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TRANSFORMATION TOWARDS SUSTAINABLE
AND RESILIENT WASH SERVICES

Building an integrated water, waste-water and power facility in Kibera as a research platform: lessons learned

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The Kibera Town Centre [KTC]has provided water and waste water treatment in the Kibera slum of Nairobi since July, 2014. This paper outlines the operational and engineering successes and failures in this four-year period, and describes the design, implementation, and operation of a real-time data acquisition system to support both operations and research. A primary research objective is to evaluate new technologies suitable for total potable reuse in a slum setting, inviting collaboration in the design of water quality sensors and data analysis systems.

Setting

In the Kibera community, over 300,000 inhabitants[i] prove daily that human ingenuity can find a way to obtain adequate water despite major inadequacies both in clean water distribution and in sewage and waste disposal. The Kibera Town Centre [KTC] was designed and built in the center of Kibera in 2014 to create a new supply of clean drinking water, and to provide water services for toilets, laundry, and showers. Water is sourced from a 300-meter borehole into a previously untapped aquifer beneath Kibera, and on-site waste water treatment facilities treat the daily use of two thousand people utilizing its twenty showers, twenty-toilets and laundry facilities.

The majority of the Kibera community lives in a flood-plain of the Ngong branch of the Nairobi River, threatened repeatedly by ever-more-intense flood events that inundate low-lying housing, schools, food and water supplies.[ii]

Sited on an area of Nairobi that once housed the troops of the King's African Rifles, Kibera's clean water distribution system depends on hundred-year-old piping systems built to service now-vanished barracks, supplemented by piping installed by Nairobi Water and Sewerage Company along peripheral roads. In the interior of Kibera, one distribution pipe extending for over one kilometer has been tapped in hundreds of places by a series of informal distribution systems, managed by independent water vendors. Water service is intermittent, and water quality fluctuates daily, due to biological contaminant intrusion into cracked piping systems.

Biological water quality tests at over twenty Kibera water points conducted over a six month period by KTC show a repeated pattern of peak contamination in the two days following each rainstorm, and complete contamination in flood periods, which may last up to two weeks.[iii] In 2018, particularly intense rains have overwhelmed poor drainage systems and flooded homes and schools.

In Kibera, piped sewage collection systems do not exist, save in four areas at the perimeter of Kibera where seventy-year-old collection mains were installed by the British.[iv] Waste treatment is primarily by septic tank, with exhaustion often carried out manually, due to lack of access for exhauster trucks or vehicles.

System design and implementation

In 2010, the Human Needs Project began the first of dozens of community meetings in the thirteen villages of Kibera, Nairobi, to discuss the design of a water and community center. One year later, Nairobi City Council issued a 30-year Temporary Occupancy License for land at Kamukunji Grounds, the political heart of Kibera. Prime Minister Raila Odinga endorsed the project. A collaboration between the University of California, Davis Sanitary Engineering Department and several California and Canadian-based engineering firms designed an advanced waste water treatment plant for 2,000 daily visitors, and, in 2012, excavation began of the underground anaerobic and aerobic treatment vaults for the three-story Kibera Town Centre.

After two years of construction, redesign, training, and community review, the KTC opened on July 24, 2014. Four hundred Kiberan workers were trained to build the building. Thousands of kilograms of concrete was poured. Thirty Kiberan managers were selected from thousands of applicants from Kibera, and those selected now manage the KTC.

For 1,500 days, the KTC water treatment plant has processed an average of 70 cubic meters of borehole water per day for distribution in Kibera Olympic Primary School and the Gatwekera and Soweto West communities, as well as for use in the KTC toilet, shower, cafe and laundry facilities. The waste-water treatment plant processes 20-30 cubic meters per day by a combination of aerobic and anaerobic processes, utilizing specialized horizontal roughing filters, trickling filters, and slow sand filtration.

Research goals

In parallel with establishing an operational water and wastewater plant, KTC aspires to provide a research platform for study of slum water treatment. As distributed treatment alternatives emerge, KTC plans to study their deployment, effectiveness, and cost.

KTC's research goal is to partner with the water research community to discover, adopt, develop, install, and evaluate technologies and techniques that might enable net zero energy and net zero water systems to be built in slums world-wide.

This implies constant improvement in data acquisition systems. To evaluate the feasibility and cost-effectiveness of total potable reuse combined with resource recovery from wastewater, new data acquisition systems must be developed.

Today, operating in the center of the largest slum in East Africa provides actual time and cost data for some components of future systems. However, to evaluate future investments in distributed systems, including developing analyses of household or small-compound -level Point of Use treatment requires new, innovative systems, and new insights from the research community.

Today's research projects at KTC assess novel forms of fluoride removal, sensor design and implementation for biological and ionic systems, real-time data acquisition, biofilm management, and plant operation. However, KTC sensors today track only the clean water systems. Designs for monitoring the waste water systems, and for monitoring point of use systems are ongoing.

Current Research Platform 2018: clean water system, real-time sensor and data acquisition system

As of February, 2018, KTC deploys 19 sensors across the clean-water treatment system. Real-time (500 millisecond) data measures flow rates, temperature, tank levels, pH, and power usage for three of our 21 pumps. We capture fluoride and chlorine levels by daily manual testing, but have budgeted for installation of on-line sensors to enable research in alternative fluoride removal technologies.

Data is transmitted by 4-20 milliamp feeds, by digital feeds, and by pulse feeds to a sophisticated integrated circuit manufactured by XIO Water Systems in California, based on technology developed by Berkeley Control Systems, now acquired by General Electric for real time control of nuclear plants.

Data is converted to a common format, encrypted, and sent from the data integration center at KTC in Kibera across the Internet to Amazon Web Services utilizing HTTPS. A 24-feed system, operating 24-hours a day, costs less than $2000 USD to install. Operating costs are power, Internet access, and AWS storage fees that vary by volume.

All data collected since April, 2016 resides on Amazon Web Services. It is available for further data exploration and processing. We are developing an appropriate API for free access to our performance data., and are developing data visualization dashboards, including preconfigured Jupyter notebooks for future data manipulation, exploration, and prediction by machine learning algorithms.

The KTC experience demonstrates that new, inexpensive networked real-time water data acquisitions systems are deployable in slum water systems. As IoT standards emerge, academic research systems developed at numerous universities and deployed world-wide are seeing off-the-shelf commercial vendors emerge at reasonable price-points to supply and support such systems.

One objective of KTC is to maintain an ongoing evaluation of their capabilities. KTC now has an ongoing evaluation of two US based systems — XIO Water Systems[v] and AMI Global[vi] — and is exploring new systems from China. With proper design, and new, inexpensive electronics, these systems can provide modern, secure, replacement systems for outmoded, insecure, and extremely expensive SCADA systems now widely deployed in the water utility industry.

Preliminary analysis of 1,500 days of clean water production

KTC has provided, on average for 1,500 days, 70 cubic meters of clean water meeting all WHO and Kenyan water quality standards.

Average fluoride level in raw borehole water arriving at KTC is 6-8.5 parts per million. Application of activated alumina treatment reduces fluoride level in all delivered drinking water to a range of 0.7 to 1.5 ppm, but is expensive, leading to KTC research into less expensive alternatives.

A thorough cost-accounting of all expenses involved in producing potable water yields a final cost, including fixed and variable operating expenses, of 240 Kenyan shillings per cubic meter. Raw borehole water arrives at the treatment level of KTC at a 65 Kenyan shilling per cubic meter cost. Treated waste water arrives at the final distribution point at a 35 Ksh per cubic meter cost, and next phase installation of final treatment, to enable potable reuse, is ongoing.

Of the daily 70 cubic meters of potable water produced, 15 cubic meters is provided to drinking, washing, food preparation, and showers in the KTC building. 50 cubic meters is provided to Olympic Primary School, a school with 4,500 students, and for sale at several water points in the Olympic School area.

A significant component of daily operation in Kibera is power instability, the loss of electrical power for the operation of the 21 pumps inside the facility. This unreliability has led us to install a 140 kW photovoltaic panel system in addition to our existing ten panels of solar thermal hot water. Upon completion of this installation, we expect to have enough electrical storage to enable us to run all pumps for a ten-hour period without use of Kenya Power from the municipal grid, or use of our back-up diesel.

Our most significant failure has been inadequate preparation for data loss due to power outages, Internet failures, and political unrest. As a result, our time-series data suffer from gaps and outages.

On average, we experience more than ten power or phase outages a week, due in part to the lack of power access in the slum. Irregular connections to one of the three phases emerging from local distribution transformers cause major phase variations, and phase-to-phase voltage fluctuations., causing pump malfunction. During times of political disruption, we may lose power for days at a time.

Current Research Platform 2018 waste water treatment system

All elements of the KTC waste water treatment system were designed to be easily constructed in an urban slum environment. Design requirements included: minimal presence of pumps, with careful attention to gravity flow, tank wall heights, tank lip design, and tank entry and exit locations to minimize energy use while maximizing mixing.

KTC is in planning stages for design of a comprehensive waste water monitoring system utilizing advanced biological sensors. Price points for PCR-based technology for DNA sequencing are still high, but the size and power demand has decreased[vii].

We base our design on the existing system deployed by the University of California, Davis, in its Dunnigan Rest Stop research facility near Davis, California.[viii]

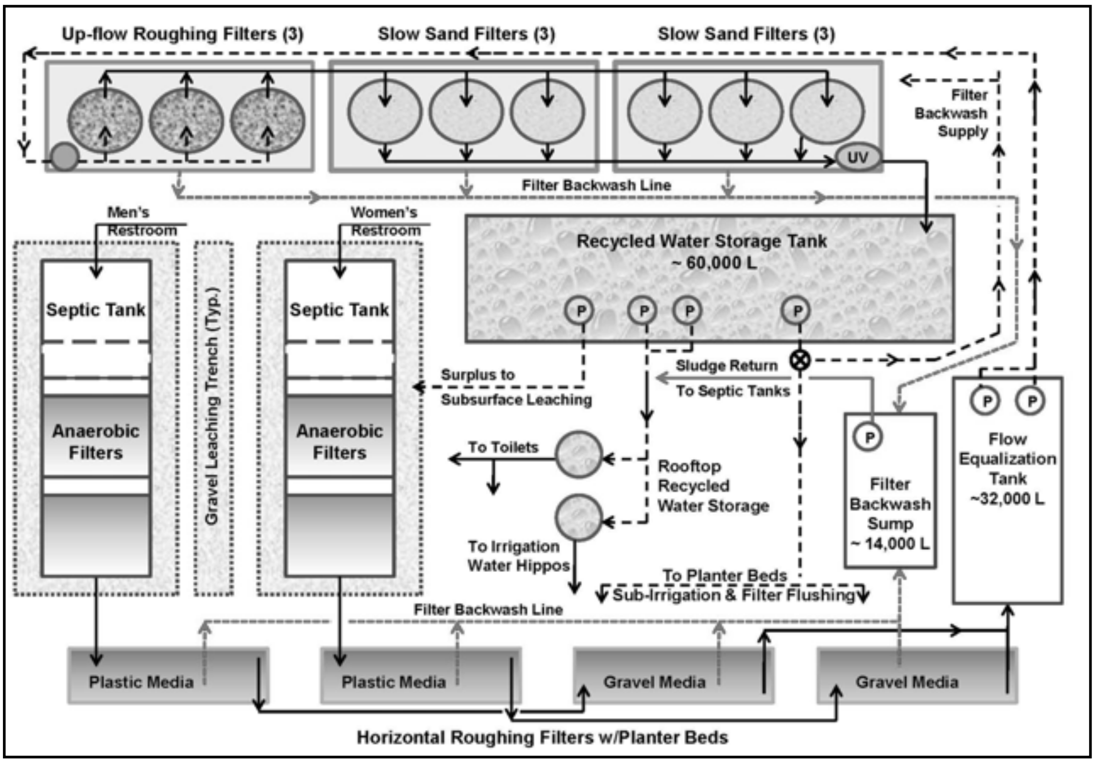

Figure 1. Diagram of KTC Waste Water treatment flow components: All elements are potential sites for sensors and testing components. The flow is from Septic Tank to Anaerobic Filters to Horizontal Roughing Filters to Flow Equalization Tank, then pumped to Up-Flow Roughing Filters, then through Slow Sand Filters, then to final Recycled Water Storage Tank, to await final finishing and disinfection.

KTC has provided, on average for 1,500 days, 20 cubic meters of processed waste water meeting all Kenya standards for biological contamination. This water is used in gardens, in construction projects, as toilet flushing water in KTC toilets, in laundry washing, and in local car wash installations. Installation of final finishing by a combination of new UV-C LED elements, combined with turbidity-controlled intensity control, may enable adequate treatment for potable reuse.

Our water treatment facility was designed in 2010 to test an evolving system of technologies in, as George Tchobanoglous and Harold Leverenz have described, "the continuum of alternatives for wastewater management infrastructure"[ix] Our current set of alternatives, drawn from the Tchobanoglous continuum, was designed by Harold Leverenz and the University of California Davis Department of Civil and Environmental Engineering[x] and by the California environmental engineering firm Questa Engineering[xi].

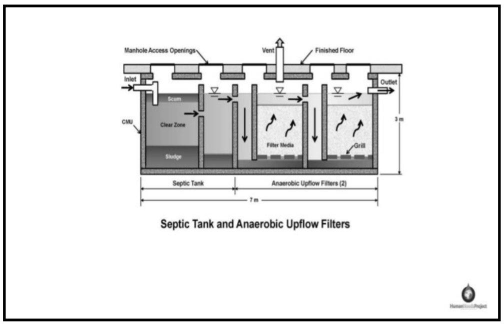

Figure 2. Diagram of septic tank and anaerobic upflow filters: notice lengthening of transport path to maximize residence time and enhance mixing

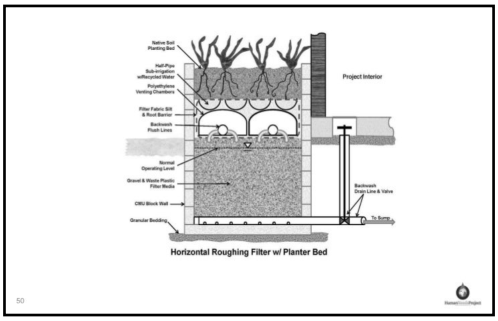

Figure 3. Diagram of Horizontal Roughing Filter: these elements are deployed in the front of the building, adding the visual attraction of the planting bed

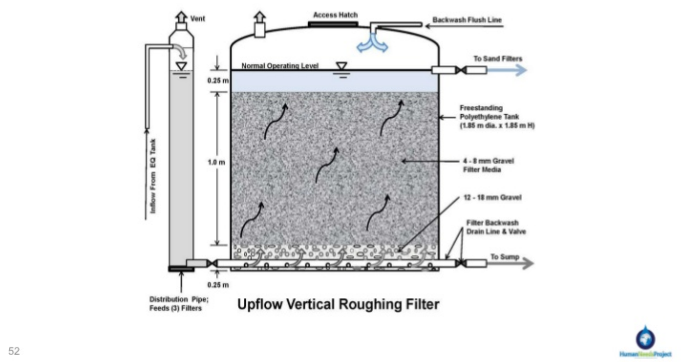

Figure 4. Up-flow Vertical Roughing Filter

Its primary features are:

Collection of all building waste-water in initial septic tank: black water from toilets, grey water from sinks and showers; grey water from food processing; grey water from laundry.

- Initial anaerobic chamber processing. Residence time ~ 3 hours
- Horizontal roughing filters, with extremely dense biofilm concentration on a plastic substrate manufactured from twisted and cut plastic water bottles formed from polyethylene terephthalate or PET, known as “plavel”
- Downflow trickling filters
- Upflow trickling filters
- Slow sand filters
- UV and chlorine disinfection

At the time of initial design, we did not include two components we now regard as essential: source separation for urine and solid material, and total methane recovery for our anaerobic processes. Installation of a complete sensing and water quality monitoring system for all elements of our waste water facility will enable us to closely monitor the species distribution of microbial and protozoan biota, so that we may have a better understanding of treatment efficacy. Emerging understanding of the differential impact of species variation may enable us to shrink the size of the treatment elements of the system, in order to create a system capable of functioning at the single household level.

Accounting matters. Water, wastewater and power providers are standardizing on a common chart of accounts, to allow collaboration, coordination, and cross-organization comparison. East African utilities have agreed to bring all utilities into the international framework of regulatory accounting tools designed in collaboration with the US National Association of Regulatory Utility Commissioners.[xii] We are adjusting our Chart of Accounts to be compliant with this fundamental element for accurate analysis of costs adopted by the Kenya Energy Regulatory Commission.[xiii]

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Notes

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