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LOCAL ACTION WITH INTERNATIONAL COOPERATION TO IMPROVE AND SUSTAIN WATER, SANITATION AND HYGIENE SERVICES

Evaluating novel gravity-driven membrane (GDM) water kiosks in schools

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This paper presents results of the field evaluation of three gravity driven membrane (GDM) water kiosks purifying Victoria lake water in schools in Uganda. The study evaluated the technical performance of the systems and the feasibility of the operation and maintenance concepts over two years of operation, as well as the financial viability of the business model and management concept and overall system sustainability. The results show that GDM water kiosks are a simple technology capable of treating turbid surface water and can autonomously supply good quality water to schools and communities. They require little maintenance, are simple to operate and maintain, and with trained local O&M team support, they offer sustainability of operation in remote low-income areas. The business and management model evaluation has not yet been completed and is ongoing.

Introduction

This project was implemented to evaluate the feasibility of gravity driven membrane (GDM) filtration for drinking water treatment at schools and communities in Uganda. Starting in January 2015, three GDM systems were constructed in the schools of Busime, Bulwande and Lugala, located in Busia and Namayingo Districts in Eastern Uganda to treat water from Lake Victoria. The water kiosks supply safe drinking water to about 1650 school children, as well as to the communities living in the catchment area of the schools. The schools and communities mainly rely on Lake Victoria for drinking water and before this project, consumed the water without treatment. WASH trainings were integrated into lessons at the schools to increase awareness regarding safe water, hygiene and sanitation. The objectives of this study were to:

- evaluate the design of the water kiosks and the resources needed to construct them using largely locally available materials (with the exception of the membrane modules and solar pumps)
- evaluate the technical performance of the system regarding water quality improvement, capacity and flow rate requirements
- develop and evaluate a suitable operation and maintenance (O&M) concept and assess these needs in relation to available resources
- evaluate the business and management concept, and
- assess the overall sustainability of the concept, as well as its scale-up potential.

GDM water kiosks

System design

The GDM water kiosks treat up to 6000 L/day of water pumped from surface and/or ground water sources. Figure 1 shows the system set-up. Thesystem consists of two major components: the water intake structure and the water treatment part. The intake structure is located at the lake shore and includes an infiltration well and a low cost solar pump (Ennos, Switzerland) placed in the solar pump house, which acts as the support structure for the photovoltaic cells and restricts access to the pump. The solar pump delivers water uphill through a pipeline stretching underground up to the school. At the school, raw water is collected into a 6000

L storage tank (tank 1) and flows into tank 2 which contains membrane elements. Raw water is filtered by gravity, using the pressure difference between the top of tank 2 and the permeate outflow positioned at 1/3 of the tank, through a flat sheet ultrafiltration membrane with a pore size of 20-40 nm. This allows for the removal of protozoa, bacteria and viruses by size exclusion (Peter, 2015). Three membrane modules (MICRODYN-NADIR Biocell 25, Wiesbaden, Germany) are used per system, providing an overall membrane area of 75 m^2. Purified water is collected into another 6000 L tank (Tank 3) elevated about 1m above the permeate outflow to allow for low but sufficient tap pressure in the four taps positioned in the water kiosk which delivers water to the customers. When the solar pump is not in operation due to reduced solar irradiation or runs only part of the day during the rainy season, rain water is collected in the same tank. Spilled and overflow water is collected in a soak away trench positioned behind the system.

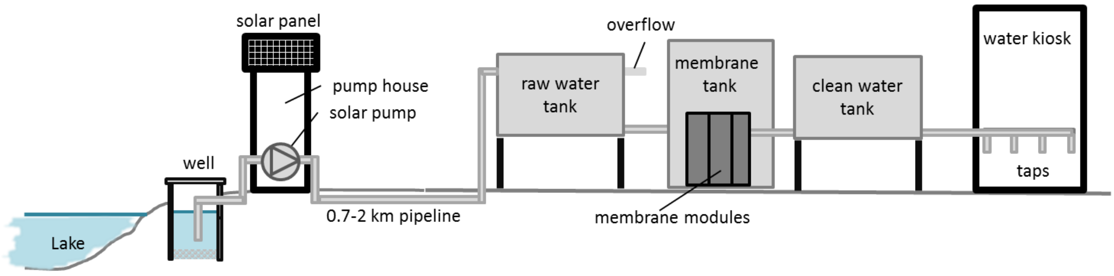

Figure 1. GDM system set-up

Background of the GDM technology

Most ultrafiltration membrane based systems for drinking water production at any scale are operated at a pressure of over 100 mbar (few household filters) to 1 bar (larger scale systems), with frequent automatic or manual backwashing and chemical cleaning. With GDM, water is filtered through the membrane at a very low pressure (10-100 mbar). No pumping, backflushing or cleaning is necessary to allow sustainable operation and avoid clogging. Water flux stabilizes at 2-10 L per hour per square meter of membrane and filters can be operated without maintenance for five to eight years with even very turbid water (over 300 NTU). This is possible due to the phenomenon of flux stabilization occurring at very low operating pressure. Without cleaning, all particles, including microorganisms, accumulate on the membrane surface, which creates a biofilm platform. The biological activity in the biofilm leads to the formation of cavities, which combine into channels. As a result, the biofilm becomes porous and allows passage of water. A state of equilibrium is established between the deposition of organic matter and bacterial cells and their degradation, aggregation and sedimentation, leading to a low but stable flux. Stable flux is sustained for years of operation without the need for chemical cleaning of the membranes (Peter-Varbanets et al., 2010, 2011).

O&M concept tested in the study

Major operation and maintenance (O&M) procedures conducted monthly include flushing of the membrane tank, shock-chlorination of the clean water tank and network, cleaning of the solar panel, water intake structure, maintenance of the solar pump and visiting critical control points within the system and distribution network. Local engineers at the Nalwire Technical Institute in Busia were trained to address all issues related to the operation and maintenance (O&M) of the solar pump, as well as the system in general, and showed great commitment to the project and creativity in solving problems using locally available resources. System operators were extensively trained using a specially composed manual for operation and maintenance of the system. The principles and structure of the manual are based on the Water safety plan manual of the WHO (Bartram et al, 2009). A detailed description of the GDM system and its elements, regular procedures, critical control points, as well as hazard and risk analysis are summarized in the document. O&M of the system is financed through the income earned through the sale of water at the kiosks. It is not yet clear if the income of such a low number of kiosks may provide the financial basis to sustain a comprehensive O&M service in long-term.

Business set-up
Treated water is provided to the schools for free and is sold to the communities at a price of 100UGX (0.026 EUR) per jerry can in Bulwande and Busime and at a monthly rate of 3000 UGX (0.86 EUR) with a maximum of 5 jerry cans collected per day in Lugala. Management and operation of the water kiosks in Bulwande, Lugala and Busime are supervised by a management committee that consists of representatives from the schools at each site, members of the water users committee, as well as from the organization Water School Uganda. Each management committee hired an operator for the water kiosk. Money collected through sales or subscription fees are transferred to a central bank account controlled and monitored by Water School Uganda and overseen by the management committees.

WASH trainings in schools
Meetings took place with the District Education Officers to integrate the WASH training into the official school curriculum over the two years of the project. This led to permission being given to integrate the WASH trainings into the regular curriculum of the schools in both Districts and to assess the viability of its implementation. A “Train the Trainer” approach was taken with teachers at all three schools, who were trained to teach WASH, using the Safe Water School manuals.

Field methods
The technical evaluation of the system’s performance focused on microbial water quality, turbidity improvements, flowrate and capacity under stable operating conditions. Three methods were used to assess the water consumption and flow rate:

- The number of jerry cans of water sold to the communities and used by the schools was recorded daily by the kiosk operators in a book.
- Water meter readings were recorded regularly at all three schools.
- Data loggers to measure and log the water pressure in all three tanks were installed during the period of operation. Membrane flux were calculated or modelled based on this data.

Systematic monitoring of microbial water quality at five different points within the system as well as at four taps was conducted weekly from the start of the project until June 2016. After June 2016, monthly monitoring of microbial water quality was implemented. The water was monitored for indicator organisms, such as *Escherichia coli* (*E.coli*), and total coliforms. They were measured using standard membrane filtration procedures, as well as plating using Compact Dry Plates EC (Nissui) and incubation at 36°C. Membrane integrity tests were conducted by challenge filtration of raw water spiked with non-pathogenic Enterococci bacteria at the beginning of the project and in May 2016. In addition, further advanced microbial water quality methods were applied, but the data is not presented here.

Additional water quality parameters measured weekly until June 2016 were: Turbidity by using the Palintest Turbidity meter, dissolved oxygen and total dissolved solids by using the HACH 40d multimeter. Chlorine concentrations after shock-chlorination of the clean water tank were estimated using the Pooltester.

Household surveys were conducted to gather information from households in the catchment area of the kiosks on water, sanitation and hygiene conditions, practices, attitudes and beliefs. For the household survey, baseline data was collected in September 2014 and final evaluation data was collected in April-May 2016. A total of 338 (baseline) / 317 (evaluation) randomly selected households were interviewed, and every x-th household was selected in accordance with standard random sampling selection procedures. Quantitative data was collected from households using structured questionnaires during face-to-face interviews with closed ended, multiple choice questions on household demographics, water consumption patterns relating to different sources, water treatment practices, beliefs related to risks associated with water, hygiene and sanitation practices, as well as household asset information required to calculate a wealth index. Data was imported into SPSS for statistical analysis. General water handling practices and hygiene conditions were analysed using descriptive statistics. Bivariate associations between different factors and diarrhoea incidence were calculated using chi-square.

Results and discussion

Microbial water quality
Figure 2 shows the number of samples classified into the four risk categories proposed by WHO in the water safety planning approach (WHO, 2011). All samples collected from the Lake usually used by people to

abstract drinking water have shown intermediate or high levels of contamination. 97.3% of all samples collected after the membrane, 92.8% of the samples collected from the safe water storage tank as well as 95% of all samples collected directly from the tap correspond to the low risk category with most of the samples showing 0 or 1 *Escherichia coli*/100 ml. A few samples containing higher *E.coli* numbers were measured at the starting phase of operation of the system due to improperly tightened connections. One event of contamination of the clean water tank occurred for undefined reasons in Lugala in April 2016. Since May 2016, all samples measured at the taps or in the safe water storage tank were free of *E.coli*.

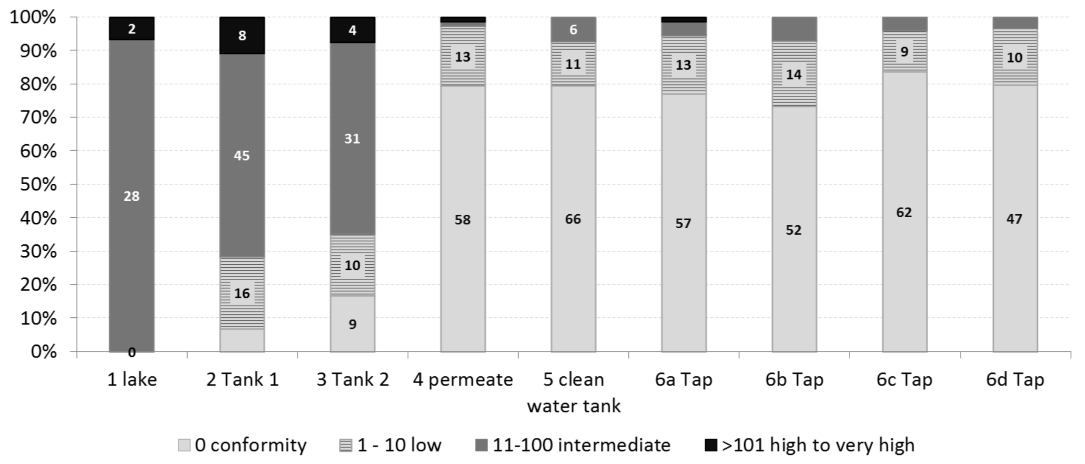

Figure 2. Number of samples in four E.coli count categories: 0, 1-10, 11-100 and >100 E.coli/100 ml for all three schools monitored during the period of November 2015-December 2016

Water flow and capacity

The lowest flowrate was measured in Bulwande. After almost 1 year of operation, this system had a stable flowrate of 0.22 m^3/h, corresponding to the flux of 2.95 L/h.m^2, considering conditions when the tank was almost full (75-100 mbar). In Lugala, the stable flowrate of 0.39 m^3/h measured after 8 months of operation corresponded to a flux of 5.2 L/h.m^2. In Busime, a flowrate of 0.8 m^3/h was measured corresponding to the flux of 10.7 L/h.m^2, which is very close to the initial membrane flux of 11.6 L/h.m^2 under similar pressure. In Busime, the conditions were not yet stable at the point of latest data processing (May 2016) since clear rain water predominantly fed the system between April to May 2016. The flowrates observed in all systems were sufficient to cover the average daily demand for water in all schools in about 6.5 hours of filtration. Thus, all systems have shown to have sufficient residual capacity. Due to the reduction of the pressure difference in the membrane tank and the clean water tank during filtration, the clean water tank was filling only partially leading to the reduced pressure in the taps observed in Bulwande.

Water sales and kiosks income

Figure 3 shows volume of water collected by schools or sold to the community for each month.

The relatively low consumption at the beginning of operation of each kiosk as well as in October 2016 in Lugala is caused by a system shut-off due to technical reasons. All three schools use about 10m^3 or less of water per month. The volume of water sold to community is considerably higher in Lugala than in the two other sites (784 m^3 /year in 2016 for Lugala compared to 223 m^3 /year in Busime and 172 m^3 /year in Bulwande). The longer distance to lake or other alternative water sources in Lugala (about 1.5 km) as well as lower costs of water through a monthly subscription fee can be possible causes of higher sales.

For all three kiosks, the sales of water resulted in the total collection of 3`298`100 UGX (868 EUR), while the total expenditures were 592`000UGX (155 EUR) covering all operational costs which include mainly, the salary of the kiosk operators as well as for small repairs (changing taps, door locks) since the beginning of operation of the kiosks, resulting in a total cash collection of 2`705`900 UGX (712 EUR). In spite of the higher sales of water in Lugala, the total profit generated in all schools is similar due to the lower price of water in Lugala.

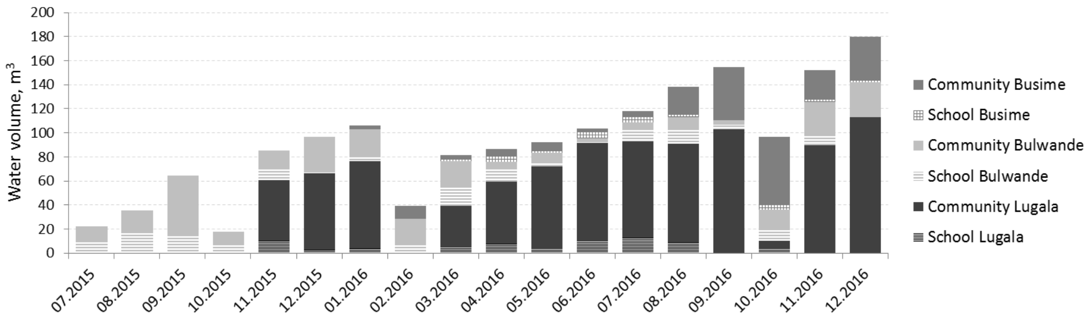

Figure 3. Volume of water collected in three kiosks per month

The business model as well as the evolution of the income and expenditures are further being evaluated. According to the current savings development, it will be possible to carry out major repairs of the pump if required (a new pump costs about 400$). Membrane modules are the most expensive element of the system. Membrane producers guarantee 8-12 years of trouble-free operation. In our case, the life expectancy can be estimated to be even higher since mechanical stress and chemical cleaning are not applied in GDM.

The total investment costs of one kiosk were approximately 18000$. Optimization of the design and construction would lead to the reduction of investment costs for one kiosk to approximately 15000$.

Household survey

The average household consisted of 6.45 people, with an average of 3.1 children going to school. Contrary to results obtained during the baseline data collection, the education levels revealed to be much lower with 62% of interviewees not having received any school training, 28% completed primary school, 8.5% secondary school and 0.9% had a higher education. A household had in average of 19’600 UGX available per week.

The utilization of different water sources changed significantly since baseline data collection. A much higher percentage of people now use safe drinking water sources. As Table 1shows, 46.7% of people now use water from the borehole instead of 19.8% at baseline, also a total of 57.7% of households said that they buy water from the water kiosk for drinking. The use of water from the lake for drinking purpose has decreased from 72.5% to 30.9%.

Table 1. Utilization of different water sources for drinking

Water sources	Borehole	Dug well	Lake	Rainwater	Vendor	Kiosk	Piped
Baseline, Sept. 2014, n=338	19.8 %	5.3 %	72.5 %	2.1 %	0.3 %	0	0
Evaluation, May 2016, n=317	46.7 %	5.7 %	30.9 %	12.9 %	0	57.7%	0

People pay for water from the borehole as well as for water from water kiosk. 40.1% of households pay for a monthly subscription for water from the borehole, while 4.1% pay per jerry can. 85% of people say that they pay a monthly subscription fee of 1000 UGX for water from the borehole, while the jerry can costs 300 UGX (39%) or 500 UGX (31%).

Reported diarrhoea incidence was reduced since the collection of baseline data. Diarrhoea incidence of adults decreased from 19% to 6%, while diarrhea incidence of children below the age of 5 decreased from 35% to 14%. Factors significantly associated with a reduction of diarrhea incidence were: the use of water from the water kiosk ($\chi^2(13)=47.8$, p=0.000 for adults, $\chi^2(27)=192.4$, p=0.000 for children <5), the use of water from the borehole ($\chi^2(39)=75.7$, p=0.000 for children), if the household’s toilet was rated as clean by the interviewer during the observation ($\chi^2(2)=10.2$, p=0.006 for adults, $\chi^2(3)=8.1$, p=0.045 for children <5) and the type of handwashing facilities available in the household ($\chi^2(6)=13.3$, p=0.039 for children <5).

Conclusion and recommendations

System performance. Systematic water quality evaluation revealed that the GDM systems are able to treat water to a good quality. Recontamination of the taps and of the clean water tank is a risk to water safety, however, due to the lack of residual disinfectants. Monthly shock-chlorination of the clean water tank, distribution pipe and taps is implemented to minimize these risks. The feasibility of providing a continuous dose of chlorine for residuals is considered and will be evaluated in the future.

Flowrates measured in the systems showed that stable flux values between 2-6 L/h.m^2 have been achieved in two systems in spite of the relative low quality of the raw water in regard to turbidity and organic matter content. In Busime, higher flux values were measured due to limited operation time. In Bulwande, tap pressure is perceived by consumers as too low. This is due to the relatively small height difference between the outflow of tank 3 and the position of the taps as well as suboptimal tap design. This issue will be addressed in the near future.

O&M sustainability. Guidelines for operation and maintenance (O&M) were developed and the operators and engineers of Nalwire Technical Institute were carefully trained in the implementation of the O&M process. The long term goal is to set-up a local competence centre for O&M of GDM technology and solar pumps at Nalwire Technical Institute. The solar pump produced in India by the Solar Pump Association Switzerland (SoPAS) revealed to be most vulnerable to environmental conditions, inadequate operation and lack of maintenance. Local access to pumps and their spare parts is critical for long-term sustainability. A supply chain for these are currently in the process of being established in Uganda by Solar Pam Association Switzerland with strong participation of the Nalwire Engineers, which further strengthens local capacity.

Acceptance. The household survey conducted in May 2016 revealed that the communities appreciate the water kiosks, particularly since their children now access safe water in the schools. The consumption of lake water at the three sites has decreased from 73% at baseline data collection to 41%. 65% of the households use only safe water sources now and 58% of the households use the kiosk water. Some of the households still use unsafe water sources, however, and the number of safe water customers could still be increased.

Business and management. The business of the water kiosks connected to the GDM systems is currently managed by the school management together with representatives from the community. Operators have been hired by the schools. Even though the schools are able to currently generate a profit from the sale of water and savings are accumulating, business management of the kiosks could be improved through capacity development in business management and promotion activities to increase the sale of safe water in the communities and further reduce the consumption of untreated water. Focused business training and marketing would contribute to long-term sustainability of the water kiosks.

Outlook. Two new water kiosks are being planned in the same area. The follow-up activities will focus on further strengthening of local capacities in O&M, business management of the kiosks, evaluation of the optimized design, and address water quality and hygiene concerns at the household level.

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