USAID/Uganda Water Infrastructure Project

COST-BENEFIT ANALYSIS

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USAID/UGANDA WATER INFRASTRUCTURE PROJECT

COST-BENEFIT ANALYSIS

Final Report

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Photo Credit: Flickr. Tine Frank. "Solar powered borehole provides water during severe drought"

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ABBREVIATIONS AND ACRONYMS

CBA	-	Cost-Benefit Analysis
CPI	-	Consumer Price Indices
DALY	-	Disability-Adjusted Life Year
DHS	-	Demographic and Health Survey
FEWS NET	-	Famine Early Warnings System Network
GBV	-	gender-based violence
GNI	-	Gross National Income
ha	-	hectares
kg	-	kilograms
KII	-	Key Informant Interview
KWACM	-	Karamoja Water Access Cost-Benefit Analysis model
MIRR		Modified internal rate of return
MoWE	-	Ministry of Water and Environment
NPV	-	Net Present Value
O&M		Operations and maintenance
PV	-	Present Value
QALY	-	Quality-Adjusted Life Year
RWSSD	-	Rural Water Supply and Sanitation Department
TLU	-	Total Livestock Unit
UBOS	-	Uganda Bureau of Statistics
UGX	-	Ugandan Shilling
USAID	-	Unites States Agency for International Development
USD	-	United States Dollar
VSL	-	Value of a Statistical Life
VSLY		Value of a Statistical Life year
WASH	-	water, sanitation, and hygiene

EXECUTIVE SUMMARY

USAID has been involved in development work in Uganda since the early 1960s and has provided significant support to the country's water sector over the years. The water sector has been a priority area for USAID in Uganda due to the country's significant water resource challenges, including inadequate access to safe water and poor sanitation facilities.

Karamoja is a sub-region located in northeastern Uganda, bordering South Sudan and Kenya, and home to around 1.2 million people with more than half the population comprised of women and children below the age of 18. Limited access to clean water is a significant challenge in Karamoja resulting in a high incidence of waterborne diseases. In addition, the lack of water resources has led to low agricultural productivity and frequent food shortages. To help address some of the water stress related challenges faced in Karamoja, USAID/Uganda is considering a resilience and water, sanitation, and hygiene (WASH) activity. As a precursor to that, USAID/Uganda mission tasked the USAID/Learning, Evaluation and Analysis project (LEAP III) to conduct cost-benefit analysis (CBA) of four different water infrastructure technologies: (1) boreholes with handpumps, (2) boreholes with solar pumps, (3) subsurface storage (sand dams), and (4) surface storage (valley tanks).

CBA is a widely used tool to evaluate the economic feasibility of public projects and policies. The LEAP III team developed a model, called the Karamoja Water Access CBA Model (KWACM) to estimate the returns to investments in these four technologies. For each benefit and cost stream, we estimated the impact using different approaches including literature review, secondary data analysis, and key-informant interviews (KIIs). The LEAP III team, in consultation with USAID/Uganda, identified five main streams of benefits: 1) time to collect water benefits (opportunity cost of time), 2) health benefits (reduction in morbidity and mortality), 3) educational benefits (increased school enrollment and attendance), 4) agricultural benefits (increased crop yield from irrigation and reduced livestock mortality), and 5) gender based violence benefits (decrease in instances of gender based violence due to a decrease in time spent traveling to collect water). For costs, the LEAP III team estimated the capital and operations and maintenance costs for the four technologies.

The analysis finds that three of the four technologies have high returns. Borehole with handpump, borehole with solar pump and sand dam all have benefit-cost ratios that exceed two (every dollar invested returns over two dollars in economic benefits), driven by health benefits and agricultural benefits. On the other hand, the valley tank has a benefit-cost ratio lower than one, driven by high upfront installation costs, suggesting that it is currently not a worthwhile investment.

1. BACKGROUND

Karamoja is a sub-region located in northeastern Uganda, bordering South Sudan and Kenya.[1] It comprises eight districts: Abim, Amudat, Kaabong, Kotido, Moroto, Nabilatuk, Nakapiripirit, and Napak. Around 1.2 million people reside in Karamoja, with more than half the population comprised of women and children below the age of 18. Agriculture is the primary livelihood in the region, with 84 percent of communities reporting crop farming as the major economic activity.[2] Most of the agriculture is subsistence, with low productivity levels relying on rainfed agriculture. Major staple food crops include cassava, millet, maize, potatoes, rice, and sorghum.[3] Second to crop farming, livestock rearing accounts for 10 percent of primary livelihoods, largely concentrated in the more arid climate zones of Karamoja. It is a semi-arid region with low and erratic rainfall, making it one of the driest regions in Uganda. In part due to its harsh climate and long history of conflict,[4] Karamoja remains the least developed region in Uganda, with income poverty, food poverty, and illiteracy affecting 60 percent, 70 percent, and 68 percent of the population, respectively.[5]

Access to clean water is a significant challenge in Karamoja. Limited access to clean water has resulted in a high incidence of waterborne diseases such as cholera, diarrhea, and typhoid fever. In addition, the lack of water resources has led to low agricultural productivity and frequent food shortages, exacerbating poverty and malnutrition challenges. The dire health conditions in Karamoja are further aggravated by gender-based violence, which is often linked to water collection. Women and girls are often responsible for collecting water, and the long distances they must travel to access water sources make them vulnerable to violence and sexual assault. The lack of locally accessible water resources, therefore, has far-reaching implications for the health, agricultural productivity, and safety of the Karamojong people.

USAID/Uganda is considering a water infrastructure activity in Karamoja. As a precursor to that activity, USAID/Uganda has asked the Learning, Evaluation and Analysis project (LEAP III) to conduct a cost-benefit analysis (CBA) focusing specifically on the incremental costs and benefits of four different water infrastructure technologies: (1) boreholes with handpumps, (2) boreholes with solar pumps, (3) subsurface storage (sand dams), and (4) surface storage (valley tanks). The results of this analysis will be used to inform a subsequent feasibility study and, ultimately, the types of water technology that are selected to be constructed within each target catchment area. This report is organized as follows: Section Two provides a background to the project, describes the features of an ex-ante CBA, and presents a discussion of the technology identification, specification, and benefit estimation. Section Three presents the data sources used in conducting the CBA. In Section Four, we discuss our main assumptions. Section Five presents the main results of the CBA, followed by the findings of a sensitivity analysis. Sections Six and Seven conclude with a discussion of the findings and recommendations.

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[1] See Annex 1

[2] Uganda Bureau of Statistics. "Uganda National Household Survey 2016/2017 Report." 2017.
Uganda Bureau of Statistics. "Northern Region – Parish Level Profiles (Census 2014)." 2019.
Uganda Bureau of Statistics. "Population By Sex For 146 Districts." 2022.

[3] Uganda Ministry of Water and Environment. "Awoja Catchment Management Plan." 2015.

[4] United Nations Population Fund. "Leaving no one behind in Karamoja." Population Matters, Issue 07, August 2018.

[5] Famine Early Warnings System Network. "Karamoja Enhanced Market Analysis." 2016.

2. PROJECT DESCRIPTION

USAID has been involved in development work in Uganda since the early 1960s, providing significant support to the country's water sector over the years. The water sector has been a priority area for USAID in Uganda due to the country's significant water resource challenges, including inadequate access to safe water and poor sanitation facilities. Uganda also faces challenges related to water governance, water scarcity, and climate change, which have led USAID to prioritize efforts to improve the management of water resources, expand access to clean water and sanitation services, and promote sustainable water use practices.

USAID has worked with a range of partners in Uganda to implement water sector programs, including government agencies, NGOs, and private sector organizations. These programs have included initiatives focused on improving water supply infrastructure, promoting sustainable water management practices, strengthening water governance, and expanding access to safe drinking water and sanitation services in rural and urban areas. As part of the US government's Global Water Strategy 2022-2027, Uganda was designated as one of the high-priority countries in Africa.[6]

To help address some of the challenges faced in Karamoja, USAID/Uganda is considering a resilience and water, sanitation, and hygiene (WASH) activity that would support the improved functionality and efficient utilization of existing water sources and the expansion of access through rehabilitation or construction of new water sources.[7] While the Activity will ultimately contain several components, this CBA focuses specifically on the incremental costs and benefits of four different water infrastructure technologies: (1) boreholes with handpumps, (2) boreholes with solar pumps, (3) subsurface storage (sand dams), and (4) surface storage (valley tanks). The Activity is expected to implement interventions within the boundaries of three water catchment areas that cover the vast majority of the Karamoja region: Lokok, Awoja, and Lokere. As such, the beneficiaries of the Activity are the 1.2 million people of Karamoja, over half of whom are women and children below age 18. Both demographics are key beneficiaries of the Activity, as women and children often bear the primary responsibility for water collection in rural Ugandan households.[8] In this study, we present an ex-ante CBA of the four proposed water infrastructure technologies that could help address the water scarcity and associated health, agricultural productivity, and safety challenges in Karamoja.

2.1. FEATURES OF AN EX-ANTE CBA

CBA is a widely used tool to evaluate the economic feasibility of public projects and policies. CBA may be conducted at different times in a project or policy life cycle. For this study, we are conducting an ex-ante or prospective CBA. An ex-ante CBA is conducted before a decision is made to undertake or implement a project. An ex-ante CBA can be used to assess the potential impacts of a future project. The key features of an ex-ante CBA are as follows:

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[6] USAID. "United States Global Water Strategy 2022-2027". 2022.

[7] USAID. "Concept Note: Cost-Benefit Analysis of the USAID/Uganda Water Infrastructure Project." 2022.

[8] Uganda Bureau of Statistics. "Northern Region – Parish Level Profiles (Census 2014)." 2019.
Uganda Bureau of Statistics. "Population By Sex For 146 Districts." 2022.

1. **Identification of Alternatives:** The first step in an ex-ante CBA is to identify the alternatives available to address the problem at hand. In this case, per USAID/Uganda mission's guidance, we analyze four water technologies to address water scarcity in Karamoja: boreholes with handpumps, boreholes with solar pumps, subsurface water storage, and surface water storage.
2. **Assessment of Impacts:** The next step is to assess the potential impacts of each alternative on society. In consultation with the USAID/Uganda mission, we identified a range of impacts including improved health, reduced violence, increased agricultural productivity (crop and livestock), and increased school attendance.
3. **Valuation of Impacts:** The third step is to assign monetary values to the identified impacts. Valuation can be a challenging task, especially for non-market goods such as improved health and safety. In this report, we will discuss the various methods used to value the impacts.
4. **Comparison of Alternatives**: The fourth step is to compare the costs and benefits of each alternative.
5. **Sensitivity Analysis:** The final step is to conduct sensitivity analysis to test the robustness of the results. Sensitivity analysis involves varying key assumptions and parameters to see how the results change.

In this study, we implement a CBA model called the Karamoja Water Access CBA model (KWACM) in Microsoft Excel to compute the key results of the analysis. The variables of policy interest in a CBA model are the net-present value (NPV), benefit-cost ratio (BCR), the internal rate of return (IRR), and the modified internal rate of return (MIRR). The **NPV** is computed by subtracting the present value of the costs from the present value of the benefits over the span of the project's life. We need to calculate the present value of costs and benefits because future costs and benefits cannot be compared directly with present costs and benefits since the value of money changes over time due to inflation, interest rates, and other economic factors. By discounting future costs and benefits to their present value, we can adjust for this time value of money and make more accurate comparisons between different options or projects. By dividing the total present value of the project's benefits by the total present value of its costs, we obtain the **BCR**. This is a ratio indicating how many dollars of benefits are generated for every dollar of costs incurred. If the BCR is greater than one, it means that the project is expected to generate more benefits than costs, making it financially viable. Another financial metric we obtain from the CBA model is the **IRR**. This calculates the rate of return of a project based on its estimated future cash flows. In other words, it is the discount rate at which the present value of all benefits of a project equals the present value of costs, that is, a NPV of zero. The IRR is used to evaluate the potential profitability of an investment and to compare different investment opportunities. A higher IRR indicates a more profitable investment. Additionally, we also calculated the **MIRR**, which corrects a shortcoming in the IRR formula which assumes that all project net profits are reinvested at the project IRR; per the USAID CBA guideline, we stipulate that profits are reinvested at the same rate as the financial discount rate, 12 percent in this case.

Upon consultation with the USAID/Uganda mission, for the purposes of this analysis we estimate all benefits and costs at the level of a typical community in Karamoja. Based on secondary literature and

KIIs, we estimate that a typical community consists of 30 households, with an average household size of six.[9] In the next section, we present the four technology alternatives analyzed in this report.

2.2. TECHNOLOGY DESCRIPTION

This analysis includes four proposed water infrastructure technologies: boreholes with handpumps, boreholes with solar pumps, subsurface water storage, and surface water storage. In what follows, we specify a locally feasible form of each technology.

2.2.1. BOREHOLES WITH HANDPUMPS

This technology involves drilling a borehole into an aquifer to access groundwater, which is then pumped to the surface using a handpump. These boreholes are typically dug to a depth of 80 m, which is usually able to access groundwater (the local groundwater table averages 60-90 m).[10,11] The handpump is a simple technology that can be operated by community members. The borehole with handpump technology has the potential to provide a reliable and safe source of water to communities in Karamoja, although two factors are important to note. First, households need to travel to the handpump location to collect water, so their time to collect water is not reduced to zero. And second, since the water must be carried home and stored before use, there is a potential for the safety of the water to be compromised. With adequate maintenance, a borehole with handpump can continue to provide safe water if the groundwater level remains stable. From our desk review of available literature and KIIs, we learned that boreholes are prevalent in Karamoja, albeit with a high failure rate – approximately 70 percent of installed boreholes are no longer functioning.[12] Maintenance is the biggest factor behind their failure, with lack of skilled technicians and quality parts being significant cofactors. Based on MoWE and other data sources, we estimate capital costs of $9,133 per borehole, with an annual maintenance and parts replacement cost of $91. For boreholes with handpump in the CBA model, water is accessed at the borehole site and carried home, typically in 20-liter jerry cans. We estimate that a handpump serves a single typical Karamoja community of 30 households.

2.2.2. BOREHOLES WITH SOLAR PUMPS

This technology is like the borehole with handpump technology, except that the water is pumped to the surface using a solar-powered pump. The solar pump is more efficient than the handpump and can pump water over longer distances. The borehole with solar pump technology has the potential to provide a reliable and safe source of water to communities in Karamoja while also reducing the energy costs associated with pumping water. A solar powered borehole installment will usually include:

- The drilling site;

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[9] Rural Water Supply and Sanitation Department (RWSSD). "Karamoja Strategic WASH Investment Plan 2021-2030." Uganda Ministry of Water and Environment (MoWE), 2021. Draft.

[10] KfW Development Bank. "Drought Resilience in the Karamoja Sub-Region (Feasibility Study)." 2017. *Draft.*

[11] Weis Engineering. "Boreholes in Uganda." https://weisengineering.com/cost-of-drilling-a-borehole-in-uganda/. Accessed April 10, 2023.

[12] Rural Water Supply and Sanitation Department (RWSSD). "Karamoja Strategic WASH Investment Plan 2021-2030." Uganda Ministry of Water and Environment (MoWE), 2021. Draft.

- A structure built to house the pump;
- An array of solar panels;
- A 20 m^3 elevated reservoir tank that serves a total of 3000 people;
- Piped transmission from drilling site to reservoir;
- Piped transmission from reservoir to tap stands and/or home connections.

Compared to the handpump technology, solar powered boreholes represent a significantly larger scope of investment, with accompanying improved features. A key feature is the option for piped gravity-fed water transmission to homes. We estimate capital costs of an installed borehole with a solar pump to be $43,502, with an annual operation and maintenance (O&M) cost of $435. For boreholes with solar pump in the CBA model, water is transmitted directly to homes in the community. Given that the total number of people served by this technology is 3,000, this suggests that each installation can serve about 16 communities.

2.2.3. SURFACE WATER STORAGE - VALLEY TANKS

Valley tanks are considered primarily a source of water for production – that is for livestock and irrigation purposes. Valley tanks are open surface water reservoirs, typically with capacity ranging between 10,000-20,000m^3. They are constructed to mitigate water stress during dry spells in pastoral communities such as Karamoja. Valley tanks are commonly found in gently sloping valleys because these areas can generate sufficient runoff water that can be harvested in the dugout reservoirs.[13]

In Karamoja, the MoWE considers valley tanks a priority in providing water for production, with a strategic vision of establishing tanks in every parish.[14] Since the water in valley tanks is not considered safe for household use without proper treatment, all planned and implemented valley tanks must include a borehole with handpump. We estimate the capital cost of a 20,000 m^3 valley tank to be $290,130, with an annual O&M cost of $2,901. For valley tanks, water is abstracted into troughs for livestock watering, and users must bring their livestock to the tank to use this water. A small-scale irrigation scheme is included whereby water is transmitted to nearby fields. We assume that a valley tank will meet the water needs for livestock and irrigation of 500 people, which represents approximately three communities.

2.2.4. SUBSURFACE WATER STORAGE - SAND DAMS

There are many different types of subsurface storage technology available. Based on our desk review and KIIs, we chose sand dams for this analysis. This technology involves building a concrete barrier across a seasonal river or stream to collect and store rainwater runoff. Once the barrier is built, it takes one or two rainy seasons for the river to first fill up with the runoff, and then with the sand that the runoff carries downstream. At the end of the rainy season, the water collected by the barrier seeps

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[13] Salman et al. "Strengthening Agricultural Water Efficiency and Productivity on the African and Global Level: Status, Performance and Scope Assessment of Water Harvesting." In T. Zhang & Y. Cao (Eds.), Agricultural Water Management: Proceedings of the Workshop on Innovative Techniques for Sustainable Irrigation Management, 28 June-1 July 2015, Valenzano, Italy (pp. 157-171). Springer International Publishing.

[14] Rural Water Supply and Sanitation Department (RWSSD). "Karamoja Strategic WASH Investment Plan 2021-2030." Uganda Ministry of Water and Environment (MoWE), 2021. Draft.

under the collected sand in the riverbed. The sand acts as a natural filter. Even though only a small amount of the runoff is held back by the barrier, it represents a significant quantity of water. Sand dams in Kenya often meet water needs for communities of a thousand people, their animals, as well as irrigation needs.[15]

The MoWE considers water from sand dams primarily for production, that is, for use by livestock and for agriculture. Any household use requires a treatment system. In Karamoja, the MoWE implements strict guidelines on the construction of sand dams; key features of these guidelines include:

- Sand dams must be accompanied by nearby boreholes to allow for access to water for household consumption.
- To prevent contamination of the water, a public use latrine is also required near a sand dam.
- Sand dam design must include specification for water abstraction for small-scale irrigation (pump, pump house structure, and gravity-fed transmission system) and provide for livestock watering trough.

Sand dams can also make significant contributions to the environment. They allow for the water to recharge underground aquifers, prevent soil erosion, and reduce silting in the river. Sand dams also perform as check dams to slow down runoff when constructed in the early stage of the river where the slope of the riverbed and the velocity of flow are high causing riverbed erosion. Sand dams are widely recognized as a sustainable solution for storing water in semi-arid areas with limited surface water resources. Sand dams are a relatively new technology in Karamoja with little data on capital costs. Based on sand dams implemented in Kenya and elsewhere, we estimate capital costs to be $75,504. We use the cost data for water abstraction, transmission to fields etc. from valley tanks since they are likely to be comparable. Sand dams are often assumed to have no maintenance cost, but from KIIs and review of the literature we find that dams can suffer from siltation, losing their effectiveness. We factor this in with an annual O&M cost of $755. For sand dams, water is pumped from the reservoir to watering troughs where communities must bring their livestock to use the water. Water is also piped to nearby fields for small-scale irrigation. We assume that a sand dam will meet the water needs for livestock and irrigation of 1,000 people, representing approximately six typical communities.

TABLE 1: COSTS BY TECHNOLOGY

TECHNOLOGY	CAPITAL (USD)	ANNUAL OPERATIONS & MAINTENANCE (USD)	NUMBER OF COMMUNITIES SERVED
Borehole with handpump	9,133	91	1
Borehole with solar pump	43,502	435	16
Valley tank	290,130	2,901	3
Sand dam	75,504	755	6

Source: Authors' calculations, 2023 Karamoja Water Access CBA Model.

Note: All dollars are constant 2021 values. Operations and Maintenance costs accrue annually for 20 years, while capital costs accrue once at the beginning of the project.

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[15] Makau, J. "Sand Dams: A low cost solution to water scarcity in arid areas." In Proceedings of the 2016 Environmental and Sustainability Management Accounting Network (EMAN) Conference (pp. 77-85). EMAN Europe. 2016.

In the next section, we describe the main benefits in the CBA model and their valuation.

2.3. IDENTIFICATION AND VALUATION OF BENEFITS

Provision of improved WASH infrastructure can have wide ranging benefits to a society. Upon consultation with USAID/Uganda, as well as through information gathered through KIIs, we identify and focus on the benefit streams discussed below. In valuing these benefits, we encounter the usual challenge of a CBA, namely the non-market nature of many of them. For example, while we value not being sick, there is no market price available for not being sick. The first best measure of the value of not being sick could come from a willingness-to-pay survey which would gather household data from the beneficiaries on the amount of money they would pay to avoid contracting disease from consuming water from an unprotected source. In the absence of such a survey, we rely on other sources of data that allow us to best approximate the economic value of the benefit. In the following subsections, we describe how we estimated each benefit stream. All benefits are calculated at the level of a typical community:

2.3.1. TIME TO COLLECT WATER

Time to collect water is valued from an opportunity cost of time perspective, that is, the value of the alternative use of that time. We estimate the value of time saved due to a water technology by multiplying the following:

- The number of households in a community;
- The number of people in each household who collect water;
- The number of times per day water is collected;
- The number of days per year water is collected;
- The daily wage rate of a person in USD;
- The percentage of time saved due to the new technology.

2.3.2. HEALTH

Health benefits accrue in two streams in our model: through reduction in morbidity and reduction in mortality from water that contains pathogens. For mortality, we use the reference value of a statistical life (VSL) published by the United States Department of Transportation. Using the gross national income (GNI) ratio between the US and Uganda and an income elasticity of 1, we convert this reference value to the value of a single life in Uganda.[16] With demographic data, we estimate the number of children living in a typical community. We use the infant mortality rate due to diarrhea to determine the number of potential deaths. We limit our focus on children under the age of five because they are especially vulnerable to diarrheal diseases, and accounted for 41 percent of all diarrheal deaths in Uganda in 2019.[17] Finally, we find that safe drinking water, such as water sourced from a borehole and piped

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[16] Robinson, Lisa A., James K. Hammitt, and Lucy O'Keeffe. "Valuing mortality risk reductions in global benefit-cost analysis." *Journal of Benefit-Cost Analysis* 10, no. S1 (2019): 15-50, https://doi.org/10.1017/bca.2018.26

[17] Global Burden of Disease Collaborative Network. Global Burden of Disease Study 2019 (GBD 2019) Results. Seattle, United States: Institute for Health Metrics and Evaluation (IHME), 2021. https://ourworldindata.org/diarrheal-diseases

directly to home, leads to a 73.5 percent lower chance of developing diarrhea,[18] giving us the potential impact size for the intervention. In contrast, water sourced from a borehole and carried home for consumption leads to a 45 percent lower chance of developing diarrhea. For morbidity, using the prevalence of diarrhea in under-fives, we calculated the annual number of diarrheal incidences in under-five children in a typical community in Karamoja. We calculate the average cost of a health facility visit due to diarrhea, to get the value of the total number of diarrheal incidences. A secondary stream is avoided caregiving time. We estimate this by multiplying the annual diarrheal incidences in a typical community and the number of days of illness per incidence, to get the annual number of days of illness in under-fives. Then we use the typical wage rate of caregivers (domestic work) to obtain the value of the caregiver's time.

2.3.3. EDUCATION

Education benefits are estimated as an increase in lifetime earnings due to years of schooling. Currently, many potentially school going children are not in school due to poor water and sanitary conditions in schools.[19] A water infrastructure investment will increase the number of children that go to school, resulting in an increased number of child school years. We value the effect of school enrollment as the product of:

- The number of new students due to increased enrollment;
- The number of years the new students will work following graduation;
- The average annual wage, in USD per year;
- The additional years of schooling the new student received;
- The increase in annual wage due to an additional year of schooling, as a percentage, estimated as a 16 percent increase for each year.[20]

2.3.4. AGRICULTURE

Agriculture benefits accrue from increased crop yields and resultant greater revenues due to irrigation, and reduction in livestock deaths. We use cereals (maize) to represent crops because of the current state of low intensity subsistence farming in Karamoja. With the availability of irrigation and greater yields, households may turn to more profitable crops, but the model does not currently account for this. We estimate the increased revenue for the community by multiplying:

- The average area cropped per household (hectares per household);
- The average net revenue per hectare from two harvests of maize using local type seed;

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[18] Nantege, Robinah, Dickson Kajoba, Christopher Ddamulira, Fred Ndoboli, and David Ndungutse. "Prevalence and factors associated with diarrheal diseases among children below five years in selected slum settlements in Entebbe municipality, Wakiso district, Uganda." *BMC pediatrics* 22, no. 1 (2022): 1-8, https://doi.org/10.1186/s12887-022-03448-2

[19] Stites, E., Athieno, B. and Dyer, C. 2022. "Educating Girls in Karamoja, Uganda: Barriers, Benefits, and Terms of Inclusion in the Perspectives of Girls, Their Communities, and Their Teachers." Karamoja Resilience Support Unit (KRSU), Feinstein International Center, Friedman School of Nutrition Science and Policy at Tufts University, Kampala, Uganda

[20] Kavuma, Susan Namirembe, Oliver Morrissey, and Richard Upward. *Private Returns to Education for Wage-employees and the Self-employed in Uganda*. No. 2015/021. WIDER Working Paper, 2015, https://doi.org/10.35188/UNU-WIDER/2015/906-0

- The increase in net revenue due to irrigation relative to rain-fed (percent);
- The number of households in a community.

For livestock, the value of prevented livestock deaths at the community level is calculated by multiplying:

- The number of households in the typical community, in households;
- The percent of households that own livestock;
- The average number of livestock owned per household that owns livestock;
- The average sale price of livestock, in USD;
- The average percent of livestock that die due to drought;
- The annual frequency/probability of drought;
- The percent by which mortality is reduced due to irrigation; we assume the mortality is halved due to access to water.

2.3.5. GENDER-BASED VIOLENCE

Gender-based violence reduction benefits accrue due to reduced exposure of vulnerable women and children collecting water. As water sources are placed within each community, water collectors' time spent collecting water will be reduced, lowering the probability of exposure to violence. While there exists a large body of online discussion around this topic, there are no research studies that specifically quantify the value of gender-based violence (GBV) in Uganda (or Africa) and none that quantifies the value of reduction in GBV from water infrastructure investments. Instead, we rely on a United Kingdom-based study for the value of GBV and a Ugandan study to infer potential reductions in that violence.[21,22] While these studies do not specifically provide costs related to GBV experienced during water collection activities, we use the values as a proxy for estimating the value of reduced GBV due to water infrastructure closer to homes. To calculate the value of avoided GBV in a community, we multiply the following:

- Number of women aged 15-49 in a typical community;
- Percentage of women who have experienced physical violence during water collection in the past 12 months;
- Proportionate VSL year (VSLY) of women in Uganda;
- Average physical cost of domestic abuse;
- Percent reduction in domestic abuse due to intervention;
- Reduction in physical cost of domestic abuse.

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[21] Oliver, Rhys, Barnaby Alexander, Stephen Roe, and Miriam Wlasny. "The economic and social costs of domestic abuse." *Home Office (UK)* (2019).

[22] Green, Donald P., Anna M. Wilke, and Jasper Cooper. "Countering violence against women by encouraging disclosure: A mass media experiment in rural Uganda." *Comparative Political Studies* 53, no. 14 (2020): 2283-2320, https://doi.org/10.1177/0010414020912275

3. CBA DATA SOURCES

The costs and benefits data for the CBA model were obtained from several sources. Two central sources were the cost estimates shared by the MoWE, and cost and benefit information obtained through KIIs. Further, we conducted a desk review of literature provided by USAID/Uganda and the MoWE, our own literature review and secondary data analysis. We present the central outcomes of the literature review, secondary data analysis, and KIIs in the subsections below.

3.1 DATA FROM LITERATURE REVIEW

In addition to the documentation provided by USAID/Uganda and from the KIIs, we collected and reviewed literature on the costs and benefits of improved water access. First and foremost, our benefit valuation methods are either consistent with or representative of the existing literature on the cost-benefit of improved water resources. The literature also provided context for the cost figures from our KIIs and provided a basis for ground-truthing subsequent KIIs. The literature review also provided guidance and quantitative values for the benefit streams. While all the values incorporated into the model can be found on the "Source Data" tab of the KWACM, a few of the key quantitative figures found through the literature review are included below:

- **Returns to schooling rate.** This Uganda-specific value forms the basis of the education benefit calculation.
- **Labor rates.** We used daily and annual wage rates for different occupations to calculate the opportunity cost of time, which informed both the health and time to collect water benefit streams. For caregiver's time, we used mean wage rates for domestic work and for time to collect water we used mean wages for agricultural labor in Karamoja. We also used the agricultural labor rates to value the increase in school enrollment, with a person's annual earnings increasing by a set percent for each year of schooling completed. Due to lack of sufficient data, we were unable to specifically consider gender-specific factors such as wage gaps.
- **Gender-based violence.** Values from the literature include the number of incidences of violence experienced, the QALY losses from physical injury from domestic abuse, and the reduction in GBV from GBV interventions, which was used to approximate the percent reduction in GBV due to an improved water source.

3.2 SECONDARY DATA ANALYSIS

Parallel to the literature review, we analyzed secondary data from the Uganda National Panel Survey 2018-2019, Uganda Standard Demographic and Health Survey 2016, Uganda: Malaria Indicator Survey, 2018-19, the Uganda Bureau of Statistics, and UNICEF data. When possible, we restricted the data to districts of Karamoja, and when not possible, the northern region of Uganda or the country of Uganda. The data sources were particularly helpful in collecting:

- **Population demographics**, such as percent by gender and percent by age. These values informed any sex- or age-disaggregated benefit streams, including health, time to collect water, and gender-based violence.
- **Water collection time** specific to the Karamoja sub-region. These values informed the "reduction in time to collect water" benefit stream. We used the average value as the model default, and the 25th and 75th percentile values as the ranges for the model dashboard.

- **Household agricultural production and value**. This includes the average land area cropped per household in Karamoja, which informed the increase in agricultural revenue benefit stream. It also includes the average number of livestock holdings per household in the northern region of Uganda, and the average sale price of said livestock, which informed the reduction in livestock mortality benefit stream.
- **Prevalence of gender-based violence** in the Karamoja sub-region. Per the 2016 Standard DHS survey, 32 percent of women aged 15 to 49 experienced physical violence in 12 months prior to the survey. This informed the "reduction in gender-based violence" benefit stream.

3.3 KEY INFORMANT INTERVIEWS

We conducted outreach to the list of informants provided by USAID/Uganda and were ultimately able to conduct five interviews (see Annex II). All five KIIs provided valuable local context that helped ground-truth assumptions and further develop the cost and benefit streams. The key takeaways and subsequent model implications are summarized below.

3.3.1. EMPHASIS ON LIVESTOCK REARING AND PASTORALISM

UNICEF, KfW Development Bank, and the MoWE all emphasized the significance of livestock rearing and pastoralism in Karamoja instead of crop farming in some districts. For instance, Kotido district was cited as a primarily pastoral district. To reflect livestock rearing as a primary livelihood in Karamoja in the model, these three key informants encouraged the inclusion of increased livestock production as a benefit stream. UNICEF and KfW Development Bank also cautioned against valuing increase in crop production too heavily. We incorporate this information into the model by adding a new benefit stream for livestock, and as discussed above, limiting agricultural benefits to only staple crops, that is cereals.

- ***Model implication:*** Added "increased livestock production" as a benefit stream.

3.3.2. REDUCTION IN CONFLICT

Both the MoWE and the KfW Development Bank (which works closely with the MoWE) discussed a chain of effects from improving water access in Karamoja, with water access allowing for irrigation, irrigation allowing for increased crop yields leading to potential increase in crop farming and decreased nomadic pastoralism, and finally decreased nomadic pastoralism in turn leading to decreased conflict in the region. In parallel, water access allowing for localized livestock watering and rearing would further decrease nomadic pastoralism. Unfortunately, while this issue is addressed variously in MoWE documents and other sources, at this time there is no hard data available that will allow for the estimation of this benefit.[23]

- ***Model implication:*** Added a user feature for estimating "reduction in conflict", as a function of lives and cattle saved. This portion of the model is intended as a convenience feature and can be specified and incorporated in the model with minor adjustments should data become available.

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[23] Rural Water Supply and Sanitation Department (RWSSD). "Karamoja Strategic WASH Investment Plan 2021-2030." Uganda Ministry of Water and Environment (MoWE), 2021. Draft.

3.3.3. INCREASED SCHOOL ATTENDANCE

UNICEF and MoWE emphasized increased school attendance and retention as a potentially major benefit of an improved water resource, particularly when the water access point is at or near the school, as many of UNICEF's current implementation projects in Uganda are. UNICEF mentioned that clean water access at schools lowers the water collection burden on children of schooling age (particularly for girls, who are more often tasked with water collection duties than boys), and reduces absenteeism for girls, as clean water allows for improved menstrual hygiene. The MoWE affirmed this, citing testimonies they have received.

- ***Model implication:*** Added "increased school enrollment and attendance" as a benefit stream.

3.3.4. THE CULTURAL CONTEXTS SURROUNDING GENDER-BASED VIOLENCE

Representatives from UNICEF emphasized considering societal and cultural contexts in assessing the impact of improved water access on GBV. They reported that domestic and gender-based violence can be pervasive in some pastoralist communities and no data are available currently to quantify, assess or value GBV. On a comparable note, we learned from an NGO informant that teenage pregnancies do not always involve violence and are normalized to an extent in some cultures. No key informants were aware of quantitative data or study findings to specifically inform the quantifying or valuation of a reduction in gender-based violence.

- ***Model implication:*** Created dashboard functionality that allows the user to vary the weight of the calculated value of the "reduction in gender-based violence" benefit stream.

3.3.5. OPERATIONS AND MAINTENANCE

Consistent with the literature, the O&M of water technologies, more specifically the lack thereof, was cited in all our KIIs. The founding of O&M structures and the collection of tariffs to support the longevity of water technologies was also discussed. An NGO informant discussed the maintenance of boreholes with handpumps at length, emphasizing that borehole rehabilitation is crucial to address the serious failed service delivery crisis, characterized by "over-spending and under-benefiting". The informant's NGO has developed and successfully tested a borehole technician payment structure that lowers annual borehole servicing costs to $300 per borehole per year and ensures the reliability and longevity of crucial rural water access points. We further learned that while a 24-hour borehole service response is feasible throughout most of Uganda, service in the Karamoja region is less responsive.

- ***Model implication:*** Built out the O&M costs section, with maintenance costs accruing annually as a share of capital costs.

4. MAIN MODEL ASSUMPTIONS

The estimations developed in the Karamoja Water Access CBA model are based on some central assumptions described below.

4.1. TECHNICAL

All analysis within the CBA model is conducted at the level of a "typical community". Since there are no feasibility or hydrogeological studies done for this study, we decided on a typical community as the unit of analysis, upon consultation with the USAID/Uganda mission. Based on our literature review, we found a typically sized Karamojong community contains approximately 30 households. Using the average household size in Uganda, this implies that a typical community comprises 180 people. All costs and benefits in the model are apportioned accordingly.

Based on MoWE guidelines, the model is estimated over a 20-year horizon, meaning that we assume the four technologies will function and generate benefits for 20 years.

Per USAID guidelines, we assume a 12 percent discount rate. Other agencies have stipulated different standards, for example, the World Bank typically uses 10 percent as does the United Nations Development Programme. The choice of discount rate does influence the analysis. For instance, a relatively higher discount rate implies that future benefits carry less weight in the analysis than upfront costs.

We assume that all investments in the CBA only have partial equilibrium effects. This means that investments, and beneficiaries' actions (such as using irrigation water) are small enough that they do not have significant effects on overall supply and demand of goods and services in the market, such that they influence market prices. However, this assumption may not hold if the investments made are significant enough to affect the overall supply and demand of the market, leading to changes in prices.

We use the official exchange rate (annual average for 2021) from the World Bank to convert Ugandan Shillings to United States dollars. We use the World Bank's Consumer Price Indices (CPI) to convert all nominal figures to constant 2021 dollars (all sources fully referenced in the model).

Finally, we have not used shadow wage rates—as is done in settings where capital is scarce—primarily for consistency. Some of the benefits we model use local wage rates, e.g., time spent collecting water is valued at local wage rates. This is amenable to adjustment to the shadow wage rate. However, due to the nature of the cost information available to us we were not able to make adjustments to wages in our cost analysis. We had monolithic cost figures i.e., the cost figures for the four technologies we had access to were not broken down and did not include separate costs for labor. Therefore, we were not able to adjust wages in our cost figures. Adjustment to wages would result in reduction in costs values and a reduction in benefit values. It should also be noted that benefits that utilize the wage rate i.e. time saved in water collection, do not constitute a large part of the total benefits. Given all of this, we did not adjust wage rates to their shadow value.

4.2. FEASIBILITY

Per the concept note for the activity, and as discussed above, since feasibility studies have not yet been conducted the CBA model assumes that all four infrastructure technologies are theoretically feasible in the targeted catchment areas. That is, the installation of the technologies is supported by the geo-physical conditions (underground water tables), availability of water (precipitation), and the demographics served. The benefits calculations also assume feasibility on the user side. That is, based on the per capita consumption of water provided by the MoWE (50 liters per day per person), and estimates of water use quantities for livestock and agriculture, we assume that the technologies as installed will successfully serve a certain number of communities for each technology.

As discussed earlier, Karamoja receives at least one brief but heavy wet spell a year, characterized by flooding, and up to 40 percent of the precipitation leaving Karamoja as runoff. This suggests that feasibility is a reasonable assumption for both sub-surface and surface storage technologies. Feasibility for boreholes is usually tied to the state of underground water tables. From KIIs, we find that critical cofactors to feasibility are careful scoping, design, implementation, and maintenance. For instance, in some cases boreholes failed due to poor site selection based on convenience (nearness to communities) versus actual availability of groundwater. So long as proper investments are made in the design phase, boreholes can be feasible.

4.3. MODEL NAVIGATION

The CBA model was developed in Microsoft Excel. It has been designed to be user-friendly and to allow for future updates as needed by the Mission. The spreadsheet consists of six main sheets – a. Dashboard, b. Borehole with Handpump, c. Borehole with Solar pump, d. Valley Tank, e. Sand Dam, and f. Source Data. The layout of the spreadsheet and key features are briefly described below.

The “Dashboard” tab has two sections. The "Dashboard" section provides a snapshot of the performance of all four technologies – namely the BCR, NPV, PV of Costs, PV of Benefits, the MIRR, the IRR, and the share of Individual Impacts on the PV of Benefits. The “Settings” section contains a suite of user input options that allow for a variety of flexible alterations to the model, including alterations to the discount rate, lifespan of technologies, and the factor by which water availability impacts different benefit streams. Each input option is annotated with the default value, the possible input range, and other useful information.

Each of the four technology sheets (as well as the hybrid option sheet, as described in the Recommendations section of this report) are laid out identically as follows. The years of operation are in columns, while variables of interest are in rows. The first section, “Overall Project” presents a snapshot of key values for that technology, like the dashboard. Under the section titled “Benefits,” the different benefit streams are computed, with relevant data populated within subsections. A third section, “Costs” lists the costs of each technology. All values within the technology sheets are either formulae, or linked to the Source Data sheet; that is, no numeric inputs are “hard coded” within the technology sheets.

The first column of each technology sheet indicates with an asterisk (*) when a variable is available for alteration via the dashboard. Columns A-D in the “Dashboard” tab and columns B-E in the four technologies tabs provide a simple number scheme to identify and refer to each item within the technology sheets. The Source Data tab contains all reference values used for computations in the technology sheets. Further information on model navigation can be found in the “READ ME” tab of the model.

5. RESULTS

As discussed, a project decision hinges on three criteria from a CBA, namely, the NPV, the IRR, and the BCR. In the following section we report the main findings from our analysis, followed by a sensitivity analysis of the results.

5.1. FINDINGS

Using the Karamoja Water Access CBA model, we estimate the BCR, NPV, PV of benefits, PV of costs and IRR for each of the four technologies for a typical community in Karamoja (Table 2).

We find that:

- Borehole with solar pump has the highest BCR of 6.64 i.e., for each dollar invested the economic return is $6.64. This is followed by sand dam and borehole with handpump, with BCRs of 4.77 and 2.88 respectively. Therefore, these three technologies are high return investments that more than pay for themselves. Valley tank has a BCR of 0.79, meaning that the present value of benefits is less than the present value of costs, making it an unfavorable investment choice.
- Sand dam has the highest NPV of $55,512, followed by borehole with solar pump and borehole with handpump at $44,009 and $18,408 respectively.
- Valley tank has the highest present value of benefits at $90,785, exceeding sand dam with a present value of benefits at $70,249. Borehole with solar pump and handpump have lower present value of benefits of $51,815 and $28,214 respectively.
- Valley tank has the highest PV of costs per community at $114,353, followed by sand dam, borehole with handpump and borehole with solar pump: $14,737, $9,806, and $7,807, respectively.
- Borehole with handpump, borehole with solar pump and sand dam all have MIRR of about 13 percent. Valley tank has the lowest MIRR of the four technologies at 11.7 percent. Other than valley tanks, all three technologies have a high IRR. Borehole with hand pump and sand dam have IRRs of about 38 and 43 percent, respectively, while borehole with solar pump has an IRR of about 89 percent. In other words, for the PV of benefits to equal the PV of costs, the discount rate would have to be 89 percent for borehole with solar pump, and 38 percent and 43 percent for the other two technologies. For reference, the model is estimated using a 12 percent discount rate, so these values represent a high rate of return.

5.2. SENSITIVITY ANALYSIS

We conduct a sensitivity analysis to understand how responsive the results are to major changes in the components used in the analysis. Specifically, we vary costs (capital and O&M) and each benefit stream by 10 percent and by 20 percent. By varying these within a reasonable range, we can see how much the results of our analysis change, and whether our conclusions and recommendations still hold under different scenarios. We report our findings in Table 3 below. The full outputs of the sensitivity analysis are presented in Annex III.

Under all variations of costs and benefits, our ranking of the four technologies remains unchanged. Further, the order of magnitude of the model estimates also remains relatively unchanged. Changes to specific benefit streams do not substantially change our results. Only with a 20 percent reduction in all benefits, we find a reasonable drop in the NPV. In summary, the model results prove robust to significant increases in costs and decreases in benefits.

TABLE 2: CBA MODEL RESULTS

ITEM	BOREHOLE WITH HANDPUMP	BOREHOLE WITH SOLAR PUMP	VALLEY TANK	SAND DAM
Benefit Cost Ratio	2.88	6.64	0.79	4.77
NPV	$18,408	$44,009	$(23,569)	$55,512
PV of Benefits	$28,214	$51,815	$90,785	$70,249
PV of Costs	$9,806	$7,807	$114,353	$14,737
Modified Internal Rate of Return	13.2%	14.1%	11.7%	13.8%
Internal Rate of Return	38.6%	89.2%	8.3%	43.0%
Share of Individual Benefits on the PV of Benefits				
Reduction in diarrhea mortality	69%	61%	21%	22%
Reduction in diarrhea morbidity	3%	2%	1%	1%
Increase in agricultural revenue	0%	0%	63%	63%
Increase in livestock revenue	0%	0%	6%	6%
Reduction in time to collect water	8%	11%	3%	3%
Reduction in gender-based violence	17%	23%	5%	5%
Increase in school enrollment	3%	2%	1%	1%

Source: Authors' calculations, 2023 Karamoja Water Access CBA Model.
Note: Negative values in parentheses

TABLE 3: SENSITIVITY ANALYSIS RESULTS – BENEFIT COST RATIO

SCENARIO	BENEFIT COST RATIO			
	BOREHOLE WITH HANDPUMP	BOREHOLE WITH SOLAR PUMP	VALLEY TANK	SAND DAM
All defaults	2.88	6.64	0.79	4.77
<u>Cost variation</u>				
Increase capital costs by 10%	2.63	6.07	0.73	4.36
Increase capital costs by 20%	2.43	5.60	0.67	4.01
Increase O&M costs by 10%	2.86	6.59	0.79	4.72
Increase O&M costs by 20%	2.84	6.55	0.78	4.68
<u>Benefit Variation</u>				
Reduce reduction in diarrhea mortality benefits by 10%	2.68	6.23	0.78	4.66
Reduce reduction in diarrhea mortality benefits by 20%	2.48	5.82	0.76	4.56
Reduce reduction in diarrhea morbidity benefits by 10%	2.87	6.62	0.79	4.76
Reduce reduction in diarrhea morbidity benefits by 20%	2.86	6.61	0.79	4.76
Reduce increase in agricultural revenue benefits by 10%	2.88	6.64	0.74	4.47
Reduce increase in agricultural revenue benefits by 20%	2.88	6.64	0.69	4.17
Reduce reduction in livestock mortality benefits by 10%	2.88	6.64	0.79	4.74
Reduce reduction in livestock mortality benefits by 20%	2.88	6.64	0.78	4.71
Reduce reduction in time to collect water benefits by 10%	2.85	6.56	0.79	4.75
Reduce reduction in time to collect water benefits by 20%	2.83	6.48	0.79	4.74
Reduce reduction in gender-based violence benefits by 10%	2.83	6.48	0.79	4.74
Reduce reduction in gender-based violence benefits by 20%	2.78	6.33	0.79	4.71
Reduce increase in school enrollment benefits by 10%	2.87	6.63	0.79	4.76
Reduce increase in school enrollment benefits by 20%	2.86	6.61	0.79	4.76
Reduce reduction in conflict benefits by 10%	2.88	6.64	0.79	4.77
Reduce reduction in conflict benefits by 20%	2.88	6.64	0.79	4.77
<u>Overall Variation</u>				
10% reduction in all benefits	2.59	5.97	0.71	4.29
20% reduction in all benefits	2.30	5.31	0.64	3.81

Source: Authors' calculation, 2023 Karamoja Water Access CBA Model.

6. ANALYSIS

Our results demonstrated that three of the four proposed technologies have large BCRs, ranging from 2.88 to 6.64. These high BCRs are to be expected, as basic investments—such as the ones studied here—will yield very large marginal net benefits as they uplift human wellbeing and productivity from a relatively low baseline level.

Benefits for both borehole technologies are driven by the large health impacts of access to clean water, followed by reductions in GBV from reduced time spent collecting water. The borehole with solar pump investment generates a much greater health benefit than simple boreholes: $32,843 compared to $20,233 per community. This difference is driven by the borehole with solar pump's ability to deliver water directly to people's homes. While access to safe water improves health in both cases, piping to home preserves the "safe water chain" and a greater reduction in diarrhea mortality is realized using the borehole with solar pump technology.[24] Additionally, the fact that boreholes with solar pumps deliver water directly to the home also substantially reduces exposure to GBV, $12,143 compared to $4,767. Next, turning to costs, while a single borehole with handpump is significantly cheaper than a single borehole with solar pump, the latter's cost per community served is lower since it is able to serve many more people. A borehole with a solar pump, accompanied by a 20,000-liter storage tank and piped transmission to homes can serve up to 3,000 people, or about 16 typical Karamojong communities, while a borehole with handpump serves a single community. This combination of factors make borehole with solar pump the best performer when considering BCR.

A potential limitation of this result, when compared to a borehole with handpump, is an unaccounted economic cost of "coordination". Unlike a borehole with handpump, which is a simple technology that can be readily deployed with almost immediate accrual of benefits, a borehole with a solar pump is a major undertaking involving planning, consultation, appropriate site selection for maximum coverage of water users as well as yield of water. These factors can potentially increase the "economic" cost of installing boreholes with solar pumps, driving the BCR down. Nonetheless, this reduction would likely still result in a large positive BCR. Additionally, as currently modeled, the two borehole technologies do not accrue any agricultural benefits. However, there is anecdotal evidence from KIIs of kitchen gardens being watered by solar powered boreholes. Similarly, small troughs for livestock feeding may also be possible using the solar powered technology. We did not find any data to meaningfully incorporate these potential benefit streams into the model. Nonetheless, the estimates from the CBA model are likely an undercount and a well-designed solar powered borehole has a potentially larger BCR than reported.

In contrast to boreholes, which provide water for household use, sand dams and valley tanks are primarily considered water sources for agricultural production in Uganda. As such, the primary drivers of benefits for these technologies are increased crop agricultural revenues and reduction in livestock loss. It is important to note that the CBA model only considers the potential gains in agricultural value due to an increase in yields of existing crops. This is a strong assumption, because with consistent supply of irrigation water (as is likely with high quality sand dams) it is plausible and likely for farmers to switch to high value crops, as well as for solely pastoralist households to begin crop farming. These activities

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[24] World Health Organization (WHO). "Preventing Diarrhoea Through Better Water, Sanitation and Hygiene: Exposures and Impacts in Low- and Middle-income countries." 2014.

have the potential to drive the BCR higher for these two technologies. Although valley tank performs the poorest from a BCR perspective, it has the highest present value of benefits of all four technologies. This result is driven by the fact that valley tanks can fill up in a single rainy season, accruing benefits only one year after construction, whereas a sand dam can take at least two seasons of rainfall before sufficient sand accumulates to make the dam operational.

A limitation of the analysis of sand dams in this model is the exclusion of environmental benefits. A well designed and executed sand dam has potentially large positive environmental impacts including reversing desertification, revitalizing plant life surrounding the dam area, and recharging aquifers that communities rely on. Due to lack of sufficient research on this issue and data, these streams of benefits are not included in the model, implying that a successful sand dam could have a significantly larger BCR.

Under current MoWE plans, water for production facilities such as valley tanks and sand dams must include a point source of water for consumption, usually a borehole with handpump. This implies that for both water for production technologies, a third of the PV of benefits is accrued from reduction in diarrhea mortality. In absolute terms, this is approximately the same as that found in borehole with handpump i.e., $19,000 per community. Finally, the exorbitantly high cost of a valley tank (land excavation, installing the tank, providing security with fencing etc.) while only serving approximately half the number of communities served by a sand dam makes it the poorest performer in the model.

As discussed earlier, this analysis restricts focus to the five benefit streams identified through consultation with USAID/Uganda. It is important to recognize that the model estimates therefore represent only a subset of overall benefits that may accrue to Karamojong communities from water infrastructure investments. Further, data limitations did not allow for full estimation of some benefit streams. Thus, the findings from the Karamoja Water Access CBA Model are likely to be a lower bound for the potential net benefits from this activity.

7. RECOMMENDATIONS

The analysis suggests that any of the three technologies with BCRs higher than one (borehole with handpump, borehole with solar pump and sand dam) are worthwhile investments. However, the analysis does enable prioritization of investments. Specifically, for maximum net benefits to individual well-being, we recommend **borehole with solar pump** as it has the highest return per dollar of investment with a BCR of 6.64. **Sand dams** represent the largest agricultural net benefits, while providing reasonable health benefits; with a BCR of 4.77 this technology represents the next highest return per dollar invested.

Given the different benefit streams provided by the two top investments however, we recommend considering a fifth "hybrid" technology – **sand dam including borehole with solar pump** (Table 4).[25] This option represents all the benefits of having water piped to homes, as well as the benefits flowing from agricultural productivity and livestock production. We extended the CBA model to estimate benefits and costs from this "hybrid" technology and find that it provides the largest welfare gain outperforming the four existing technologies with an NPV of $77,343. Since this technology costs more, the BCR of 4.43 ranks third after the two top performers. Even though the returns per dollar invested are lower than that of the two top performers, the total net benefit to society (as measured by NPV) of combining the two technologies is the greatest. Therefore, we consider this a strong investment choice deserving serious consideration.

TABLE 4: CBA MODEL RESULTS INCLUDING HYBRID OPTION

ITEM	BOREHOLE WITH HANDPUMP	BOREHOLE WITH SOLAR PUMP	VALLEY TANK	SAND DAM	SAND DAM + BOREHOLE WITH SOLAR PUMP
Benefit Cost Ratio	2.88	6.64	0.79	4.77	4.43
NPV	$18,408	$44,009	$(23,569)	$55,512	$77,343
PV of Benefits	$28,214	$51,815	$90,785	$70,249	$99,887
PV of Costs	$9,806	$7,807	$114,353	$14,737	$22,544
MIRR	13.2%	14.1%	11.7%	13.8%	13.7%
Internal Rate of Return	38.6%	89.2%	8.3%	43.0%	49.2%

Source: Authors' calculations, 2023 Karamoja Water Access CBA Model.
Note: Negative values in parentheses

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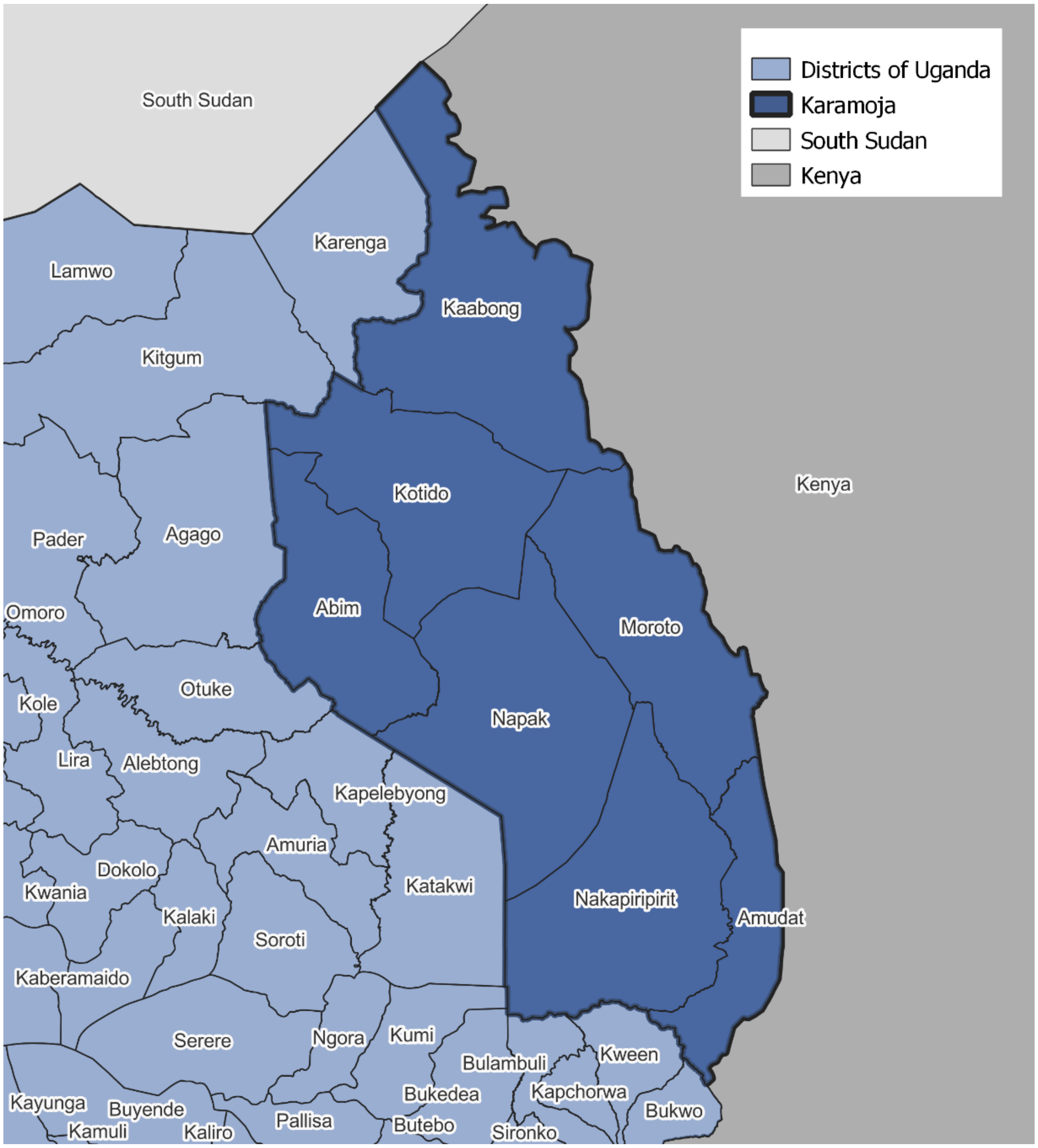
[25] The borehole with solar pump replaces the simple borehole with handpump that was originally embedded in the sand dam technology package.

It is clear from the analysis that there is potential for achieving significant benefits for Karamojong communities from water infrastructure investments. To reap the benefits of such investments, it will be important to coordinate investment decisions with existing efforts on the ground in Karamoja, including those of the Ministry of Water and Environment, Ministry of Agriculture, Animal Industry and Fisheries, and other local partners. Careful consideration must be given to coordination issues and maintenance issues, including incentives for technicians, but also access to and availability of replacement parts. The results of this analysis should help to build a firm foundation upon which investment decisions can be made.

ANNEX I: MAP OF KARAMOJA



Source: Shapefiles downloaded from Humanitarian Data Exchange. Map created in QGIS.

ANNEX II: KEY INFORMANT INTERVIEWS

ORGANIZATION
UNICEF
KfW Development Bank
JICA
Uganda Ministry of Water and the Environment
Whave Solutions

ANNEX III: SENSITIVITY ANALYSIS RESULTS

TABLE 5: SENSITIVITY ANALYSIS RESULTS – NET PRESENT VALUE

	Net Present Value (USD)			
Scenario	**Borehole with Handpump**	**Borehole with Solar Pump**	**Valley Tank**	**Sand Dam**
All defaults	18,408	44,009	(23,569)	55,512
Increase capital costs by 10%	17,495	43,281	(34,197)	54,131
Increase capital costs by 20%	16,582	42,554	(44,825)	52,750
Increase O&M costs by 10%	18,341	43,955	(24,376)	55,382
Increase O&M costs by 20%	18,274	43,901	(25,182)	55,251
Reduce reduction in diarrhea mortality benefits by 10%	16,466	40,836	(25,511)	53,998
Reduce reduction in diarrhea mortality benefits by 20%	14,524	37,664	(27,453)	52,484
Reduce reduction in diarrhea morbidity benefits by 10%	18,327	43,896	(23,668)	55,434
Reduce reduction in diarrhea morbidity benefits by 20%	18,246	43,784	(23,768)	55,357
Reduce increase in agricultural revenue benefits by 10%	18,408	44,009	(29,294)	51,100
Reduce increase in agricultural revenue benefits by 20%	18,408	44,009	(35,020)	46,689
Reduce reduction in livestock mortality benefits by 10%	18,408	44,009	(24,082)	55,117
Reduce reduction in livestock mortality benefits by 20%	18,408	44,009	(24,595)	54,721
Reduce reduction in time to collect water benefits by 10%	18,175	43,413	(23,802)	55,332
Reduce reduction in time to collect water benefits by 20%	17,941	42,818	(24,036)	55,152
Reduce reduction in gender-based violence benefits by 10%	17,932	42,794	(24,045)	55,128
Reduce reduction in gender-based violence benefits by 20%	17,455	41,580	(24,522)	54,745
Reduce increase in school enrollment benefits by 10%	18,321	43,921	(23,656)	55,450
Reduce increase in school enrollment benefits by 20%	18,233	43,833	(23,744)	55,388
Reduce reduction in conflict benefits by 10%	18,408	44,009	(23,569)	55,512
Reduce reduction in conflict benefits by 20%	18,408	44,009	(23,569)	55,512
10% reduction in all benefits	15,587	38,827	(32,647)	48,487
20% reduction in all benefits	12,766	33,646	(41,726)	41,462

Source: Authors' calculations, 2023 Karamoja Water Access CBA Model.
Note: Negative values in parentheses

TABLE 6: SENSITIVITY ANALYSIS RESULTS – PRESENT VALUE OF BENEFITS

SCENARIO	PRESENT VALUE OF BENEFITS (USD)			
	BOREHOLE WITH HANDPUMP	BOREHOLE WITH SOLAR PUMP	VALLEY TANK	SAND DAM
All defaults	28,214	51,815	90,785	70,249
Increase capital costs by 10%	28,214	51,815	90,785	70,249
Increase capital costs by 20%	28,214	51,815	90,785	70,249
Increase O&M costs by 10%	28,214	51,815	90,785	70,249
Increase O&M costs by 20%	28,214	51,815	90,785	70,249
Reduce reduction in diarrhea mortality benefits by 10%	26,272	48,643	88,842	68,735
Reduce reduction in diarrhea mortality benefits by 20%	24,330	45,471	86,900	67,221
Reduce reduction in diarrhea morbidity benefits by 10%	28,133	51,703	90,685	70,172
Reduce reduction in diarrhea morbidity benefits by 20%	28,052	51,591	90,585	70,094
Reduce increase in agricultural revenue benefits by 10%	28,214	51,815	85,059	65,838
Reduce increase in agricultural revenue benefits by 20%	28,214	51,815	79,334	61,426
Reduce reduction in livestock mortality benefits by 10%	28,214	51,815	90,271	69,854
Reduce reduction in livestock mortality benefits by 20%	28,214	51,815	89,758	69,459
Reduce reduction in time to collect water benefits by 10%	27,980	51,220	90,551	70,069
Reduce reduction in time to collect water benefits by 20%	27,747	50,625	90,317	69,889
Reduce reduction in gender-based violence benefits by 10%	27,737	50,601	90,308	69,866
Reduce reduction in gender-based violence benefits by 20%	27,261	49,387	89,831	69,482
Reduce increase in school enrollment benefits by 10%	28,126	51,728	90,697	70,187
Reduce increase in school enrollment benefits by 20%	28,039	51,640	90,609	70,125
Reduce reduction in conflict benefits by 10%	28,214	51,815	90,785	70,249
Reduce reduction in conflict benefits by 20%	28,214	51,815	90,785	70,249
10% reduction in all benefits	25,393	46,634	81,706	63,225
20% reduction in all benefits	22,571	41,452	72,628	56,200

Source: Authors' calculations, 2023 Karamoja Water Access CBA Model.

TABLE 7: SENSITIVITY ANALYSIS RESULTS – PRESENT VALUE OF COSTS

	PRESENT VALUE OF COSTS (USD)			
SCENARIO	BOREHOLE WITH HANDPUMP	BOREHOLE WITH SOLAR PUMP	VALLEY TANK	SAND DAM
All defaults	9,806	7,807	114,353	14,737
Increase capital costs by 10%	10,719	8,534	124,982	16,118
Increase capital costs by 20%	11,632	9,261	135,610	17,499
Increase O&M costs by 10%	9,873	7,860	115,160	14,868
Increase O&M costs by 20%	9,940	7,914	115,967	14,998
Reduce reduction in diarrhea mortality benefits by 10%	9,806	7,807	114,353	14,737
Reduce reduction in diarrhea mortality benefits by 20%	9,806	7,807	114,353	14,737
Reduce reduction in diarrhea morbidity benefits by 10%	9,806	7,807	114,353	14,737
Reduce reduction in diarrhea morbidity benefits by 20%	9,806	7,807	114,353	14,737
Reduce increase in agricultural revenue benefits by 10%	9,806	7,807	114,353	14,737
Reduce increase in agricultural revenue benefits by 20%	9,806	7,807	114,353	14,737
Reduce reduction in livestock mortality benefits by 10%	9,806	7,807	114,353	14,737
Reduce reduction in livestock mortality benefits by 20%	9,806	7,807	114,353	14,737
Reduce reduction in time to collect water benefits by 10%	9,806	7,807	114,353	14,737
Reduce reduction in time to collect water benefits by 20%	9,806	7,807	114,353	14,737
Reduce reduction in gender-based violence benefits by 10%	9,806	7,807	114,353	14,737
Reduce reduction in gender-based violence benefits by 20%	9,806	7,807	114,353	14,737
Reduce increase in school enrollment benefits by 10%	9,806	7,807	114,353	14,737
Reduce increase in school enrollment benefits by 20%	9,806	7,807	114,353	14,737
Reduce reduction in conflict benefits by 10%	9,806	7,807	114,353	14,737
Reduce reduction in conflict benefits by 20%	9,806	7,807	114,353	14,737
10% reduction in all benefits	9,806	7,807	114,353	14,737
20% reduction in all benefits	9,806	7,807	114,353	14,737

Source: Authors' calculations, 2023 Karamoja Water Access CBA Model

TABLE 8: SENSITIVITY ANALYSIS RESULTS – MODIFIED INTERNAL RATE OF RETURN

SCENARIO	MODIFIED INTERNAL RATE OF RETURN BOREHOLE WITH HANDPUMP	BOREHOLE WITH SOLAR PUMP	VALLEY TANK	SAND DAM
All defaults	13.2%	14.1%	11.7%	13.7%
Increase capital costs by 10%	13.1%	14.0%	11.6%	13.6%
Increase capital costs by 20%	13.0%	13.9%	11.5%	13.5%
Increase O&M costs by 10%	13.2%	14.1%	11.7%	13.7%
Increase O&M costs by 20%	13.2%	14.1%	11.7%	13.7%
Reduce reduction in diarrhea mortality benefits by 10%	13.1%	14.1%	11.7%	13.7%
Reduce reduction in diarrhea mortality benefits by 20%	13.0%	14.0%	11.7%	13.7%
Reduce reduction in diarrhea morbidity benefits by 10%	13.2%	14.1%	11.7%	13.7%
Reduce reduction in diarrhea morbidity benefits by 20%	13.2%	14.1%	11.7%	13.7%
Reduce increase in agricultural revenue benefits by 10%	13.2%	14.1%	11.6%	13.7%
Reduce increase in agricultural revenue benefits by 20%	13.2%	14.1%	11.5%	13.6%
Reduce reduction in livestock mortality benefits by 10%	13.2%	14.1%	11.7%	13.7%
Reduce reduction in livestock mortality benefits by 20%	13.2%	14.1%	11.7%	13.7%
Reduce reduction in time to collect water benefits by 10%	13.2%	14.1%	11.7%	13.7%
Reduce reduction in time to collect water benefits by 20%	13.2%	14.1%	11.7%	13.7%
Reduce reduction in gender-based violence benefits by 10%	13.2%	14.1%	11.7%	13.7%
Reduce reduction in gender-based violence benefits by 20%	13.2%	14.1%	11.7%	13.7%
Reduce increase in school enrollment benefits by 10%	13.2%	14.1%	11.7%	13.7%
Reduce increase in school enrollment benefits by 20%	13.2%	14.1%	11.7%	13.7%
Reduce reduction in conflict benefits by 10%	13.2%	14.1%	11.7%	13.7%
Reduce reduction in conflict benefits by 20%	13.2%	14.1%	11.7%	13.7%
10% reduction in all benefits	13.1%	14.0%	11.6%	13.6%
20% reduction in all benefits	12.9%	13.9%	11.5%	13.5%

Source: Authors' calculations, 2023 Karamoja Water Access CBA Model

TABLE 9: SENSITIVITY ANALYSIS RESULTS – INTERNAL RATE OF RETURN

SCENARIO	INTERNAL RATE OF RETURN			
	BOREHOLE WITH HANDPUMP	BOREHOLE WITH SOLAR PUMP	VALLEY TANK	SAND DAM
All defaults	39%	89%	8%	43%
Increase capital costs by 10%	35%	81%	7%	40%
Increase capital costs by 20%	32%	75%	6%	38%
Increase O&M costs by 10%	39%	89%	8%	43%
Increase O&M costs by 20%	38%	89%	8%	43%
Reduce reduction in diarrhea mortality benefits by 10%	36%	84%	8%	42%
Reduce reduction in diarrhea mortality benefits by 20%	33%	78%	8%	42%
Reduce reduction in diarrhea morbidity benefits by 10%	39%	89%	8%	43%
Reduce reduction in diarrhea morbidity benefits by 20%	38%	89%	8%	43%
Reduce increase in agricultural revenue benefits by 10%	39%	89%	7%	41%
Reduce increase in agricultural revenue benefits by 20%	39%	89%	6%	39%
Reduce reduction in livestock mortality benefits by 10%	39%	89%	8%	43%
Reduce reduction in livestock mortality benefits by 20%	39%	89%	8%	43%
Reduce reduction in time to collect water benefits by 10%	38%	88%	8%	43%
Reduce reduction in time to collect water benefits by 20%	38%	87%	8%	43%
Reduce reduction in gender-based violence benefits by 10%	38%	87%	8%	43%
Reduce reduction in gender-based violence benefits by 20%	37%	85%	8%	43%
Reduce increase in school enrollment benefits by 10%	39%	89%	8%	43%
Reduce increase in school enrollment benefits by 20%	39%	89%	8%	43%
Reduce reduction in conflict benefits by 10%	39%	89%	8%	43%
Reduce reduction in conflict benefits by 20%	39%	89%	8%	43%
10% reduction in all benefits	35%	80%	7%	40%
20% reduction in all benefits	31%	71%	5%	37%

Source: Authors' calculations, 2023 Karamoja Water Access CBA Model

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