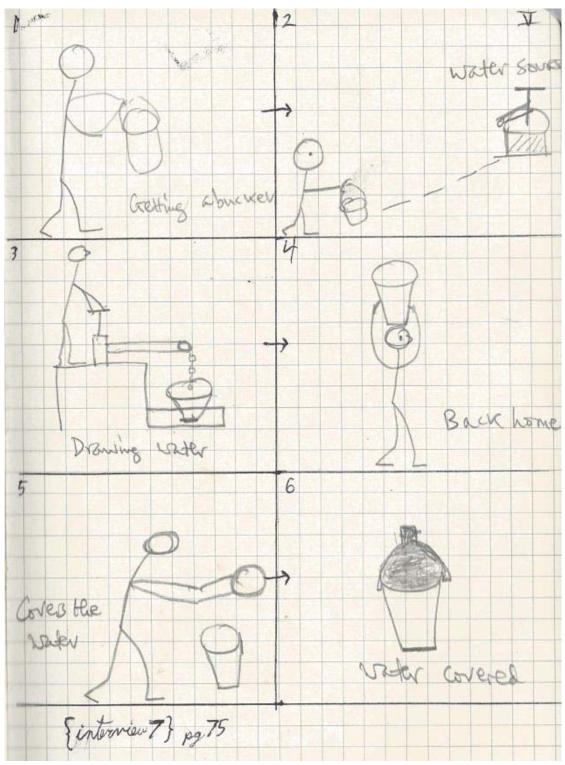
(F1): Takes bucket to open well
(F2): There are so many women, waiting to draw water
(F3): Women are drawing water
(F4): Another woman is drawing water
(F5): Some women are still waiting for water
(F6): One woman leaves with a full bucket, one leaves with a partial bucket, and one leaves in tears because there is no more water in the well. It is finished.
"First one has water. Second one has some. Last one goes home crying"
1.
2.
III
3
4
5
6
{interview 5} pg 73
June 18, 2014
Water runs out, one has full, next less, last none

Fig. 3



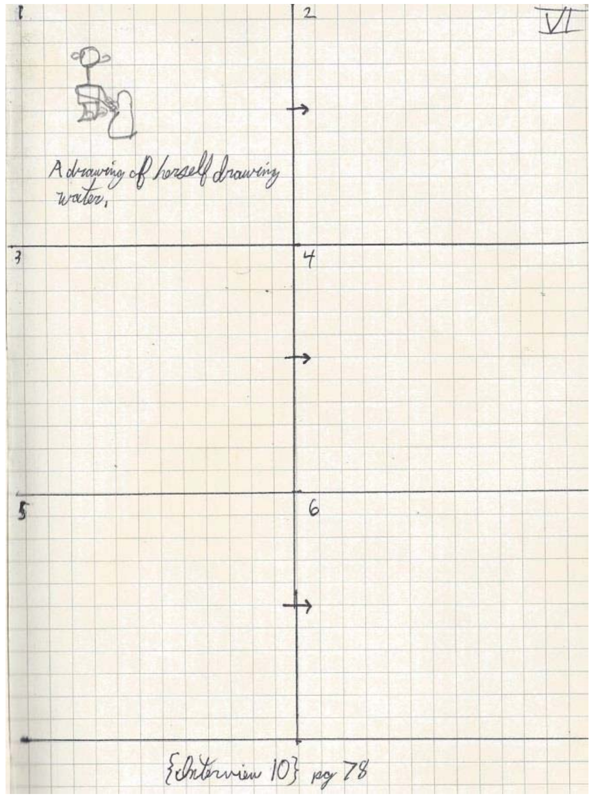
(F1): A woman draws water from the well.
1
2
IV
3
4
5
6
{interview 6} pg 74

Fig. 4



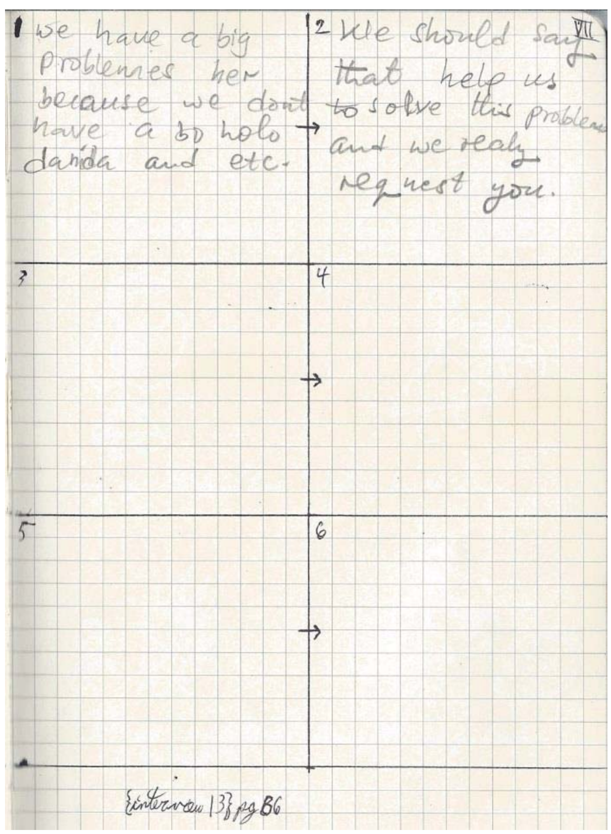
2
V
Getting a bucket
Water sourc
3
4
Drawing water
Back home
5
6
Covers the water
Water covered
{interview 7} pg 75

Fig. 5



VI
A drawing of herself drawing water.
{Interview 10} pg 78

Fig. 6



VII
we have a big problemes her because we dont have a bo holo danda and etc.
We should say that help us to solve this problem and we realy request you.
{interview 13} pg 86

Fig. 7


1
2,
VIII
drawing water from open well using a pail on a string
Walking w/ bucket to chizima
3.
4.
Carrying water back home
Putting bucket down
5
6.
cooking w/ water and 3-stone fire
drawing water again for drinking
{interview 18, pg 92}

Fig. 8

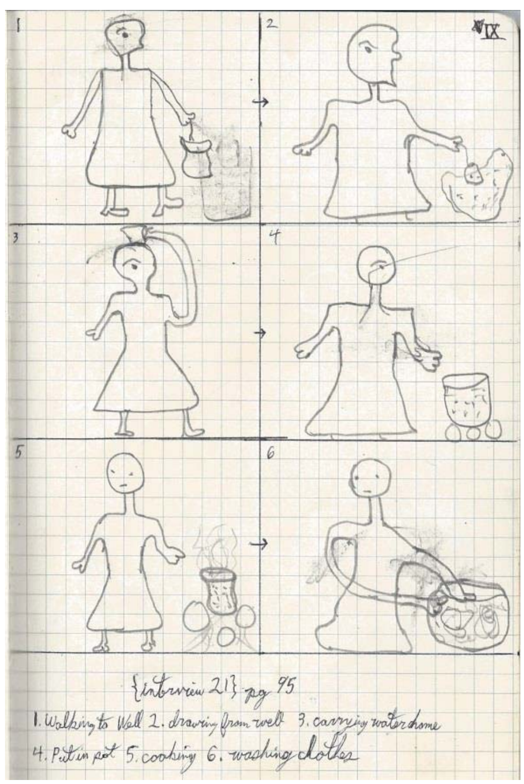

1
2
IX
3
4
5
6
{interview 21} pg 95
1. Walking to Well 2. drawing from well 3. carrying water home
4. Put in pot 5. cooking 6. washing clothes

Fig. 9

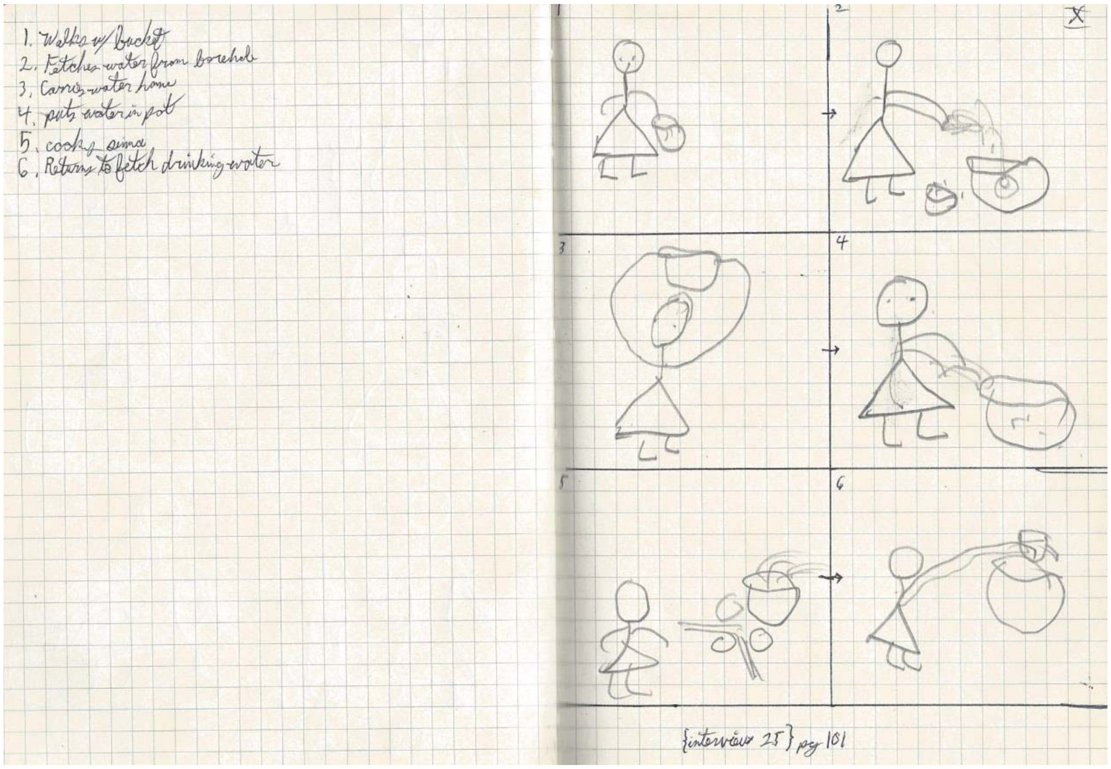


Fig. 10

Note: Fig. 10 is drawn by the same participant that drew Fig. 8.

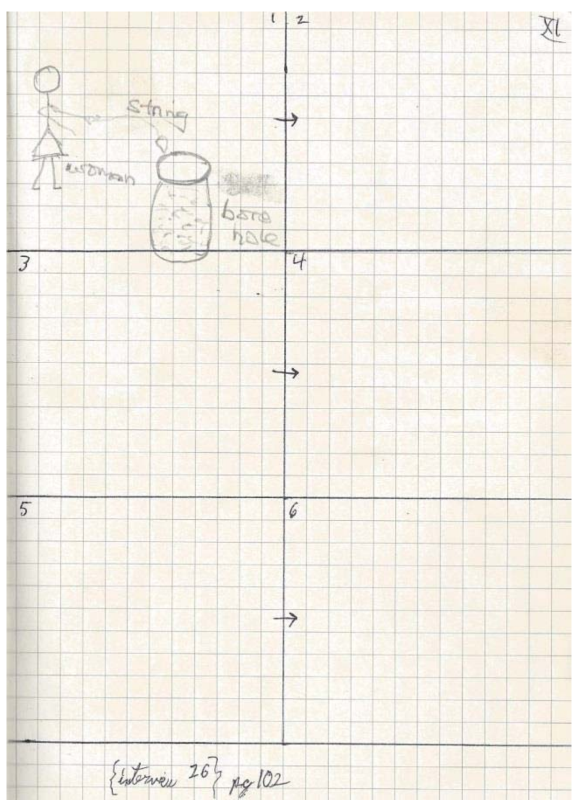


Fig. 11

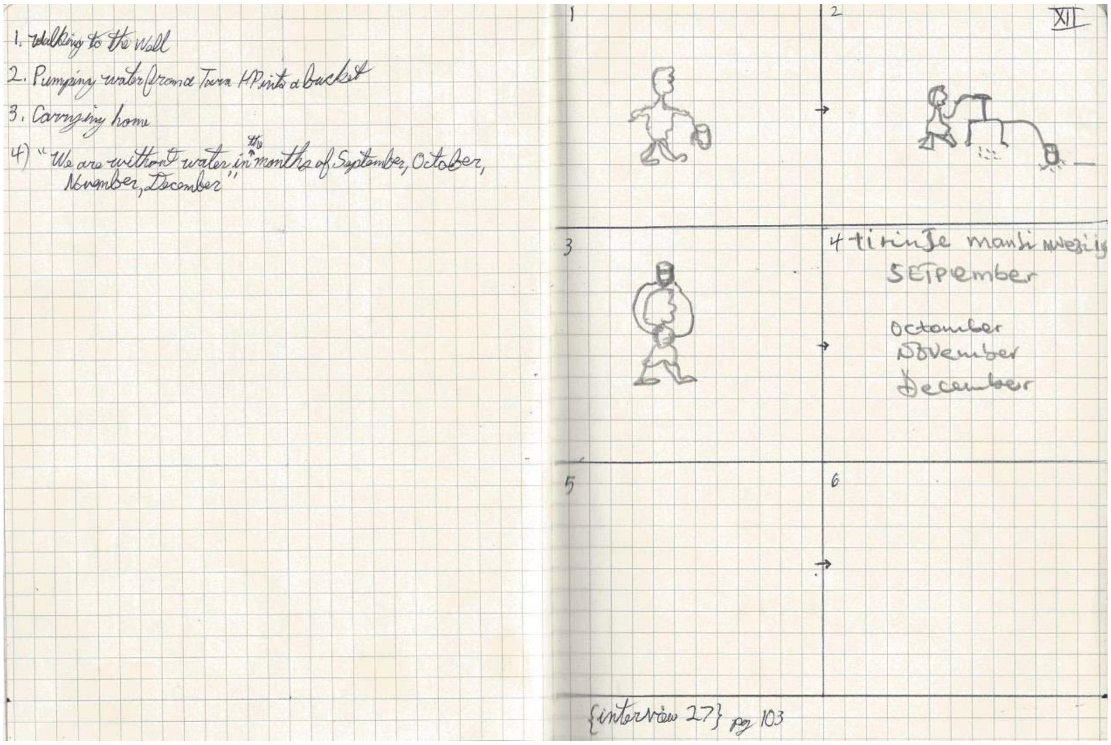

1. Walking to the Well
2. Pumping water from a Tara HP into a bucket
3. Carrying home
4) "We are without water in the months of September, October, November, December"
XII
4 tirinJe mansi mvezi
SEtPember
Octomber
NOvember
December
{interview 27} pg 103

Fig. 12

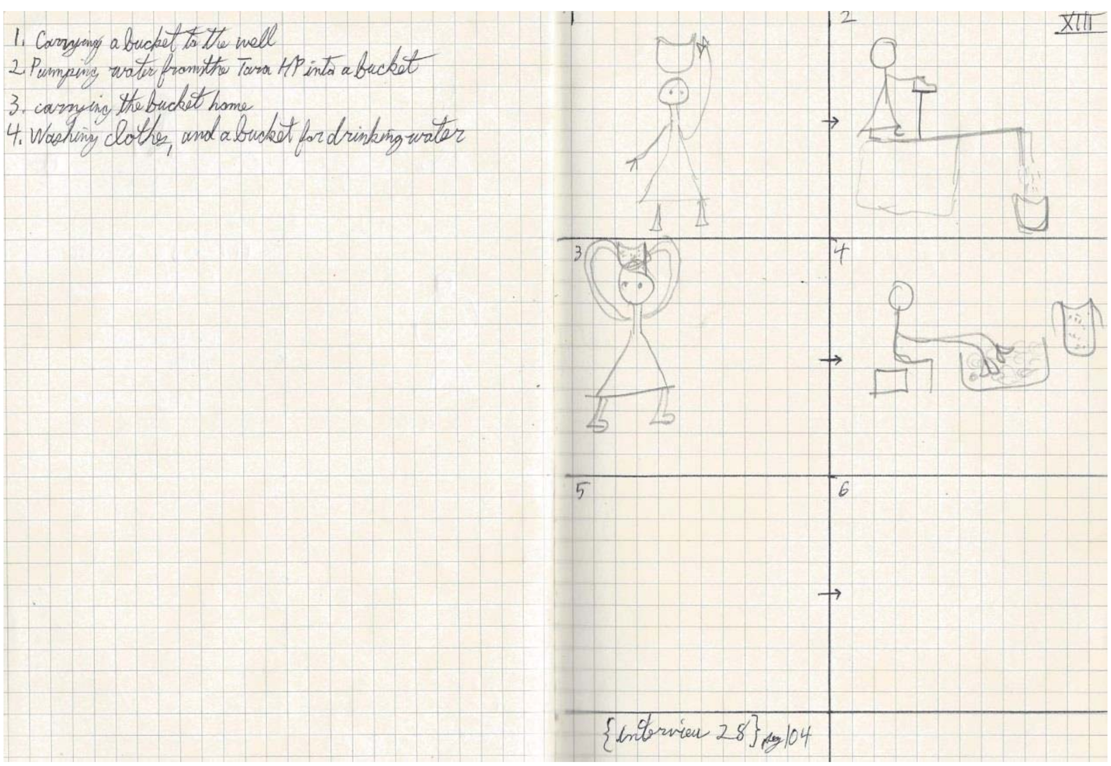

1. Carrying a bucket to the well
2. Pumping water from the Tara HP into a bucket
3. carrying the bucket home
4. Washing clothes, and a bucket for drinking water
XIII
{interview 28} pg 104

Fig. 13

9. Bibliography

Bath, A.H. "Hydrochemisty in groundwater development: report on advisory visit to Malawi." Report on Advisory Visit, Blantyre, 1980.

Boyd, J. Hayden. "Why Are The Pumps Not Working? Diagnosis and Possible Remedies." Monitoring and Evaluation Report, Davidson, NC, 2011.

Central Intelligence Agency. *Central Intelligence Agency* . n.d. www.cia.gov (accessed September 21, 2014).

Chato, Dr. John. *Simple Pumps for Shallow Wells*. Urbana: University of Illinois, 2002.

Hooydonck, Jan Van. *Development of Code of Practice for Groundwater Development in the SADC Region*. Lilongwe: Groundwater Consultants Bee Pee, 2001.

IDEO. "Human Centered Design Toolkit." *IDEO*. n.d. http://www.ideo.com/work/human-centered-design-toolkit/ (accessed December 4, 2014).

Malawi Standard Board. *Borehole and shallow well quality-Specification*. Standards specification, Blantyre: Malawi Bureau of Standards, 2005.

McNicholl, Duncan. "Accessing handpump spare parts: a study of Northern Malawi." *35th WEDC International Conference*. Loughborough, 2011. 1-8.

Mission, Marion Medical. *Shallow Well Cost!* n.d.

National Statistical Office. *2008 Population and Housing Census*. Census, Zomba: Republic of Malawi, 2008.

Nellemann, Soren. *Cost, Financing, and School Effectiveness of Education in Malawi*. Education Country Status Reports, The World Bank, 2004.

Shaw, David, and James Manda. *Exploring the long term sustainability of water, sanitation and hygine services in Salima District, Malawi*. Post-implementation monitoring survey, WaterAid, 2013.

United Nations. *Millennium Project*. 2006. http://www.unmillenniumproject.org/goals/gti.htm (accessed September 17, 2014).

WHO, UNICEF. *Global Water Supply and Saniitation Assessment*. Joint Monitoring Program Report, Geneva: World Health Organization, 2000.

World Health Organization. *World Health Statistics*. 2010.