Alternative Analysis

Executive Summary	
Community:	Kibuon
Country:	Kenya
Chapter:	Harvard SEAS Chapter
Submittal Date:	12/9/2019
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REIC and other mentors:	Christopher Lombardo (REIC, Faculty Advisor), Nisheet Reddy EIT (Mentor), Avery Meyer EIT (Mentor)
Scope of Work for the project (50 words)	Given the current lack of clean and accessible water in Kibuon, the goal is to design and construct 2-3 of wells in the community to provide water for the approximately 1600 people living in Kibuon.
Scope of Work for the analysis (100 words)	This analysis will select between 5 different well configuration alternatives designed based on the locations of potentially viable well drilling locations in the community.
Proposed Next Step (100 words)	After the preferred alternative has been selected and approved, the Harvard SEAS Chapter will begin preparation of the Construction Drawings and Implementation Trip Plan. The team expects to construct the first well in May/June 2020.
Describe Recent Contact with Community, NGO, and in country partners. (100 words)	The Chapter's primary contact is Paul Olango — the team's in country contact who also plays the role of a community guide and translator having previously worked with other EWB chapters in the nearby communities of Lela and Bondo - and Julius Amara, the projects coordinator of the Kibuon CBO. The chapter regularly communicates with Paul and Julius via WhatsApp, email and scheduled calls every two weeks over Skype. Lastly, the chapter has been in contact with a local well drilling company called WECCO (Wuoth Ogik Education and Charitable Community Organization) that has worked on projects in the neighboring communities.
Describe the Chapters current fundraising goals and milestones. (100 words)	The program is on track to fundraise for the implementation.
☒	**IS THE PROGRAM STILL ON TRACK TO MEET THE EWB PROJECT EXPECTATIONS?**

Privacy: EWB-USA may release this report in its entirety to other EWB-USA chapters or interested parties. Once the report is approved any member in Volunteer Village will be able to find and view the plan. Please do not include personal or sensitive information.

Project Timeline

Major Milestone	Original Date	Current Date	Description
Program Adoption Date	12/31/18		
Previous Project in Program Date Constructed	N/A		
Project Approval Date	3/28/19		
Completed Assessment Trip	6/11/19		Trip conducted to sign partnership agreement and to start data collection for a water provision system
Planned Implementation Trip	N/A	6/15/20	Trip to construct first well.
Planned Implementation Trip	N/A	6/20/21	Trip to construct second well and monitor first well.

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1. Project Description

1.1 Project Background and History

The Harvard SEAS EWB Chapter began its partnership with the Kibuon community in January 2019 when it adopted the Kibuon Program. The CBO, the Kibuon Projects Committee, initiated the Kibuon Water Project and a partnership with EWB to improve access to clean water for local residents. The Kibuon Projects Committee was founded in January 2016 amongst members with familial relations. It was then reformed in 2017 by holding nominations for members from different regions of the community to increase representation and inclusivity; this new model matched that of CBOs in nearby communities that had also partnered with different EWB chapters.

The Harvard Chapter completed its first assessment trip during the summer of 2019. During the assessment trip, the chapter had an opportunity to meet with community leadership and learn about the local political structure within Kibuon, conduct 40 household surveys to understand water usage patterns and issues, create a geographic map reflecting the demographics of the community, and interview medical professionals at local dispensaries to understand the primary health concerns of the community. Throughout the assessment process, the chapter collaborated closely with community leadership, Julius Amara and Paul Olang'o, who will continue to serve as liaisons with the community as the chapter enters the alternative analysis phase of the project.

1.2 Project Context

The project is located in the Migori county, Kenya, in the Kibuon community. The community consists of 1600 people living in four regions: A (Nyamilu), B (Sindyania), C (Ombolwanda), D (Wii Yao). These regions were originally separate communities that were joined together by the CBO to form Kibuon for the purpose of applying for a partnership with Engineers Without Borders USA on a project. The boundaries of the community were determined by the CBO as well. Roughly speaking, these form four quadrants aligned along a central valley running the length of the community.

The community mainly consists of houses, farmland, empty lands, and a few public buildings; eight churches and a school on the edge of the community. All the roads in the community are dirt roads with the biggest road running along the outside of the community. There is also a school right outside the edge of the community and a health clinic which serve community members. Houses in the community do not have electric power, and most of the community is not connected to the grid, except for the school. Additionally, there are electric poles near the edge of the community outside of region B and on the edge of region A.

Currently, there are three main sources of water used by community members. Some of the houses have gutters on their roofs to collect rainwater, but rainwater does not currently meet the full need of the community. Another source is natural shallow springs near the central valley of the community and shallow hand dug wells found around the community. These sources usually dry up in the dry season, therefore in the dry season a lot of community members get their water from wells in the nearby communities of Bondo and Lela; they either have to walk long distances to get to the wells or they hire motorcycles to get the water from the wells which is not affordable for most of the houses in the community. While the water from the wells in Bondo and Lela is clean, the water at the springs in Kibuon contains high levels of E. Coli. as per the travel team's testing. This shown in Appendix 5.2.2.

The community map developed during the assessment trip is shown below in Figure 1.1. The four regions are outlined, and all homes, latrines, landmarks, water sources and potential well sites are marked according to the legend.

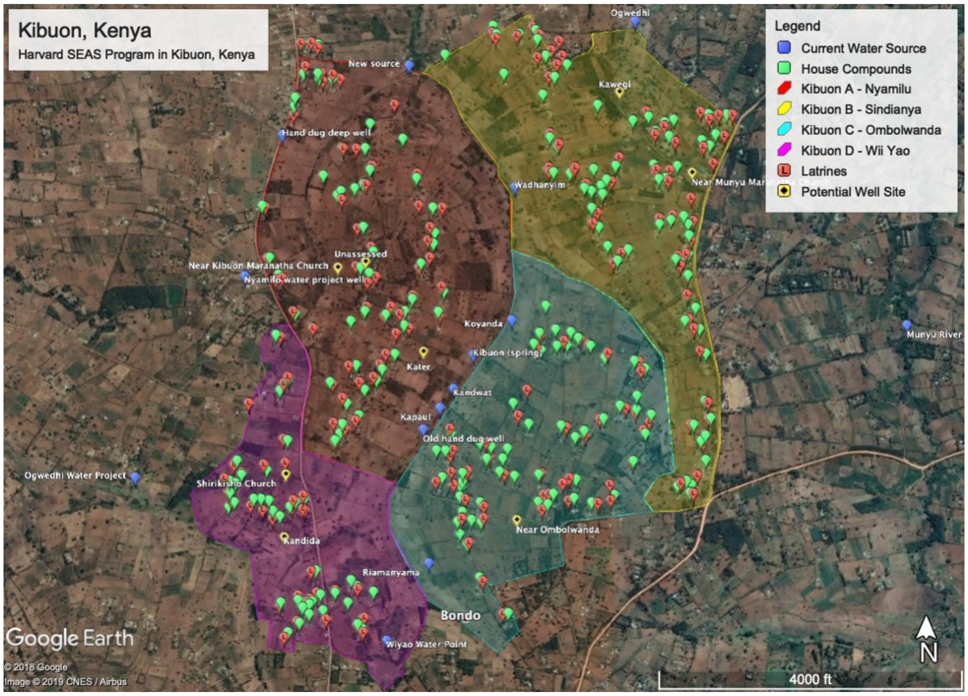


Figure 1.1: Map of the Kibuon community

1.3 Project Goals and Objective

Due to the complications with the current water sources, the goal of this project is to implement a more reliable, cleaner, and closer source of water for the Kibuon community. This will allow children to show up on time to school and stay for the full day of education, provide the community with an easier ability to grow and maintain crops, therefore boosting income and food stability, and decrease the amount of water borne illness occurring in the community due to the current water sources, such as diarrhea and fever. The travel time required by most members to obtain water will be reduced, as well as lines will be shorter, allowing the designated water collectors to spend more of their time supporting their family or the community in other ways.

In addition to providing them with a source of water, community interviews were conducted to gather feedback that will be integrated into the construction of the project. The community can then develop a sense of ownership over the well. By incorporating community members in maintenance, the project may be as useful as possible, for as long as possible. This will also allow the community to further expand the project on their own as they wish to do so.

Overall, water is not only necessary for the bare necessities such as drinking and watering crops, it also has a major social and developmental influence. By establishing a safer, more reliable source of water in the community of Kibuon, the community can continue developing through:

1. The improvement of education of youth in the community and their experience in school. They will be spending less time collecting water and will not be forced to miss school to collect water. Additionally, there will be clean water available for use at the school thus improving hygiene and making students more comfortable at school.

2. The improvement of the functions of the health clinic which currently relies on a broken water catchment system as its only source of water. Thus, improving the health treatment currently available to members of the community.

3. Allowing community members to invest more time in their small businesses and farms, potentially allowing for the expansion of these businesses or their improvement which would benefit the community as a whole

4. Decreasing the gender barrier between males and females in the community by reducing the burden placed on adult women in the community who are the main people responsible for collecting water.

1.4 Scope of Work

Given the current lack of clean and accessible water in Kibuon, the goal of the project is to help fulfill this need for the approximately 1600 people in the community. The community has expressed a strong preference for the construction of several wells in order to create more reliable sources of water. The five-year plan for the Kibuon Project is to eventually construct however many water projects are needed to meet the demands of the full community. However, the scope of the portion of the project is limited by the finances of the community and government regulations. Government regulations require the construction of wells at least 800 meters apart, while due to the high cost of drilling a well, the number of wells constructed cannot surpass the funding stipulations (5% of costs must be covered by Kibuon). Thus, given these constraints, the scope of this trip will involve the construction of a single well. Following the assessment of different well locations and other water needs, the construction of one or two other wells is planned for the upcoming five years.

1.5 Potential Solutions Considered

To meet the community's goal of a clean, reliable, year-round water source, the project team is anticipating drilling multiple boreholes and installing pumps. During a meeting held on the May 2019 assessment trip, seven possible borehole locations were identified throughout the Kibuon community. Throughout the fall 2019 semester, the project team assessed each well site for access, contamination potential, community impact, and other factors.

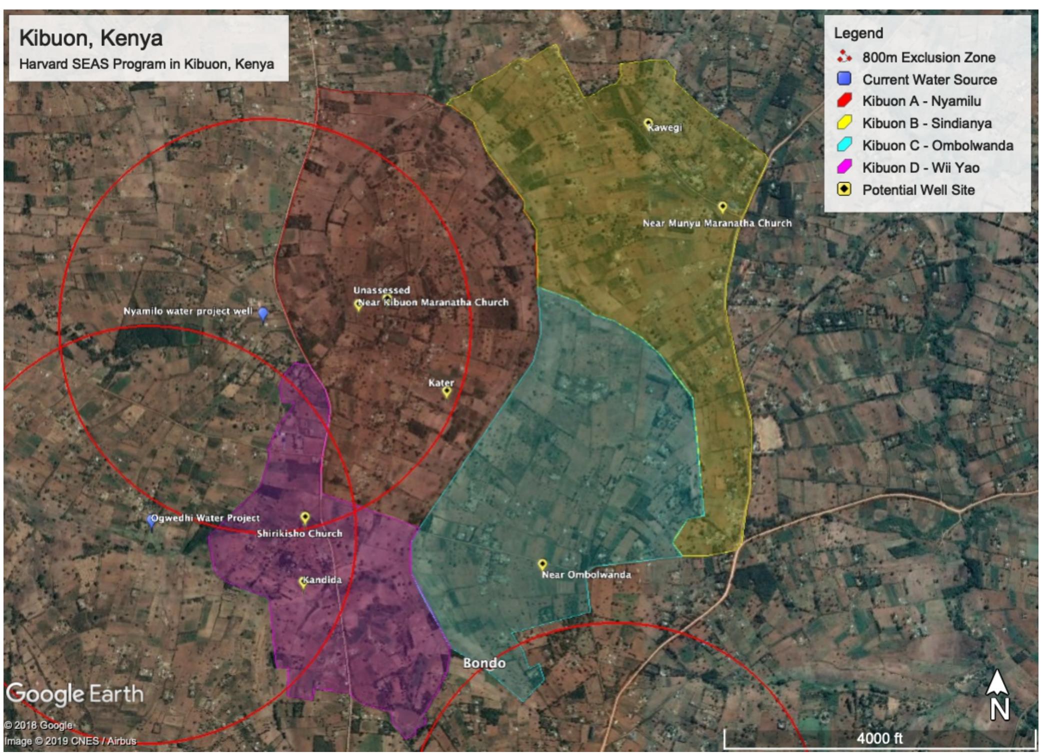


Figure 1.2: Existing wells and all potential well sites in and around Kibuon

The existence of the three wells shown in Figure 1.2 eliminate four of the possible well sites suggested by the community. As such, the four potential well sites being considered are: Kater, Kawegi, Munya Maranatha Church, and Ombolwanda as shown in Figure 1.3. Note: While Kater is within the 800m exclusion zone of the Nyamilo well, it is near the edge, meaning the location could be shifted slightly to be outside of the 800m radius.

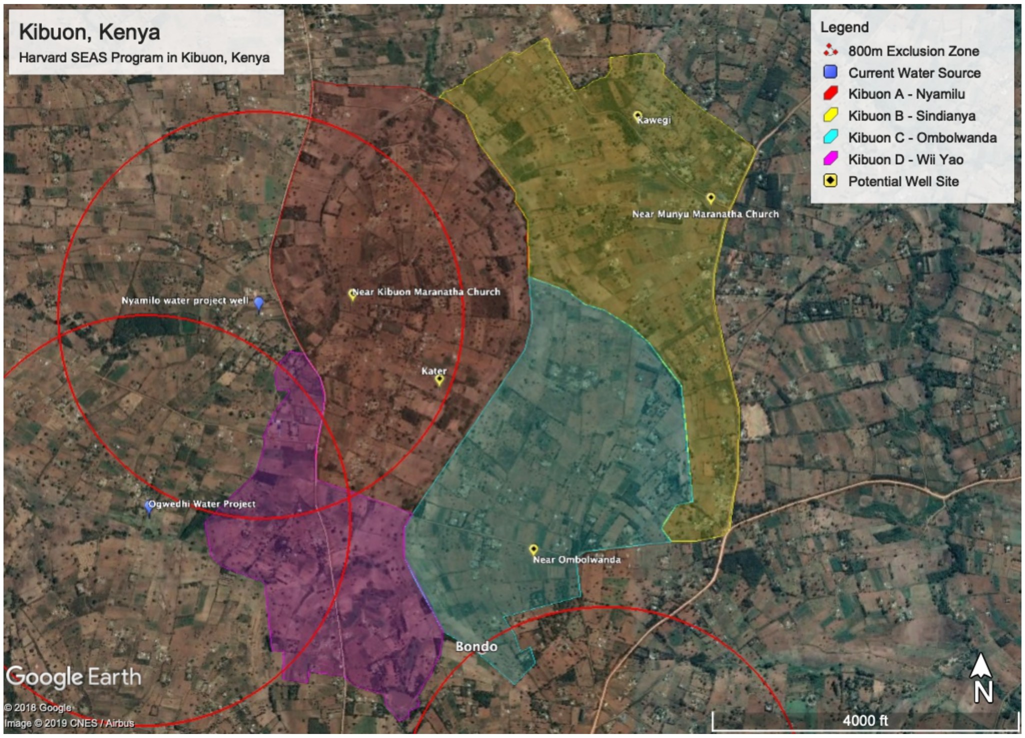


Figure 1.3: Existing wells and all potential well sites being considered in and around Kibuon

1.6 Harvard SEAS Chapter Project Team

Students: There are 12 students that are active members of the Harvard SEAS Chapter and involved in the Kibuon Project.

Project Leads: Billy Koech and Tatheer Adnan are the current project leads. They are the main leadership for the students working on the project and are primary contact for the rest of the project team. Billy Koech is also one of the translators since Swahili is his native language (which is one of the languages spoken in Kibuon).

Harvard Chapter Co-Presidents: Eva Cai and Nicole Trenchard are the current Harvard College Chapter Co-Presidents. They are largely responsible for the organization of the chapter, including setting goals for the upcoming year. They are also responsible for communicating with EWB-USA and state representatives. This includes updating EWB-USA on what is happening with the project and updating the project team with updates form EWB-USA/the state representatives.

Faculty Advisor: Dr. Chris Lombardo plays several key roles in the success of the project team. Dr. Lombardo is a current Associate Director of Undergraduate Studies in the Harvard School of Engineering and Applied Sciences. Dr. Lombardo has BS degrees in Electrical Engineering and Physics from the University of Maryland and his MS and PhD in Electrical Engineering from The University of Texas. He first began work with EWB in 2004, and since then has worked on projects in Ecuador, Mexico, Cameroon, Panama, Peru, the Dominican Republic and Tanzania. He has also been a leader both regionally and nationally within EWB-USA. He is a current member of the EWB-USA Board of Directors. All of these experiences will be crucial for his work as REIC, faculty advisor, travel mentor and health/safety officer for the Kibuon project team, and the overall success of the team.

Mentors: Nisheet Reddy (structural engineer at GEI consultants and Vice President of the Boston Professional Chapter) and Avery Meyer (structural engineer at WSP USA and member of the Boston Professional Chapter) are the Kibuon project team's mentors. Avery Meyer was a mentor for the chapter's previous Tanzania project. He is the acting as the International Development Lead and will be working to make sure that our work is culturally appropriate, and technology and construction practices are feasible. Nisheet has experience working as a mentor in Tanzania, for a project that designed a dual catchment and tank system.

1.7 Community Partners

The Kibuon Projects Committee herein referred to as the Community Based Organization (CBO) is the highest deciding authority on project matters along with the Harvard SEAS Chapter. Founded in 2016 to write the ICP community program application, it is formed by 17 nominated members of the Kibuon community, they represent the Kibuon community. They will serve as on the ground project support, will be in in charge of the fundraising activities as well as the post implementation maintenance. While the team was in Kibuon they formally met with the CBO on two formal occasions: once in the beginning of the trip and once on the last day before departure. The Harvard SEAS EWB team was impressed by the Kibuon Project Committee's structure and proactivity both during the trip and in the months beforehand.

Beside the CBO, Harvard SEAS Chapter has an in-country partner named Paul Olang'o. He and his father, Charles Olang'o support the project in different ways. They are members of the neighboring Lela Community that have worked with Oregon State University and San Francisco Professional Chapters. Charles and Paul were also involved in the EWB-USA project done in Bondo (another neighboring community) by Hope College. Paul Olang'o assists in logistical planning for chapters' trips to the community as well as on the ground support. They also help with translation during meetings with the community and served as the van drivers and hosts during the last project assessment trip.

Harvard SEAS has already formally signed a Partnership Agreement a local drilling and community development organization Wuoth Ogik Education and Charitable Community Organization expressed interest in signing a contract with Harvard SEAS chapter. It is a local company that consists of drilling professionals who have experience conducting hydrogeological studies and drilling wells in the neighboring communities of Migori county. Their community education initiatives set them apart from typical drillers because they not only drill wells but also focus on teaching communities how to maintain them. WECCO plans to sign a partnership with the chapter should the chapter decide to drill a well with them.

Last but not least, the team met with some local government members with the intention of helping the community partner with the local government for the purpose of securing project funding, but the chapter is still in the process of pursuing this. The current main contact in the local government is the Minister of Water and Energy for Migori county – Hon. Rebecca Ghati Maroa. Besides the main contact, Kibuon also has a representative in the county assembly by the name Hon. Aran Aran Patrick.

2. Alternatives

The following power requirements, cost estimates, and calculations apply to all five well alternatives considered in this report. All the alternatives have two wells and the three power options are being considered for all the different well locations. In general, an electric pump is preferred over a hand pump for each location. The main differences between the different power options are installation costs, pump flow rates, costs of materials, and operations and maintenance. It does not seem very feasible to have a manual hand pump to provide enough water for this large number of people.

Power requirements to meet basic water demand

Assuming each alternative will serve 100% of the people in the community and that the number of people is split roughly equally between the wells in the alternative, each well would need to provide enough water for 800 people. The following hours of pumping would be needed each day for each well, shown for each different power option.

Equation used for calculation

$$Pumping\ time\ \left(\frac{hr}{day}\right) = \frac{population}{\#\ of\ wells} * 20\left(\frac{L}{person * day}\right) * \frac{1}{pump\ rate\ \left(\frac{L}{min}\right) * 60\ \left(\frac{min}{hr}\right)}$$

	Pumping rate	Number of people per well	Hours of pumping needed
Solar pump	50 L/minute	800	5.3
Electric pump	50 L/minute	800	5.3
Hand pump	18 L/minute	800	14.8

A pumping rate of 50L/minute is assumed for the solar and electric pumps because that is the minimum flowrate for most of the electric pump models available from suppliers that were used for the cost estimate (such as Davis and Shirtliff[1]) so this would provide the maximum number of pumping hours needed.

The pumping rate for the hand pump is based on the pumping rate observed in the Bondo well. During the assessment trip, the travel team monitored the usage of the well in Bondo which uses a manual hand pump and took an average of the amount of time taken by people to fill up a 20L jerrycan.

Pumping requirements and regulations

The Water Resources Management Authority (WRMA) which is a state corporation under the Ministry of Water and Irrigation in Kenya has specific pumping regulations that must be adhered to when constructing a borehole/well. These regulations will apply to all the well alternatives listed below. The Kenya Water Act (2002)[2] only allows pumping at a rate of up to 60% of the applied test-pumping rate, for a maximum period of 10 hours per day; for the calculations above, this would be adhered to by the solar and electric pump without affecting the amount of water needed to be produced, but for the manual hand pump this would mean a decrease in the amount of water produced which might not meet the need of the community. Additionally, a flowmeter is required for any type of pump and a way to measure the water levels; this is particularly important because if the water level is low and pumping is continued it could cause damage to the well components and might require more frequent maintenance.

Initial cost estimates

Initial cost estimates for each power option assuming all the wells will be drilled to a depth of 160m:

- Well with a manual pump: $22,300USD - $22,900USD
- Well with a solar powered pump: $24,132USD
- Well with a pump connected to the grid: $23,500USD – $26,500USD

*Breakdown of estimated cost is available in Appendix 5.4.

[1] Davis and Shirtliff Catalog
[2] Kenya Water Act

The possibility of using grid-tied power

To power the pump with electricity from the grid, a step-down transformer would need to be installed. As of now, it seems that the procedure to get electricity at the well site will be to reach out to the Kenya Power and Lighting Company (KPLC) who will, for a fixed fee, provide a meter box to bring power to the well site, and it would be their responsibility to install the transformer if needed. To apply for electric power to be provided at the well site, there is an application and a need for a certificate from a certified electrician.

2.1 Alternative 1 – Ombolwanda and Kawegi

In this alternative, the first well will be constructed in region C near Ombolwanda. The second well will be in region B in Kawegi. Based on the solar path data collected on the assessment trip, Ombolwanda has the best sun coverage out of all the potential well sites considered. However, it does not have any utility poles nearby, eliminating the possibility of grd-tied power. Therefore, if a well is to be constructed at Ombolwanda, there are two power options for the pump: a solar powered pump or a manual hand pump. As for Kawegi, the site has the worst solar coverage out of the potential well sites considered with only 5 hours of unshaded sunlight on average in a day, However, it has a utility pole 18m away from the site. Therefore, if a well is to be constructed at the Kawegi site the power options for the pump would be a manual hand pump, or an electric pump.

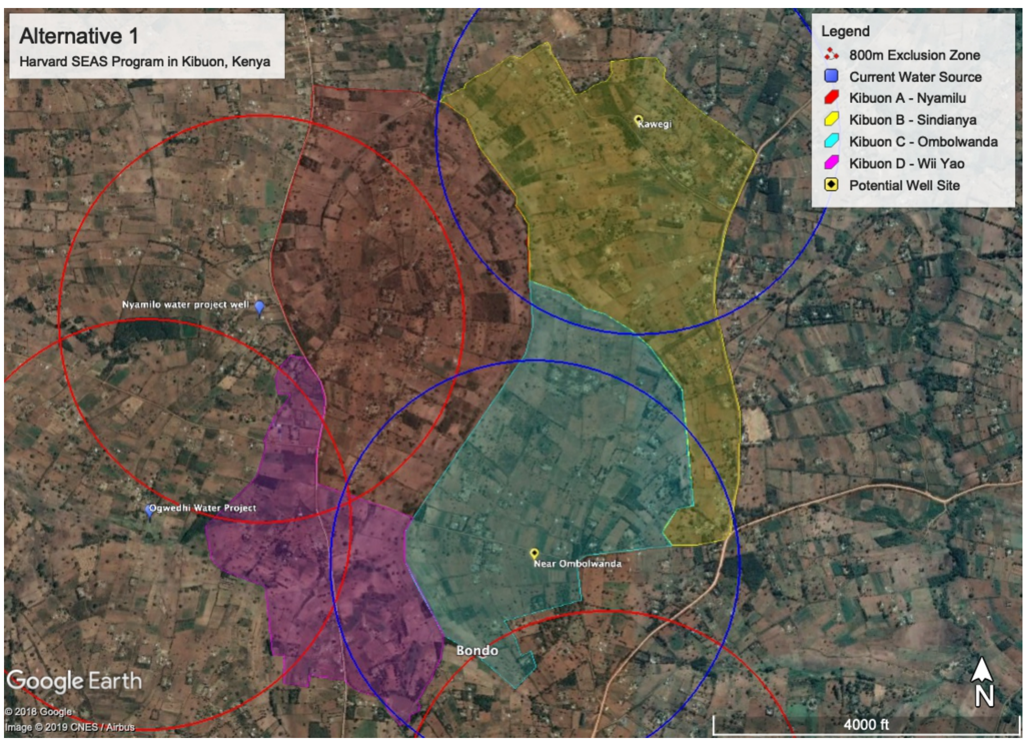


Figure 2.1: Map of Kibuon visualizing Alternative 1

2.2 Alternative 2 – Ombolwanda and Munyu Maranatha Church

The first well will be constructed near Ombolwanda in Region C, similar to Alternative 1. The second well will be constructed near Munyu Maranatha Church in Region B. Based on the solar path data, the site at Munyu Maranatha Church experiences a lot of shading. For this reason, a manual pump would likely be installed at this well. Additionally, this site is 29m away from a utility pole. This means that in the future, the manual pump could be replaced by an electric pump if transformer installation is possible. As mentioned before, the site at Ombolwanda receives high sun coverage, making solar power the optimal choice for this location.

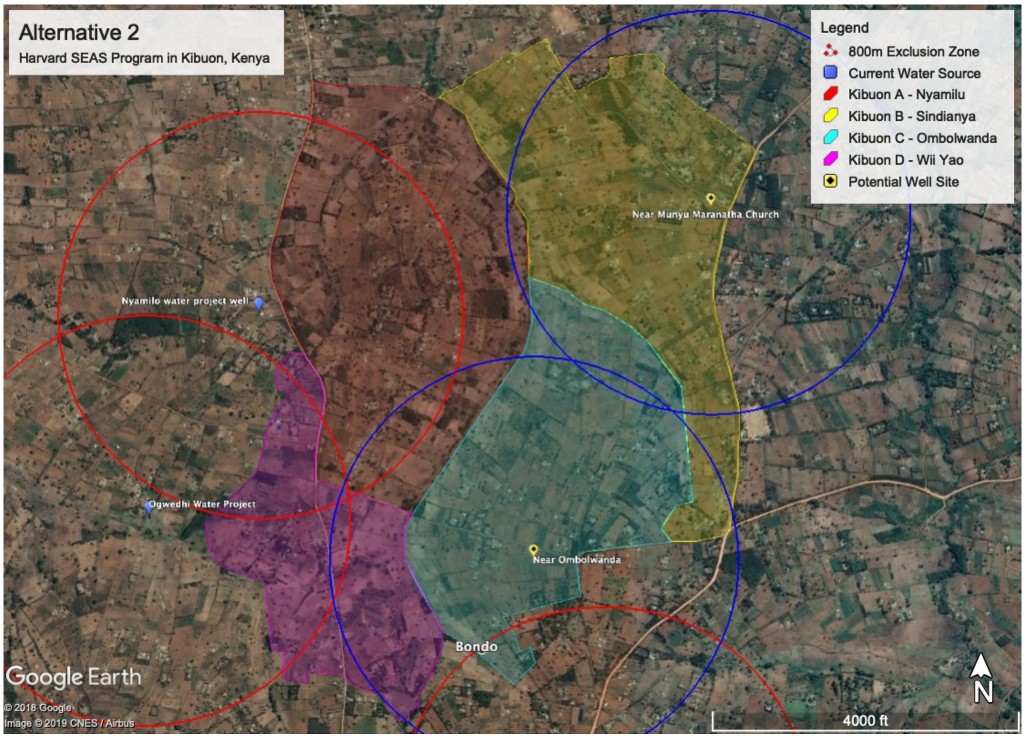


Figure 2.2: Map of Kibuon visualizing Alternative 2

2.3 Alternative 3 – Kater and Kawegi

Alternative 3 will include one well at Kater and another one at Kawegi. The site for Kater that the travel team assessed falls within 800 meters of wells in neighboring communities, so the well site will have to be moved to a site outside of the radii of these two wells in order to uphold government regulations. The project committee plans to reassess the location of this well site, which makes it difficult to give a good idea of how this well will be powered. The current site that the travel team looked at for Kater gets 10 hours of sunlight today making it a viable option for solar power, but since the site will most likely be moved. The reassessment is necessary in order to truly determine solar reliability of this site. This is why this alternative is not higher on the list. Kawegi ranks poorly on solar reliability only getting 5 hours of sunlight/day. This means that there would need to be a different way to power this well. This site would require either a manual hand pump or a grid-tied electric pump. There is an electric pole 18m away from this site, but a transformer would need to be installed, which could be expensive.

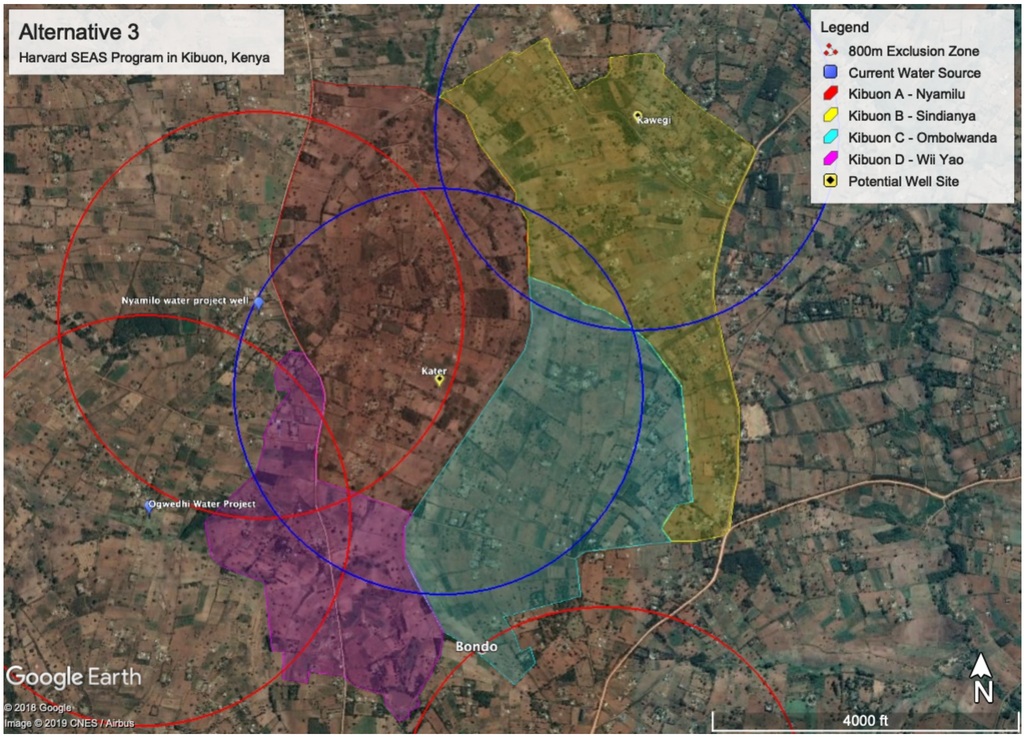


Figure 2.3: Map of Kibuon visualizing Alternative 3

2.4 Alternative 4 - Kater and Munyu Maranatha Church

Alternative 4 will include one well at Kater and another one near the Munyu Maranatha Church Alternative 4 would require a solar pump for Kater and Munyu Maranatha Church is intended to have a grid-tied electric pump, but a transformer must first be added to a nearby pole. Because there are still unknowns about this process, the plan is to investigate this well during the next trip. A handpump is an alternative option for the one near the Munyu Maranatha Church. Additionally, although the current exact location of the Kater well on the map violates the 800m required distance between two wells, by shifting it slightly out of the Nyamilo well zone, that violation can be resolved. The community had identified that general region as being a good place to put a well, so even when shifting the exact well site slightly, the suggestion of the community will still be met while also satisfying the government regulations. There are no latrines within 50m for either well site, therefore also within government regulations.

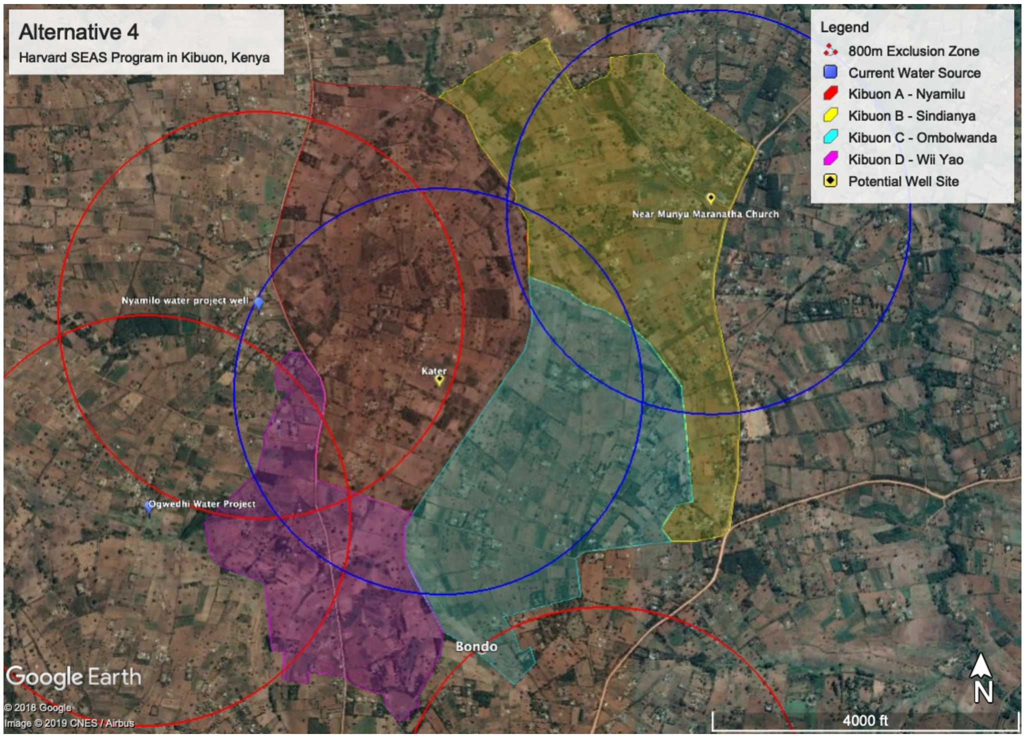


Figure 2.4: Map of Kibuon visualizing Alternative 4

2.5 Alternative 5 – Ombolwanda and Kater

Alternative 5 will include one well at the Kater site and one well near Ombolwanda. The wells would be built during separate implementation trips, likely a year apart. Both wells will likely be powered by solar panels due to the need for high pumping efficiency, but hand pumps are also being considered.

These two sites were chosen primarily for their low risk of latrine contamination (no latrines are within 100m of either well site) and their good accessibility for drill rigs. One caveat to this alternative is that Kater would need to be moved slightly east to be outside of the legally mandated 800m buffer of a well located just outside of Kibuon to the west. In addition, wells at Kater and Ombolwanda would need to be at least 800m from each other (as indicated by the 800m buffer zones on the map).

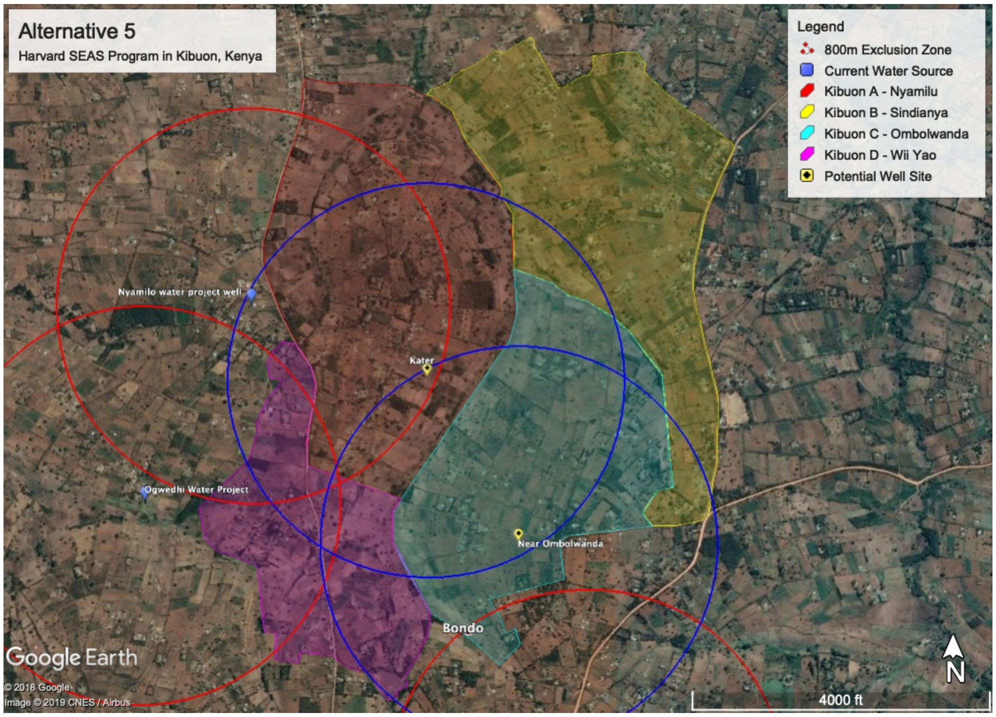


Figure 2.5: Map of Kibuon visualizing Alternative 5

3. Comparison

3.1 Criteria

1. **Percentage of houses within 1km**

   This criterion measures the percentage of households that will be within 1km of at least one well for the alternative. 1km fits within the World Health Organization guideline that delineates no access and basic access to water.[3] The alternatives were evaluated to see what percent of the community will be served by a water source within a 1km distance. The alternative was given a 1 if it served more than 80% of households, a 0 if it served 75-80%, and a -1 if it served less. While this metric is informative for highlighting the variation between alternatives, it is incredibly important to also review Figure 5.6 which illustrates the household distance distribution for each alternative; while there are slight variations, the data is almost identical between alternatives.

2. **Distance to Nearest Roads (Ease of Access)**

   This metric indicates how accessible a well location is for construction and motor vehicles. It may be impossible to bring a drill rig to a well site located further than 50m from the road. Additionally, motorbikes may not be able to access the area without roads, especially in the rainy season. Alternatives with both sites 50m or less from the road was assigned a score of 1, alternatives with a site located 50-100m from the road received a 0, and alternatives with a site further than 100m was given a -1.

3. **Distance to latrines**

   This metric indicates the number of latrines present within a certain radius of the wells. Latrines pose a threat to water contamination and should thus be as far from wells as possible. Kenyan government regulations mandate at least a 50m buffer between wells and latrines. However, other countries and international organizations recommend a 100m buffer. Thus, alternatives with latrines within 50m were eliminated, while alternatives with latrines between 50-100m away were assigned a 0, and alternatives with all latrines more than 100m away were given a 1.

4. **Well usage and overlap**

   After determining the number of households around each well within a radius of 1.25km, the number of households each individual well would serve could be predicted. This criterion was created to determine how many people would be using each individual well in the alternative to determine each well's popularity. An overlap percentage was also calculated to determine to what extent the two wells in the alternative were serving the same group of households. The radius was chosen as 1.25km because 3 of the alternatives reach >99% of the population within this distance and the remaining 2 alternatives reach 90% of the population within this distance, so the overlap data and predicted usage can better capture the total population (as opposed to a 1km radius). The overlap is calculated as the number of households that are within 1.25km of *both* wells in each alternative divided by the number of unique households served. While normally high overlap percentages would indicate that the wells are repetitive in serving a select population, it was determined that since each alternative already reaches a very large majority of the Kibuon community, it is unlikely that a particular population is being underserved or overserved. Instead, high overlap may be beneficial in case one well ever stops functioning because accessibility to the other well would still be high. In this criterion, the predicted usage was also calculated, predominantly under the assumption that for households where both wells are roughly equidistant, they are more likely to go to the less crowded well.

[3] The Right to Water, The World Health Organization

Therefore, to score this criterion, the alternative was given a -1 if overlap was between 0% to 30%, 0 if it was between 30% to 60%, and 1 if it was greater than 60%.

5. **Power source for pump**

   The pump that will eventually draw water from the well can be powered in several ways. It is possible to install a hand pump at every well location. However, this is not preferable to the low pump rate of hand pumps (~18L/min) and anecdotal evidence of poor performance of wells with handpumps near the community. Considering the other potential pump types, only some locations have sufficient sunlight over the course of the day and across seasons to justify the installation of a solar pump. Similarly, only some well sites are located close enough to the electric grid to allow for the potential installation of a transformer. While both solar and electrically powered pumps operate at the same rate (minimum of 50L/min), there are still some questions surrounding feasibility of an electric pump as significant information is needed concerning the process and cost of working with the Kenya Power and Lighting Company (KPLC) to install a transformer. However, solar pumps and PV arrays are definitely a viable and sustainable option. Thus, alternatives where at least one location allows for a solar pump were given a 1, and alternatives where both locations required a hand pump, grid tied power, or were unknown were given a 0.

6. **Data availability**

   Despite the amount of data collected during the Project Assessment Trip in May 2019, there are still knowledge gaps that impose significant barriers to the construction of some wells. Currently, the location discussed at the Women's Meeting and designated as Kater overlaps with the government mandated 800m exclusion radius of the Nyamilo and potential Ombolwanda wells. As discussed above, its location may be shifted, but the feasibility of solar power and the exact conditions of the new potential site are unknown. Alternatives that require moving a well to a new, unknown location received a -1, while all other alternatives receive a score of 0.

7. **Community Input**

   After establishing the five alternatives, the team informed the CBO of the different options and requested input. The CBO ranked the alternates from most preferred to least preferred as shown here: Alternative 4, 2, 3, 1, 5. They expressed an inclination to have Munyu Marantha drilled first then followed by Kater. In addition, they were hesitant about alternative 5 citing concerns about the proximity of the two wells to each other. No concerns were raised for the other alternatives. Their input was recorded and factored into Section 3.3.

3.2 Climate Change

3.2.1 Summary of Anticipated Climate Change

According to the Kenya Climate Risk Profile published by USAID in 2018, by 2050, Kenya is expected to experience an increase of average temperatures (+1.2-2.2 C), with warming greatest in the west. Additionally, Kenya will experience longer heat waves (+9–30 days), and increased average rainfall, mainly from October to May.[4] Although heavy rainfall events will become more intense and frequent, dry spells will increase in severity. According to Aqueduct's Water Risk Atlas, the total blue water supply (surface water and ground water replenished by rainfall) in 2030 is expected to be 1.2 times greater than that of 2010.[5]

This data partially agrees with the anecdotal information collected on the assessment trip. Surveyed community members shared that in the last ten years, the area has gotten hotter, springs have dried up, rainfall has become more irregular and delayed, and there have been heavy, destructive storms. However, their responses to the climate

[4] Climate Riskk Profile Kenya, USAID
[5] Aqueduct Water Risk Analysis

change survey questions may not fully represent trends from the last decade due to difficulties with translation and the community's general unfamiliarity with the concept of climate change.

3.2.2 Summary of Impact of Climate Change

The anticipated impact of climate change has already affected community members' agricultural work. According to survey results, the increased temperatures and longer heat waves have made farming particular crops more difficult and spring sources less reliable. In community interviews, the project team learned that crops have also been affected by the increased irregular rainfall which raised the flood line in the valley a bit higher and caused occasional storms which destroy crops.

On the other hand, the data reported by Aqueduct's Water Risk Atlas mentioned in section 3.2.1 of the 20% increase in total blue water supply suggests that there might be a more plentiful water table. However, increased demand for water may place a strain on local aquifers.

3.3 Matrix

Table 3.1: Qualitative discussion of alternatives' criteria scores

Criteria	Alternative 1 – Ombolwanda and Kawegi	Alternative 2 – Ombolwanda and Munyu Maranatha Church	Alternative 3 – Kater and Kawegi	Alternative 4 - Kater and Munyu Maranatha Church	Alternative 5 – Ombolwanda and Kater
1. Houses within 1km	176 houses, or 80%	170 houses, or 77%.	185 houses, or 84%.	188 houses, or 85%.	169 houses, or 76%.
2. Distance to nearest road	Ombolwanda is 45m from the nearest road; Kawegi is 13m from the nearest road	Ombolwanda is 45m from the nearest road; Munya Maranatha is 34m from the nearest road	Kater is 150m from the nearest road; Kawegi is 13m from the nearest road	Kater is 150m from the nearest road; Munya Maranatha is 34m from the nearest road	Kater is 150m from the nearest road; Ombolwanda is 45m from the nearest road
3. Distance to latrines	No latrines within 100m.	2 Latrines 90m from Munyu Maranatha Church.	No latrines within 100m.	2 Latrines 90m from Munyu Maranatha Church.	No latrines within 100m.
4. Well usage overlap	Ombolwanda is 1.25km from 140 houses (63%). Kawegi is 1.25 km from 95 houses (43%). Overlap is 9% (20 houses). Predicted use: 120 users at Ombolwanda, 95 users at Kawegi, 6 users undetermined.	Ombolwanda is 1.25km from 140 houses (63%). Munyu Maranatha is 1.25 km from 102 houses (46%). Overlap is 21% (42 houses). Predicted use: 100 users at Ombolwanda, 100 users at Munyu Maranatha, 21 users undetermined.	Kater is 1.25km from 197 houses (89%). Kawegi is 1.25 km from 95 houses (43%). Overlap is 32% (71 houses). Predicted use: 111 users at Kater, 111 users at Kawegi.	Kater is 1.25km from 197 houses (89%). Munyu Maranatha is 1.25 km from 102 houses (46%). Overlap is 35% (78 houses). Predicted use: 111 users at Kater, 111 users at Munyu Maranatha.	Kater is 1.25km from 197 houses (89%). Ombolwanda is 1.25km from 140 houses (63%). Overlap is 69% (137 houses). Predicted use: 100 users at Kater, 100 users at Ombolwanda, 21 users undetermined.
5. Power source for pump	Ombolwanda has hand pumping and solar as potential power sources. Kawegi has tree cover but is close to the power grid, and therefore could have a handpump or electric pump.	Ombolwanda could have a handpump or solar pump. Munyu Maranatha Church could have a handpump or electric pump.	It is unknown what power sources Kater could have as it must be moved to a new location. Kawegi could have a handpump or electric pump.	It is unknown what power sources Kater could have. Munyu Maranatha Church could have a handpump or electric pump.	It is unknown what power sources Kater could have. Ombolwanda could have a hand pump or solar pump.

6. Data availability	There is sufficient data to immediately construct wells at Ombolwanda and Kawegi.	There is sufficient data to immediately construct a well at Ombolwanda and Munyu Maranatha Church.	Kater must be moved and there is insufficient data on its new potential location. There is sufficient data to immediately construct a well at Kawegi.	Kater must be moved and there is insufficient data on its new potential location. There is sufficient data to immediately construct a well near Munyu Maranatha Church	Kater must be moved and there is insufficient data on its new potential location. There is sufficient data to immediately construct a well at Ombolwanda.
7. Community Input					Community feels as if these two sites are too close to one another

Table 3.2: Quantitative scoring of alternatives by criteria

Criteria	Assigned weight	Alternative 1 – Ombolwanda and Kawegi	Alternative 2 – Ombolwanda and Munyu Maranatha Church	Alternative 3 – Kater and Kawegi	Alternative 4 - Kater and Munyu Maranatha Church	Alternative 5 – Ombolwanda and Kater
1. Houses within 1km	3	1	0	1	1	0
2. Distance to nearest road	2	1	1	-1	-1	-1
3. Distance to latrines	1	1	0	1	0	1
4. Well usage overlap	2	-1	-1	0	0	1
5. Power source for pump	1	1	1	0	0	1
6. Data availability	1	0	0	-1	-1	-1
7. Community Input	1	0	1	0	1	-1
Unweighted sum		**3**	**2**	**0**	**0**	**0**
Weighted score		**5**	**2**	**1**	**1**	**0**

3.4 Description of Comparison Results

In order to compare the alternatives and reach a decision on the most practical option, there must be a thorough analysis of all the criteria aforementioned and their implications.

3.4.1 Accessibility

First, user distance must be prioritized. Distance from households is arguably one of the most important criteria because it is an indication of user accessibility. Comparing the percentage of houses within 1km of the wells, Alternatives 1, 3, and 4 take the lead here, with Alternatives 2 and 5 performing marginally worse. Most of the alternatives would be serving a similar number of households within 1km. Alternatives 1, 3, and 4 are within a 1km distance of 80%, 84%, and 85% of households in the community, respectively. The difference between Alternative 1 and Alternative 4 is 9 houses, which is marginal enough to still consider Alternative 1 a strong candidate. Alternative 2 and 5 don't perform as well, serving 77% and 75% of the households. For the sake of thoroughness, a 1.25km distance (15-minute walk) will also briefly be discussed. For Alternatives 3 and 4, 100% of the households in Kibuon are 1.25km or less away from at least one well. For Alternative 1, 99% of all the households are 1.25km away, with only 6 houses being between 1.25-1.5km away. Alternatives 2 and 5 both are 1.25km away from 90% of the community. Alternatives 1, 3, and 4 are the best options for these metrics.

3.4.2 People Served

Another critical factor for choosing an alternative is the number of people each well in the alternative would serve and whether the populations served would be evenly distributed between the two wells (Criterion 5). If the number of households going to each well is drastically skewed, this may indicate a future difficulty to generate O&M funds for one of the wells depending on whether the funds are shared between the wells. The overuse of one well may also cause more accidents or damage, increasing the need for maintenance. Furthermore, analyzing the regions predominantly served by each well can shed light on the equality of access provided by the alternative and its potential social and regional impact. It can also give data on how much water would need to be pumped from each well, and whether the installed pumping rates could meet that demand by either hand, solar, or electric pump. Separately, this allows for an estimate of the wait time at each well and an approximation of the queue buildup. Therefore, the performance of each alternative in this criterion can have a drastic impact on the sustainability of the project and its integrity in preserving equality.

There are 221 households in total in the community. If considering a 1.25km radius for Alternative 1, Ombolwanda alone serves 140 houses (63%) and Kawegi alone serves 95 houses (43%), and the overlap is 9% (20 houses). It is probable that with overlap, usage will even itself to a more half-half distribution since households are more likely to go to the less crowded well. Accounting for this, Ombolwanda would have 120 users and Kawegi would have 95 users. The remaining 6 households outside of the 1.25km radius may use either well. Although it is not perfectly in half, this distribution is reasonable to avoid over-stressing the water table of a single well.

Alternatives 2, 3, and 4 all perform similarly to Alternative 1, with overlap percentages ranging from 9 to 15%. The distribution for Alternative 2 considering a 1.25km radius is very reasonable (140 houses for Ombolwanda alone and 102 houses for Munyu Maranatha alone), and the overlap is 21% (42 houses). Accounting for this overlap, the predicted household usage in Alternative 2 would be 100 users for Ombolwanda and 100 users for Munyu Maranatha, plus 21 houses that may use either well.

Alternatives that involve Kater are unique and have high overlap by nature because Kater alone is within 1.25km of 197 households (89% of the community). This is reflected in the results for Alternatives 3, 4, and 5. For Alternative 5, within 1.25km there are 197 houses (89%) from Kater alone and 140 houses (63%) from Ombolwanda alone, the overlap is 69% (137 houses), and the expected usage is the same as Alternative 2: 100 users at Kater and 100 users at Ombolwanda, with the remaining 21 users outside a 1.25km radius using either well. This overlap may actually be beneficial should either well become nonoperational since the remaining well would still be in close proximity to a large population. However, this alternative also only reaches 200 households within a 1.25km radius, whereas as previously mentioned, Alternative 1 reaches 215 households and Alternatives 3 and 4 reach all 221 households.

For Alternative 3, within 1.25km there are 197 houses (89%) from Kater alone and 95 houses from Kawegi alone with an overlap of 32% (71 houses). The predicted usage is 111 users at Kater and 110 users at Kawegi. For Alternative 4, the overlap is 35% (78 houses) and the expected usage is the same: 111 users at Kater and 110 users at Munyu Marantha. With all of this data, it becomes very difficult to quantify which alternatives perform the best, so predicted usage and overlap are analyzed separately. The even distribution of users to each well is relatively consistent across the alternatives; they all show an approximate half-half distribution so it is safe to assume that the effects of skewed distribution previously discussed would not take major effect. The remaining concern thus lies in ensuring equality of access and regional impact, which is reflected in the overlap percentages. There is less likely to be water access inequality if regions have access to not just one, but two wells. This is also ideal in the case that one well becomes dysfunction because it means most of the population will still be within a reasonable distance of the other well. Thus, the best performing alternative for this criterion is Alternative 5 at about 70%, followed by Alternatives 3 and 4 in the 30% range, and Alternatives 1 and 2 in the 10% and 20% range.

3.4.3 Construction

The next important consideration is the accessibility of the land for construction. The proximity of each well location to a main road will greatly affect the ability of a drill rig to access the desired site, and its status as cultivated or clear land may require additional work to prepare the land. Regarding roads, all the sites potential well sites considered are less than 50m away from a road except for Kater, which is 150m away. Alternatives 1 and 2 immediately take the lead with a nearby road less than 50m away for both their well sites since neither of them include Kater. Alternatives 3, 4, and 5 all include Kater, so they are at a larger disadvantage with the 150m road distance. Furthermore, the particular site that the travel team surveyed for Kater is actually within 780m of a well in a neighboring community which violates the Kenyan required standard of 800m between all wells. Therefore, the precise location of Kater will have to be slightly shifted, and there is little information about whether the shifted site will be cultivated or uncultivated, only that it will most likely still be more than 150m away from a main road. The team's original site assessment of Kater shows that the land is clear, and for all the other potential well sites the land is cultivated. Therefore, if Kater is cultivated then all the alternatives will have both wells on cultivated land. If Kater is on clear land, then Alternatives 3, 4, and 5 will have an advantage. However, due to the ambiguity of Kater at this stage, the safest assumption is that it is cultivated, so all alternatives perform the same in this aspect. Thus, based on road access, Alternative 1 and 2 take the lead for this criterion, and Alternatives 3, 4, and 5 are at the same disadvantage.

3.4.4 Solar Power and Electric Power Grid Access

For the well alternatives listed, there are three options for water pumps: manual hand pump, solar powered pump, and electric grid tied pump. Out of the three options, solar and grid tied pumps are more favorable than manual hand pumps because they have higher flow rates and can provide larger amounts of water to support the needs of the community. Currently, there is no a stepdown transformer located in Kibuon even though high voltage lines exist in the community; while the chapter's in country partner is currently inquiring about the government procedure to install a transformer and connect the well to the grid, currently the information is not available and it is not possible to know whether or not a grid tied electric pump is a feasible option. For the well alternatives where solar powered is being considered, more information is available since solar path data was collected on the assessment trip in June, so the well design process can begin without the need for additional information. Ombolwanda is currently the only well site with enough information to construct a reliable solar powered pump, so in terms of this criterion (power source for pump), any alternative with Ombolwanda received the highest score, because construction can begin with Ombolwanda while data is being collected for the second well site. For all other well sites, if design is to begin immediately without additional data collection, the only pump that can be installed in a manual hand pump which has major disadvantages compared to the two other pump types. Therefore, any alternative that does not have Ombolwanda as the first well option received a lower score. This puts alternatives 1,2, and 5 at a major advantage over alternatives 3 and 4.

3.4.5 Information Availability

Another major piece of information that is currently unavailable is the exact location of Kater, as previously mentioned, Kater is 780m from an existing well in a neighboring community, which is below the minimum distance 800m. Therefore, the location of Kater has to be shifted to a new location close by, so there is no information available for Kater for solar data, no location to conduct a hydrogeological study, or no easy way to assess construction accessibility data remotely. Therefore, for the data availability criterion, any alternative with Kater as one of the well locations received the lowest score possible. This puts alternatives 3,4, and 5 at a disadvantage compared to the other alternatives.

3.4.6 Summary

To summarize the results, it is beneficial to outline in which categories each alternative took the lead, had a slight disadvantage, and had a major disadvantage. It is also important to consider the relative weights of each category.

1. Alternative 1 – Ombolwanda and Kawegi
    - Advantage: User distance/accessibility, Road access, Latrines
    - Slight disadvantage: Security
    - Major disadvantage: Overlap

2. Alternative 2 – Ombolwanda and Munyu Maranatha Church
    - Advantage: Road access, Security

- Slight disadvantage: Latrines
- Major disadvantage: User distance/accessibility, Overlap

3. Alternative 3 – Kater and Kawegi
   - Advantage: User distance/accessibility, Latrines
   - Slight disadvantage: Overlap, Security
   - Major disadvantage: Road access

4. Alternative 4 - Kater and Munyu Maranatha Church
   - Advantage: User distance/accessibility, Security
   - Slight disadvantage: Overlap, Latrines
   - Major disadvantage: Road access

5. Alternative 5 – Ombolwanda and Kater
   - Advantage: Overlap, Latrines
   - Slight disadvantage: Security
   - Major disadvantage: User distance/accessibility, Road access

From this it is clear to see that Alternative 2 and 5 are the least favorable options because neither of them meets the standard set by the other wells for user distance/accessibility, the most important criterion. They also are disadvantaged regarding overlap and road access respectively, the other two major criteria.

Alternatives 3 and 4 are more favorable because they prioritize user distance/accessibility but are both slightly disadvantaged in overlap and majorly disadvantaged in road access. These criteria are heavily weighted so even though they do well in latrines and security, it does not suffice. While Alternative 1 also has a major disadvantage in overlap, it is at least superb in road access which is more than what the other alternatives offer. Latrines and security also fair well with Alternative 1.

Therefore, the conclusion is clear that Alternative 1 is the most practical and preferable alternative.

3.5 Preferred Alternative

Based on the assessment of every suggested alternative, Alternative 1 – Ombolwanda and Kawegi, is most preferable. Unlike other alternatives, it proposes sites that are ready for construction thanks to the sufficient information gathered regarding those two sites. it does not require additional measurements, tests or need for a reallocation of the sites.

Alternative 1 is the only alternative offering the option of constructing a solar pump powered well and an electric pump without the need of reallocating the well sites elsewhere as would be the case for the alternatives 3,4 and 5. Thanks to the high sun coverage of Ombolwanda of 11hours/day, Kibuon can have a well powered by solar panels. Kawegi, on the other hand, is strategically located 18m from the power grid, the closest distance of all the sites, which will facilitate the construction of an electric pump. In addition, Alternative 1 is closer to the road (less than 50m away) which facilitates the access to the wells at all seasons and accommodates the access of the drill rig to the desired site. Both wells would then meet the needs of the community in terms of water quality and quantity. The decision as to which type of well will be built will depend on the amount raised for this project. Furthermore, the wells proposed in Alternative 1 have no latrines within 100m hence considerably reducing the risk of contamination and ensuring the provision of quality water.

Overall, Ombolwanda and Kawegi can serve approximately all the households in the Kibuon community by themselves. Both sites account for a distribution of 120 houses for Ombolwanda and 95 houses for Kawegi good enough not to exhaust the usage of a single well.

4. Next Steps

Looking into the future of the Kibuon project, the long-term goal is to provide the community with additional water infrastructure to meet their needs. The Kibuon Projects Committee initially proposed the construction of several wells in order to meet all quadrants of the community and provide them with continual potable water access. The project scope for this individual trip will likely only involve the construction of one solar powered well and the Ombolwanda location. This is due to the fact that there is sufficient daily sunlight at this location and all factors are known. Since Kawegi is the second preferred location, this trip will involve the assessment of potential power sources for the site. Kawegi faces the challenge of poor sunlight exposure (see section 5.2.1.3) but proximity to a potential grid. This trip will involve the assessment of nearby sites and their solar potential as well as the technical feasibility of installing a transformer.

Despite the fact Kawegi is the preferred location, other potential sites will still be assessed and considered. Kawegi is 18m from the grid, while Munyu Maranatha is 29m from the grid. Following a full assessment of the cost of adding a transformer, given other factors of accessibility, Munyu Maranatha may be selected instead. Additionally, there is the potential to install a hand pump first at either location, and then convert it to an electric pump. The Kater location currently overlaps with preexisting wells in nearby communities, but given a small move, could become a feasible future option for a solar pump.

In the near term, the project team will hire a licensed driller to conduct a hydrogeological study at the top well sites prior to the May 2020 trip. The results of this study will determine the exact specifications for the well design.

Despite the fact Kawegi is the preferred location, other potential sites will still be assessed and considered. Kawegi is 18m from the grid, while Munyu Maranatha is 29m from the grid. Following a full assessment of the cost of adding a transformer, given other factors of accessibility, Munyu Maranatha may be selected instead (especially if the results of the hydrogeological study reveal this location will have a higher predicted flowrate). Additionally, there is the potential to install a hand pump first at either location, and then convert it to an electric pump. The Kater location currently overlaps with preexisting wells in nearby communities, but given a small move, could become a feasible future option for a solar pump.

Future trips (likely in May 2021) will involve the drilling and installation of a second well at the Kawegi site, as well as the possible assessment of a future third well site if necessary.

5. List of Attachments

5.1 Attachment A: Drawing Package

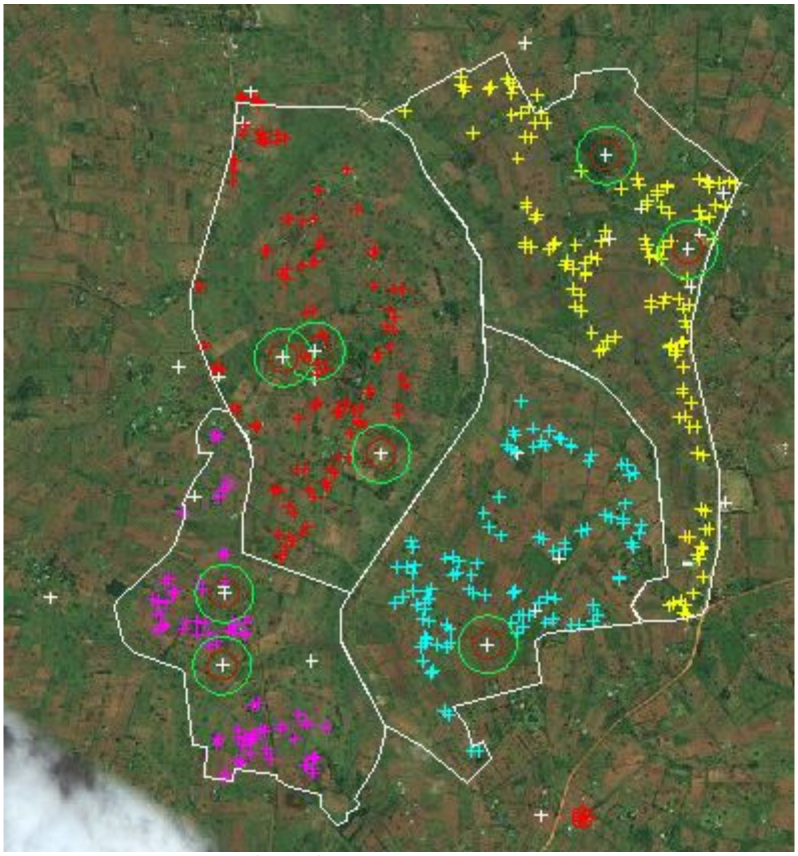
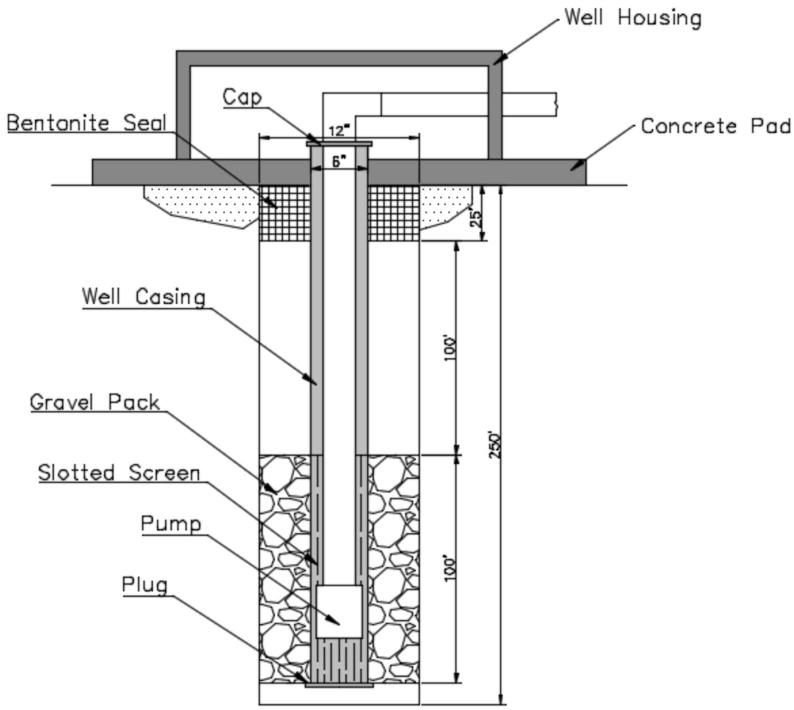
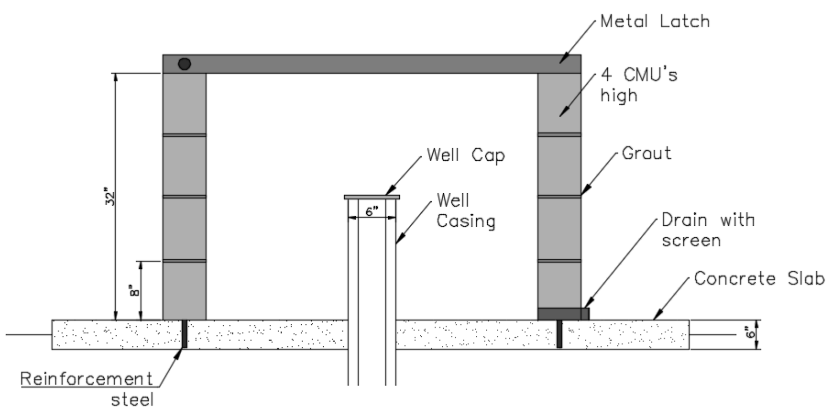
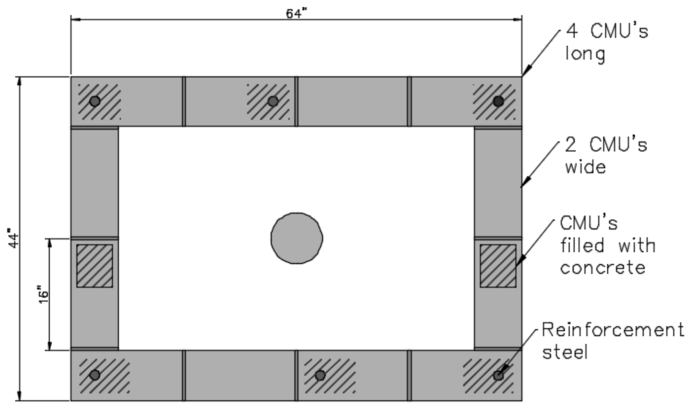


Figure 5.1: Initial map and site plan transferred from Google Earth to Civil 3D


Well Housing
Cap
Bentonite Seal
Concrete Pad
12"
6"
25'
Well Casing
100'
250'
Gravel Pack
Slotted Screen
Pump
Plug
100'


Metal Latch
4 CMU's high
Grout
Well Cap
Well Casing
6"
32"
8"
Drain with screen
Concrete Slab
6"
Reinforcement steel

Side View


64"
44"
16"
4 CMU's long
2 CMU's wide
CMU's filled with concrete
Reinforcement steel

Top View

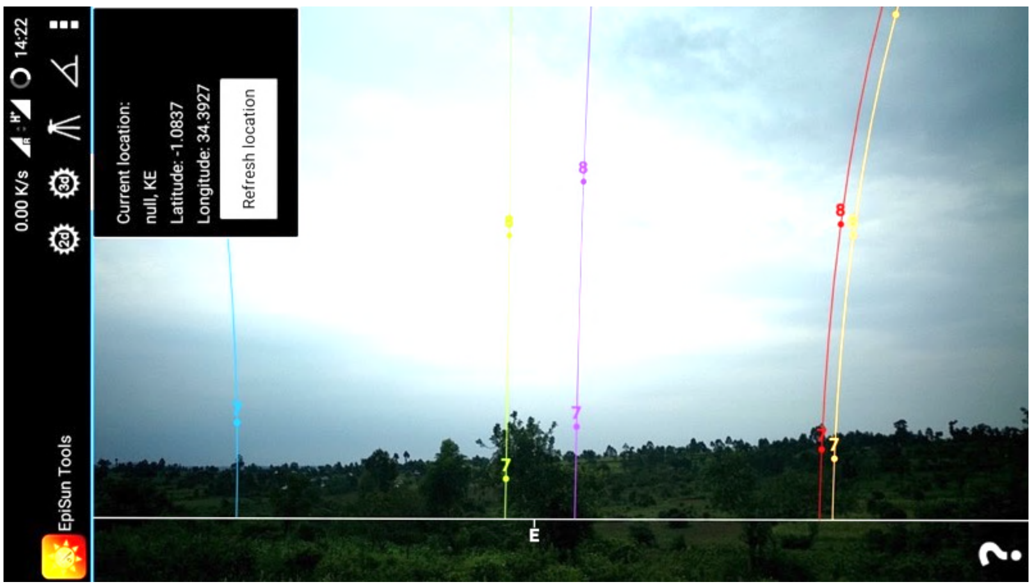
5.2 Attachment B: Data from Previous Assessment Trip

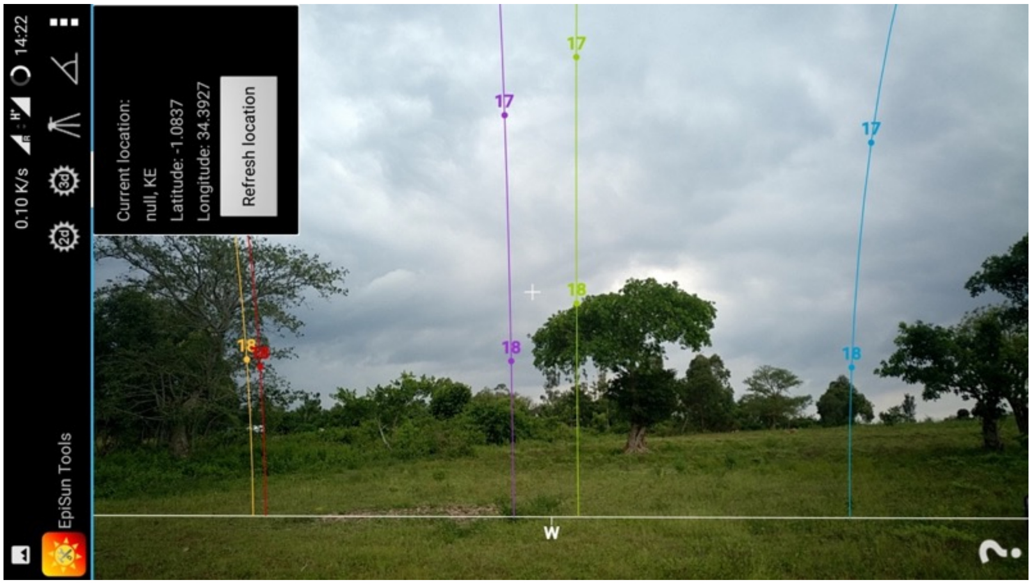
5.2.1 Well Site Assessment

Data from the May/June 2019 Assessment trip is attached below for the four potential well sites that were not eliminated by latrine locations or proximity to other preexisting wells. The map of all remaining potential well sites is shown in Figure 1.3. Below the site assessment data will be presented for each of the seven assessed well sites. Images from EpiSun Tools have the following sun traces: winter = blue, spring = green, summer = yellow, autumn = violet, current day (June 9-10, 2019) = red.

5.2.1.1 Kater

Sector	Kibuon A – Nyamilu
GPS Coordinates	-1.086971, 34.394797
Soil Type	Silty Gravel with Sand (GM): Coarse grained soil, ~%35 gravel, ~%25 sand, ~% 40 fines
Electric Utility	N/A
Solar Survey	Very few shading issues at dawn throughout the year. In the summer this site will experience shading beginning around 17:00.
Accessibility	No latrines or homes within 100m.

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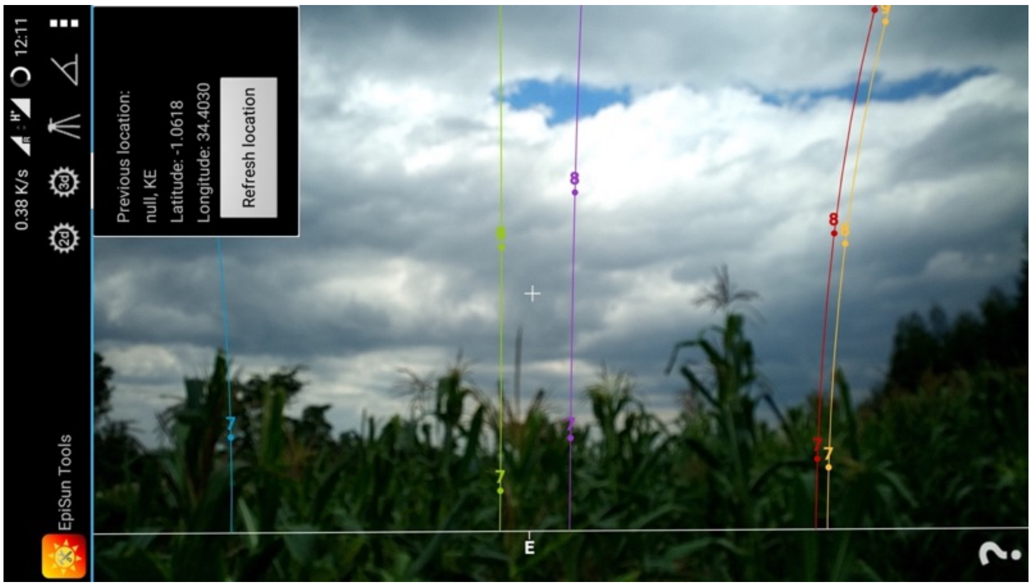
Current location:
null, KE
Latitude: -1.0837
Longitude: 34.3927
Refresh location
EpiSun Tools
17
18
W

5.2.1.2 Near Munyu Maranatha Church

Sector	Kibuon B – Sindyania
GPS Coordinates	-1.080579, 34.404386
Soil Type	Silty Gravel with Sand (GM): Fine grained soil, Brown, ~55% fines, ~35% gravel, ~15% sand, organic matter present
Electric Utility	There is an electric utility pole at a heading of 28° and distance of 29m.
Solar Survey	Very few shading issues at dawn throughout the year. In the summer this site will experience shading beginning around 14:30.
Accessibility	Good access for a drill rig due to the presence of a wide road running past Maranatha Church. The site is ~30m from the main road and the nearest latrine is ~80m away.



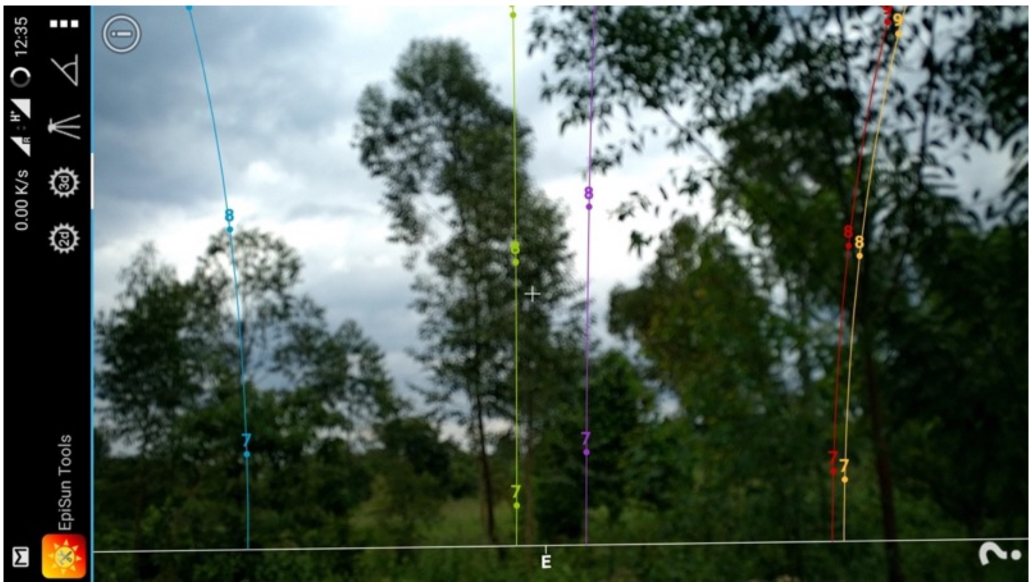

1.12 K/s
12:11
EpiSun Tools


0.00 K/s
12:11
EpiSun Tools


0.30 K/s
12:11
EpiSun Tools
Previous location:
null, KE
Latitude: -1.0618
Longitude: 34.4030
Refresh location

5.2.1.3 Kawegi

Sector	Kibuon B – Sindyania
GPS Coordinates	-1.077636, 34.401824
Soil Type	Silty Gravel with Sand (GM): Coarse grained soil, ~45% fines, ~35% gravel, ~20% sand
Electric Utility	There is an electric utility pole at a heading of 236° and distance of 18m.
Solar Survey	There are significant shading issues in the morning ending around 8:00 or 9:00 in the winter and spring. These shading issues continue until 10:00 in the summer. In the winter there are shading issues from 12:00–14:00. In the evening there are relatively few shading issues throughout the year which begin around 17:00.
Accessibility	Good road access, but uneven terrain with some trees and boulders. Currently cultivated. Home nearby but no marked latrines within 100m.

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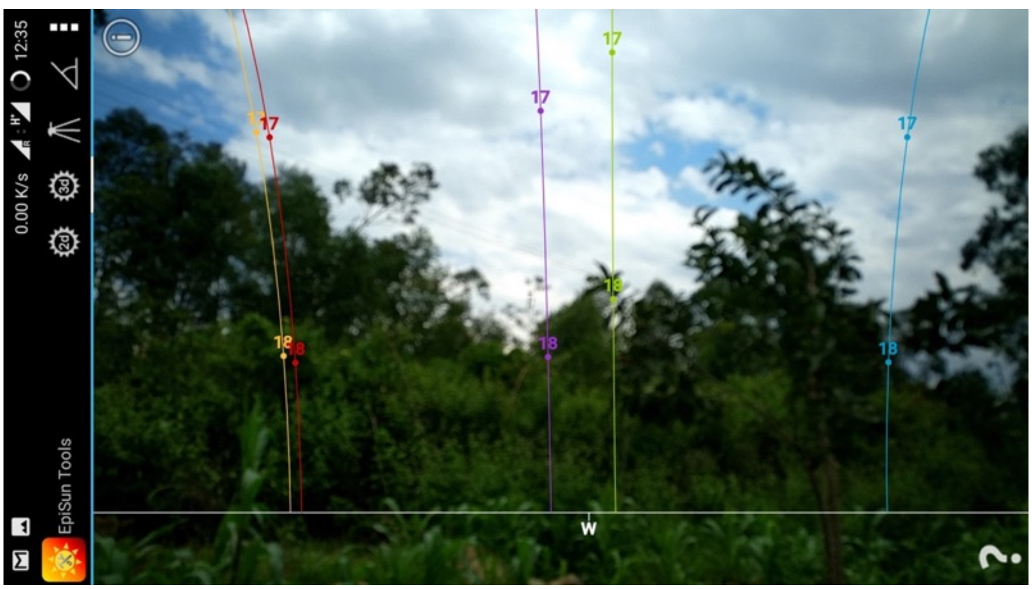
EpiSun Tools
10
9
8


12:35
0.21 K/s
EpiSun Tools
11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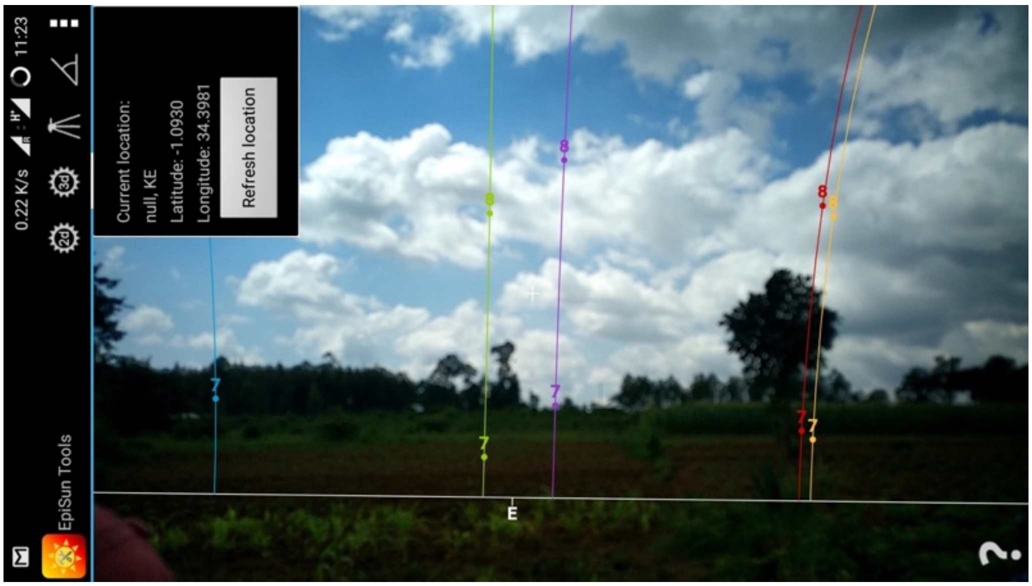
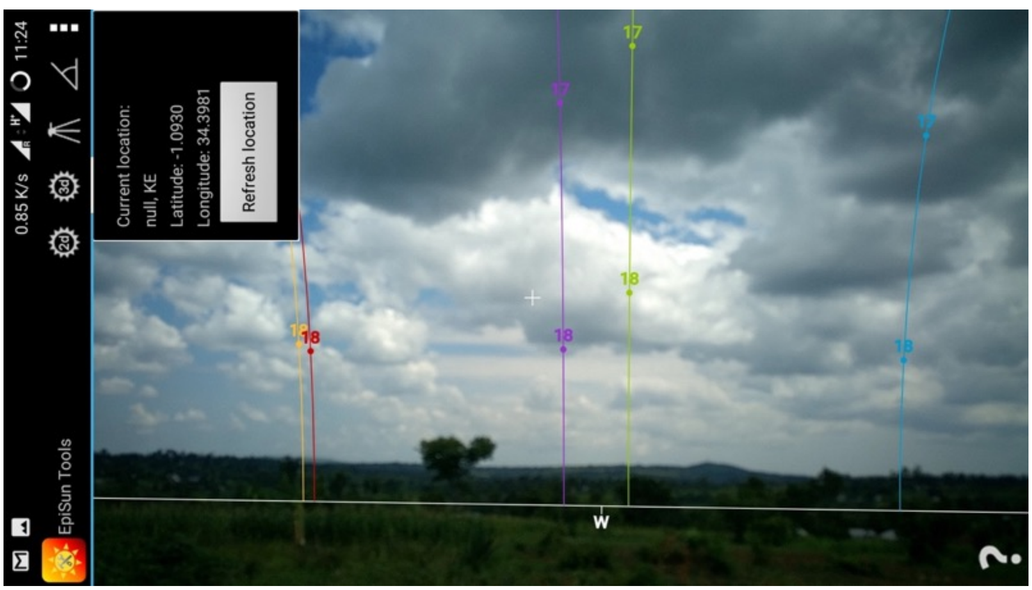
17
18
W

5.2.1.4 Near Ombolwanda

Sector	Kibuon C – Ombolwanda
GPS Coordinates	-1.092940, 34.398123
Soil Type	Gravelly Silt with Sand (ML): Fine grained soil, Brown, ~50% fines, ~35% gravel, ~15% sand
Electric Utility	N/A
Solar Survey	There are no significant shading issues throughout the year. In the summer there may be some shading until 8:00.
Accessibility	Access to wide road next to property with no major obstructions. Property currently cultivated. No latrines or houses within 100m.





5.2.2 Water Quality Data

	pH	TDS (ppm)	Hardness (ppm)	Alkalinity (ppm)	Nitrate (ppm)	Nitrite (ppm)	Phosphate (ppm)	Ammonia (ppm)	Metals, bivalent (ppb)	Total Coliform (CFU)	*e.coli* (CFU)
Kenyan Standard[6]	6.8-8.5	1500	500	No standard	10	3*	No standard	0.5	Cu: 100 Co: No standard Zn: 5000 Cd: 5 Ni: 70* Hg: 1	0	0
Wadhanyim	7.2	66	20	180	0	0	5	0.5	< 10	TMTC	16 15 15
Ogwedhi	7.2	113	250	180	< 0.5	0.15	5	0	<10	TMTC	> 20 11
Hand Dug Deep Well	6.8	81	120	120	0	0	5	0.5	<10	TMTC	1 1 2
Koyanda	6.2	40	50	40	2	0.15	15	0.5	<10	TMTC	44 40 31
Kibuon	6.8	61	120	80	0	0	15	1.0	<10	TMTC	30 > 30 > 30
Kondwat	6.8	108	250	180	0	0	5	0	<10	TMTC	8 12 18
Kapaul	6.8	58	120	40	0	0	5-15	0.5	<10	TMTC	8 12 11
Riamanyama	6.2	42	50	40	0.5	0	15	0	<10	TMTC	25 29 23
Wiyao	6.8	76	120	80	0	0	5	3-6	<10	TMTC	1 4 5
MCA Taps	8.4	148	425	240	0	0	5	0.5	50-100	2 3 1	0 0 0
Bondo A – Hope College EWB	6.8	171	425	240	0	0	5	0	<10	N/A	N/A
Lela B – OSU/SF Prof EWB	6.8	128	250	240	0	0	30	0	100	N/A	N/A
Bondo Kiosk	8.4	133	250	240	0.5	0	5	0.5	100	N/A	N/A

[6] Guidelines On Drinking Water Quality And Effluent Monitoring, Kenya Water Services Regulatory Board. If a Kenyan standard could not be found, the entry is marked with * and the WHO standard was used.

5.3 Attachment C: Pictures

5.3.1 Kuria Well Site

Figure 5.2: Kuria Tank Stand

Figure 5.3: Electric Pump & Well

Figure 5.4: Private Electric Pump Installed by WECCO

5.3.2 Lela Hand Pump Assessment

5.4 Attachment D: Material Pricing Data and Detailed Cost Estimates

Base well cost		
Item	**Cost (USD)**	**Source**
Hydrogeological survey	$ 750	WECCO meeting
Drilling (160m)	$ 16,000	WECCO meeting
Water Quality testing	$ 250	Kiburanga post trip report
Well drilling permit	$ 900	Kiburanga post trip report
Furnish and Install casing and screen	$ 2,500	Lela post trip report
Furnish and install gravel pack	$ 600	Lela post trip report
Total cost	**$ 21,000**	

Solar Powered Pump		
Item	**Cost (USD)**	**Source**
Solar electric pump	$ 1,700	AltE
Solar panels (6 x 300W panels)	$ 1,074	AltE
Total cost of well	**$ 23,774**	

Grid tied Electric Pump		
Item	**Cost (USD)**	**Source**
Electric pump	$ 500	Davis Shirtliff
Installation of transformer	2,000-5,000	Kenya Daily Nation Newspaper
Total cost of well	**23,500-26,500**	

Manual Handpump		
Item	**Cost (USD)**	**Source**
Hand pump	1200-1800	WECCO meeting
Concrete base for manual pump	$ 100	WECCO meeting
Total cost of well	**22,300-22,900**	

Tank Cost		
Tank size	**Cost**	**Source**
10,000L	$ 750	Migori hardware store
15,000L	$ 1,346	Toptank
24,000L	$ 2,288	Toptank

Item	Store Location	Unit(s)	Price (KSH)	Note
PVC Downspout	Kion Hardware	#	???	
Gutter Brackets	Kion Hardware	#	???	
3" pipe	Kion Hardware	13ft long sections	???	
4" pipe	KIon Hardware	20ft long sectios	???	
Gutter	Kion Hardware	16ft long sections	???	
Metro PVC Primer & Glue	Kion Hardware	Container of # oz	???	Not in stock/store
10,000L Poa Tank	Kion Hardware	Tank	78,000	
10,000L KenTank	Kion Hardware	Tank	76,000	
Simba Cement	Kion Hardware	## lb bag	700	
DumuBlue Cement	Kion Hardware	## lb bag	600	
Sand	Kion Hardware	medium load (10 tons)	18,000 to deliver (price unclear)	
Gravel/Aggregate	Kion Hardware	medium load (10 tons)	20,000	
#10 Rebar	Kion Hardware	40 foot section	660	
#8 Rebar	Kion Hardware	40 foot section	500	
Concrete Mixer + Operator	Kion Hardware	day		
CMU 6"X 9"	Kion Hardware	brick	70	
CMU 9"X 9"	Kion Hardware	brick	80	
Wire Mesh Light Gague	Kion Hardware	sheet (4' X 8')	500	
Wire Mesh Medium Gague	Kion Hardware	sheet (4' X 8')	700	
Wire Mesh Heavy Gague	Kion Hardware	sheet (4' X 8')	1200	
Spade	Kion Hardware	unit	500	
Drillbits	Kion Hardware	unit		Not in stock/store
1 1/4" Metal Pipe	Kion Hardware	13ft or 14ft long sections	450	
10,000L KenTank	Ritu Enterprises	tank	73,000	
5,000L KenTank	Ritu Enterprises	tank	32,000	
2,000L KenTank	Ritu Enterprises	tank	13,500	
10,000L TopTank	Ritu Enterprises	tank	73,000 ± 1,000	
5,000L TopTank	Ritu Enterprises	tank	32,000 ± 1,000	
2,000L TopTank	Ritu Enterprises	tank	13,500 ± 1,000	
Metal Reducer	Ritu Enterprises	unit	???	
PVC Downspout	Ritu Enterprises	unit	???	
Cement Mixer & Operator	Ritu Enterprises	day	7,000	
Binding Wire	Ritu Enterprises	roll (25 kilos)	3,200	
Binding Wire	Ritu Enterprises	length (1 kilo)	150	
Consumer Meter	Ritu Enterprises	unit	3,500	
Master Meter	Ritu Enterprises	unit	???	

5.5 Attachment E: Additional Decision Criteria Considered

In addition to the criteria discussed in Section 3.1, the team identified other factors that could inform the selection of preferred alternatives. They were not included in our finalized list because the five alternatives performed similarly in these categories. In other words, the differences between the alternatives were negligible, which would result in equal scores.

1. **Distribution of Household distances**

   This metric describes the number of households within 500 meters, 800 meters, 1000 meters, and 1200 meters of an alternative. It also describes the distances from each well location to each household. Even though the individual wells had different distance distributions, it can be seen in the chart of alternatives that all alternatives had a similar distribution of household distances. Therefore, this category was not included in the final comparison criteria.

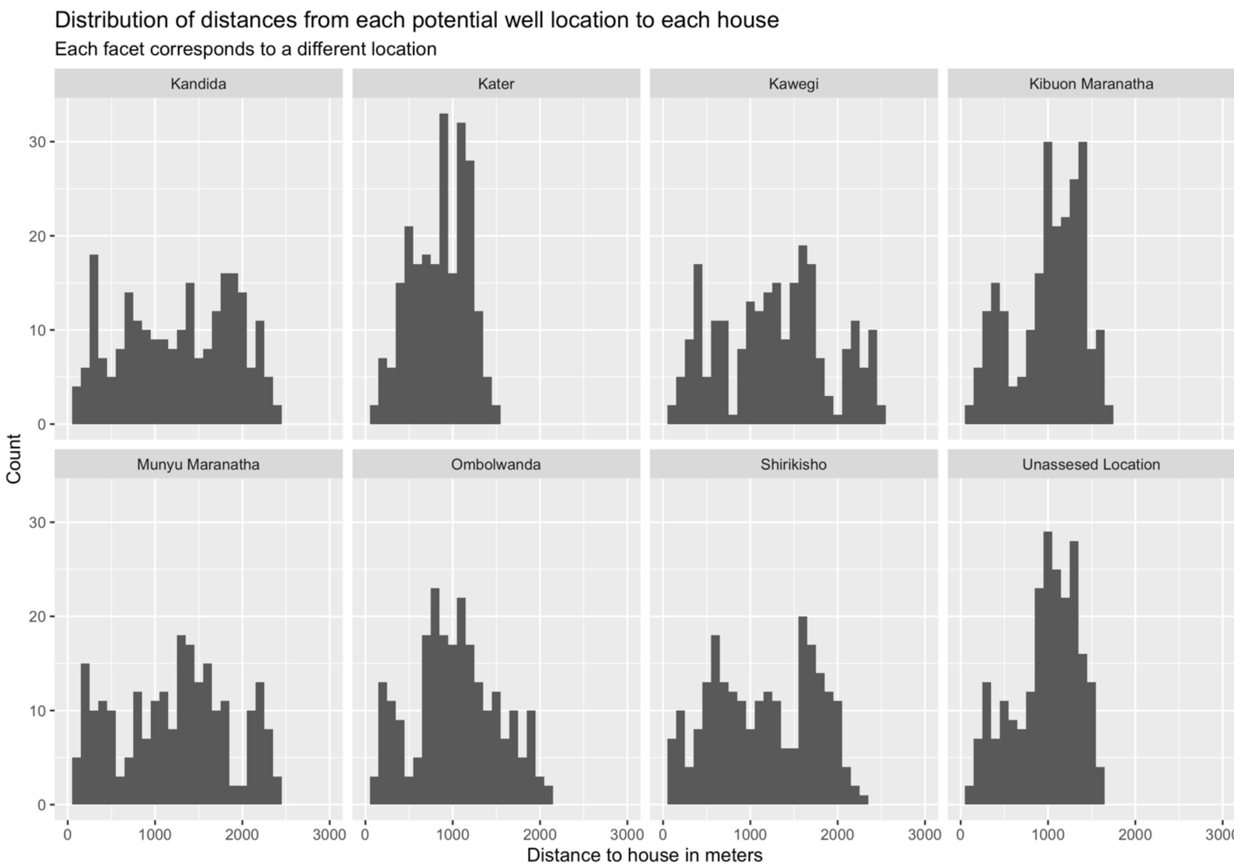


Figure 5.5: Distribution of distances from each well location to each house

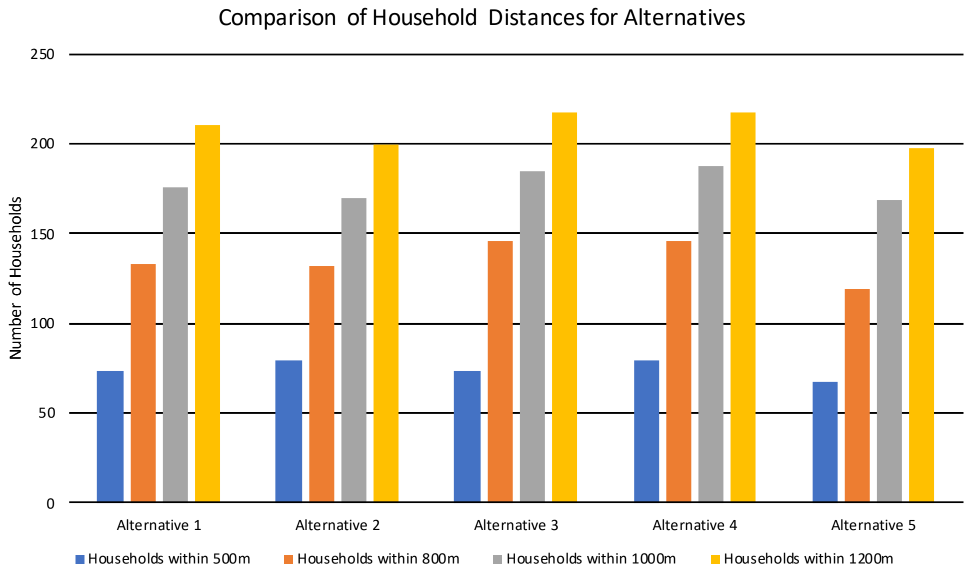


Figure 5.6: Chart comparing the number of houses within 500m, 800m, 1000m, and 1200m of either well in each alternative.

2. **Average distance from households to alternative**

   This metric reports the average distance between all house compounds and the alternative. Because community members will likely visit the well nearest to them, the average is calculated using the distance of the well closest to each household. Every alternative had a similar average distance of approximately 700m, so this was not included in the final comparison criteria.

3. **Distance from Farthest Household**

   This metric indicates the maximum distance between a household and any of the wells. The distance was determined on Google Earth using the "measure" tool and thus measures absolute distance, not distance via roads. All alternatives had a farthest distance between 1.2km and 1.7km.

4. **Unobstructed Land**

   This metric was designed to specify whether or not the potential well site was cleared or if it was occupied by either crops, trees or other factors that could obstruct the construction of a well at that location. However, all the well sites were found to be cultivated land and therefore received the similar scoring and were excluded from the final comparison criteria.

5. **Immediately nearby homes (Security of system)**

   This metric indicates whether there are houses nearby, which could affect the security of the well. If there are houses around the well site, that site would presumably be safer because there would be more activity and witnesses around the well that would deter vandalism or theft. The community has invested their own time and money into the well, so nearby residents are more likely to discourage or prevent theft they saw it occurring. The distances were determined on Google Earth by drawings circles around each well site in each alternative. Every alternative had homes within approximately 100m, so it was not included in the final comparison criteria.

Table 5.7: Qualitative discussion of additional criteria considered

Consideration	Alternative 1 – Ombolwanda and Kawegi	Alternative 2 – Ombolwanda and Munyu Maranatha Church	Alternative 3 – Kater and Kawegi	Alternative 4 - Kater and Munyu Maranatha Church	Alternative 5 – Ombolwanda and Kater
1. Distribution of Household distances	See Figure 5.6				
2. Average distance to homes	701.6 m	714.6 m	668.5 m	650.3 m	736.5 m
3. Distance of farthest household to well	1.5 km (household in Kibuon A)	1.67 km (household in Kibuon A)	1.24 km (household in Kibuon A)	1.25 km (household in Kibuon D)	1.48km (household in Kibuon B)
4. Unobstructed land (cultivated land)	Both cultivated	Both cultivated	Kawegi is cultivated land. Kater: Unknown	Both cultivated	Ombolwanda is cultivated Kater: Unknown
5. Immediately nearby homes	Kawegi: nearest home 105m. Ombolwanda: nearest home 103m.	Ombolwanda: nearest home 103m. Munyu: nearest home 62m away.	Kater: nearest home 111m away. Kawegi: nearest home 105m.	Kater: nearest home 111m away. Munyu: nearest home 62m away	Kater: nearest home 111m away. Ombolwanda: nearest home 103m

5.6 Attachment F: Kenyan Water Laws and Standards

The Kenya Water Act, passed in 2002 and last updated in 2016, contains a number of relevant regulations.[7]

1. **Permitting:** Section 26 states that a permit is not required for "any development of ground water," so long as the development is not located within 100 meters of surface water or "within a ground water conservation area." All potential well sites in Kibuon would thus not require permitting.

2. **Notice:** Section 45, or the Fourth Schedule, details the process of the Abstraction of Ground Water, regardless of if a permit is required. It dictates that "no person shall construct or begin to construct a well without having first given to the [Kenya Water] Authority notice of his intention to do so. Additionally, the person constructing a well "shall keep a record of the progress of the work, which shall include:
    a. measurements of the strata passed through and specimens of such strata
    b. measurements of the levels at which water was struck
    c. measurements of the quantity of water obtained at each level, the quantity finally obtained and the rest level of the water."
    d. Any person authorized by the Authority shall have free access to the well and collected records.

3. **Records:** A person constructing a well shall, within one month of the cessation of the construction, send to the Authority
    a. a complete copy of the record, together with the specimens referred to in the record; and particulars of any test made, before such cessation of the construction, of the yield of water, specifying
        i. the rate of flow throughout the test and the duration of the test
        ii. where practicable, the water levels during the test and thereafter until the water has returned to its natural level; and
        iii. a statement of whether, in his opinion (as determined by tasting) the water is suitable for drinking or is highly mineralized, as the case may be; and (d) if required by the Authority, such water samples as it may consider necessary. The constructor shall file with the Authority a statement sworn or affirmed specifying in detail the manner in which such work was done. The statement shall be filed within thirty days after the completion of the work.
    b. Form can be found online here[8]

4. **Waste:** No person shall cause any groundwater to be wasted, except for the purpose of testing the supply or cleaning/repairing the well. This includes:
    a. abstract from any well water in excess of his reasonable requirements and which he cannot use in a reasonable and beneficial manner
    b. conduct the water from any well through any channel or conduct so that more than twenty per cent of the water is lost between the point of appropriation and the point of beneficial use (No person shall permit the waste of more than 20% of the water in conducting the water from the point of appropriation of the well water to the point of beneficial use)
    c. use any water from any well for the purpose of domestic use or the watering of stock, except where such water is carried through pipes fitted with float valves or other satisfactory means of control, to prevent waste.

5. **Contamination:** "Every person abstracting ground water by means of a well shall, in order to prevent contamination or pollution of the waste:
    a. effectively seal off to a sufficient depth any contaminated or polluted surface or shallow water in rock openings or soft broken ground
    b. effectively seal the top of the well between the surface casing and the internal pump column, and the suction or discharge pipe
    c. dispose of all return or wastewater by means other than by return to the well

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[7] Kenya Water Act 2016
[8] https://wra.go.ke/wp-content/uploads/2019/05/Completion_Certificate.pdf

d. extend the well casing to a point not less than twenty centimeters above the elevation of the finished pump house or pump pit floor
e. use either welded or screw type well joints on the casing, if made of metal
f. dispose of effluents or drainage from any household, stable, factory, trade premises or other premises in such a manner as will prevent any such effluent or drainage from reaching such seal or ground water"

6. **Other Wells:** Although there is no hard and fast rule requiring that wells be a certain distance apart according to the 2016 Kenya Water Act, there is a chance of negatively impacting another well's water supply when a new well is drilled within 800m. According to the 2012 Kenya Water Act,[9] "Where any well is being constructed within 800 meters of an existing well, the Authority may by notice require the person constructing the well to apply tests, to be specified in the notice, to the existing well and to supply to the Authority the particulars of the results of such tests including the rate of pumping and rest levels of water.

[9] Kenya Water Act 2012