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**TRANSFORMATION TOWARDS SUSTAINABLE
AND RESILIENT WASH SERVICES**

**Life cycle analysis: assessing the capital and operational
expenditure of handpump preventive maintenance**

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This study aims to quantify the Capital Expense of rehabilitating 47 U2 hand pumps located in Kumi District, Uganda, as well as the ongoing Operational Expense of maintaining them. Results are meant to inform the resources required to reliably maintain hand pump functionality. Three influencing factors were investigated: the average cost of rehabilitation compared to age and depth of water source, the average annual cost of hardware replacement based on the expected lifespan of each pump component, and the actual cost of hardware replaced in the months following rehabilitation. Analysis shows no significant correlation between Capital Expenditure and either source depth or age. An estimate of the Operational component of life cycle cost determined that a U2 hand pump incurs an average annual Operational Expenditure of 469,397 UGX (\$126.74), although the actual expenditure may be lower in the period immediately following source rehabilitation.

Introduction

A life-cycle costing encompasses technical expenses incurred in implementing continuous adequate water supply services for a target population in a given geographical location. Understanding the life cycle cost of water infrastructure is critical in achieving equitable and sustainable service delivery. Costs can only be compared and then adequately assessed in relation to specific levels of service, evaluated by quality, quantity, reliability and accessibility. In order to provide a sustainable service, technical and financial support systems must be established to facilitate immediate repair should a break down occur and allow for the eventual replacement of infrastructure after its operational life-span is exceeded (IRC, 2016).

In Uganda, hand pumps installed on either shallow wells or deep boreholes are the most common type of improved rural infrastructure. With 944,739 people obtaining access to an improved water source as of June 2017, coverage is high, but functionality remains relatively low at 85% – a 3% decrease from June 2015 (Government of Uganda, 2017). Many pumps become chronically non-functional and require costly rehabilitation as a result of infrequent ongoing maintenance. The lump sum of a major rehabilitation is often difficult for communities to pay, and the availability of government and international aid resources limits the number of rehabilitations that can be conducted in a given year. The challenge is therefore to understand the true cost of preventing the need for rehabilitation of rural water pumps, and to structure payment systems so that service providers can sustainably meet preventive maintenance and immediate repair costs through locally generated resources.

By offering preventive maintenance contracts whereby communities pay a small annual fee, Whave Solutions Ltd is able to provide maintenance services using a network of rural service technicians in conjunction with a supply chain of hand pump components to prevent breakdowns and minimize the time that pumps are non-functional. The viability of the model hinges on understanding the true cost of preventive maintenance for these water sources, and ensuring that community contributions and close collaboration with government are able to generate the resources needed to ensure continuous functionality. This paper presents analysis of data on Capital Maintenance Expenditure (CapManEx) and Operational Expenditure (OpEx) collected in respect of rehabilitations and preventative maintenance of U2 hand pumps in Kumi District as part of its ongoing service for 47 communities.

Background

Life cycle costing of rural water supply infrastructure is not a new concept. The WASHCost project developed by IRC in 2008 applied standard accounting and financing practices to the rural water, sanitation and hygiene sector to develop a life cycle costing approach which was then applied in several different low and middle income countries. The project assessed the level of service provided in order to fill a gap between the cost of WASH services in areas not served by utilities and the expenditure required to ensure the long term sustainability of these services. This approach was intended to be used by governments, donors and service providers to develop and maintain cost databases and incorporate them into service delivery models. The WASHCost research indicated that failure to finance recurrent expenditure was a significant contributor to the occurrence of breakdowns and poor service delivery (IRC, 2016) (IRC, 2013).

The challenge for service providers is knowing the exact costs of delivering a service and when these costs will be incurred during the operating life of specific infrastructure. Robust longitudinal data for specific pumps is difficult to obtain, often because formal records are non-existent and because community knowledge of past breakdown occurrences is unreliable. Despite commendable efforts, however, findings from other studies cannot be simply applied to new contexts to develop models of costs over time, and local service providers are still likely to have to conduct their own analysis to determine how to become financially viable.

In 1995, Uganda standardized the type of hand pump to be fitted to shallow wells and deep boreholes in an effort to phase out other less effective, lower quality designs (Government of Uganda, 2013). The U2 Deep Well Pump is a conventional, lever action, reciprocating hand pump that lifts water from depths of up to 50 m from within boreholes and dug wells (Baumann & Erpf, Sept. 2005).

Aims and scope

The aim of the study is to quantify the Capital Expenditure of rehabilitating rural hand pumps as well as the ongoing Operational Expenditure of maintaining them. Three aspects of hardware costs were investigated:

1. The average cost of rehabilitation compared to age and depth of a pump;
2. The average annual cost based on the expected lifespan of each pump component; and
3. The actual cost of hardware replaced in the months following a rehabilitation.

The calculations combine expert opinion and available data from the rehabilitation and maintenance of 47 sources in Kumi District from July 2016 to present in order to consider the hardware cost of maintaining functional hand pumps. The first two calculations assume an average annual cost; the third considers a non-linear cost profile whereby a major rehabilitation can be followed by a longer period of comparatively minor costs. By considering these different types of costs, it is expected to help service providers consider the cash flow requirements needed to sustain maintenance services.

Methodology

Rehabilitation works were carried out on 47 water sources in Kumi District during an 8 month period from July 2016 to March 2017. In order for this rehabilitation work to take place, the communities at each water source were originally required to provide a small capital contribution towards the cost of restoring functionality and agree to enter into a 5 year service agreement following the date of the rehabilitation. This contract would then entitle the community to ongoing preventive maintenance and rapid response to breakdown. The service arrangement was established and the average breakdown duration for all 47 sources in the year 2017 was 1.5 days.

To track the initial cost of hardware during rehabilitation, a database was set up which allowed every pump component installed to be logged and the corresponding total cost to be calculated to facilitate real time analysis. In the months following rehabilitation, the ongoing hardware expense or OpEx was also captured to be used in life cycle analysis. This database was then combined with the experience of local service technicians who had spent years maintaining water sources in Kumi District and could estimate the expected life of each pump component. Therefore, it was possible to verify expert opinion against available data for specific components that required more frequent repair since initial installation.

Additional data sources were also used to conduct cost analysis. Baseline source mapping was conducted to assess the technical, political and social challenges that may have been faced when entering into a service contract with the local communities. These surveys gathered a vast amount of data including GPS data, source depth and original installation date which was later used in the analysis of rehabilitation CapEx.

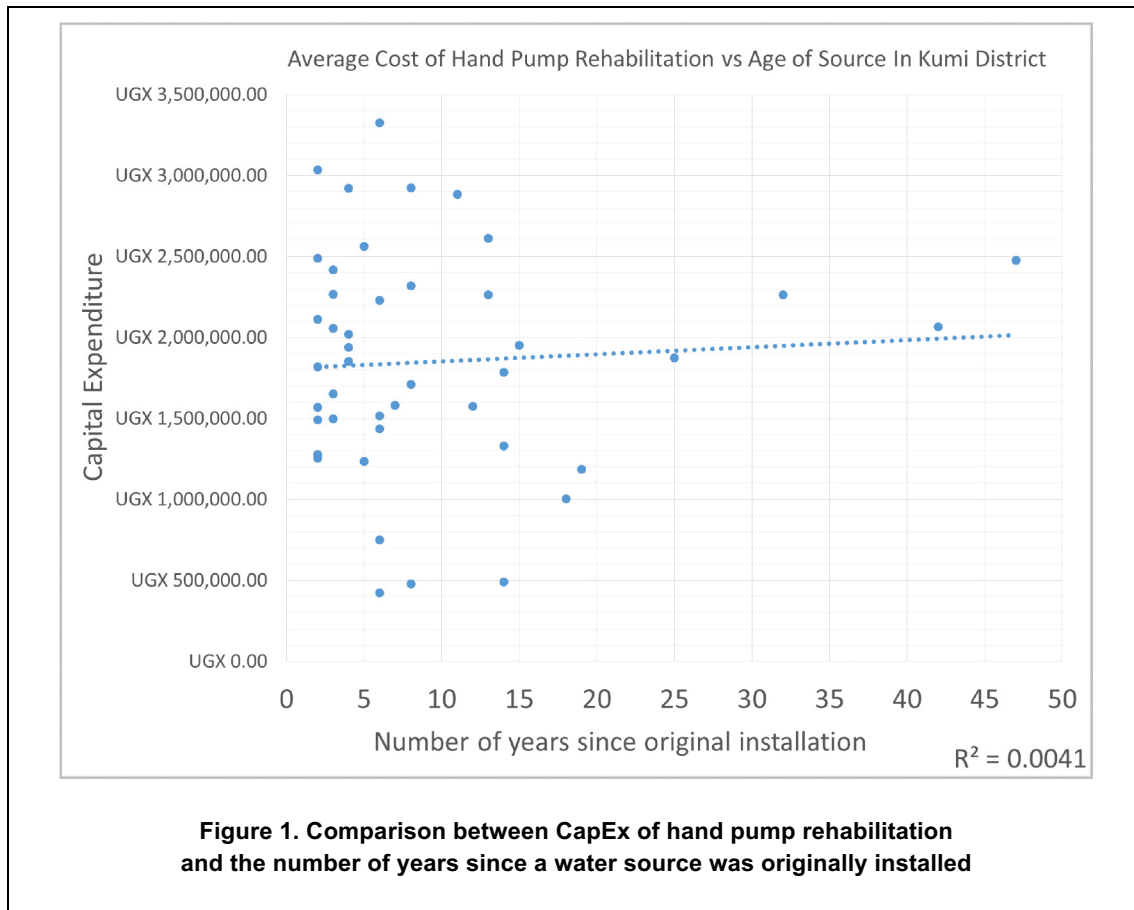
Results and discussion

Since July 2016, 87,614,800 UGX (approx. \$23,656) was invested in rehabilitating 47 rural water sources in Kumi District. A breakdown of the average cost per source rehabilitated is shown in Table 1.

Table 1. Breakdown of CapEx invested in Kumi Distri 2016	
Total Cap-Ex spent on rehabilitations in Kumi District	87,614,800.00 UGX (23,656.00 USD)
Average Cap-Ex per rehab	1,864,144.68 UGX (503.32 USD)

The majority of boreholes rehabilitated in Kumi were shallow wells with a depth of less than 30 meters, typically less than 20 years old. Rehabilitation costs can be analyzed against both of these parameters to investigate how accurately source age or depth might predict the cost of rehabilitation.

Using information gathered during source mapping exercises, the cost of rehabilitation was compared to the age of a water source in order to identify whether older sources required a greater capital contribution in order to restore functionality. Where the data was available, rehabilitation cost was plotted against source age to produce the graph shown in Figure 1.



The data indicates that there is no clear correlation between the age of a source and the Capital Expenditure required to rehabilitate it. The condition of each hand pump varied greatly, and age is therefore not a sufficiently accurate predictor of the cost of rehabilitation. This is supported by the low R^2 value of 0.0041 which indicates a significantly weak positive correlation.

The depth of each rehabilitated source was then compared against rehabilitation cost (Figure 2).

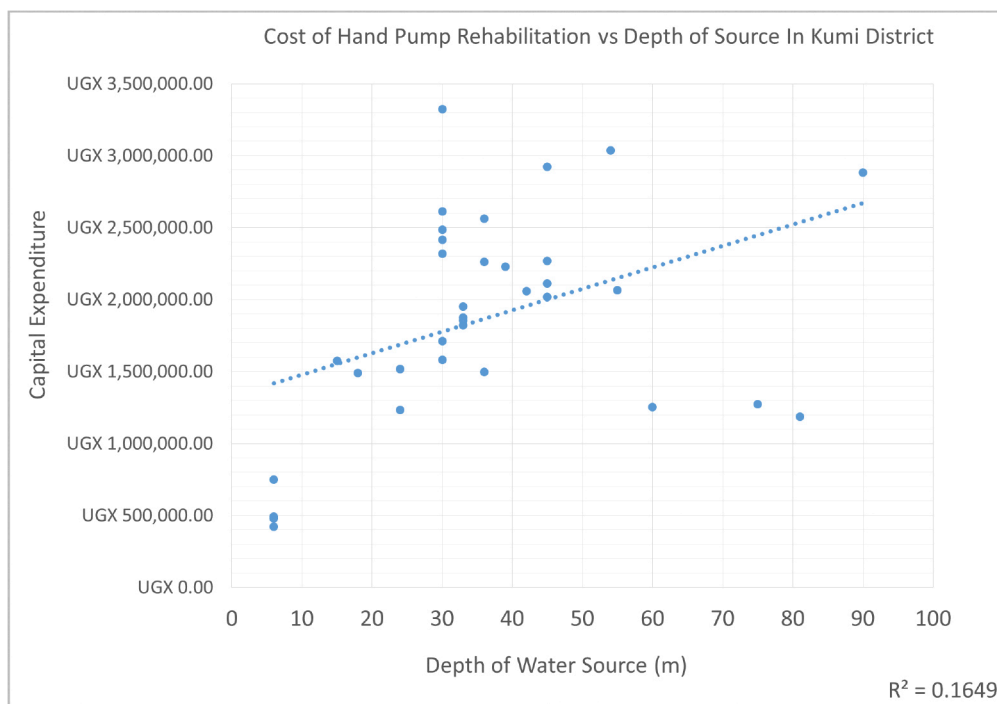


Figure 2. Comparison between depth of source and CapEx incurred rehabilitating source

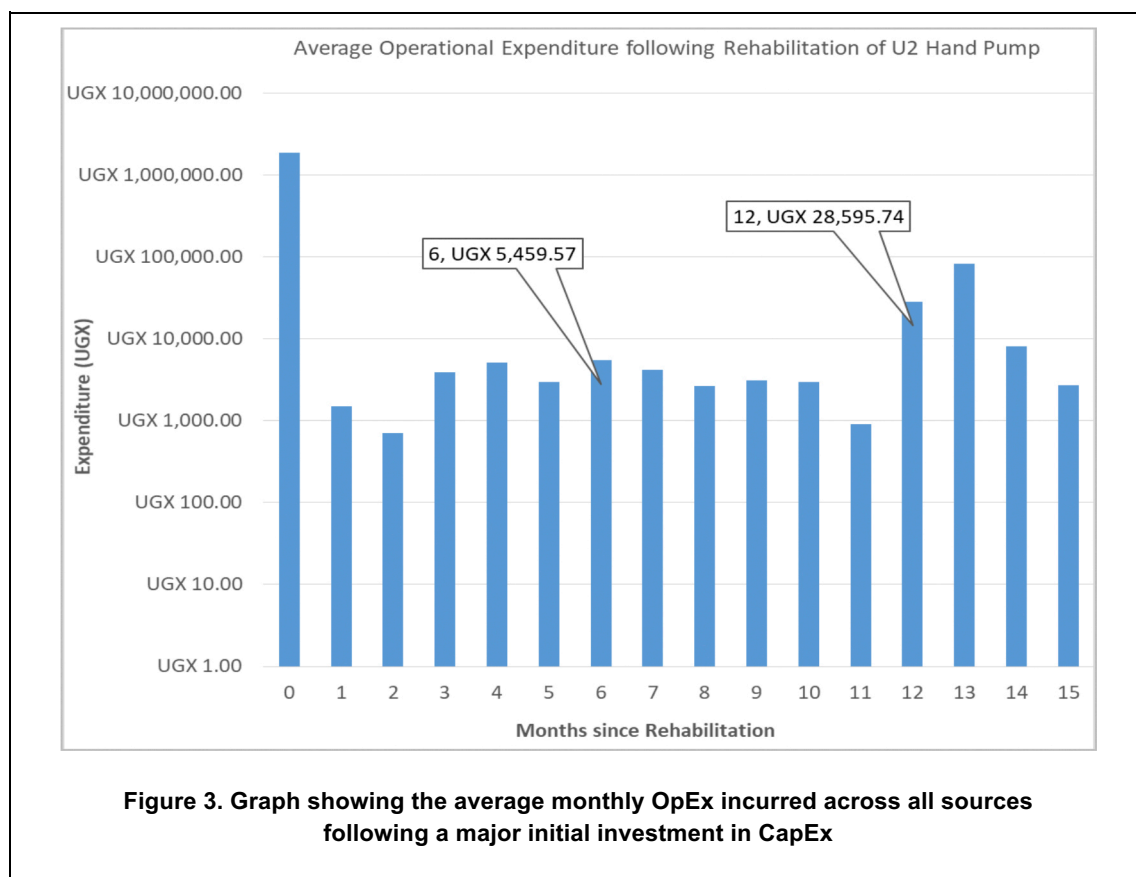
The analysis shows only a minor correlation between source depth and Cap-Ex., with an R^2 value of only 0.1649. Therefore, the depth of the source is not a sufficiently accurate predictor of the rehabilitation cost, which is contrary to the prediction that the deepest boreholes would require the highest capital investment to restore functionality. The cost of pump maintenance over its life cycle could therefore not be based on the depth of each water point or the number of years since its installation.

The life span of each pump component was investigated next in order to estimate annual expenditure on preventative maintenance and develop a comprehensive cost model on which to base contract fees. First, the cost of each pump component was established with a competitive in-country supplier. These costs were then divided by their estimated operating life obtained from discussions with hand pump mechanics and technicians. The resulting Operational Expenditure for U2 hand pump components, excluding the rods and pipes was calculated at 199,033 UGX (\$53.74) per annum. The pump rods and pipes were considered separately as a result of the variability in source depth and because they have the biggest impact on the total cost of maintaining a hand pump. For a U2 there are four different down hole specifications available but when comparing, quality, cost and operating life, uPVC pipes with stainless steel couplings and stainless steel connecting rods were selected as the standard downhole configuration for U2 water points. Again local service technicians were consulted for estimated life spans of these components and the Op-Ex per rod and pipe length per year was calculated at 18,097.19 UGX (\$4.72). To obtain realistic estimates for total life cycle costs, the range of depths of rehabilitated hand pumps was considered along with existing water sources which were mapped in other districts in 2017. Based on these depths, three costing tiers were developed which include shallow (<30 m), deep (< 50 m) and extra deep (<80 m). In order to establish a total annual cost given the variability in source depth, the depth of rehabilitated sources was reviewed and 12 pipes (36.58 m) was chosen as an acceptable average. An additional expense of 2730.77 UGX (\$0.71) was then added to the overall cost of the rising main to account for the annual cost of replacing the stainless steel coupling which connects the rising main to the pump head. The total annual costs for maintaining a U2 hand pump was then calculated by combining the Op-Ex for the pump components with that of the rods and pipes, factoring in a 50,000 UGX float to cover repairs on the concrete apron and drainage channel. A total Operational Expenditure of 468,930.05 UGX (\$124.11) was determined as the annual maintenance of a U2 hand pump. However, to achieve full cost recovery whilst planning for future Capital Maintenance Expenditures, (Cap-Man-Ex) the estimated Op-Ex of preventive maintenance was required be as accurate and reliable as possible. Considerable effort was therefore made to switch to real time life cycle cost analysis by collecting data from maintenance

and repairs conducted over time following a rehabilitation. To achieve this, local service technicians were asked to fill in maintenance logs following every instance of part replacement. These logs were then used to track the frequency with which parts were replaced following a major rehabilitation. The average monthly cost of maintaining all 47 sources was then calculated following ‘month zero’, the month during which the rehabilitation occurred.

Figure 3 presents the average Operational Expenditure per month per source, which represents the preventative maintenance conducted by local service technicians. During the first 11 months following rehabilitation, the average monthly Op-Ex did not exceed 6000 UGX (\$1.56). During months 12 and 13 the average Op-Ex increases dramatically in response to the preventative maintenance system. A “PM12” is conducted every 12 months and involves the replacement of minor components that, according to the hand pump mechanics, are most likely to fail and cause a breakdown. These parts include the ball bearings located in the pump handle and the rubber seals and seating’s found in the cylinder. By scheduling the replacement of these parts, whilst simultaneously conducting a full inspection of the above and below ground components, technicians are able to maximise functionality and avoid instances of breakdown. It can then be seen that the average Op-ex subsequently decreases following a “PM12”, indicating that instances of part replacement return to a sustainable level following the twelve month.

Whilst only 15 months of data are currently available, it can be hypothesised that investing in the on-going maintenance of these hand pumps will reduce the probability of any part failing in any given year, thus mitigating a major breakdown and the associated Capital Maintenance Expenditure (Cap-Man-Ex) required to restore functionality. Figure 3 presents a logarithmic scale of the ongoing maintenance costs in the months following a major rehabilitation of the water source.



The study of U2 hand pump Op-Ex was followed by the development of a database designed to establish the life cycle costs of each pump component. This database calculates the number of days between the installation and the replacement of specific parts in specific water sources. The total operating life of each component replaced was then divided by the total number of sources maintained in the district to find the average lifespan of each component in years. The unit cost of each component was then divided by its corresponding average life span to find the annual cost incurred to replace the part at the end of its operating

life. These costs were then compared against those established through consultation with local technicians in order to check their validity. With limited Op-Ex data currently available, this analysis was only possible for minor components expected to be replaced after 12 months and was therefore not presented in this study. However, as more information is fed into this database, the accuracy of currently calculated annual costs will increase and the annual costs of major components will become available as they reach and surpass their predicted operating life spans. Over time it is hoped that the average life span of each component will exceed recommendations made by local technicians, thereby reducing the annual cost of each component.

Conclusions and moving forward

Through the application of a preventative maintenance system, the cost of hardware in terms of OpEx can be kept at a minimum and occurrences of CapManEx can be significantly reduced. The data presented in this paper was collected over a relatively small period of time, and more data over a longer time period will increase the quality and reliability of future analysis. The benefit of this early review, however, is that the collection process can be constantly redesigned and refined. For example, by tracking the number of days between the replacement of a specific component at a specific water source, not only is it possible to identify the most frequently replaced parts but also flag instances where parts are being replaced prematurely. Recording data in this way also reduces human error where life cycle assessments are based on memory. Many components are expected to remain in good working order for several years during which time information can be misplaced or forgotten by local technicians.

Table 2. Summary of CapEx and OpEx costs for the U2 hand pump

Average Capital Expenditure invested in rehabilitating U2 hand pumps	1,864,145 UGX (503.32 USD)
Average Monthly Operational Expenditure following rehabilitation	10, 396.60 UGX (2.81 USD)

Table 2 presents a summary of the main economic findings of this paper. Although these costs were calculated using a relatively small data set, they allow practitioners to consider the overall cost of pump maintenance, and to structure cash flow availability to respond to different resource needs at different stages of pump life cycle.

The other key finding of this paper was that the predicted cost of rehabilitation should not be based on source age and depth as the condition of each pump varies greatly. The operating life of each component, informed by the recommendations of local technicians, should be used to establish a conservative estimate for the annual operational expenditure. Based on this, it is recommended that service providers commit approximately 470,000 UGX (\$124) annually to hardware in order to maintain pump functionality.

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