Reducing the burden of rural water supply through greywater reuse: a case study from northern Malawi

Evan Newcomer, Courtney Boyd, Laban Nyirenda, Emmanuel Opong, Shannon Marquez and Rochelle Holm

ABSTRACT

Greywater reuse has potential for non-potable applications that conserve freshwater resources in water-stressed areas especially in sub-Saharan Africa. The feasibility of reusing greywater for domestic activities in a rural area of Malawi, Africa, was evaluated from microbiological and public acceptance perspectives. Median *Escherichia coli* concentrations for eight domestic greywater sources (handwashing, laundry, runoff from a tap apron, bathing, cleaning a home/kitchen, cleaning a water collection container, washing plates and soaking vegetables) ranged from 100 to >20,000 colony forming units (cfu)/100 ml. Twenty-four of 47 greywater samples tested (51%) met the World Health Organization guideline for unrestricted use of greywater for irrigation. Pertinently, 80% (4/5) and 60% (3/5) of greywater samples from handwashing stations and bathing had *E. coli* less than the WHO guideline. Users reported greatest acceptance of reusing greywater for growing food and washing clothes, especially when the greywater source was bathing. Acceptance was closely tied to a household's economic standing, geographic location, and first-hand knowledge of reusing greywater. Greywater reuse practices in rural areas, especially targeting bathing water as suitable from bacteriological and user perception criteria, can help mitigate the impacts of water stress in sub-Saharan Africa.

Key words | developing countries, domestic greywater reuse, *E. coli*, public acceptance, total coliform

Evan Newcomer
Department of Civil, Architectural, and Environmental Engineering,
Drexel University,
3141 Chestnut St,
Philadelphia,
PA 19104,
USA

Courtney Boyd
Center for Interdisciplinary Inquiry,
Drexel University,
3141 Chestnut St,
Philadelphia,
PA 19104,
USA

Laban Nyirenda
Northern Zone WASH,
World Vision Malawi,
Box 610,
Mzuzu,
Malawi

Emmanuel Opong
World Vision International,
P.O. Box 2870,
Mbabane,
Swaziland

Shannon Marquez
Office of Global Health,
Dornsife School of Public Health, Drexel University,
Room 735 Nesbitt Hall, 3215 Market Street,
Philadelphia,
PA 19104
USA

Rochelle Holm (corresponding author)
Centre of Excellence in Water and Sanitation,
Mzuzu University,
P/Bag 201,
Mzuzu 2,
Malawi
E-mail: *rochelle@rochelleholm.com*

INTRODUCTION

The World Health Organization (WHO) credits stress on global freshwater resources and demands associated with increasing populations as the main drivers behind an increase in the reuse of greywater for agricultural purposes (WHO 2006). Greywater includes domestic wastewater which is generated by sources that are separate from human waste such as bathing, laundry, and handwashing stations, i.e. unconnected from a toilet or urinal, and can result from around 80% of freshwater usage in certain residential areas (Jamrah *et al.* 2007). Reusing greywater for applications that do not require potable water supply, such as producing food and watering plants, has been seen to

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result in savings of freshwater resources that could be used for other beneficial purposes (Jamrah *et al.* 2007). Reduced pollution discharges, promotion of groundwater recharge and increased food production have also been identified as potential benefits of reusing greywater (Madungwe & Sakuringwa 2007). Economic benefits of water reuse can be especially pronounced in regions dealing with water scarcity and high potable water costs (Ghaitidak & Yadav 2013). In the case of residential schools in India, environmental and health benefits were valued to be substantially higher than the capital construction costs associated with installing a greywater reuse system for food production and flushing toilets (Godfrey *et al.* 2009). According to Hall *et al.* (2014), low-income rural households that use water for productive purposes such as raising livestock can benefit from multiple-use water systems (MUS), which are designed to provide water for more than one specific purpose.

Previous studies have determined that greywater quality is site-specific (Jamrah *et al.* 2007; Mohamed *et al.* 2013). The short-term flow and composition of greywater depend on the source, time period of water-use activities and products used in the greywater source, such as soaps or cleaning agents (Eriksson *et al.* 2009). Contaminants of concern in greywater reuse include conductivity, total suspended solids, levels of *Escherichia coli*, biochemical oxygen demand (BOD), chemical oxygen demand, pH, salinity and heavy metals (Jamrah *et al.* 2007; Finley *et al.* 2008; Mohamed *et al.* 2013). But greywater reuse also has human-dimension factors. As reported by Hespanhol (1997), 'Public acceptance of the use of wastewater or excreta in agriculture and aquaculture is influenced by socio-cultural and religious factors.' Ilemobade *et al.* (2013) found in South Africa the acceptability of reusing domestic water was more favourable for toilet flushing than irrigation, with user perceptions of 'smell' and 'colour', as well as the value of savings in current water tariffs by the potable water saved being important. Additionally, Jamrah *et al.* (2007) found respondents who were opposed to greywater reuse cited safety, environmental, and religious concerns more frequently than either of the perceptions that reuse would pollute groundwater or not be viable from a financial perspective.

In Malawi, the National Water Policy (Malawi Government 2005) promotes water recycling and reuse for urban and peri-urban areas, but does not specifically target rural areas. In rural northern Malawi, water source options include piped water and community handpumps (both machine and manually drilled) as well as household point-of-use water treatment (Holm *et al.* 2016). However, the water supply in Malawi is fragile and increasingly impacted by climate change, as characterized by frequent drought and floods (Pauw *et al.* 2010; Chidanti-Malunga 2011). Food insecurity is also a major concern in rural Malawi, linked to inconsistent rainfall brought on by climate change (Murphy *et al.* 2016).

The purpose of this study is to evaluate the feasibility of reusing domestic greywater in applications that reduce the burden of collecting potable water in rural communities as examined using household surveys, focus group discussions, and by testing water samples for the presence of total coliform and *Escherichia coli* in a rural area of northern Malawi. The study findings are applicable for northern Malawi and other water-stressed areas of sub-Saharan Africa.

METHODS

We surveyed 123 households and collected 47 domestic greywater samples in Traditional Authority (TA) Timbiri and Sub-Traditional Authority (STA) Nyaluwanga, which are located in the Nkhata Bay District of northern Malawi (Table 1). Focus group discussions were convened with members of the local Water Users' Association (WUA), who are responsible for managing water access in the study area. Respondent households were in proximity to the Chikwina-Mpamba gravity-fed water distribution system, which covers an area of approximately 57 km^2 and whose ongoing development has been supported by the non-governmental organization World Vision Malawi (WVM). Approximately 1,400 households are served by the gravity-fed scheme. Geographic boundaries were determined by which of the system's six storage tanks supplied the tap nearest the respondent's household. The number of respondents interviewed from each geographic area was proportional to the total number of taps supplied by each tank. Greywater samples were collected at the conclusion of 47 (one sample per household) of the 123 household interviews, generated from a variety of domestic sources

Table 1 | Total number of water samples and households surveyed for each tank's geographical region

Tank no.	No. greywater samples	No. water point samples	No. households surveyed	Total no. taps supplied	Tank capacity (m^3)
1	7 (15%)	7 (15%)	19 (15%)	24 (9%)	150[a]
2	9 (19%)	9 (19%)	25 (20%)	60 (22%)	50[a]
3	9 (19%)	9 (19%)	15 (12%)	29 (11%)	50[a]
4	5 (11%)	5 (11%)	19 (15%)	15 (6%)	50[a]
5	15 (32%)	15 (32%)	39 (32%)	132 (49%)	90[a]
6	2 (4%)	2 (4%)	6 (5%)	10 (4%)	25
Total	47	47	123	270	415

[a]*Source:* World Vision Malawi (2015).

that respondents had on hand at the time of the interview. After collecting each greywater sample, survey teams additionally collected a sample directly from the water source where the greywater originated.

Water samples were collected in sterile 180-ml Whirl-Pak® bags with a sodium thiosulfate dechlorinating agent (Nasco, Ft. Atkinson, Wisconsin), and transported to the laboratory at Mzuzu University in insulated containers for same-day analysis (within 6 hours of collection). Each water sample was collected and tested in duplicate. From each sample, 1 ml was removed and analyzed for total coliform and *E. coli* using 3M™ Petrifim™ *E. coli*/Coliform Count Plates (3M, St. Paul, Minnesota). Samples were incubated for 24 ± 2 hours at 35°C. On each day that samples were collected, two equipment blanks were prepared using tap water that had been boiled for 30 minutes and allowed to cool for 2 hours. After the incubation period, visible microbial colonies were counted using 10× magnification.

Household surveys were administered in the local vernacular (Chitumbuka) as a digital survey using Open Data Kit (ODK) software (Open Source, University of Washington, Seattle, Washington) hosted on android smart phones. The survey consisted of four sections: demographics, economic indicators, household water usage and willingness to pay for improvements to the respondent's current water source. Relative economic wealth was estimated by a series of questions related to the respondent's occupation, seasonal crop yields, number of livestock owned, and number of items a household owned on a list of six common accessories (bicycle, cellphone, radio, television, cook stove, and refrigerator). Acceptance of greywater reuse was assessed through a series of questions with response options ranging from unwilling to willing to reuse water from a particular source (bathing or washing clothes by hand) for a particular domestic activity (growing food, bathing, washing clothes by hand, cooking). Two focus group discussions were convened with four and five WUA members respectively. Participants in focus group discussions were asked questions related to the history and operation of the gravity-fed scheme, as well as ongoing water reuse practices in the study area.

Data were analyzed using Microsoft Excel and SPSS version 24. Ethical clearance for the study was obtained from the Republic of Malawi National Commission for Science and Technology (Protocol P05/16/100). Informed consent was collected from each respondent prior to administering a survey or collecting a water sample.

RESULTS AND DISCUSSION

The study included 123 surveyed households, inclusive of 805 people. Eighty-eight percent (98/111) of respondents who answered the question reported it took 10 minutes or less to gather water from their primary water source, while the remainder either took 11–20 minutes (5%; 5/111) or did not know how much time it took (7%; 8/111). Eighty-eight percent (108/123) of interviewees said that a piped water connection, from the gravity-fed distribution system, was one of their primary water sources. However, inconsistent service at the piped water sources was a commonly reported problem during both household surveys and focus group discussions which caused people to resort to

alternative sources when piped water was not available. Alternative sources were not quantified during this study.

The presence of *E. coli* was variable between domestic greywater sources (Table 2) and geographic areas (Table 3). Median levels of *E. coli* ranged from 100 colony forming units (cfu)/100 ml for handwashing stations to >20,000 cfu/100 ml for greywater from washing vegetables and cleaning a home/kitchen. Greywater sources also exhibited variability in levels of total coliform, with median concentrations ranging from 9,100 to >20,000 cfu/100 ml. For greywater after cleaning a home/kitchen and washing vegetables, each sample contained >20,000 cfu/100 ml. Total coliform bacteria come from a variety of sources and will regrow in untreated water, which means they are not strongly indicative of fecal contamination in greywater, unlike *E. coli* (WHO 2011). The WHO guideline for using greywater for the unrestricted irrigation of root crops that will be consumed without being cooked is an arithmetic mean of 1,000 *E. coli* colonies per 100 ml (WHO 2006). The most stringent WHO guideline is applied to root crops that will be eaten raw, as root crops would come into direct contact with greywater during irrigation and have a relatively higher risk of disease transmission, as opposed to other crop types, such as tall-growing fruit trees. Twenty-four of the 47 greywater samples tested (51%) had less than the WHO guideline of 1,000 *E. coli* cfu/100 ml. The median *E. coli* concentration of five out of eight (63%) greywater category sources tested was less than 1,000 cfu/100 ml. One-sample sign tests were used to determine whether the median *E. coli* concentration of greywater from each source differed significantly from the WHO guideline (WHO 2006). It was found that each source except cleaning a home/kitchen (>20,000 cfu/100 ml, $N = 7$, $p = 0.016$) did not differ significantly from the WHO guideline (WHO 2006). The median *E. coli* concentration of greywater samples was less than the WHO guideline for unrestricted irrigation of root crops for only three geographic areas (Tanks 2, 3, and 6). One-sample sign tests showed that the median *E. coli* concentration of each geographic area was statistically equivalent to 1,000 cfu/100 ml. Chi-squared tests were used to determine that the geographic area of a sample was not strongly related to the amount of *E. coli* or total coliform ($X^2(N = 47) = 99.505$, $p = 0.356$, and $X^2(N = 47) = 70.775$, $p = 0.161$, respectively).

Results indicate median greywater concentrations generated in the study area by the tested category activities are typically acceptable for use in gardening or irrigation applications from a microbial standpoint, except when coming from cleaning a home/kitchen or washing vegetables. Even so, treatment is still recommended prior to reuse, to mitigate any risk of disease transmission (WHO 2006). One or more of the combinations of techniques

Table 2 | *E. coli* and total coliform test results by domestic greywater source

	***E. coli* (cfu/100 ml)**				**Total coliform (cfu/100 ml)**				
Greywater source	**Maximum**	**Mean**	**Median**	**Minimum**	**Maximum**	**Mean**	**Median**	**Minimum**	***N***
Bathing	8,800	3,300	400	0	>20,000[a]	10,600	9,100	1,600	5
Cleaning home/kitchen	>20,000[a]	16,200	>20,000[a]	2,500	>20,000[a]	>20,000[a]	>20,000[a]	>20,000[a]	7
Cleaning water collection container	>20,000[a]	6,900	700	0	>20,000[a]	17,100	>20,000[a]	2,300	6
Handwashing station	13,600	2,900	100	0	>20,000[a]	17,400	>20,000[a]	10,800	5
Runoff from tap apron	6,500	6,500	6,500	6,500	11,400	11,400	11,400	11,400	1
Washing clothes	>20,000[a]	3,400	600	0	>20,000[a]	18,000	>20,000[a]	6,800	14
Washing plates	>20,000[a]	5,900	600	0	>20,000[a]	14,800	>20,000[a]	1,300	7
Washing vegetables	>20,000[a]	>20,000[a]	>20,000[a]	>20,000[a]	>20,000[a]	>20,000[a]	>20,000[a]	>20,000[a]	2
WHO guideline for unrestricted irrigation[b]	–	≤1,000	–	–	–	–	–	–	

– No established value.

[a]Result was too numerous to count, upper limit of detection for this method is reported.

[b]World Health Organization (2006).

Table 3 | *E. coli* and total coliform test results by tank number

	***E. coli* (cfu/100 ml)**				**Total coliform (cfu/100 ml)**				
Tank No.	**Maximum**	**Mean**	**Median**	**Minimum**	**Maximum**	**Mean**	**Median**	**Minimum**	***N***
1	>20,000[a]	7,100	2,500	0	>20,000[a]	16,300	>20,000[a]	2,500	7
2	>20,000[a]	6,300	400	0	>20,000[a]	12,700	>20,000[a]	1,300	9
3	>20,000[a]	9,000	600	0	>20,000[a]	18,500	>20,000[a]	6,800	9
4	>20,000[a]	10,100	10,700	0	>20,000[a]	18,200	>20,000[a]	10,800	5
5	>20,000[a]	5,500	1,100	0	>20,000[a]	18,100	>20,000[a]	2,300	15
6	400	300	300	200	>20,000[a]	15,600	15,600	11,200	2
WHO guideline for unrestricted irrigation[b]	–	≤1,000	–	–	–	–	–	–	

– No established value.
[a]Result was too numerous to count, upper limit of detection for this method is reported.
[b]World Health Organization (2006).

identified by the WHO to reduce pathogens in wastewater for agricultural applications (i.e. drip irrigation or allowing time for pathogens to die off prior to food consumption) should be considered based on the end use being targeted (WHO 2006). In the rural, low-income study area of northern Malawi, it may be possible to improve food security and generate income while at the same time filtering and making use of greywater, by focusing on planting fruit trees at the outlets of bathing areas and water point aprons. This is already an ongoing practice in some, but not all, parts of the study area, as stated during focus group discussions. Many community water points were observed by the research team to drain excess water onto the open ground without any attempt at reuse (Figure 1). Another study found that, even though concentrations of fecal coliforms were high in greywater, concentrations in crops that were irrigated with the greywater but did not have edible portions contacted by greywater were not statistically different than crops that were grown using tap water (Finley *et al.* 2008). *E. coli* testing results also suggest that domestic greywater in the study area may be acceptable for reuse in applications that do not involve contact with food or water supplies, such as for brick making, a common income generator in rural Malawi. However, no respondent or focus group discussions cited brick making for greywater reuse, despite numerous family brick-making operations observed by the research team. This may be due in part to the practice of contracting this work out to other labourers, either through formal or informal contracts. Low-cost filter media materials, including bark, activated charcoal, and sand filters have been found to be effective at improving quality by reducing greywater BOD by 98%, 97%, and 75% respectively (Dalahmeh *et al.* 2012). Further research into low-cost filter media materials is needed for the study area of northern Malawi.

Respondents' willingness to reuse greywater depended greatly on both the type of greywater and the reuse

Figure 1 | Wastewater outlet and drainage from a water point, Chikwina-Mpamba.

application being proposed (Figure 2). Regardless of the final application, respondents were more willing to reuse treated water that had been used for bathing than water from washing clothes that had been treated. This preference may have been influenced by the products and contact surfaces involved in each type of use. The most favourable source-application combinations by respondents were washing clothes (46%; 56/123) and growing food (41%; 50/123) with treated bath water, followed by growing food (39%; 48/123) and washing clothes (33%; 41/123) with treated water from cleaning/washing clothes. This compares to studies in Oman, which found that 76% of respondents also perceived reusing greywater for gardening as acceptable (Jamrah *et al.* 2007), and peri-urban Bangkok, where 74% of respondents found reuse of treated greywater acceptable for watering plants (Jiawkok *et al.* 2013). Results from work in Accra, Ghana, showed 40% of urban respondents who consumed street food would eat salad that had been irrigated with wastewater (Antwi-Agyei *et al.* 2016).

Chi-squared tests revealed relationships between a household's economic wealth and its willingness to reuse treated greywater that were statistically significant in all cases except those involving cooking. Fifty-eight percent (14/24) of households that owned three or more accessories, an indication of higher wealth, were 'willing' or 'somewhat willing' to re-wash clothes with treated water, while only 27% (27/99) of respondents with two or fewer accessories, an indication of lower wealth, were willing to do the same ($X^2(N = 123) = 8.386$, $p = 0.004$). Conversely, the highest level of education attained by the head of household was only significantly related to reuse willingness in one case, which was reusing treated water from washing clothes to rewash clothes ($X^2(N = 123) = 13.906$, $p = 0.003$).

For the questions about the willingness to reuse greywater that was generated by bathing, respondents from the areas of Tank 3 and Tank 4 were least willing. For the four cases involving greywater made by washing clothes, respondents from Tanks 3 and 4 showed the least willingness to reuse greywater for washing clothes and cooking, and ranked in the bottom three (out of six tank areas) for the remaining two cases. Conversely, respondents from Tanks 5 and 6 were the two most willing areas to reuse greywater in five out of the eight cases presented during interviews. For each of the eight reuse cases, either Tank 5 or Tank 6 had the highest proportion of respondents either 'willing' or 'somewhat willing'. Results for respondents from Tank 6

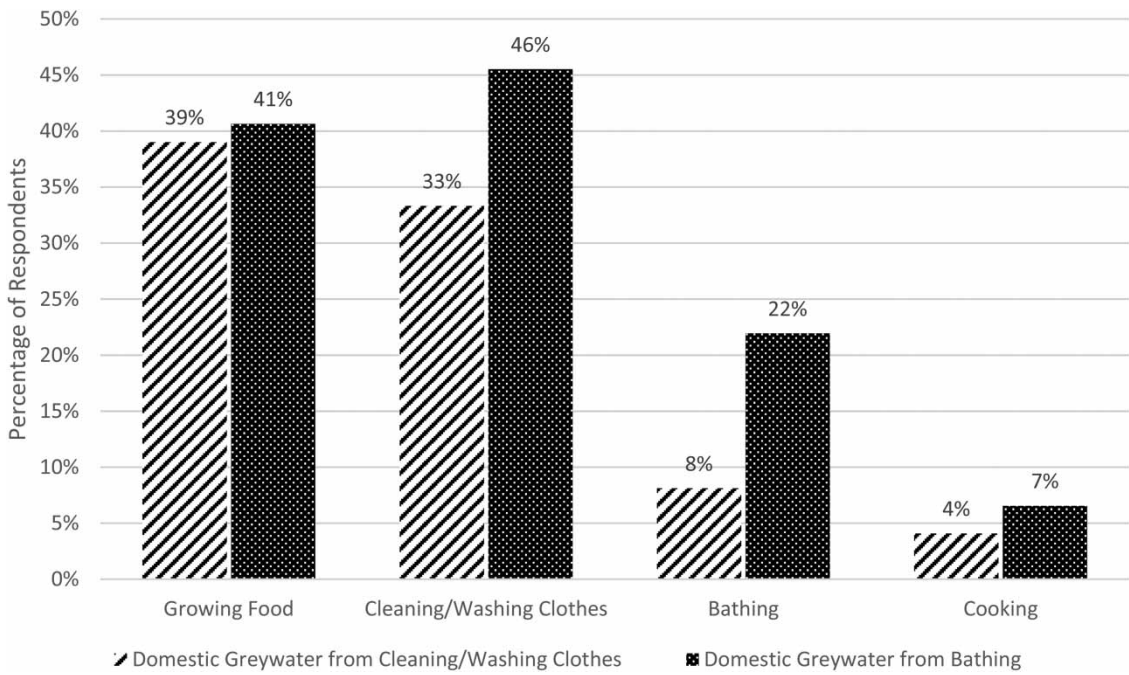

Figure 2 | Acceptability of reusing two types of domestic greywater for domestic activities.

may be skewed, due to the small number of interviews conducted in this area. Five of the eight reuse cases were found to be strongly related to the geographic area that respondents lived in, as determined by chi-squared tests. Tanks 4 and 3 had the smallest proportion of respondents who owned greater than two accessories and had the fewest and third fewest proportion of respondents currently reusing water, respectively. Respondents in the Tank 4 area also reported the greatest average distance from their home to the nearest market town (7 km, $N = 19$). These demographics are in contrast to Tanks 5 and 6, which had the highest proportion of respondents with more than two household accessories and also the highest proportion of respondents currently reusing water. This finding indicates that even in a limited geographic area, perceptions can vary. Households with greater relative economic wealth and greater familiarity with water reuse practices were more willing to find greywater reuse acceptable than households at the opposite end of those spectra.

In each of the reuse cases, the percentage of 'willing' or 'somewhat willing' respondents was greater among those who already reuse water, and for five out of the eight cases, the percentage was twice as much amongst households that are currently reusing water. Chi-squared tests revealed the relationship between current reuse and acceptability was statistically significant in five out of eight cases (growing food with water from washing clothes and each of the four scenarios involving reuse of bath water). This indicates the acceptability of reusing greywater is related to the source, final application, respondent's economic standing, geographic location within the system, and first-hand experience with greywater reuse. It should be noted that relationships associated with the tank area of a resident's household are not only determined by geographic area, but may also be affected by the quality of water service from the tank itself. Furthermore, in rural water systems, like the gravity-fed scheme in the study area, it cannot be assumed that source water is initially free of *E. coli* or fecal contamination, even before being used for domestic activities.

Sixteen percent (20/123) of respondents stated that they currently reuse water after it has been used once, with reported reuse applications including watering gardens or crops, bathing, and mopping. This is lower than studies in Bangkok which found 42% of respondents already reused wastewater (Jiawkok *et al.* 2013). Current reuse practices reported in the study area agree with findings from focus group discussions with members of the WUA responsible for managing the Chikwina-Mpamba gravity-fed system. WUA members reported that selected residents use wastewater for food production in gardens and that fruit trees had been planted at the outlets of tap aprons at multiple water points, indicating reuse of greywater is being done at a limited scale currently. Al-Hamaiedeh & Bino (2010) reported that even though treated greywater had increased the salinity and organic content of irrigated soils in Jordan, irrigated olive trees were not significantly affected, although the biological properties of some irrigated vegetables were negatively impacted.

Ongoing greywater reuse habits at the time of the survey were strongly related to both the number of accessories owned by a household and the highest level of education attained by the head of household ($X^2(N = 123) = 9.879$, $p = 0.002$ and $X^2(N = 123) = 14.695$, $p = 0.002$, respectively). At the time of the survey, 38% (9/24) of households with greater than two accessories reported currently reusing water, while only 11% (11/99) of households who owned two or fewer accessories reported that they were already reusing water. Similarly, in cases where a household head held a diploma or had completed secondary school, 100% (2/2) and 27% (8/30) of households were currently reusing water for some purpose, respectively. This contrasts with 11% (9/85) for those who had completed primary school and 17% (1/6) for those who had no schooling.

Concerns about water conservation and availability were also seen at an institutional level. During focus group discussions, WUA members explained their desire to initiate metering of connections in the gravity-fed scheme, as they were aware of residents leaving taps running for long periods of time, while not actually using the water. During the course of the study, it was also discovered that residents in certain areas would periodically shut off downstream gate valves without authorization in order to increase the pressure in their portion of the system, when undertaking water intensive activities such as brick-making. These two pieces of information show there is an unmet demand for water (at least for certain areas and times) and that freshwater resources are being wasted in the system. The observations also suggest that a MUS approach could be beneficial in water-stressed areas of rural Malawi and would support the efforts of field practitioners.

CONCLUSIONS

The purpose of this study was to assess the viability of reusing domestic greywater in a rural area of northern Malawi that has an active gravity-fed freshwater distribution system. Most study households were low-income, indicating that greywater reuse options should have a focus on low-cost solutions. Potential benefits of reuse should include the potential for increased food production, through irrigating fruit trees such as bananas and root vegetables, and income generation activities such as brick making. From a bacteriological quality standpoint, targeting reuse of bathing and handwashing water has the best potential, whereas greywater from cleaning a home/kitchen and washing vegetables has the least potential. From a user perception standpoint, willingness to reuse greywater was highest for the reuse of treated bathing water. While the public acceptability of making bricks with reused water was not quantified within the study area, using greywater for this purpose has the potential to make a positive impact as brick-making is a common income-generating use of water and has limited contact with food products. On-site treatment is recommended prior to any water reuse in order to reduce waterborne disease transmission risks. Future studies should be directed towards evaluating the public acceptability, financial impact, and microbial removal efficiency of various low-cost point-of-use greywater treatment options, including a pilot study of the best options in rural areas. Further research would also benefit from testing rural domestic greywater for a wider variety of constituents, such as metals (sodium, magnesium, calcium, and toxic heavy metals), salinity, and organisms that are indicative of viruses and parasites, in addition to total coliform bacteria and *E. coli*. Successful greywater reuse practices in rural areas, especially targeting bathing water as suitable from bacteriological and user perception criteria, can help mitigate the impacts of water stress in sub-Saharan Africa.

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REFERENCES

Al-Hamaiedeh, H. & Bino, M. 2010 Effect of treated grey water reuse in irrigation on soil and plants. *Desalination* **256** (1–3), 115–119. DOI: 10.1016/j.desal.2010.02.004.

Antwi-Agyei, P., Peasey, A., Biran, A., Bruce, J. & Ensink, J. 2016 Risk perceptions of wastewater use for urban agriculture in Accra, Ghana. *PLoS ONE* **11** (3), e0150603. DOI: 10.1371/journal.pone.0150603.

Chidanti-Malunga, J. 2011 Adaptive strategies to climate change in Southern Malawi. *Physics and Chemistry of the Earth* **36**, 1043–1046. DOI: 10.1016/j.pce.2011.08.012.

Dalahmeh, S. S., Pell, M., Vinnerås, B., Hylander, L. D., Öborn, I. & Jönsson, H. 2012 Efficiency of bark, activated charcoal, foam and sand filters in reducing pollutants from greywater. *Water, Air, & Soil Pollution* **223**, 3657–3671. DOI: 10.1007/s11270-012-1139-z.

Eriksson, E., Andersen, H. R., Madsen, T. S. & Ledin, A. 2009 Greywater pollution variability and loadings. *Ecological Engineering* **35**, 661–669. DOI: 10.1016/j.ecoleng.2008.10.015.

Finley, S., Barrington, S. & Lyew, D. 2008 Reuse of domestic greywater for the irrigation of food crops. *Water, Air, & Soil Pollution* **199**, 235–245. DOI: 10.1007/s11270-008-9874-x.

Ghaitidak, D. M. & Yadav, K. D. 2013 Characteristics and treatment of greywater – a review. *Environmental Science and Pollution Research* **20**, 2795–2809. DOI: 10.1007/s11356-013-1533-0.

Godfrey, S., Labhasetwar, P. & Wate, S. 2009 Greywater reuse in residential schools in Madhya Pradesh, India – a case study of cost–benefit analysis. *Resources, Conservation and Recycling* **53**, 287–293. DOI: 10.1016/j.resconrec.2009.01.001.

Hall, R. P., Vance, E. A. & van Houweling, E. 2014 The productive use of rural piped water in Senegal. *Water Alternatives* **7** (3), 480–498.

Hespanhol, I. 1997 Chapter 4 – Wastewater as a resource. In: *Water Pollution Control – A Guide to the Use of Water Quality Management Principles*, R. Helmer & I. Hespanhol (eds). World Health Organization (WHO)/United Nations Environment Programme (UNEP), London, UK.

Holm, R., Singini, W. & Gwayi, S. 2016 Comparative evaluation of the cost of water in northern Malawi: from rural water wells to science education. *Applied Economics* **48** (47), 4573–4583. DOI: 10.1080/00036846.2016.1161719.

Ilemobade, A. A., Olanrewaju, O. O. & Griffioen, M. L. 2013 Greywater reuse for toilet flushing at a university academic and residential building. *Water SA* **39** (3), 351–360. DOI: 10.4314/wsa.v39i3.2.

Jamrah, A., Al-Futaisi, A., Prathapar, S. & Harrasi, A. A. 2007 Evaluating greywater reuse potential for sustainable water resources management in Oman. *Environmental Monitoring and Assessment* **137**, 315–327. DOI: 10.1007/s10661-007-9767-2.

Jiawkok, S., Ittisupornrat, S., Charudacha, C. & Nakajima, J. 2013 The potential for decentralized reclamation and reuse of household greywater in peri-urban areas of Bangkok. *Water and Environment Journal* **27** (2), 229–237. DOI: 10.1111/j.1747-6593.2012.00355.x.

Madungwe, E. & Sakuringwa, S. 2007 Greywater reuse: a strategy for water demand management in Harare? *Physics and Chemistry of the Earth* **32**, 1231–1236. DOI: 10.1016/j.pce.2007.07.015.

Malawi Government 2005 National Water Policy. Ministry of Irrigation and Water Development, Lilongwe, Malawi.

Mohamed, R. M., Kassim, A. H., Anda, M. & Dallas, S. 2013 A monitoring of environmental effects from household greywater reuse for garden irrigation. *Environmental Monitoring and Assessment* **185**, 8473–8488. DOI: 10.1007/s10661-013-3189-0.

Murphy, C., Tembo, M., Phiri, A., Yerokun, O. & Grummell, B. 2016 Adapting to climate change in shifting landscapes of belief. *Climatic Change* **134** (1), 101–114. DOI: 10.1007/s10584-015-1498-8.

Pauw, K., Thurlow, J. & van Seventer, D. 2010 *Droughts and Floods in Malawi: Assessing the Economywide Effects*. International Food Policy Research Institute (IFPRI) Discussion Paper 00962, IFPRI, Washington, DC, USA. http://www.ifpri.org/sites/default/files/publications/ifpridp00962.pdf (accessed 29 August 2016).

World Health Organization (WHO) 2006 *WHO Guidelines for the Safe Use of Wastewater, Excreta and Greywater*. WHO Press, Geneva, Switzerland.

World Health Organization (WHO) 2011 *Guidelines for Drinking-water Quality*, 4th edn. WHO Press, Geneva, Switzerland.

World Vision Malawi 2015 *Chikwina Mpamba Gravity Water Fed Rural Supply Scheme: Fact Sheet – June 2015*. World Vision Malawi, Mzuzu, Malawi.

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