A novel approach for estimating urban water end use characteristics of cities in the developing world

Kenneth Muniina, Cedo Maksimovic, Nigel Graham
Imperial College London

Abstract

The design of alternative urban water supply interventions for a community located in a low-income country requires detailed and precise knowledge of the nature, frequency and intensity of various characteristic water end-uses of the community. Without the availability of this characteristic water use information, high resolution metering experiments are the usually preferred methods to measure the water use volumes. However in the developing world, these high resolution experiments are not an available option. Leaving the imprecise household interviewing process of data collection as the only option. This paper presents a novel methodology that improves and expands on the socially collected water uses data, through the use of stochastic modelling process of the water use volumes to estimate the total monthly water use of the community. The methodology not only improves the estimates of water use volumes but also provides a mathematical modelling description of the household water uses in the community.

1. Introduction

It is becoming accepted that conventional urban water supply systems across both the developing and developed world are struggling to sustain provision of appropriate water services to their users. The unsustainable behaviour of these systems is related to their inherent weaknesses such as delivering high quality potable water to all the users who require only a small fraction of the water for potable end uses like drinking or cooking (Sharma et al., 2013). As a result of this unsustainable behaviour, the centralised (or conventional) urban water service model is being ruled out as the most appropriate solution for urban water supply (Zhang et al., 2007; Sharma et al., 2010, 2013) in either the developing or the developed world.

This failure of the conventional urban water supply service model has led many authors, such as Porto et al. (2007); Bdour et al. (2009); Blackmore and Plant (2008); Fidar et al. (2010); Memon et al. (2005); Sharma et al. (2010); Zhang et al. (2007) to advocate for alternative urban water supply service models to improve sustainability. Such alternative urban water system service models are centred on a fit-for-purpose water distribution principle (Cook et al., 2009; Sharma et al., 2013) that requires the supply of water to be driven by the quality requirements of each specific end-use the water is intended for (Sharma et al., 2010). Such design of an urban water intervention requires the total water use in the community to be broken into a series of streams of the various water end-uses (Philip, 2011).

In urban communities of low-income countries, this kind of design is challenging due to the unavailability of water end-use information that is specific to these communities. However, in urban communities of the developed world, water end-use information is collected through high resolution metering experiments, as demonstrated in Al Amin et al. (2011); Athuraliya et al. (2008, 2012b); Beal and Stewart (2011); Dziegielewski et al. (2000); Heinrich (2007); Heinrich and Isaacs (2008); Jethoo and Poonia (2011); Keshavarzi et al. (2006); Lu and Smout (2010). In the developing world, high resolution metering of end-uses would be inappropriate and impractical owing to its relatively large resources requirements. Hence, social survey methods are the only feasible approach to estimate water end use volumes in these communities.

Employing social survey methods to estimate volumes of water end use, generates water use imprecise and uncertain data despite its ease. The method involves asking residents to recall their water use instead of physical measurement leading to inaccurate results (Athuraliya et al., 2008; Otaki et al., 2008). This paper therefore, provides a methodology that attempts to improve the accuracy of socially-generated water end-use data to generate a more representative and expanded quantification of water end-uses of a low-income urban water community.

2. Methods

2.1. Introduction

The methodology being suggested in this paper involves (1) the collection of representative water use data (both water end-use and billing data) of a low-income community, (2) then using this data to generate and calibrate a stochastic water end-use demand model of the community.

2.2. The Water Use Community

An urban community from south-west Uganda (Mbarara town), which has an urban resident population of $192,000$ was employed as the case for this study. The town is supplied with piped water, sourced from a river traversing the town, with a supply coverage rate of about 82% (that is percentage of mains water users against the total town population). Of the mains water users, the study however focused on the resident water user population (who represent about 80% of the mains water user population).

The community like most urban centres in the developing world, consists of a heterogeneous resident population. The heterogeneity (related to their water use behaviour) was schematised by categorising the user population into two main groups: house-connected water users and yard-tap-connected water users. House-connected water users, who are 33% of the mains supplied resident population, represent households that receive water directly in to the house, and thus employ in-door water appliances like flushing toilets, showers, and hand-wash basins. Yard-tap water users, who are 67% of the mains supplied water users, represent households that receive water by means of an outdoor tap, and thus use the water through hand-held containers. Such water users also employ on-site sanitation facilities like pit latrines implying that they do not employ any in-house water appliances. This heterogeneity is shown diagrammatically in figure 1.

The community is located in a tropical climate zone, which receives both a rainy and a dry season. In the dry season, it is expected that the water use intensity greater in the community compared to the rainy season. Therefore, in this study the water use data was collected during the dry season, but the analysis was carried for each of the wet and dry season independently. The water use in the wet season is assumed to reduce within the mains water use but increase through localised household rain water harvesting.

2.3. Data Collection

Two forms of data were employed in this study: (1) socially collected water end-use data, (2) and the measured household monthly water consumption accessed from the local water utility operator operating the piped water supply system in the community.

The water end-use data was collected by means of household interviews from a sample of randomly selected household water users (a sample size 425) during the dry season. The nature of the end-uses for each group was defined with the aid of local socio-economic experts and are shown in figure 1. For each end-use, data was collected (1) of its water use intensity (or volume), and (2) of its frequency.

Secondly to ease the measurement of the volume or intensity of water used, water users were asked to estimate their usage intensity in units of jerry cans (or in terms of cans or basins employed in the area). The local water users in the area have a better sense of the number of cans they employ than in terms of litres or cubic metres. For end-uses like toilet use (for house connections), hand washing (for both yard tap and house connections), showering (for house connections) that require further parameters to complete the end-use computation, data from the high-resolution metering study by Athuraliya et al. (2008) in Australia was employed. This data was chosen because it was a reasonable match this community, given that both communities experience similar day temperatures. Further, as an assumption, all the end-uses were assumed to have a penetration rate of 1.0, with all the water users employing them on a daily scale or weekly scale.

The other set of data employed in the study, the measured monthly consumption (or utility billing data) was accessed from the national utility, the National Water and Sewerage Corporation. In this community, like many other urban communities in the developing countries, all mains supplied water users are metered and hence their monthly consumption is regularly monitored by the utility.

2.4. Stochastic Modelling

The water use modelling is similar in principle to pulse demand modelling works in Buchberger and Wu (1995); Buchberger and Wells (1996); Rauch et al. (2003); Memon et al. (2005); Haarhoff (2006); Blokker et al. (2010); Creaco et al. (2016), but closer in detail to works by Haarhoff (2006); Blokker et al. (2010). In general the modelling involves the generation of water use volumes, through the aggregation of respective water end-uses (across different households) to generate the overall water demand of the community. In this study though, socially collected water use data is used as an input to the stochastic model, and also the study is applied to a low-income community. The pulse demand models mentioned earlier (as summarised in Rathnayaka et al. (2011); Creaco et al. (2016)) focus on applications in high-income communities.

The methodology employed to model and calibrate the water end-use volumes for each group in the community is schematised in Figure 2. The components (that is the frequency and or the intensity) of each end-use were represented as a probability distribution model. Since data collected through household interviews is susceptible to human errors (or is uncertain), the probability distribution model of each water end-use component was considered to represent its uncertainty or statistical spread. However, the position and spread parameters of the probability distribution model adopted for each water end-use component was calibrated to improve the predictability of the overall water end-use model in estimating the overall monthly water use of the community. Thus, the calibrated end-use stochastic models are taken to represent the actual end-use volume distribution of the water users in that town.

A more elaborate description of the water end-use model employed in this study, including its mathematical details, calibration and validation methods are provided in Appendix A (in the supplementary material).

3. Results

3.1. Model Calibration and Validation

The results of the calibration procedure are shown in figure 3 for both yard-tap water users and for house-connected water users, in the dry season. The aim of the calibration exercise was to use the water end-use model to predict the monthly water consumption for each of the yard-tap and the house-connected water users in the community. Hence, confirming the appropriateness of the developed water end-use model in representing overall water consumption in the community.

For all the months simulated, the measured monthly water consumption values were within the interquartile range of the model simulations as shown in figure 3a for yard tap water users and figure 3b for house-connected water users. The cumulative frequency distributions were also compared graphically as shown in figure 3c and in figure 3d, and analytically using the Kolmogorov-Smirnov test. The figures show that both the simulations and the measured consumption data are comparable numerically and statistically (with Kolmogorov-Smirnov test $h = 0$ at 5% significant level) for all the groups. Hence, it can be concluded that fitted probability distributions (of the water end-use components) are an optimal representation of the water end-use in the community.

3.2. Characteristics of the Community Water End-Use

3.2.1 Global Distribution of the Community Water Uses

Supplementary material figures A3, A4, and A5 show the results of the probability fitting process of the socially collected water consumption end-use data of the community, as well as the parameters of their respective distributions. The strength of the fit was measured with aid of the correlation coefficient (not reported in the figures) which was moderately high (> 0.8) for most of the end-uses, and hence showed good model representation of the end-uses by the probability distributions.

The results showed that the majority of the communities' water end-use frequencies and volumes or intensities required highly-skewed probability distributions such as log-normal or gamma, and in a few scattered cases with Normal and Weibull probability distributions. This implied that the highest proportion of the residential water users in the community consists of lower-end water users, with very small proportions of very large water-users.

3.2.2 Distribution of Household Size

The number of adults per household, in this study, was fitted to a log-normal distributions (in figure A3(a) for yard tap users, and in figure A4(a) for house connected users), with a geometric mean of 4.1 persons per household (for yard-tap connected users) and of 4.8 persons per household (for house-connected users). This study also showed that house connected water households contain relatively higher number of adults than yard tap connected water users.

3.2.3 Distribution of Bathing (or Showering)

Bathing (and or showering) frequency was modelled with a Weibull distribution in yard tap households (in figure A3(b)) and as Log-normal in house connected households (in figure A4(e)). The average frequency of bathing or showering in both groups was observed at about 2.0 times per day, which is higher than the average frequency of 0.7 recorded for a Dutch community in Blokker et al. (2010) or 0.73 per person per day in Athuraliya et al. (2012a). This is one of the major cultural (and may be due to climate) differences between communities in sub Saharan Africa and those of the developed world. The volume of bathing, on the other hand, used in the yard tap connected water users was estimated at an average of about 27 litres per person per day which is comparable to studies carried out in other African countries as reported in Thompson et al. (2001); Otaki et al. (2008); Nyong and Kanaroglou (1999).

3.2.4 Distribution of Dish Washing

The frequency of washing dishes (shown in figure A3(c) and figure A4(c)) for both yard tap and house connection water users was approximated with a geometric mean of 2.0 per household per day (and 2.5 for yard connected households). This frequency rate relatively higher than that observed in developed communities in Athuraliya et al. (2008) and Blokker et al. (2010), of about $0.3 - 0.5$ per household per day. This significant difference could be because of the use of dish washing machines in the developed world verses typical hand-dish-washing in this community. Dishes are washed more frequently in the developing world but at lower volumes than in the developed world. The volume of dish washing, on the other hand, for yard tap users was measured at approximately 24.4 litres per household which is moderately higher than other studies in the developing world recorded in Thompson et al. (2001); Otaki et al. (2008); Nyong and Kanaroglou (1999).

3.2.5 Distribution of other Water End-Uses

The frequency of laundry events in the community was comparable to other countries, the laundry water use in developed countries had a geometric mean of 0.3 times per day (and $0.4-0.7$ times per day for the developed world as reported in Athuraliya et al. (2008) and Blokker et al. (2010)). The laundry use volume or intensity of water end-use this study generated a geometric mean of 54.0 litres per capita for house-connected water users while in the developed world the corresponding value is $50.1-93.0$ litres per capita per day. Both external water use and general cleaning end-uses could not be compared to documented end-uses of the developed world. However, it should be noted that the external water end-use data could not be fitted to a model, and in addition the external water end-use required a negative binomial distribution (not shown in figures) to cater for a 42% penetration rate in the usage of external water services.

3.3. Improved Estimation of Water End-Uses

The final calibrated end-use volumes are detailed in table 1 showing the spread and median of the simulated end-use volumes for both yard-tap connected water users and house-connected users. The house connected households were evaluated to have a median total consumption of approximately 586.2 L/household.day (109.2 L/capita.day) while yard tap households have a median consumption of 347.9 L/household.day (60.2 L/capita.day). These consumption values are comparable to other end-use studies documented in the literature as shown in figure 4. For house connections, small to medium cities in comparable tropical climate were measured to have total household water consumption in the range $77-130$ L/capita.day as described in Nyong and Kanaroglou (1999); Keshavarzi et al. (2006); Athuraliya et al. (2008); Lu and Smout (2010). For Yard Tap consumers, the studies concentrating on water users in rural setting of low to medium developing countries in Fan et al. (2013); Nyong and Kanaroglou (1999); Keshavarzi et al. (2006); Jethoo and Poonia (2011), were measured to have end-use consumption of $68-123.5$ litres per person per day. However, these household end-use consumptions should be compared with caution.

For both house-connected water users and yard-tap users, showering or bathing was evaluated as the largest household end-use (45.5% in the house-connection users, and 43.8% in yard tap-connected users). This was followed by toilet use in house-connected users and hand-washing in yard-tap users. Also, it can be inferred from table 1 that the proportions of non-potable water end-uses were 82.8% in yard-tap and 77.7% in house-connected users. A sognificant proportion of water end-use in this community is of non-potable nature.

Finally, this study also revealed that the hand-washing in yard-tap water users, and showering (as well as hand-washing) in in house-connected water users were the most uncertain (in terms of variability) water end-uses. This high level of variability is therefore expected to sequentially the reliability of any grey water grey water harvesting interventions.

4. Discussion

4.1. Water end-use estimation methodology

White et al. (1999) states that one of the limitations of characterising the end-use behaviours and volumes of a community is the lack of reliable data on how and where water is being used. Survey data of a sample of the end-uses employed in the community can in general be collected for a community with relative ease and with lower resources compared to high-resolution metering exercises. Survey data collection therefore, would be a suitable approach for estimating water end-use characteristics of a low-income community. However, since water end use survey data is imprecise, and cannot accurately measure all community water end uses (Athuraliya et al., 2008; Otaki et al., 2008), then such end-use data collected through survey exercises should be applied in urban water design assessments with caution. This is particularly true for low income communities, and this paper therefore has presented a novel methodology to compensate for this limitation. The methodology improves on the accuracy of end-use data collected by social surveys by describing the end-use data through calibrated probability distribution models that describe the statistical spread of water end-use in the community.

In a community of the developing world, monthly metering of all water utility water users is a common practice, which makes available a representative dataset of monthly consumption of the community. This study has illustrated how this readily available dataset can be utilised to improve the estimation of water end-use approximations within a community. Monthly consumption billing data is hardly ever employed in end-use volume estimations, due to the limitations of accurately describing the temporal evolution of daily consumption to monthly values, as observed by Rathnayaka et al. (2011); Mayer et al. (1999). Hence, its employment in this study to calibrate the aggregation of end-use models is a novel approach.

4.2. Mathematical Modelling of Water end-use in a low-income community

In general, the mathematical model concept employed in this study to represent water end-use (as a building block for overall water demand) is not novel. In scientific literature, models of a similar nature were employed in Rauch et al. (2003); Haarhoff (2006); Jacobs and Haarhoff (2006, 2007); Jacobs (2007); Blokker et al. (2010, 2011) and reviewed in White et al. (1999); Rathnayaka et al. (2011). However, these models were applied to high income communities that are socially different from low income communities studied in this paper. Therefore, to adopt this concept to a low-income community these models had to be tailor-made by aggregating water end-uses that are specific to the low-income community.

Nonetheless, due to the high volume of data required for the development of water end-use models, and also due to the limited availability of community data in low-income communities. A novelty is introduced by this study related to how the study overcomes these challenges of data limitations to develop and calibrate a water end-use model of a community in the developing world.

4.3. Water end-use estimations

The results of the analysis of end-use water consumption evaluated in this study are comparable to other studies as shown in figure 4, although these comparisons should be interpreted cautiously. Firstly, it is recognised that house-connected households in Uganda significantly different to typical households in the developed world, the nature of their end-uses are not entirely the same. In the Ugandan community studied here, house connected households employ water for general household cleaning which is not represented in the end use structure of the developed world household communities.

Further, in the developed world communities, the households employ significant amounts of water for out-door irrigations (during the summer) which contributes the majority of outdoor water usage. While in this Ugandan community, (1) external water use is limited, and (2) where it is employed, it is used mainly for car washing instead of irrigation. The yard tap connected users, on the other hand, in this community, do not employ water for toilet flushing which is the major difference from house-connected users. Even for similar end-uses like the indoor water uses, this study has shown that there are still significant differences in the water consumption end-use parameters.

The differences in water end-use parameters drive the major differences between the household end-use proportions of both communities, as shown in figure 4. In this community, due to the high frequency of showering, this is the largest proportion of the overall household water use (43.8% in yard-tap users, and 45.5% in house-connected user) compared to only 24% in most developed world communities. This implies that integrated urban water interventions that target showering or bathing or hand-washing will most likely lead to a more significant impact on the performance of urban water systems in the developing world than in the developed world.

In addition, the developed methodology provides a way of describing water use in a community of the developing world, a more holistic description of water use in the community than what the socially collected end-use data can provide. The water end-use mathematical model and the methodology generated suggested by this study can be employed or extended in the design and assessment of urban water systems, especially in uncertainty or sensitivity analysis, and or, in studies that require a breakdown of water use for different water uses.

5. Conclusion

This paper has demonstrated a novel approach for simulating and evaluating water end-use volumes in an urban community of a developing country, by improving the accuracy of the household surveyed end-use data, through a stochastic modelling simulation. The modelling approach involved grouping the community into two heterogeneous subgroups (house-connected users and yard-taps users). Then for each subgroup, probabilistic regression models were developed for each category of water end-uses. The probability models for all the end-uses were then aggregated to generate the monthly consumption of the group, which was then calibrated - using the group's measured monthly billing as the "true" consumption, to get representative end-uses volumes and distributions for the community.

The evaluated water end-use volumes of the community revealed that, most of the end-uses (their components of frequency and intensity) displayed highly-skewed distributions (log-normal) characteristics. This implied that the majority of water users in the community are low-capacity water users. The approach also showed that a typical household in the community has consumption volumes of 109.2 L/cap/day for house connected user and 60.2 for yard connected users.

The simulated end-use volumes of house-connected users (who were assumed to be comparable to developed country communities) were found to be relatively lower than comparable communities in the developed world. At the same time, the yard-tap users (who were assumed to be relatively comparable to rural communities) were found to have higher end-use volumes than rural communities. The principal differences in the water end-use behaviour were found to be hidden in (1) the presence or absence of certain end-uses in this community verses developed country communities, (2) within similar end-uses, some of the end-use parameters were significantly different, reflecting a difference in water use culture of both communities. This study therefore concludes with a caution that water end-use characteristics of one community should be employed carefully in the assessment or design of decentralised systems of another community, otherwise to misleading results will be generated.

The study has shown that showering (or bathing) water end-use is, on average, the largest household water use for both house-connected users and yard-tap connected households, but it was not the most uncertain. In yard-tap customers, hand-washing was the most uncertain household water end-use, while showering was the most uncertain water end-use in the house-connected water users.

References

Al Amin, M., Mahmud, K., Hosen, K., Islam, A. M., 2011. Domestic water consumption patterns in a village in Bangladesh. In: 4th Annual Paper Meet and 1st Civil Engineering Congress. Dhaka, Bangladesh, pp. 83–85.

Athuraliya, A., Gan, K., Roberts, P., 2008. Yarra Valley Water - 2007 Appliance Stock and Usage Patterns Survey. Tech. Rep. May.

Athuraliya, A., Roberts, P., Brown, A., 2012a. Yarra Valley Future Water - Residential Water Use Study. Tech. Rep. August, Melborune, Australia.

Athuraliya, A., Roberts, P., Brown, A., 2012b. Yarra Valley Future Water - Residential water use study volume 2. Tech. Rep. August, Yarra Valley Water.

Bdour, A. N., Hamdi, M. R., Tarawneh, Z., Feb. 2009. Perspectives on sustainable wastewater treatment technologies and reuse options in the urban areas of the Mediterranean region. Desalination 237 (1-3), 162–174.

Beal, C., Stewart, R. A., 2011. South East Queensland Residential End Use Study : Final Report. Tech. Rep. 47, Urban Water Security Research Alliance Technical Report No. 47.

Blackmore, J. M., Plant, R. A. J., 2008. Risk and Resilience to Enhance Sustainability with Application to Urban Water Systems. Journal of Water Resources Planning and Management 134 (3), 224–233.

Blokker, E. J. M., Pieterse-Quirinjns, E. J., Vreeburg, J. H. G., Dijk, J. C. V., 2011. Simulating Nonresidential Water Demand with a Stochastic End-Use Model. Journal of Water Resources Planning and Management 137 (6), 511–520.

Blokker, E. J. M., Vreeburg, J. H. G., van Dijk, J. C., 2010. Simulating Residential Water Demand with a Stochastic End-Use Model. Journal of Water Resources Planning and Management 136 (1), 19–26.

Buchberger, S. G., Wells, G. J., 1996. Intensity, Duration, and Frequency of Residential Water Demands. Journal of Water Resources Management 122 (1), 11 – 19.

Buchberger, S. G., Wu, L., 1995. Model for Instantaneous Residential Water Demands. Journal of Hydraulic Engineering 121 (3), 232–246.

Cook, S., Tjandraatmadja, G., Ho, A., Sharma, A., 2009. Definition of Decentralised Systems in the South East Queensland Context. Tech. Rep. 12, Urban Water Security Research Alliance Technical Report No . 12, City East.

Creaco, E., Kossieris, P., Vamvakeridou-Lyroudia, L., Makropoulos, C., Kapelan, Z., Savic, D., 2016. Parameterizing residential water demand pulse models through smart meter readings. Environmental Modelling & Software 80, 33–40.

Dziegielewski, B., Kiefer, J. C., Opitz, E. M., Porter, G. A., Lantz, G. L., Deoreo, W., Mayer, P. W., Nelson, O. J., 2000. Commercial and Institutional End Uses of Water. Tech. rep., AWWA Research Foundation.

Fan, L., Liu, G., Wang, F., Geissen, V., Ritsema, C. J., Tong, Y., May 2013. Water use patterns and conservation in households of Wei River Basin, China. Resources, Conservation and Recycling 74, 45–53.

Fidar, A., Memon, F. A., Butler, D., Nov. 2010. Environmental implications of water efficient micro-components in residential buildings. The Science of the total environment 408 (23), 5828–35.

Haarhoff, J., 2006. Structure and data requirements of an end-use model for residential water demand and return flow. Water SA 30 (3), 293 – 304.

Heinrich, M., 2007. Water End Use and Effeciencu Project (WEEP) - Final Report. Tech. Rep. 159, Branz Limited, Judgeford, New Zealand.

Heinrich, M., Isaacs, N., 2008. Water Use in Auckland Households - Auckland Water Use Study (AWUS). Tech. Rep. October 2008, Branz Limited.

Jacobs, H., Haarhoff, J., 2006. End-Use Modelling as a Means to Predict the Effects of Water Demand Management. In: Biennial Conference of the Water Institute of Southern Africa(WISA). No. May 2002. Water Research Commision(WRC), Durban, South Africa, pp. 1 – 9.

Jacobs, H. E., 2007. The first reported correlation between end-use estimates of residential water demand and measured use in South Africa. Water SA 33 (4), 549–558.

Jacobs, H. E., Haarhoff, J., Dec. 2007. Prioritisation of parameters influencing residential water use and wastewater flow. Journal of Water Supply: Research and TechnologyâĂŤAQUA 56 (8), 495.

Jethoo, A., Poonia, M., 2011. Water Consumption Pattern of Jaipur City (India). International Journal of Environmental Science and Development 2 (2), 0–3.

Keshavarzi, a. R., Sharifzadeh, M., Kamgar Haghighi, a. a., Amin, S., Keshtkar, S., Bamdad, A., Mar. 2006. Rural domestic water consumption behavior: A case study in Ramjerd area, Fars province, I.R. Iran. Water Research 40 (6), 1173–1178.

Lu, T., Smout, I., 2010. Domestic Water Consumption : A field study in Harbin , China. In: 33rd WEDC International COnference, Ghana, 2008. No. 2007. Accra, Ghana, pp. 1 – 4.

Mayer, P. W., Deoreo, W. B., Opitz, E. M., Kiefer, J. C., Davis, W. Y., Dziegielewski, B., 1999. Residential End Uses of Water. Tech. rep., American Water Works Association.

Memon, F. A., Butler, D., Han, W., 2005. Economic assessment tool for greywater recycling systems. In: Institution of Civil Engineers - Engineering Sustainability. No. September. pp. 155–161.

Nyong, A. O., Kanaroglou, P. S., 1999. Domestic Water Use in Rural Semiarid Africa : A Case Study of Katarko Village in Northeastern Nigeria. Human Ecology 27 (4), 537–555.

Otaki, Y., Otaki, M., Pengchai, P., Ohta, Y., Aramaki, T., Aug. 2008. Micro-components survey of residential indoor water consumption in Chiang Mai. Drinking Water Engineering and Science 1 (1), 17–25.

Philip, R., 2011. Module 3 Water Supply - Exploring the Options. In: Philip, R., Anton, B., Loftus, A.-C. (Eds.), SWITCH Training Kit - Integrated Urban Water Management in the City of the Future, first edit Edition. SWITCH (EU), pp. 1 – 52.

Porto, M., Khatri, K., Vairavamoorthy, K., 2007. Challenges for urban water supply and sanitation in developing countries. In: Alaerts, G. J., Dickinson, N. L. (Eds.), International Symposium on "Water for a Changing World - Developing Local Knowledge and Capacity". Taylor and Franscis, Kala2007, pp. 81 – 100.

Rathnayaka, K., Malano, H., Maheepala, S., Nawarathna, B., George, B., Arora, M., 2011. Review of residential urban water end-use modelling. In: 19th International Congress on Modelling and Simulation. No. December. Perth, Australia, pp. 3321 – 3327.

Rauch, W., Brockmann, D., Peters, I., Larsen, T. a., Gujer, W., Feb. 2003. Combining urine separation with waste design: an analysis using a stochastic model for urine production. Water research 37 (3), 681–9.

Sharma, A., Burn, S., Gardner, T., Gregory, A., 2010. Role of decentralised systems in the transition of urban water systems. Water Science and Technology - Water Supply 10 (4), 577–583.

Sharma, A. K., Tjandraatmadja, G., Cook, S., Gardner, T., Jan. 2013. Decentralised systems - definition and drivers in the current context. Water Science and Technology 67 (9), 2091–101.

Thompson, J., Porras, I. T., Tumwine, J. K., Mujwahuzi, M. R., Katui-katua, M., Johnstone, N., Wood, L., White, G. F., Bradley, D. J., 2001. Drawers of Water II - 30 years of change in Domestic Use and Environmental Health in East Africa. Tech. rep.

White, S., Milne, G., Riedy, C., 1999. End Use Analysis : Issues and Lessons. Water Science & Technology: Water Supply 4 (3), 57– 65.

Zhang, J., Cao, X.-S., Meng, X.-Z., Aug. 2007. Sustainable urban sewerage system and its application in China. Resources, Conservation and Recycling 51 (2), 284–293.

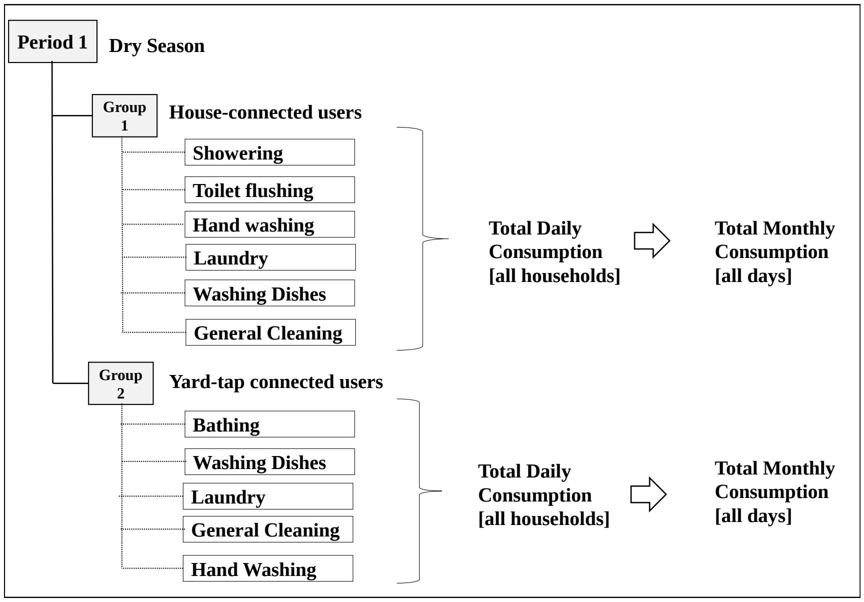


Figure 1: *A schematisation of the water user groups in the community*

Table 1: *Details of the computed water use volumes for both the yard-tap users and the house connected users*

House Type	End uses	per HH* (litres)			per capita (litres)			%	adm*
		min	median	max	min	median	max		
Yard Taps	Bathing	117.1	152.7	200.1	21.6	26.4	33.7	43.8	0.54
	Hand Washing	55.7	78.9	172.1	9.1	13.7	31.3	22.7	1.47
	Laundry	19.7	26.8	34.4	3.2	4.7	6.2	7.7	0.54
	Washing Dishes	68.6	77.4	89.7	10.5	13.4	18.2	22.3	0.27
	General Cleaning	8.39	12.0	16.4	1.4	2.1	2.9	3.4	0.67
	Total		**347.9**			**60.2**			
House Connections	Toilet Flushing	87.6	131.4	213.2	17.9	24.5	39.4	21.4	0.96
	Showering	123.9	280.0	486.0	27.1	52.1	87.5	45.5	1.29
	Hand Washing	26.3	43.5	88.0	5.3	8.1	15.9	11.8	1.41
	Laundry	13.2	19.1	27.8	2.3	3.6	5.3	3.1	0.76
	Washing Dishes	81.8	105.7	142.6	12.9	19.7	27.1	17.2	0.58
	General Cleaning	5.0	6.6	8.9	0.9	1.2	12.9	1.1	0.59
	Total		**586.2**			**109.2**			

*HH - household

*adm - absolute deviation from median

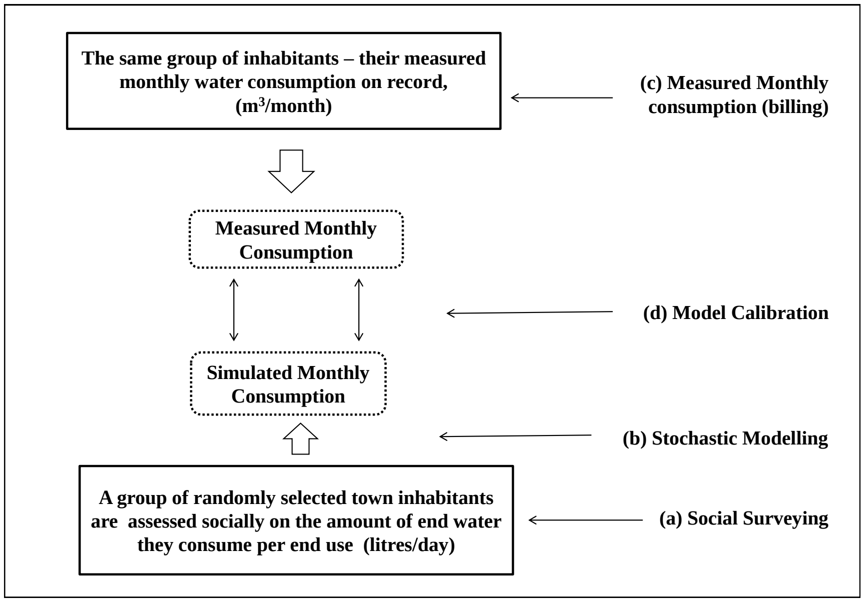
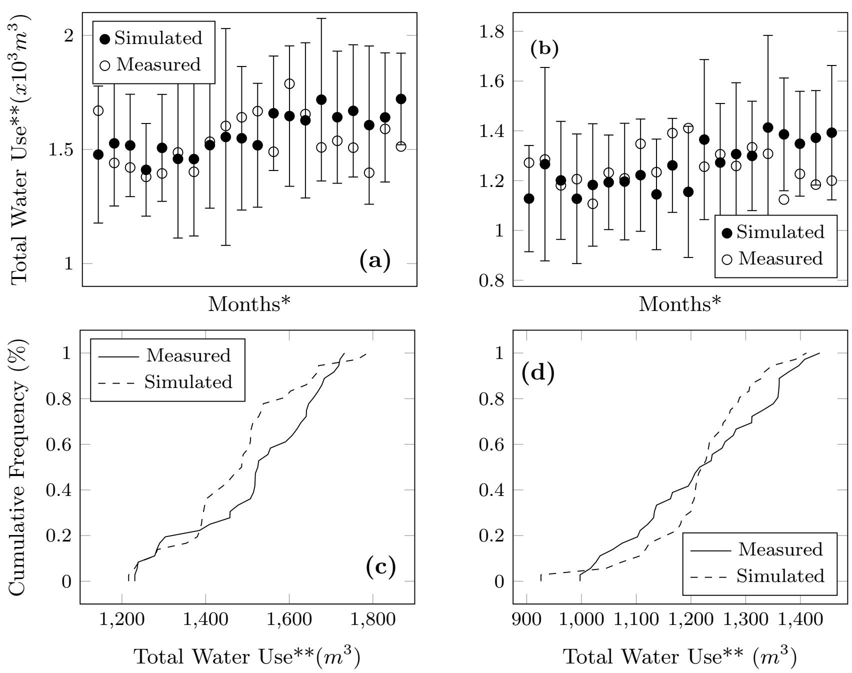


Figure 2: *The Modelling methodology approach applied*



[*] The order or nature of the month was not a subject of the research apart from the number of households measured in that month, each month was simulated independently. That is why the months are not labelled on the x-axis. [**] Total Water Use - represents the total water used up by all the households

Figure 3: *Overall calibration process results for total monthly water consumption for* ***yard-tap water users*** *shown in (a) and (c), and also for* ***house-connected water users*** *shown in (c) and (d).*

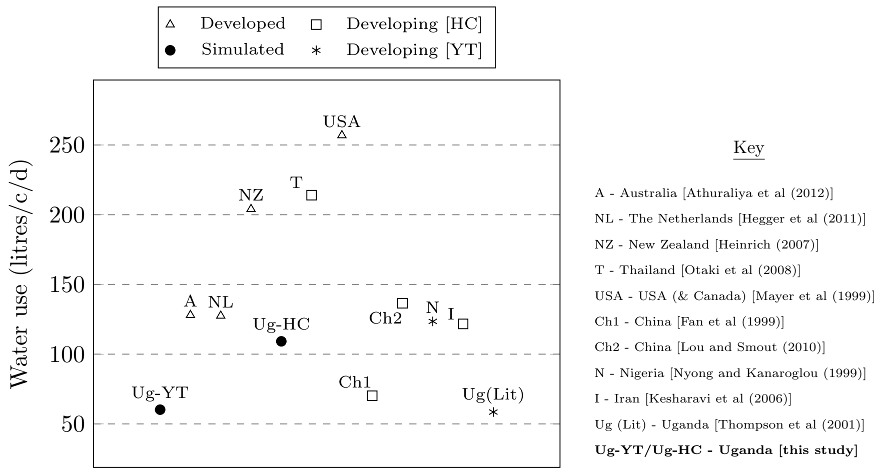


Figure 4: *Comparisons between the household water use volumes computed in this study and those from studies in other international locations (both in the developed and developing world)*

Figure 5: *Relative comparisons between the water use volumes in a typical household of a yard-tap user against one of a house-connected water user*

Table 2: *Calibration Parameters*

Category	Water end-use	Factor	Remark [Target Parameter]
Yard Taps	Bathing	0.7	No. of Jerry cans
	Washing Dishes	1.4	No. of Jerry cans
	Household Size	1.18	General Increase
	Metering Error	0	–
House Connections	Toilet Use	0.5	No. of flushes
	Showering	0.5	Intensity Volume
	Washing Dishes	0.5	Flow Rate
	Household Size	1.35	General Increase
	Metering Error	0.1 - 0.2	Uniform Distribution
General	Rain Water Use [Dry]	0.15 - 0.25	Uniform Distribution
	Rain Water Use [Wet]	0.23 - 0.50	Uniform Distribution
	Temporal Evolution factor	1.0	–