DOMESTIC ROOF WATER HARVESTING AND WATER SECURITY IN THE HUMID TROPICS

Milestone Report D 5

Project: Domestic Roofwater Harvesting in the Humid Tropics

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Introduction

Domestic roof water harvesting (DRWH) is a sub sect of rainwater harvesting which is often used as a domestic water supply source. DRWH is not a new concept as most of the rural as well as sub-urban houses in the humid tropics resorts to collecting water at times of rain. In most cases this collection has been mainly for reasons of convenience for the household rather than a planned supply option. It is well documented that difficulties in collecting water from point sources far away from the settlements or high up in the mountains drastically reduces the consumption of water. Like wise it is reasonably believed that easy accessibility of water increases the per capita consumption of water.

The DRWH project which commenced in mid 1998 with financial support from European Union looks at roof water harvesting as a option to improve the household water security in rural household. The project was particularly interested in understanding the DRWH concept in the humid tropics and its contribution to household water security. The roof water harvesting study was carried out in four tropical countries with varying degree of rainfall. Sri Lanka, and South India (Kerala and Tamil Nadu) from the Indian sub continent and Uganda and Ruwanda from East Africa. In all the four countries there is considerable use and practice of roof water harvesting at rural household level. Water harvested from the roofs are collected and stored (in some cases used on a daily basis) in containers with varying capacities. Size of the storage containers are sometimes based on the actual demand but more often the size is determined by the cost affordability factor or subsidy factor (i.e. Sri Lanka). The countries selected for the study exhibits a wide diversity in rainfall, varying from 800mm to 2500mm and above. All countries have a bimodal pattern of rainfall with a peak rainfall period from October to December. However, Sri Lanka, being an island close to the equator experiences wide annual and spatial variations, which makes rainwater harvesting more meaningful.

This report analyses various experiments conducted in the above mentioned countries with respect to domestic roof water harvesting and its contribution to “household water security” While all locations did not have homogeneous conditions to collect standardized data, a general overview can be observed from the available information. Though Kerala was one of the locations identified for the study most of the water use information was collected from the southern tip of Tamil Nadu, Kanyakumari district.

Humid Tropics

Countries belonging to humid tropics usually have a high rainfall pattern with relatively short dry periods. Depending on the country, the spatial and temporal variation in rainfall can have relatively low rainfall periods but total dry spells leading to droughts are rare. This characteristic of the humid tropics facilitate roof water harvesting considerably even from a small roof area. This type of intermittent rainfall in the humid tropics allows even small storage containers to be effective in collecting and providing adequate water for household consumption. However, it is a common practice in the humid tropics to observe the use of more than one sources of water for domestic use. Hence DRWH in the humid tropics is mostly a partial option of water for household use. In the study locations identified as South Asia and East Africa, communities use rainwater in combination with at least two other sources of water. In the African context, smaller size of the storage containers and relatively smaller roof area allows limited amount of water to be stored from each rainstorm. A similar situation can be observed in informal rainwater harvesting practices in Sri Lanka where communities collect rainwater into small kitchen utensils, 200 liter oil drums and open tanks of less than 1000 liters. However, the common character in both situations is that these collections are supplementing other sources of water to attain household water security. The advantage of being in the humid tropics is the availability of secondary and tertiary water sources, which may not be easily accessible but available. This study is expected to provide information to facilitate the understanding of water use behavior of communities living in the tropics and are also dependent on rainwater for domestic use. Attaining household water security in this context refers to using multiple sources including roof water harvesting as a option for household water.

Concept of Household Water Security

Household water security envisages availability of water as the central focus. However, this does not mean that mere availability of water is sufficient to meet the household water security. The idea of water security allows water to be considers as a natural resource a commodity and entitlement. These are all complementary perspectives that goes to establish household water security.

There are three critical factors that determine household water security. Availability, accessibility and usage. The degree of combination of these factors will determine the HWS at a given point of time. Availability of water depends on environmental factors to a greater extent and on human factors to a lesser extent (supply function). On the other hand the available water has to be distributed to households for effective use (distribution function). This means that both storage and flow of water to the households must be adequate, reliable and sustainable. Experiments with rainwater harvesting in Sri Lanka indicates that by storage of rainwater, adequacy and reliability can be attained with respect to HWS. However, due to capacity limitations and bad management practices sustainability of HWS over a long period can not be predicted.

Access to water depends on the physical location and timely availability of water as a commodity. This ensures that there is a firm control of water as a commodity by the households. Access to water can be sensitive to national policies and investment priorities. Access to water can also increase the demand for water. The type of access to water alone is a determinant in total water use. Gleick (1996) reports that, when the distance to the water source varies from more than one kilometer (stand post) to household connection, the water consumption increases by as much as 15% to 40%. In

Sri Lanka, enhanced access to water by household roof water harvesting has contributed 50% to 70 % to the total household water requirement. Hence, improved access to water can either increase the total water use or contribute substantially to the total water budget, or act in both ways,thus, reducing on the opportunity cost of time.

Water use, basically relates to ones entitlement rights. However, the entitlement rights depend on the quality of water, status of the household, environmental constraints, opportunity cost and awareness. Environmental constraints and awareness has been two major impediments to water usage among some of the rainwater communities in Sri Lanka.

While these factors consist of the main thrust of household water security, it is not without risk and uncertainty. Sever water shortages due to droughts or water table depletions due to over abstraction can affect HWS. On the other hand removal of subsidies, unavailability of labour to fetch water, sick or death of water carries can sharply increase the opportunity cost of water carriage. Therefore, determining household water security warrants multidimensional attention beyond a single sector focus.

Definition of Household Water Security

Many researchers have defined household water security depending on how they perceive the concept of HWS. One of the simplest forms of household water security is **the ratio of water supply to water demand**. If the water demand is higher than water supply then there is a water deficit while the opposite is a situation of water surplus. Under a surplus situation, it can be theoretically assumed that HWS is satisfied.

Household water security is also defined as, **“access by all individuals at all times to sufficient safe water for health and productive life”**(Webb and Iskandarani 1998). While this definition encompasses most of the salient features of HWS, definition of “safe water” can be debatable. Safe water can mean clinical safety, cultural safety or even perceptional safety. Though this definition ensures “sufficient water”, it however, does not mention “reliability” and “timely availability” of water. In a holistic definition of household water security, these factors are essential. Hence, the definition is further revised to read as” **Accessibility’ reliability and timely availability of adequate safe water to satisfy basic human needs”** (Ariyabandu 2000). These are some of the definitions, which are used in defining household water security. However, it appears that much work needs to be done to fine tune the definition of household water security

Domestic Roof Water Harvesting and Water Security

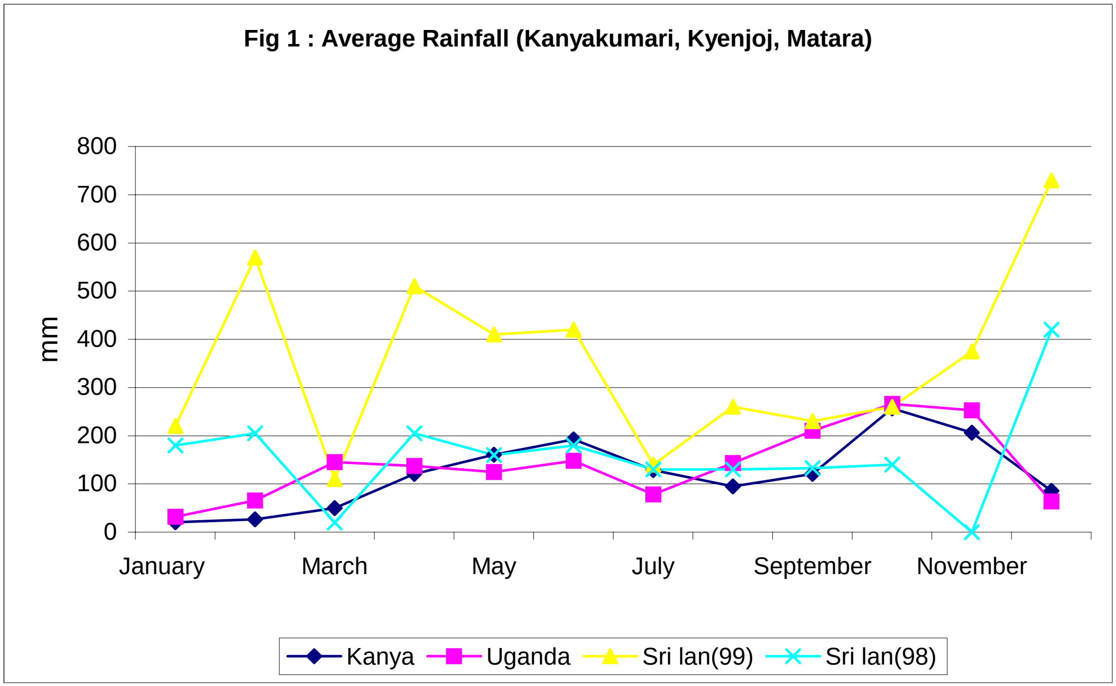
Domestic roof water harvesting in the context of South Asia and East Africa were initiated as a source of domestic water especially for drinking and cooking. This was mainly due to the belief that quality of rainwater is better than the commonly found ground water. However, stored water is used for various activities other than drinking and cooking. This in fact was quite evident in the Sri Lankan rainwater harvesting programme, specially in the wet zone, where stored water was mainly used for non premium water use activities (washing clothes, sanitary purposes, livestock and small-scale home gardening). This gave the users the added advantage of having a source of water within accessible distance for household use. Experiments conducted in Sri Lanka and Ruwanda indicate that improving accessibility of water has increased the per capita consumption of water and increased the rainwater contribution in the total water use of rural households. Studies conducted by the Anawim Trust in Tiruchendur Taluk on roof water harvesting from community centers, among coastal fishing villages, indicate that harvested rainwater has particularly benefited children, and 85% of the people in the area said that the water shortage in summer can be overcome by rainwater harvesting. Incidentally, the rainwater harvesting project of the Anawim Trust has manage to dispel the belief the people had before on RWH.. The study reports that prior to the project, people in the Triuchendur area believed that, rainwater is not suitable for drinking and cooking and rainwater can not be stored for more than few days. Since the commencement of the project people have come to accept that rainwater is a good sources for domestic use. These changes have brought about a significant increase in the water use behavior of the people and they are much more secure in terms of water than before. Studies conducted in Kyenjojo in Uganda with rainwater users indicate that 33% to 62% of the household water can be contributed by rainwater harvesting.

Hence, it is clear that in the humid tropics rainwater harvesting can make a significant contribution to the household water use and with improved accessibility and quality of water, a significant increase in household water security can be achieved.

Water Collection and Storage

Water collection and storage is a vital component of household water security. Degree of achieving household water security depends on how much one can collect and store, besides the quality of collected water. As roof is the catchment surface, the available surface area and rainfall intensity will determine the quantity that can be harvested. However, in most cases in the humid tropics, all the water that can be harvested can not be stored due to capacity limitations.

In the study locations in South Asia and East Africa, there is a significant difference in rainfall from Uganda (Kyenjojo) to Sri Lanka (Matara district), figure 1.



Source : Rees 2001, CAT 2001, Ariyabandu 2000.

However, the size of the tanks does not appear to depend on the supply of water. In the two African countries the sizes vary from 400 liters in Uganda (Kyenjojo) to 600 liters in Ruwanda (Bukora and Ndegro settlements). Incidentally, long term rainfall records from Ruwanda indicates an annual average rainfall of about 850 mm. While the annual average rainfall in the two Asian countries vary from 1400mm (Kanyakumari) to 4300mm in Matara (1999) in Sri Lanka. The tank capacities in the two Asian countries vary from 5000 liters in Sri Lanka to 10,000 liters in Kanyakumari and Tiruchendur. The large sizes in the Asian context is possibly due to accommodate all household activities including drinking and cooking for an average household of five members. The larger size capacity in the South Indian cities is due to saline ground water in Tiruchendur and lowering of the water table in Kanyakumari. In The African context it appears that the collected rain water is mainly used for drinking and cooking.

The effective roof area for water harvesting can change depending on the willingness and economic condition of households. In the African context the roof area varies from 20 $m^{2.}$ to 50 m^2 with respect to Uganda and Ruwanda, while the roof area in the South Asian context vary from 70 to $100m^2$ with respect to South Indian and Sri Lankan . In the context of Asian countries rainwater is harvested only from part of the roof, therefore there is always the opportunity of increasing the effective roof area for rainwater harvesting. With the present usable roof area, rainwater can be collected to satisfy 66% of the household water demand among the Matara rainwater user community and according to the rainwater users in Kanyakumari, a 10,000 liter tank can supply water for six months in a family of five with intermittent water supply from the central system. Incidentally, these communities believe that if they can get two cycles of 10,000 liter each in a year, that would suffice to manage a full year with intermittent water supply. Research conducted in Uganda indicates that 400-500liter jars can provide water to satisfy 60-70% of the annual water demand of rural Ugandan households under appropriate environmental condition. Research also indicates that increasing the roof areas is more beneficial than increasing the storage capacity. However, incremental benefits due to expanding roof area drops after a point due to law of diminishing returns (Rees 2001). The research explicitly indicates that in the Ugandan context there is a greater benefit in increasing the roof area than increasing additional jars (capacity).

Table 1: Comparison in the gain in demand met percentage for storage and catchment area increase - Kyenjojo Uganda

Tank size	Roof area	% age of year when there will be water	Gain
500 litres	20m^2	59.6%	
500 litres	40m^2	74.2%	+ 14.6%
1000 litres	20m^2	65.4%	+ 5.8 %

Source: Rees 2001

Table 1 indicates the gain in demand met by increasing the storage verses roof area. Hence, it is self explanatory that there is a higher gain in increasing the roof area than storage capacity. In addition, increasing the roof area can provide additional living space in the household. Meeting the household water demand over a longer period of time in a year improves the household water security over the same period of time. This situation may not agree with high rainfall conditions and already existing larger roof areas in the wet zone of Sri Lanka. With very high rainfall, there is a large waste of roof run-off which can be captured if additional storage is available. Here too the additional availability of rainwater at homestead can improve household water security given the travel time to collect water can be reduced significantly. This situation is particularly important to the dry zone of Sri Lanka, where availability of point water sources are further away from the settlements than in the wet zone. According to research conducted in Uganda household water security can be improved significantly in the first two years with additional roof and storage capacity. In the third and the fourth year meeting the water demand is marginal, thus, improvements to incremental household water security too is not significant. However, using incremental roof area, under similar conditions can achieve higher degree of water security in the third and the fourth year. (Refer RWH water use study in Kyenjojo by Dai Rees 2001, for further details).

Quality of Rainwater

To attain household water security one needs to ensure the quality of harvested rainwater. While lot of work has been done on the structural design and minimizing the cost per liter of water, precious little has been done to establish the quality of rainwater. One of the constraints to establishing guidelines to harvested rainwater is its diversity in different geographical locations. Rural verses urban, industrial verses coastal or low-income urban slums, all can have varying conditions in harvesting rainwater that can have an impact on the quality of water. Status of settlements, condition of the roofs, immediate environment and storage containers all can contribute to contamination of water if not properly maintained. Therefore, it is evident that mere availability of water alone cannot guarantee household water security unless the quality of that water is portable.

Under the present study, quality of rainwater was extensively researched at laboratory level at the Indian Institute of Technology in Delhi. In Sri Lanka, the Lanka Rainwater Harvesting Forum (LRWHF), conducted water quality tests of harvested rainwater to a limited extent. Unfortunately the studies conducted in Uganda and Ruwanda, there were not much attention given to quality of water. However, certain generalizations can be made from research carried out in Delhi.

Studying water quality with rainwater communities in Sri Lanka indicates a clear difference between “perceptional quality” and “absolute quality”. Most of the rainwater community in Sri Lanka does not drink rainwater throughout the year even if it is available. Research conducted in Sri Lanka estimates that less than 10% of the rainwater users drink rainwater as an accepted domestic water source during the dry months of June to August (Ariyabandu and Aheeyar 2000). However, 30% to 50% of users consume rainwater during some time of the year in the wet zone district of Badulla and Matara, while the percentage of users consuming rainwater at random can be as high as 70% to 90% in the dry zone areas. The latter situation is mainly due to the distance to other sources and drying up of shallow point sources. The drinking water pattern in the wet zone is primarily because of the perceptions of users towards rainwater, especially when it is roof run-off. These users assess the quality of rainwater depending on the presence or absence of leaf litter, mosquitoes or other vector borne larvae, rodents and frogs and from the physical characteristics of colour , taste and smell (Ariyananda 2001). People also strongly believe that quality of rainwater is better during the times of rainfall and two weeks there after. In storage, people believe, that rainwater deteriorate in quality. This presumption is propelled by the appearance of different specie of larvae and discoloration of stored water.

However, experiments conducted in the wet zone district of Badulla in Sri Lanka, indicates that bacterial contamination (fecal coliform) increased with the on set of the rain in November and reduces gradually towards the end of the rainy season (figure 2).

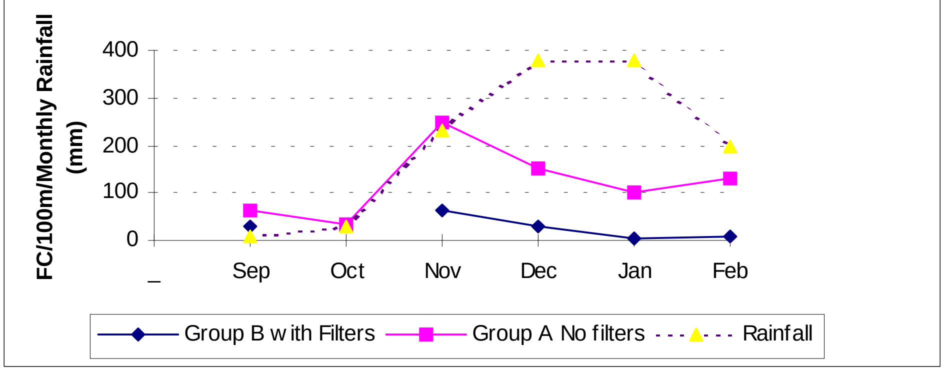


Fig: 2 Coliform per 100 ml of rainwater recorded over 6 months from Badulla district

Source: (Ariyananda 2001)

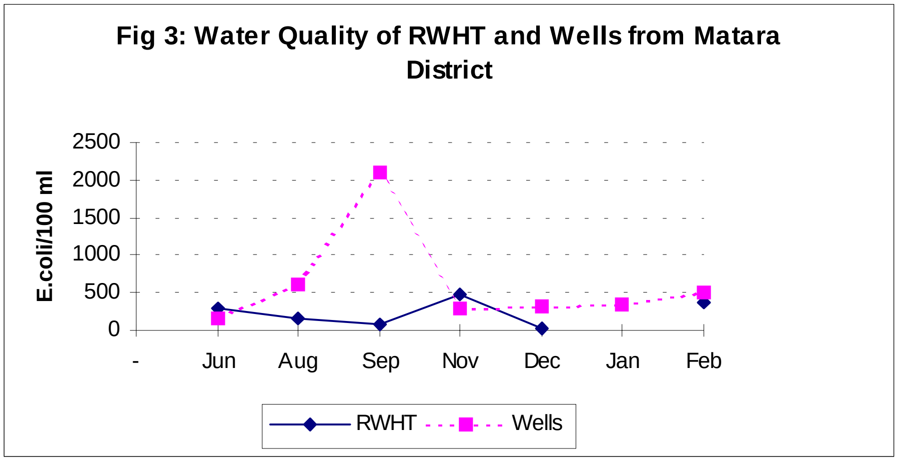
This experiment also indicates that using filters can have a significant improvement in water quality with respect to fecal coliform. (ibid 2001). Experiments conducted in Delhi under controlled laboratory conditions indicate that coliform bacteria can decay in 10 to 11 days if fresh nutrient are not added through rainwater. In the presence of limited nutrients same bacteria may take up to 20 to 25 days for complete decay. In the case of *F. streptococci* time period can vary from 2 days for complete decay in the absence of additional nutrients and 17to 20 days in the case of limited nutrients. Therefore, 20 to 25 days storage is adequate to completely eliminate these forms of bacteria if additional rainwater is not added. (Vasudevan et-at 2001)

Impact of roofing material on water contamination was tested IIT in Delhi using different types of roofing material. Using three flushes with H_2S stripes to detect bacterial contamination, the experiment concludes by saying that run-off water from tile roofs can be the most contaminated while metallic roofing is the least contaminated. In the order of preference it will be metallic roofs > asbestos> plastic> tile (ibid 2001). Heating of metallic roofs probably sterilizes the run–off water thus eliminating bacterial contamination. According to the tests conducted, even the first flush of water from metallic roofs did not change the colour of H_2 S strip to black. Hence, it can be stated that rainwater harvested from tile roofs can be more contaminated as compared to other forms of roofing and the waste of water was also high in tile roofs. This was indicated in the experiment as the third flush was hardly filled under tile roof condition. As a thumb rule the experiment recommends 1-2 mm of first flush for all roof types to wash any type of impurities. In Sri Lanka, rainwater users are requested to allow first half an hour of rain to wash the roofs before collecting it for domestic use.

One of the important findings that came out of the IIT experiments is the use of indicator bacteria. Usually, three types of bacteria, total coliform, *E. coli* and Fecal streptococcus are used as indicator bacteria to detect fecal contamination. However, extensive work done by Dr Fujioka in the tropic has revealed that *E. coli* can be present in the tropical soils, hence, dust can be a common cause of *E. coli* contamination. This was recognised in the IIT experiments and fecal coliform and *F. streptococcus* were used as indicator bacteria.

Rainwater tested with H_2S and MNP (most probable number) techniques at IIT indicates that only about 40% of the samples (out of 54) meets portability standards. However, as most of these samples were taken without employing a full first flush, there is scope for further improvement in water quality.

However, the issue is, how does quality of rainwater influence water security? Studies conducted in the wet zone of Sri Lanka indicate that consumption of rainwater is governed more by perceptions than absolute quality. Studies conducted in Matara (wet zone district) clearly indicate that very high contamination of E. coli in well water during early monsoon periods, though preference for water remains high with well water (figure 3).



Source. Ariyananda (2001)

The only positive factor in this scenario is that, human perceptions can be changed if adequate awareness can be given to users with respect to the actual quality of water they use for domestic purposes. A similar situation cannot be reported from India, as field research with user communities was not covered during the study. However, it will be interesting to note the community responses if the same research can be done in Kerala where the dug well density is highest in the world. Research conducted in drier parts of Sri Lanka (Monaragala) and South India (Kanyakumari) indicates that rainwater communities use rainwater for drinking and cooking, besides using for other activities. In this instance, it is the availability of water, convenience and lack of alternative point sources that governs the use of rainwater for consumption. Hence, during the use of rainwater for drinking and cooking, household water security would improve and with the cessation of rainwater use for these activities, household water security would decline. However, this does not mean that quality of rainwater can be ignored in a conventional RWH programme. An outbreak of water borne diseases or an increase in vector borne diseases could seriously affect household water security.

Technology

Technology research under the study was exclusively conducted by the Warwick University. Much of the technological research was concentrated on the tank design, opportunities to reduce the cost and optimum sizing of components. As there is adequate research on large systems, the study concentrated more on the smaller systems (Thomas 2001). Typically a RWH system comprises of a large tank for storage, system of gutters and down pipes and ancillary components of filters, first flush devices, out let and water extraction devices. During the course of the study much of the research work was conducted on optimizing cost and improving on the performance of the tank design. Many existing tank designs were reviewed and field design work was conducted in East Africa. Details of 20 RWH tank designs can be found at, http://www.eng.warwick.ac.uk/DTU/rainwaterharvesting/casestudies.htmThe construction work in East Africa was mainly focused on underground tanks. However, knowing the problems associated with wholly underground tanks, a partially underground tank was tested in Uganda. The similar design is presently being tested in the dry zone of Sri Lanka. Besides the work on tank designs, little research was carried out on gutter design, since most gutters observed on site suggests that they are either too large or misaligned to capture the full potential of roof run off (Thomas 2001).

The technical tank design, size of the tank and affordability all affect household water security. The commonly used designs in Sri Lanka and South India are ferro-cement and brick mortar tanks. In Sri Lanka, the decision to select the type of design was governed primarily by the environment and subsequently by choice of the users. Physical space was one of the criteria that encouraged people to opt for underground tanks. However, after two years of experience with underground tanks in the dry zone of Sri Lanka, implementers and users are increasingly becoming disappointed with the underground tanks due to leaks as a result of root penetration. This problem is presently being reported mostly by the dry zone users. Hence, it will be interesting to find out the root behavior with respect to water holding capacity of soils in the wet and dry zones in Sri Lanka. In South India, among the community RWH tanks that were constructed by ANAWIM trust, one of the problems identified was the weight of the tank lid which results in developing cracks in the $10M^3$ tanks. In Manapad, south India, the $10M^3$ temple tank had cracked due to the same reason and 6000liters of rainwater had to be drained off during the summer of year 2000. These technical defects adversely affect the water security of households who depend on these tanks for their domestic water. In Monaragala, in the dry zone of Sri Lanka, five tanks out of 15 underground tanks have developed cracks due to root penetration and had to be abandoned till repairs are carried out. The Manapad temple community had to make an additional trip to the well to collect water in the summer due to the leak, which developed in the temple RWH tank. In both these instances household water security declined due to technical defects. However, the cause for technical defects can be due to design problems or due to construction problems as it was reported from Monaragala in Sri Lanka. Sub standard construction due to sub contracting and ambitious targets placed upon village level implementing organizations are some of the common causes for construction failures

Size of the tank is a major contributory factor towards household water security. However, literature suggests that, in the humid tropics smaller size (600-1000 liter) of rainwater storage tanks can provide adequate water for a household over a longer period of time. However, this will depend on the household water demand and use of other sources of water in combination with rainwater. Small size of storage tanks can be effective where there is even distribution of rainfall throughout the year. In countries like Sri Lanka, where rainfall variability is high, larger storage tanks can be more useful in achieving household water security. This was reported from arid South East of Sri Lanka, where the dry spells are longer and alternative point sources are few in number. Incidentally, the request from these users are to increase the capacity of storage tanks beyond $5M^3$. This situation was not reported from the wet zone areas where the $5M^3$ storage was adequate in combination of other sources to satisfy household water needs. In South India, the community RWH tanks were $10M^3$ capacity, which provided for drinking and cooking water to number of families. In the Mnapad temple rainwater tank, 21 families were supplied 20 liters per day per family for drinking and cooking. In combination with water from a dug wells close to the sea (water from the fresh water lens) these families could manage to overcome the water insecurity problem during the water short dry months of June, July and August. In the UNICEF supported RWH project in the Kanyakumari district, 175 rainwater tanks have been constructed by the Center for Appropriate Technology (CAT) in Nagarcoil Tamil Nadu. Most of these tanks were $5M^3$-$10M^3$ and rainwater was used in combination with piped water supply and ground water from dug wells. Pipe water supply was unreliable and depleting ground water table reduce the water productivity of dug wells. In this situation, rainwater harvesting tanks have provided the ideal supplementary source to achieve water security. However, due to poor management, some of these tanks have been damaged and rainwater use have been limited to non consumptive water use. In certain cases total use of rainwater has been abandoned and users were forced to depend on the unreliable pipe water supply. In such situations household water security has been severely affected due to the length of time that has to be spent for collecting water from pipe systems. According to the users, a $10M^3$ tank of rainwater can be managed to supply water for six months when in combination with piped supply and dug wells. However, with the rapid depletion of the water table, dug wells are increasingly becoming non productive, hence, bore wells are now being constructed to supplement rainwater and pipe water supply.

Given all other conditions are equal, cost of rainwater harvesting units can be a determining factor to household water security. Cost per liter of water varies from US $0.03 in Sri Lanka and South India to US$ 0.37 in Ruwanda (Hartung 2001). Apparently economics of scale decide the cost per liter of collected rainwater. In Sri Lanka and South India, the capacity of the tanks vary from 5000liters to 10,000 liters. In the case of Ruwanda the capacity was only 600 liters. A contributing factor to the high cost in Ruwanda is the very high cost of raw materials for construction. However, what matters for the rural communities is the total cost of the tank. In Sri Lanka and South India the rainwater harvesting units are highly subsidized. In Sri Lanka RWH systems are 60% to 80 subsidized, in India, under the UNICEF programme community contribution was limited only to unskilled labour. In East Africa too the cost appears to be borne by the project or programme. Therefore, in developing countries cost reduction in RWH systems will promote state and NGO implementers to opt for rainwater harvesting as an option for rural water supply. Construction of more tanks will undoubtedly increase the accessibility to water, thus increasing the water security of rural households.

Various discussions are now under way to decide on cost effective rainwater structures for urban areas. In this context in-situ verses portable small structures are gaining momentum. In the Sri Lankan context it will be for urban use as a cost maximising strategy on household water use. In an urban context where household water supply is provided, low cost rainwater harvesting tanks can provide the required “grey” water for non premium water use activities. While this concept is accepted on principle, breaking through the highly subsidized urban water supply is a challenge for rainwater proponents in Sri Lanka. The situation in India too appears to be the same, where rainwater is not readily accepted in urban areas at least in the humid tropics due to high subsidy on town supply.

Water Use Pattern

Rural communities in the three countries use multiple sources of water to achieve household water security. Using multiple sources of water is primarily for quality and subsequently for convenience. Use of multiple sources are high in situations where ground water is not suitable due to salinity or hardness (i.e. North Western Coastal line of Sri Lanka). Among the rainwater communities studied under the project, use of rainwater for domestic use is always supplementary in the wet zone of Sri Lanka. In the Southern State of Tamil Nadu in India, rainwater use is primarily for drinking and cooking and in East Africa rainwater is given preference over other sources when rainwater is available.

Per capita water consumption

Demand for water is not only decided by the biological needs. Other household water need like livestock, small scale home gardens and sanitary water needs can change the consumption pattern significantly. Water consumption also depends on water availability and cultural habits of water use. Sri Lankans are considered to be lavish users of water. In Matara and Badulla households water use of rainwater communities vary from 36-54 liters per capita day. In drier areas of South India, consumption varies from 14-42 lpcd within rainwater communities. In relatively water scarce East African context, consumption vary from 5-23 lpcd in the months of October to December and from 6-19 lpcd in months of January to April in Ruwanda (Hartung 2001). In Kyenjojo, Uganda, the consumption varies from 11-23 lpcd (Rees 200). This indicates that in the Indian sub continent, where there is higher water availability, people have got accustomed to higher user pattern than rural communities in the East African humid tropics.

Research conducted else where has shown the correlation between distance traveled to water consumed. However, Rees (2000) in his study in Kyenjojo has shown that there is no strong correlation with distance traveled to water consumption. The water consumption figures of 11-23 lpcd in Kyenjojo research area appears to correlate well with estimated consumption figures for the region. However, in the Sri Lankan wet zone there is a marked difference in consumption between those who use rainwater for domestic use and non-users in the same community. Figure 4 indicates that rainwater communities in Matara consume approximately 15 lpcd more than the non rainwater users during the wet months of October, November and December. During the dry months of June July and August the increase is 10 lpcd. This clearly indicates that accessibility and availability of water increases water security for rural households. East African data from Kyenjojo indicates a time saving of 18.5 –150.8 minutes as a result of rainwater harvesting. In Sri Lanka, there is a time saving of approximately 90 minutes among rainwater communities in Matara. Distance wise East African communities save as much as 2.2 km while in Sri Lanka, rainwater users in Matara save 1.75km as a result of using rainwater. In Bukora and Ndego, Ruwanda, the closest water source in the absence rainwater is the Akagera river which is 3km away from the closest household. Though river water is available throughout the year, the quality of water is not safe to drink. Hence, availability of rainwater in storage significantly improves household water security during the rain season.

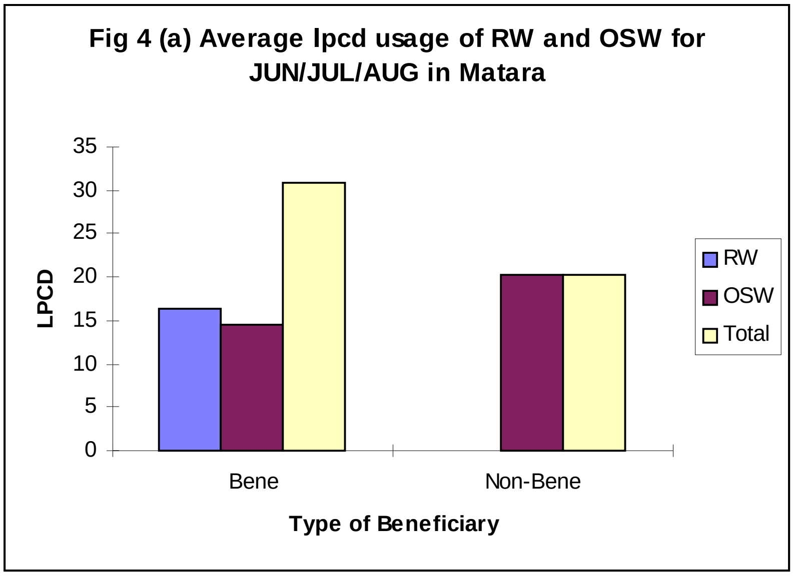
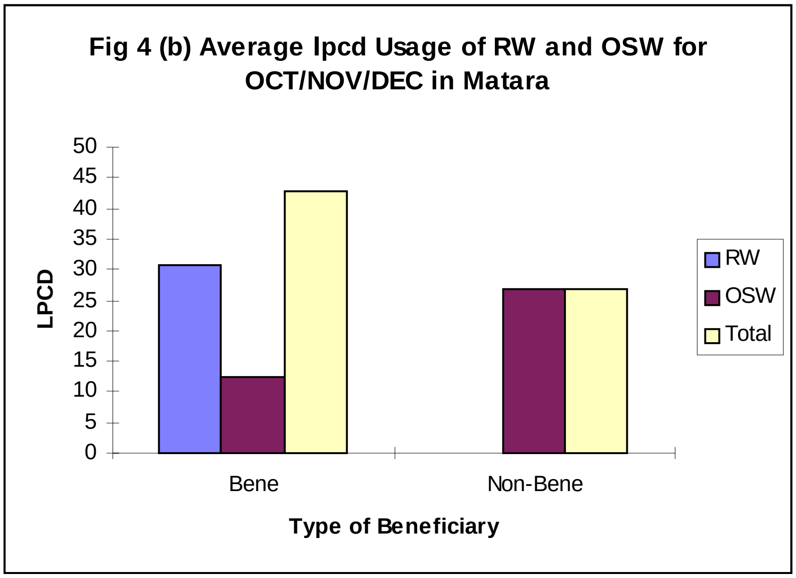


Fig 4 (a) Average lpcd usage of RW and OSW for JUN/JUL/AUG in Matara

Source. Field survey data 1999

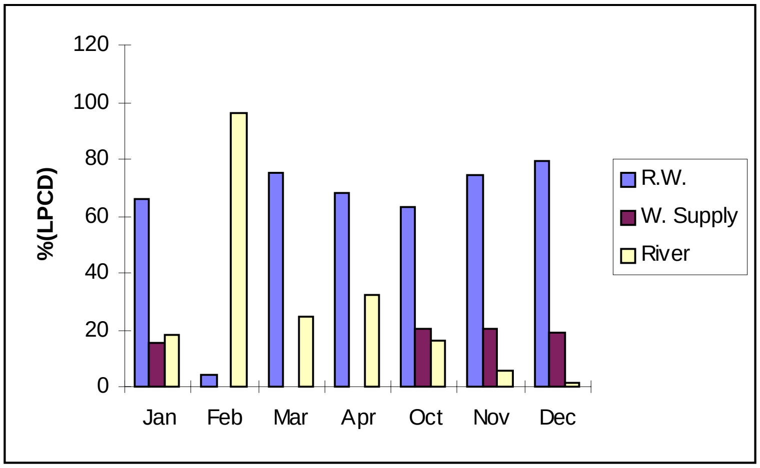


Source. Field survey data 1999
RW- Rainwater, OSW- Other source water

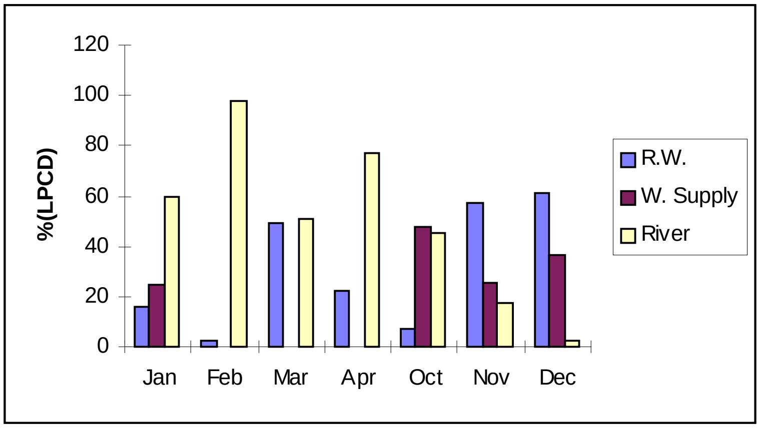
Contribution of rainwater in the total water use in the two Ruwandan villages vary from 4%-76% in Bukora and 0% -96% in Ndego The higher contributions is in the months of November and December while the lowest contribution is in the moth of February (figure 5).

Fig 5 (a) Percentage of water use by source (lpcd)
Bukora III - Ruwanda

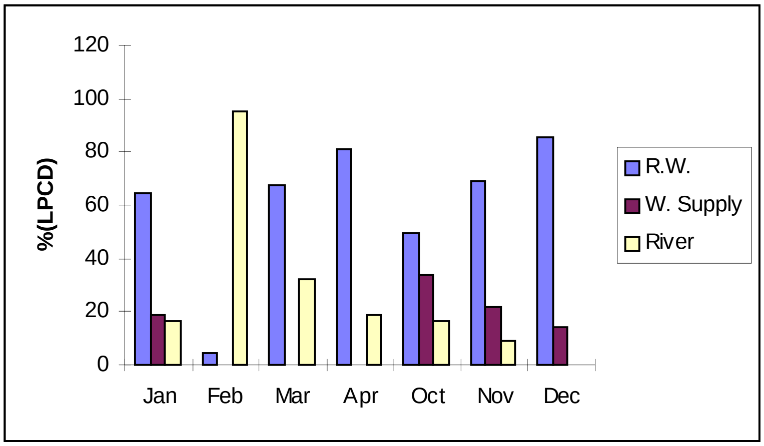
SECTOR III



SECTOR IV

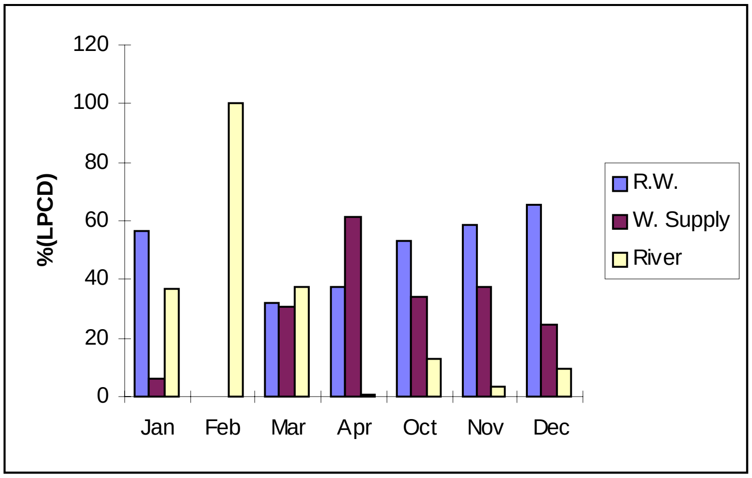


SECTOR I



Source. Hartung (2001)

Fig 5 (b) Percentage of water use by source (lpcd)
NDEGO II – Ruwanda



Source. Hartung (2001)

In Sri Lanka, the contribution from rainwater in total water use vary from 66% in Matara to 74% in Badulla. In Kyenjojo, Uganda , rainwater contribution varies from 33%-62% of the total water use. These figures indicate a significant contribution from rainwater harvesting at household level in humid tropics.

In a rapid appraisal to evaluate the impact of the Anawim Rainwater harvesting project of Triucendur in Tamil Nadu, the evaluators assessed the perceptions of children and adults separately on the impact of RWH. Table 2 indicate the results from the two groups.

Table 2 Sources and percentages of obtaining portable water

Source	Adults	Children
Public hand pumps	25%	25%
Public Taps	17.5%	15%
Dug wells	25%	25%
Public tap & RWH tank	22.5%	25%
Public tap & dug well	10%	-
Rainwater Tank	-	10%

Sources Anawim Trust (2000)

This clearly indicated the impact of RWH on children in Triucendur. Further the children have said that having rainwater tanks can overcome the water crisis period in summer and get clean water for drinking. On the other hand the adults are of the view that having water in close proximity was an advantage, water was cool and clean and this becomes a reliable source during summer when other water sources are not reliable. The adults were particularly happy that children were drinking rainwater. On the whole, 85% of the adults believe that water shortage in summer can be solved by rainwater.

Having an assured source of water within accessible distance have certainly increased the satisfaction levels of households as reported by Kanykumari rainwater users. In all research sites in the two continents, rainwater users have shown remarkable time saving due to harvesting rainwater at household level. In most cases it does not appear that there has been a significant opportunity cost of time. Hence, most households in the sub continent reported that they use the saved time to improve quality of life. Attending to children's education, engage in social events, entertainment and leisure are some of the common usages reported from Kanyakumari. Involvement in general household activities and taking care of children are the most important activities performed by households in Sri Lanka. Though nothing substantial has been reported from East African study locations, time saving may have been used for improvement in quality of life.

Household water security, therefore, is not only having adequate water at hand but also the convenience in accessing portable water at no extra cost. In most of the research locations described earlier,, household water security has been achieved but the coverage within the year depends on number of variable as described before.

During the study, the Sri Lankan partner developed a model to assess the household water security index of a given household. Results obtained from this model are discussed in the next chapter.

Modeling Household Water Security

Paper presented at Domestic Roofwater Harvesting Workshop, IIT Delhi, April, 2001.

Introduction

Modelling Household Water Security (HWS) requires assessing a household's ability to obtain the required quantity of suitable quality water for drinking, personal hygiene, other household needs and for minor economic activities. Water needs for domestic and agricultural purposes of the rural, peri-urban and urban communities depend on both availability and consumption of water. Availability of water in an area may have short-term variations that may result from hydrological changes or long-term variations that may result from unsustainable consumption by the community. Such long-term variations in available water, can affect households, communities, countries or an entire region of the world.

Urban communities of Sri Lanka depend mainly on pipe borne water supplied by the National Water Supply and Drainage Board (NWS&DB). Metered pipe borne water is provided at individual houses while free standpipes and bowsers supply the urban slums.

Urban communities may experience water cuts during periods of prolonged dry weather due to low flow in waterways supplying water to urban water supply systems. However, urban communities show resilience to such short-term changes by either reducing their water consumption or turning to alternate sources of supply.

Urbanisation has taken place in cities located mainly in the wet and intermediate zones, which receive significant rainfall distributed throughout the year. Though potential for harvesting rainwater is high, availability of high quality water at a subsidised cost discourages such endeavours.

Peri-urban communities depend largely on groundwater, obtained through large diameter wells. Households either have their own wells or access to a private/or a public well. Wells identified exclusively for drinking provide good quality water and are protected from pollution. Since a large percentage of water drawn from such sources return to the source by percolation through ground to be reused, this type of water supply-usage systems have high water security even though the consumption may be higher.

Rural communities rely mainly on surface and ground water bodies to meet their domestic requirement. This includes water for animals and home gardening as well. During periods of extended dry weather, good quality water may not be available nearby, and may have to be obtained from distant sources. This results in more time being spent on collecting, transporting and storing water, thereby reducing the productivity of the household.

The average HWS in terms of water availability *(WA)* and overall water use, $\sum_{1}^{n} w_i$ (in (lpcd)), can be expressed as:

$$HWS = \frac{WA}{\sum_{1}^{n} W_i} \qquad (1)$$

HWS$_i$ for a particular activity such as for drinking, may be expressed as:

$$HWS_i = \frac{WA_i}{W_i} \qquad (2)$$

The overall HWS can be obtained by aggregating Household Water Securities of all such activities.

However, this model seems inadequate to express the HWS of a household since it fails to model user preference and quality. A successful model should attempt to express micro level changes and their implications on HWS. This aspect can best be addressed qualitatively since the state of knowledge concerning these factors is imprecise and subjective.

This paper describes a HWS model based on Fuzzy Sets.

The Model

Models based on Fuzzy Set Theory possess a higher degree of flexibility to model complex field situations. It has the capability of representing the input parameters in terms of qualitative ratings expressed in linguistic terms (Zadeh, 1975). A fuzzy set of objects *x* is defined as a set of ordered pairs and is expressed as:

$$I = (\mu(x), x) \qquad (3)$$

where $\mu(x)$ is termed the "grade of membership of *x* in *I*". $\mu(x)$ may only take values in the closed interval [0,1]. The membership of a fuzzy set may take a discrete form or may be represented by a mathematical function with triangular, π, S, β curve shapes. This analysis uses triangular shaped Fuzzy Sets to represent five linguistic variables. These sets are distributed equally on the *x*-domain of [0,1] (refer Figure 1).

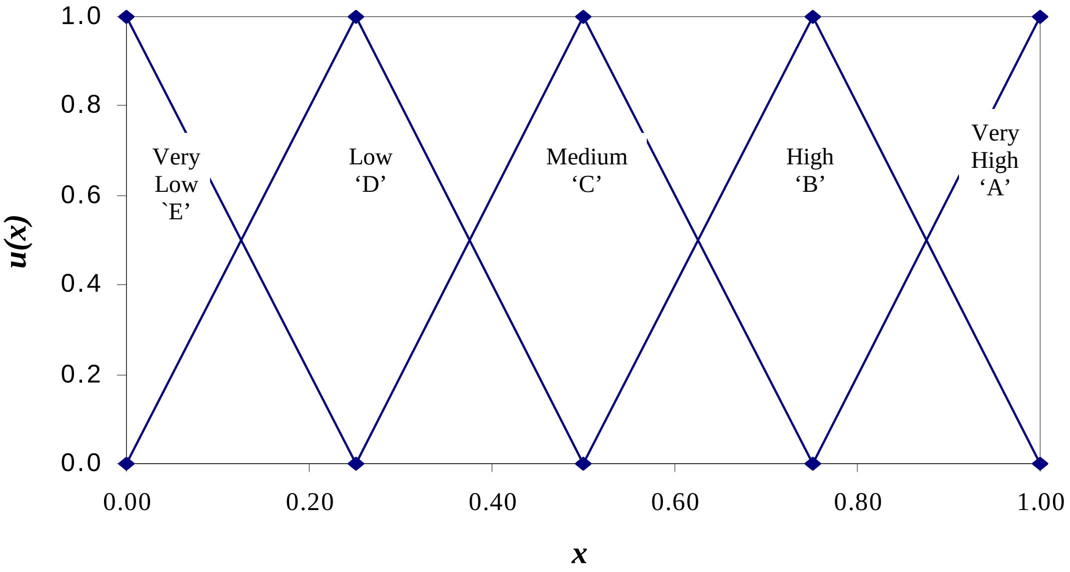


Figure 1: Triangular representation of the five linguistic variables.

A model based on Fuzzy Sets is effective in capturing the expertise of a trained field researcher. This approach does not require quantifying water use for different activities. However, if such data is available, they can be expressed using linguistic variables as described below.

As an example, let us see how the average per capita drinking water requirement is represented by a fuzzy set. If the average requirement of a particular household vary between 4 to 6 lpcd, and the requirement for the day considered is 4.5 lpcd, the water use can be expressed as an index varying between the interval [0,1] as *(4.5-4)/(6-4) = 0.25*. The Fuzzy Set `Low' represents this. An index of 0.4 can correspond to `medium', considering the membership of belongingness to the said category.

The model used in this analysis consists of a three-layer decision tree representing primary, secondary and tertiary factors. The node points where primary factors branch identifies the activities of water use. These are classified based on the source of supply namely, water obtained from ground and surface water sources (Source 1) and same supplemented with harvested rainwater (Source 2). These are identified as primary factors `ratings' and are expressed using Fuzzy Sets.

The secondary and tertiary factors represent `weights' associated with water use and are described in Tables 1-6. The secondary factors weigh the relative importance of tertiary factors for a given activity and are considered common to all households. As an example, Sri Lankan rural households give more importance to the taste of drinking water more than the haul distance. Hence `taste' has a higher weight. The tertiary weights are obtained for both wet and dry seasons and they represent the actual household conditions.

Methodology

The process of combining membership functions to represent the outcome is termed Fuzzy Integration. This section presents how fuzzy sets are combined to obtain the indices representing HWS.

i) The fuzzy sets for the respective weights for secondary and tertiary factors, w_{2j} and w_{3jk} , are combined to yield the average weight, t_j. The analysis uses *m* tertiary factors weights per activity, and the combined weight t_j, represents weights assigned for the six activities.

$$t_j = \frac{\sum_{k=1}^{m} w_{2j} w_{3jk}}{\sum w_{3jk}} \qquad (4)$$

ii) The relative use of water from the two sources, for an activity *I*, for a given day, is expressed by the normalised fuzzy sets [s_i, s_{i+6}], where *I=1,6* represents the six activities. These two fuzzy sets are combined to obtain a combined weight w_i:

$$w_i = \frac{s_i t_i + s_{i+6} t_{i+6}}{t_i + t_{i+6}} \qquad (5)$$

iii)For a given activity *I*, Household Water Security indices for individual activities F_i, are obtained by multiplying the Primary Factor Rating r_i by w_i

$$F_i = w_i r_i \qquad (6)$$

iv)The Household Water Security Index is obtained by considering as:

$$F = \frac{\sum w_i r_i}{w_i} \qquad (7)$$

The overall fuzzy distributions expressed in equations (6) and (7) are integrated using Monti-Carlo Simulation Technique as suggested in Juang et al. (1991). The mean values of the indices are plotted against time (in days) to represent the trends in water use.

Results and Discussion

This paper presents the HWS indices for four households. Table 7 lists the tertiary factor weights while Tables 1-6 describe the secondary weights for the six activities concerned. The variation of these indices with time (in days) is given in Figures 2-29. The two vertical lines shown in these graphs demarcate the wet season (period Day 1-77 and Day 232-300) and the dry season (period Day 78-231).

Household 38

This household consists of two adults and a child. During wet season harvested rainwater is used mainly for domestic activities. During dry season, stored rainwater is used only for washing clothes and in toilet. Water for other uses are hauled from a distant source. It is observed that little attempt is made to protect stored rainwater from being spoilt. Figure 2-8 shows the variation of HWS indices with time.

Household 39

This household consists of three adults. Water from the domestic rainwater-harvesting tank is used for all activities other than for drinking and cooking. The rainwater harvesting system is well managed and is used during both seasons. Water for drinking and cooking is obtained from a groundwater well located about one kilometre away from the house. During the dry season, stored rainwater is used sparingly for all their daily needs except for drinking and cooking. Figures 9-15 show the variation of HWS indices with time.

Household 41

This household consists of five adults. It maintains a well-managed domestic rainwater-harvesting tank. Stored rainwater is used for all activities during the wet season. Since quality of stored rainwater goes down with time of storage, it is used only in toilets, during the dry season. Water for drinking and cooking is obtained from a distant well located 1.2 kilometres away. Figures 16-22 show the variation of HWS indices with time.

Household 52

This household consists of five adults. Domestic water requirement except for washing clothes, which require large quantities of water, is obtained from a well, located 150m away from their home. Water quality of this source does not change over the seasons.

The occupants use another well approximately 0.5km away from home for washing clothes. Figures 23-29 show the variation of HWS indices with time.

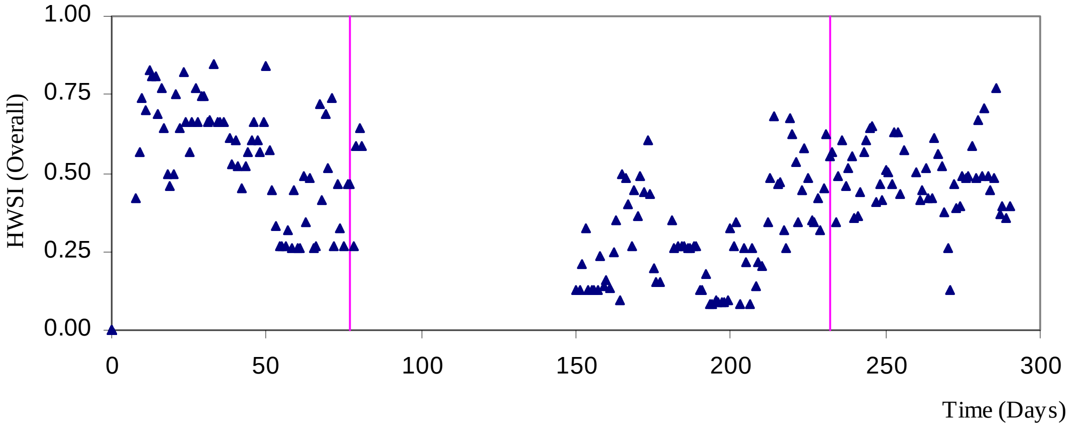


Figure 2: Variation of HWSI (Overall) with Time for Household 38 (with Harvested Rainwater).

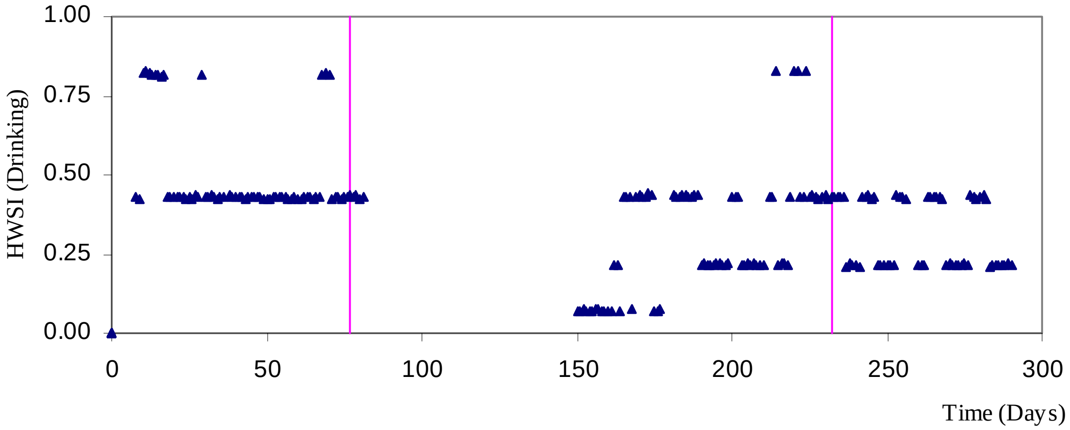


Figure 3: Variation of HWSI (Drinking) with Time for Household 38 (with Harvested Rainwater).

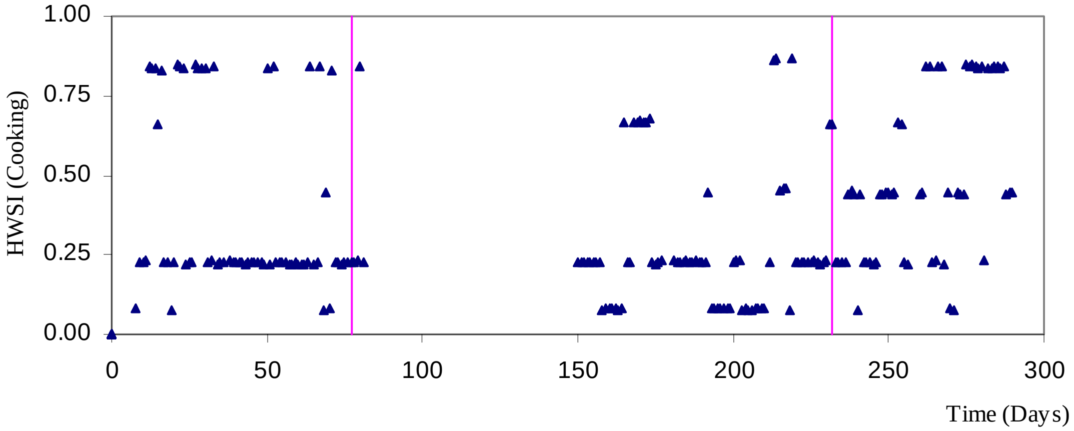


Figure 4: Variation of HWSI (Cooking) with Time for Household 38 (with Harvested Rainwater).

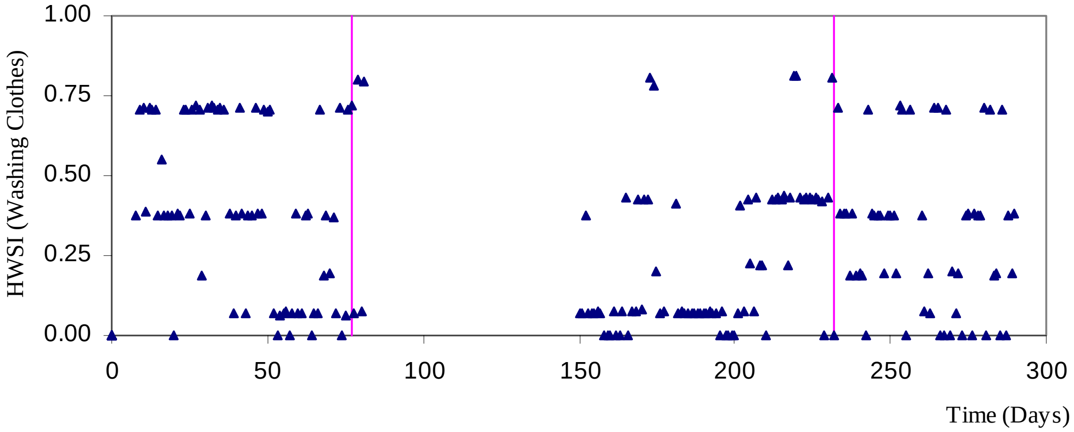


Figure 5: Variation of HWSI (Washing Clothes) with Time for Household 38 (with Harvested Rainwater).

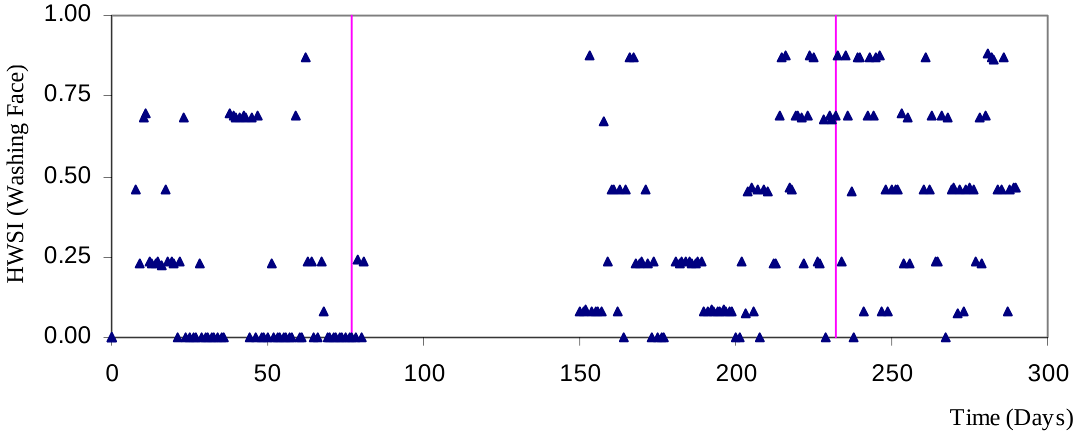


Figure 6: Variation of HWSI (Washing Face) with Time for Household 38 (with Harvested Rainwater).

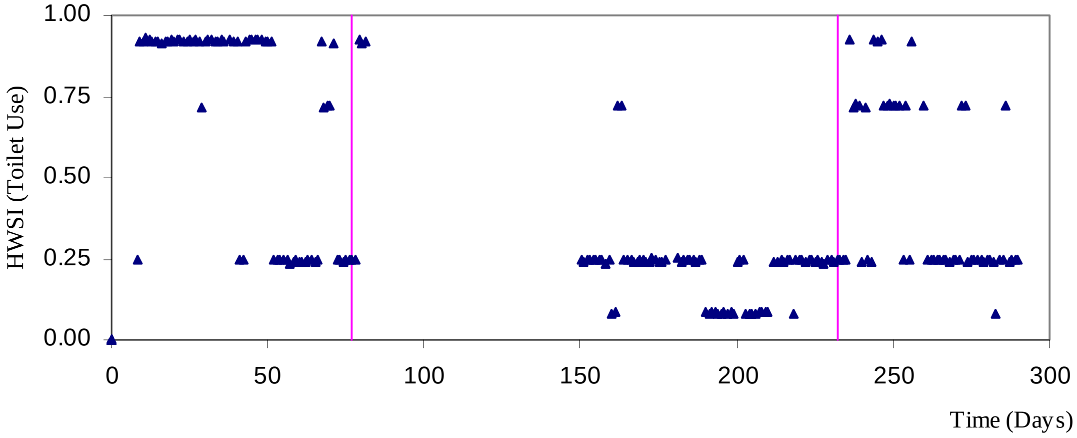


Figure 7: Variation of HWSI (Toilet Use) with Time for Household 38 (with Harvested Rainwater).

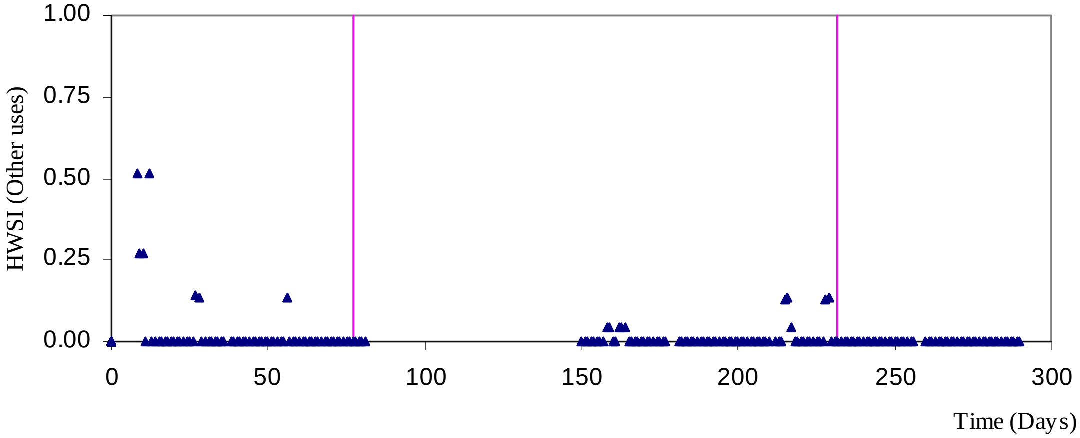


Figure 8: Variation of HWSI (Other uses) with Time for Household 38 (with Harvested Rainwater).

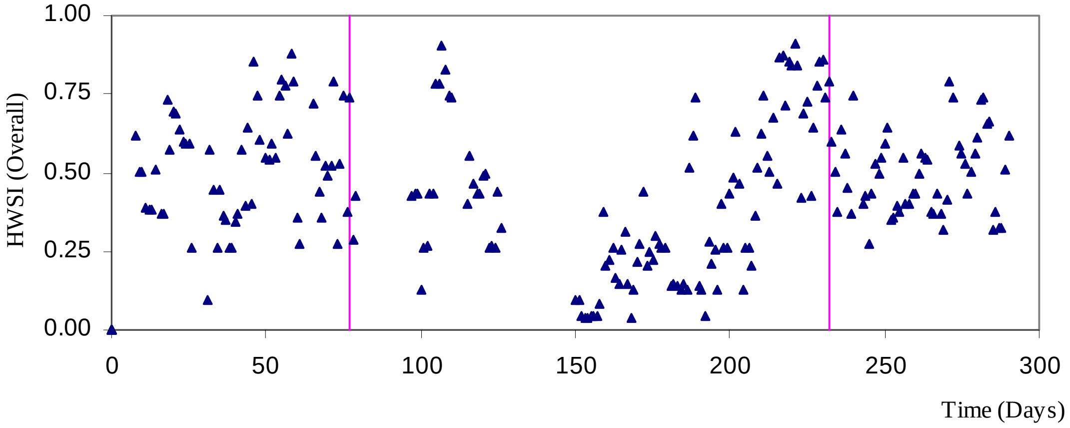


Figure 9: Variation of HWSI (Overall) with Time for Household 39 (with Harvested Rainwater).

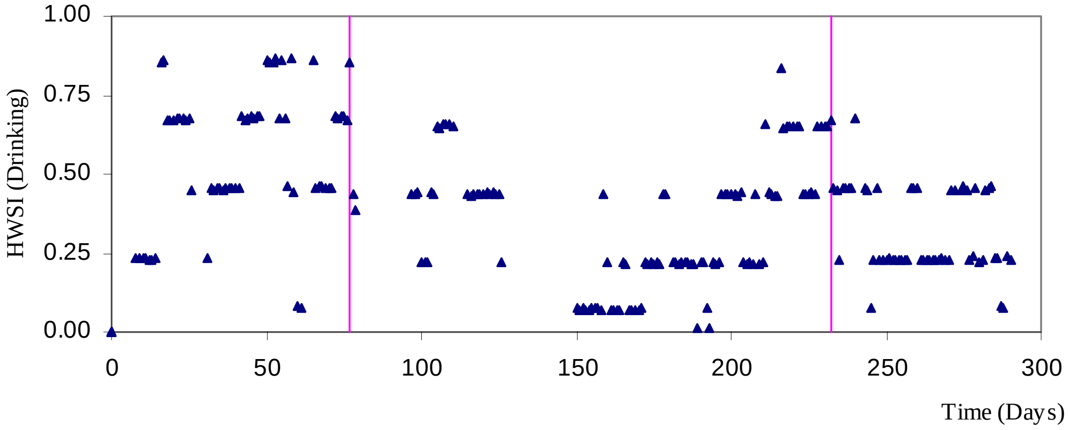


Figure 10: Variation of HWSI (Drinking) with Time for Household 39 (with Harvested Rainwater).

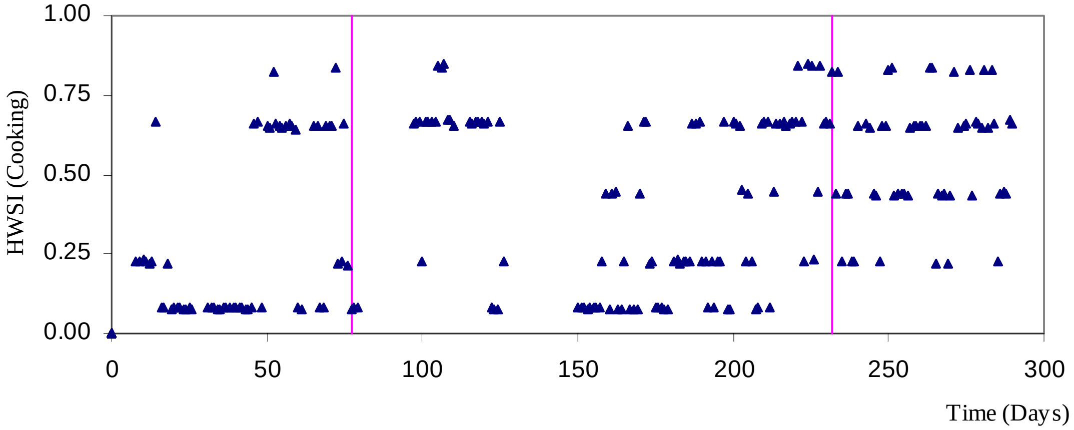


Figure 11: Variation of HWSI (Cooking) with Time for Household 39 (with Harvested Rainwater).

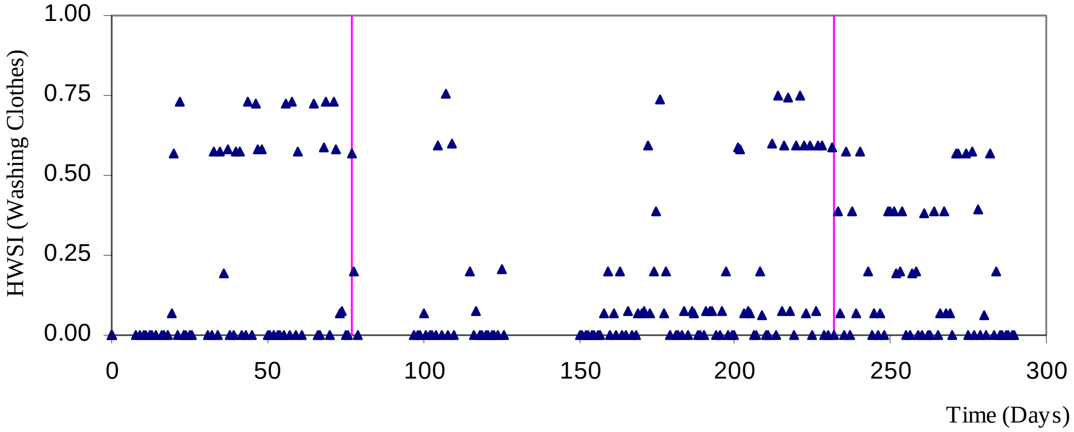


Figure 12: Variation of HWSI (Washing Clothes) with Time for Household 39 (with Harvested Rainwater).

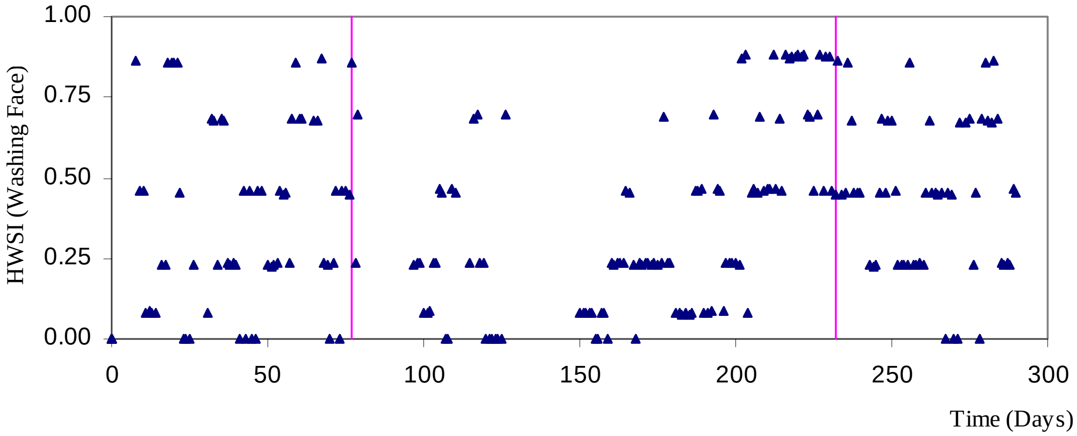


Figure 13: Variation of HWSI (Washing Face) with Time for Household 39 (with Harvested Rainwater).

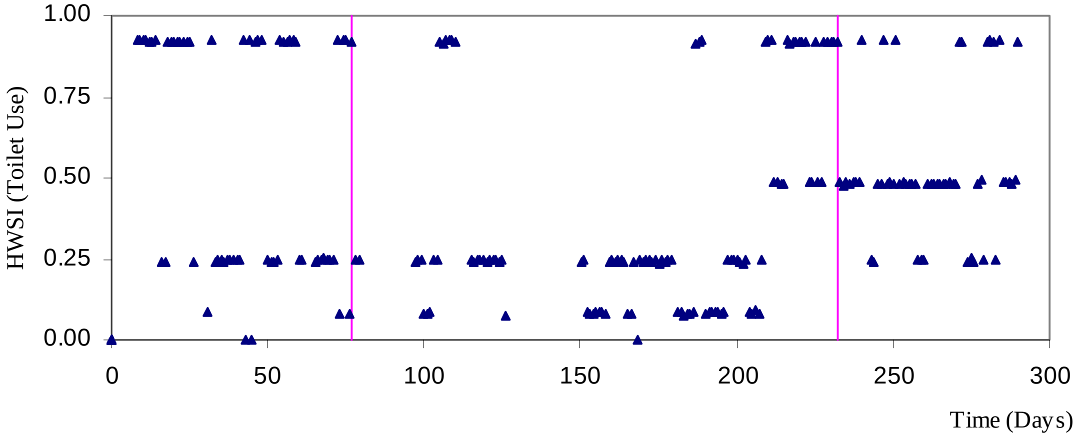


Figure 14: Variation of HWSI (Toilet Use) with Time for Household 39 (with Harvested Rainwater).

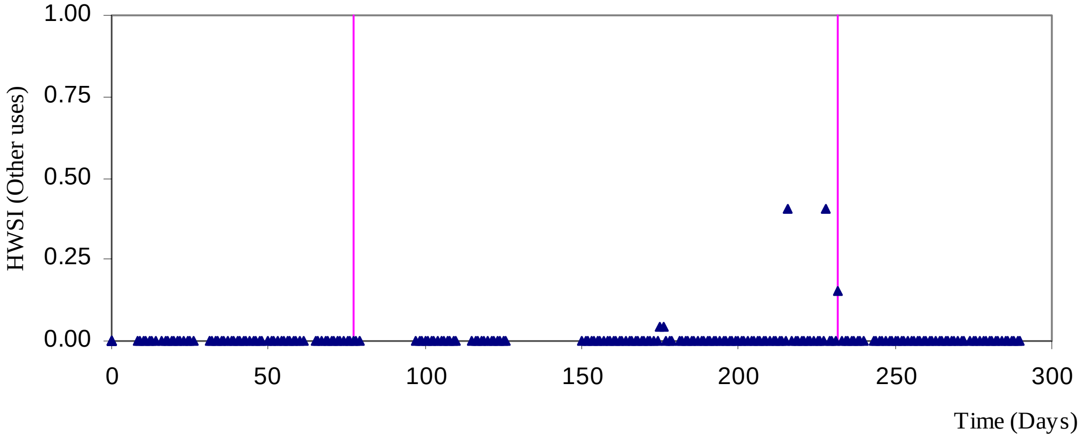


Figure 15: Variation of HWSI (Other uses) with Time for Household 39 (with Harvested Rainwater).

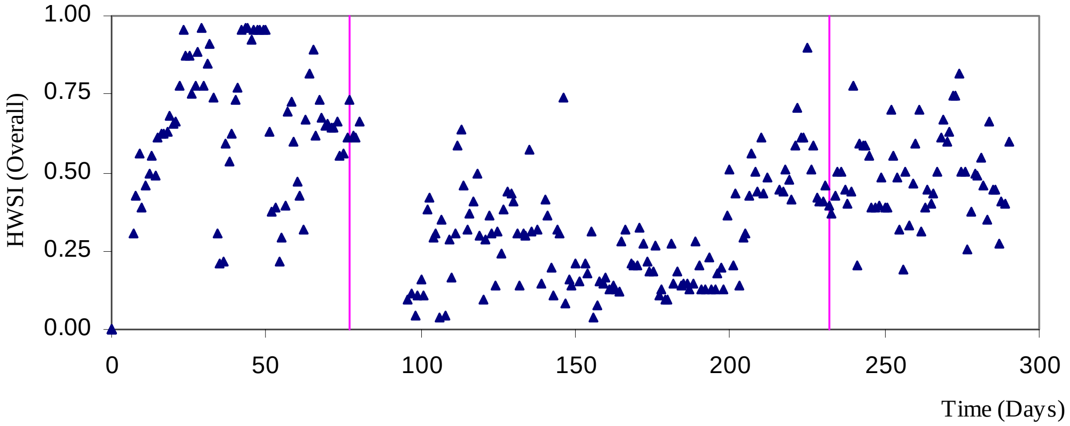


Figure 16: Variation of HWSI (Overall) with Time for Household 41 (with Harvested Rainwater).

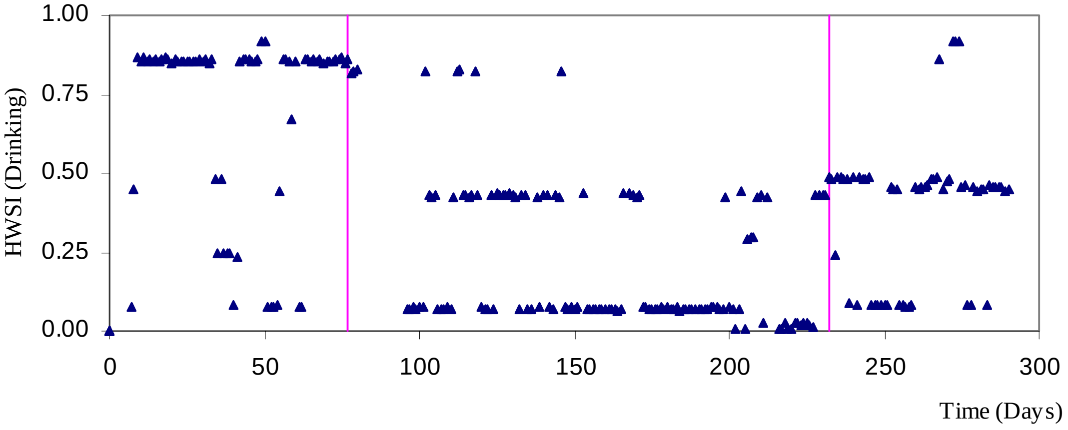


Figure 17: Variation of HWSI (Drinking) with Time for Household 41 (with Harvested Rainwater).

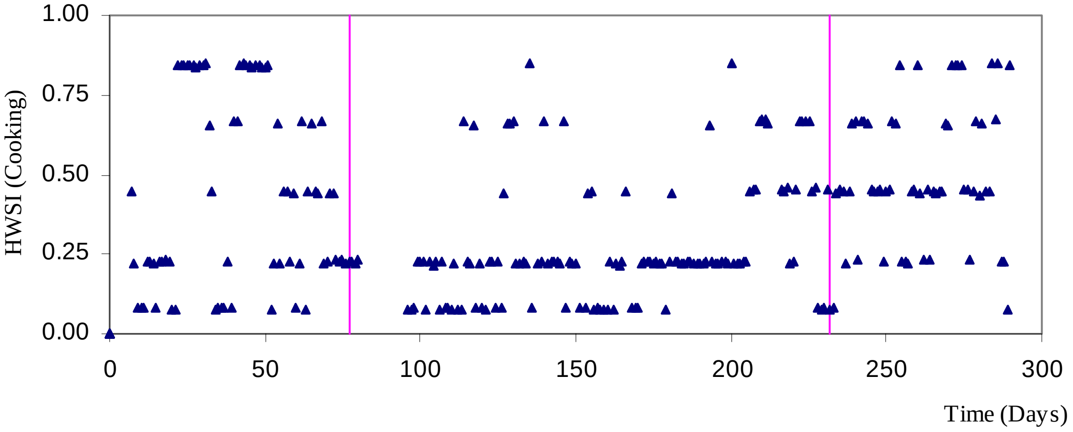


Figure 18: Variation of HWSI (Cooking) with Time for Household 41 (with Harvested Rainwater).

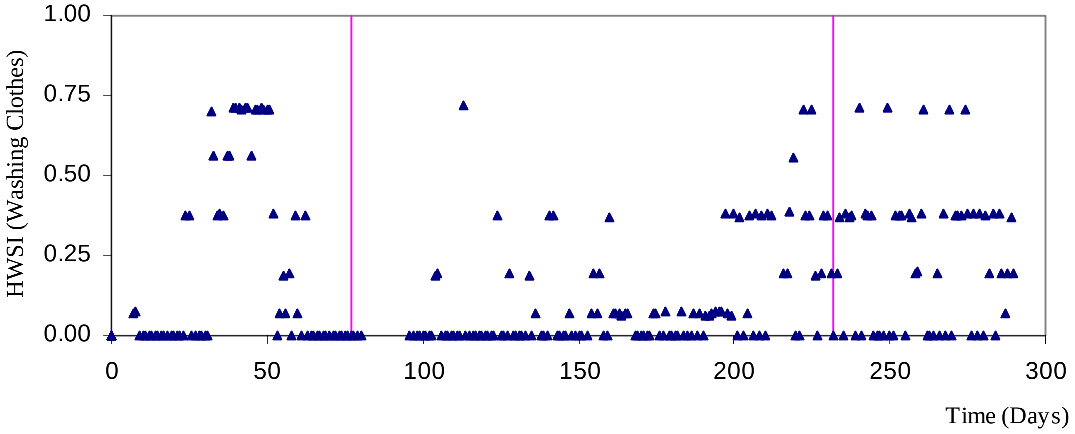


Figure 19: Variation of HWSI (Washing Clothes) with Time for Household 41 (with Harvested Rainwater).

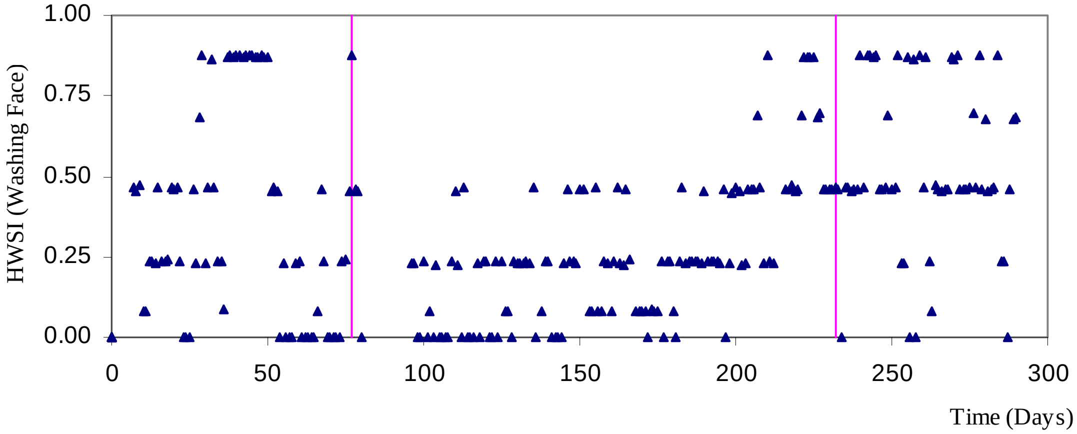


Figure 20: Variation of HWSI (Washing Face) with Time for Household 41 (with Harvested Rainwater).

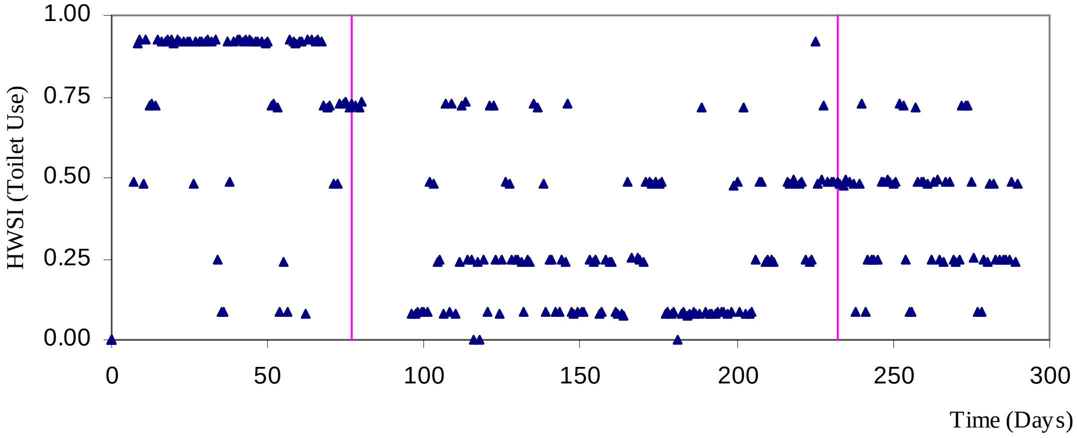


Figure 21: Variation of HWSI (Toilet Use) with Time for Household 41 (with Harvested Rainwater).

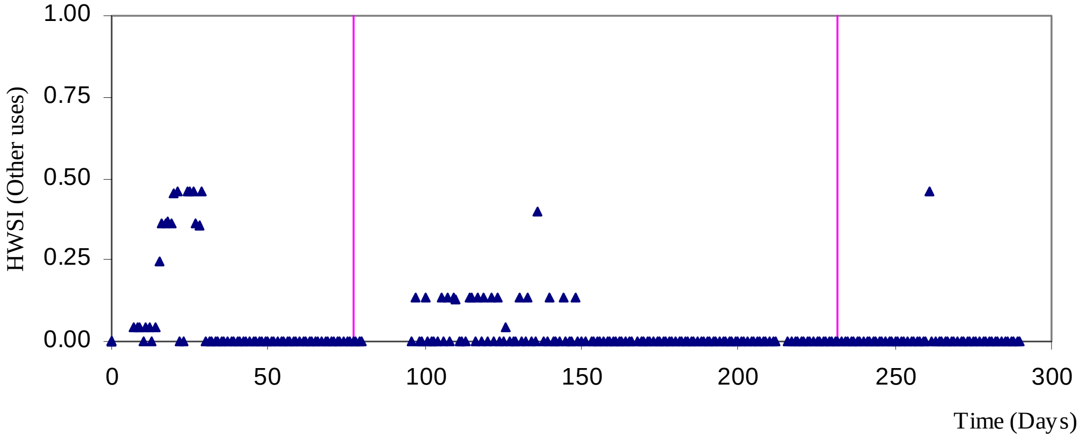


Figure 22: Variation of HWSI (Other uses) with Time for Household 41 (with Harvested Rainwater).

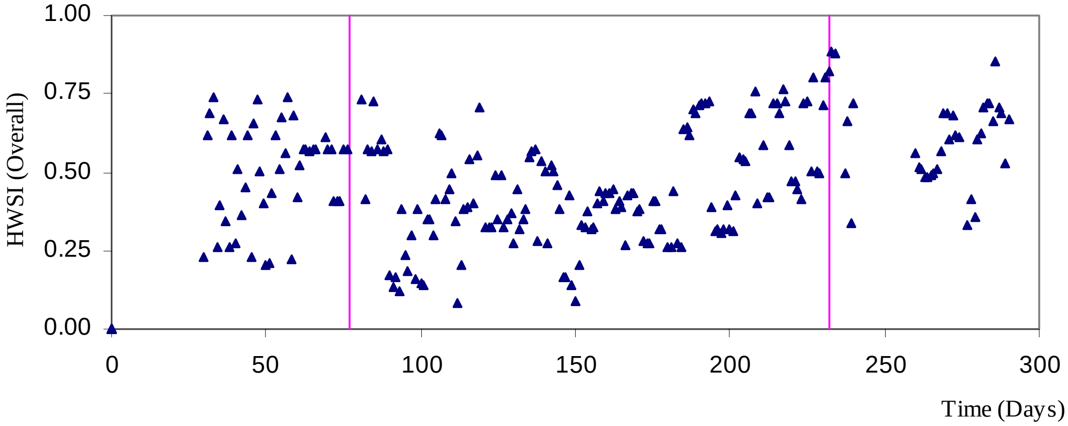


Figure 23: Variation of HWSI (Overall) with Time for Household 52.

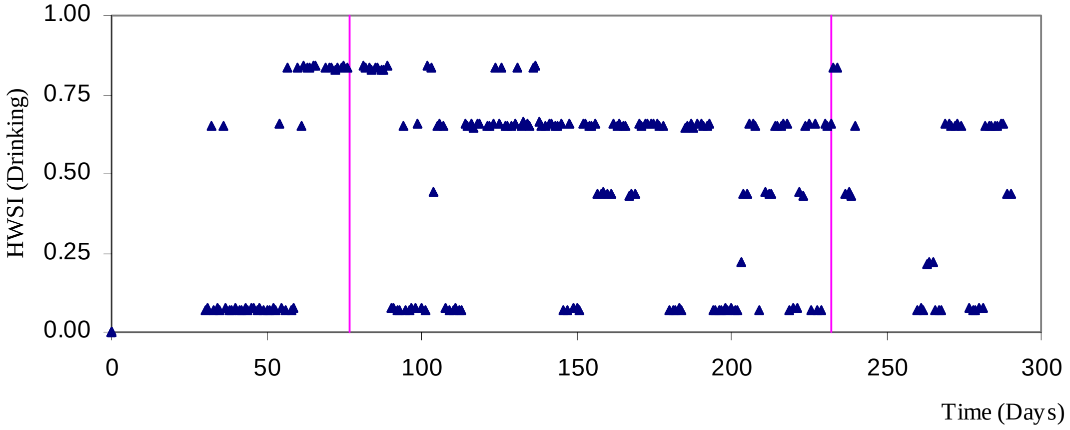


Figure 24: Variation of HWSI (Drinking) with Time for Household 52.

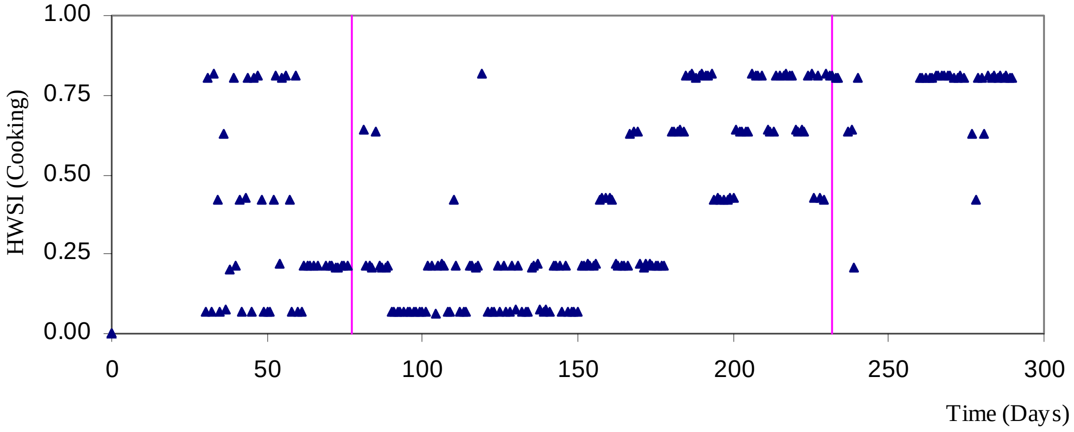


Figure 25: Variation of HWSI (Cooking) with Time for Household 52.

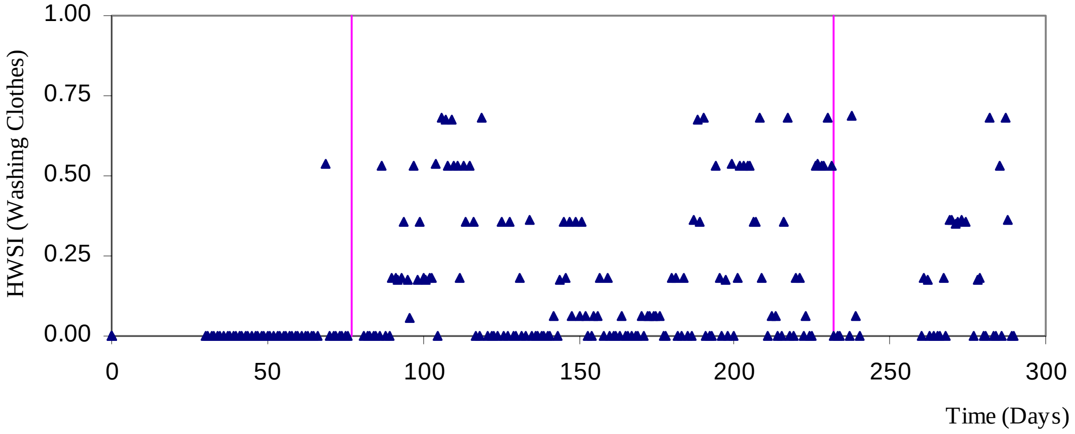


Figure 26: Variation of HWSI (Washing Clothes) with Time for Household 52.

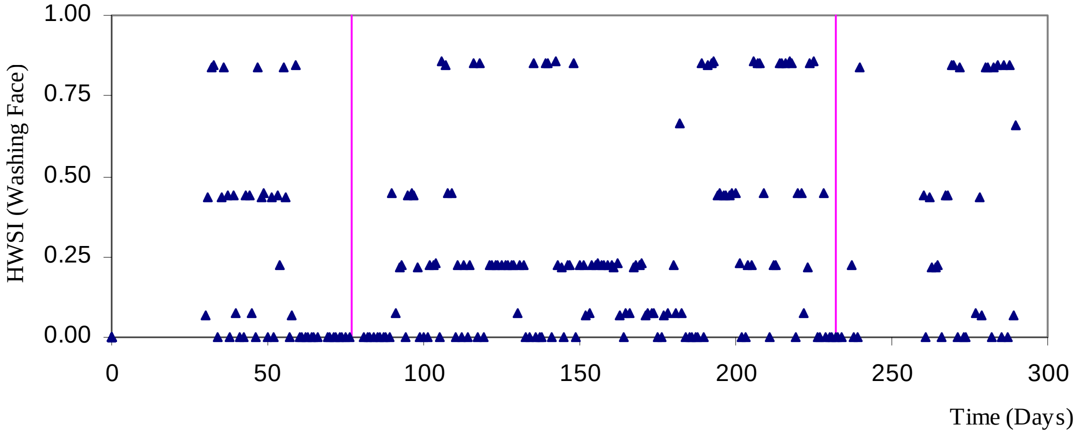


Figure 27: Variation of HWSI (Washing Face) with Time for Household 52.

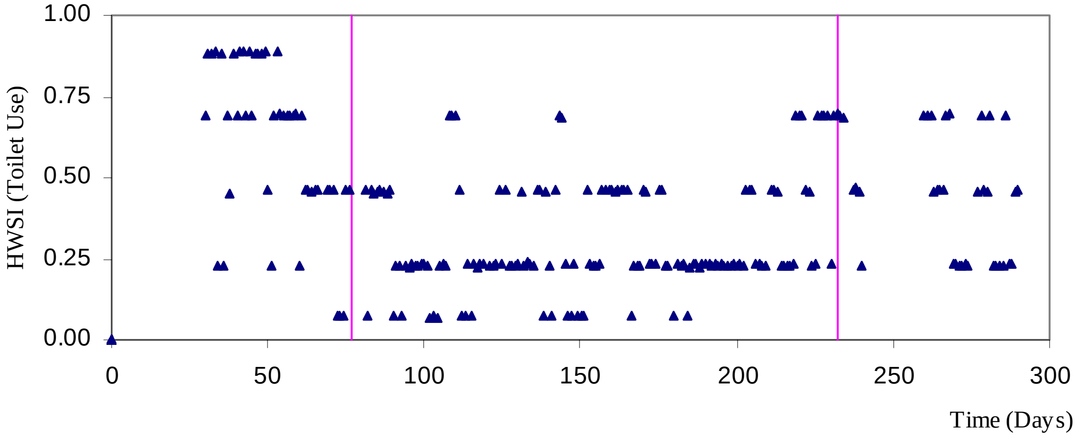


Figure 28: Variation of HWSI (Toilet Use) with Time for Household 52.

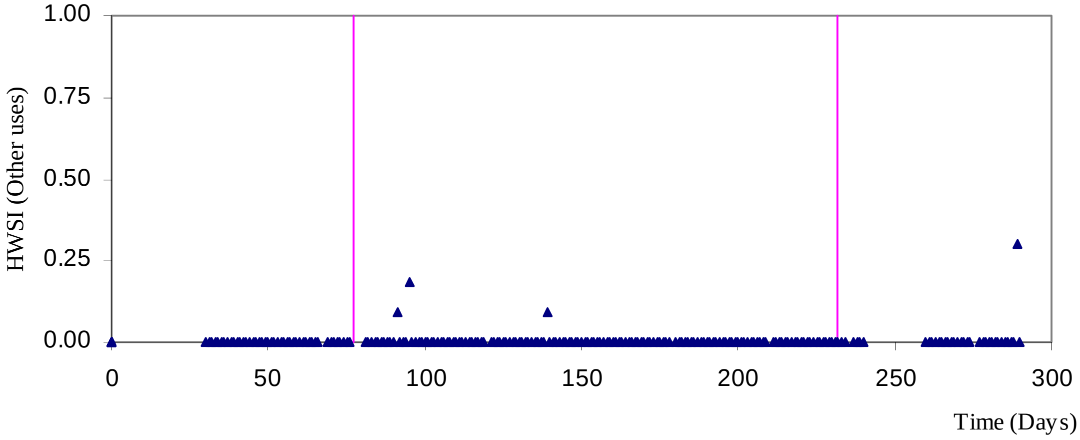


Figure 29: Variation of HWSI (Other uses) with Time for Household 52.

Summary and Conclusions

This study attempts to capture both water usage and preferences of the user. User preference is determined by assigning weights to water usage. These variables expressed in linguistic terms are represented using Fuzzy Sets. Fuzzy Sets can be used to model HWS either by using field data in a quantitative approach, or using an expert's opinion in a qualitative approach.

Rural communities in Sri Lanka are subject to moderate water stresses towards the end of the dry season and they may have to obtain water from alternate sources, which reduce their HWS. A high HWS during dry season can be achieved through domestic rainwater harvesting. It is observed that a well managed rainwater collection system increases HWS significantly compared to a poorly managed system.

The approach used in this paper can be used to model HWS in communities of different environments provided that parameters defining water security are correctly identified.

Acknowledgement

The author gratefully acknowledges the contribution of Jagath in data collection and processing. Special thanks go to colleagues at Lanka Rainwater Harvesting Forum for their valuable observations and helpful suggestions.

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Juang, C.H., Huang, X.L., and Elton, D.J., (1991), Fuzzy information processing by the Monte Carlo simulation technique., Civ. Engrg. Syst., 8(1), 19-25.

ANNEX

Table 1: Water for drinking; Secondary and Tertiary Factors and their respective Weights.

Secondary Factors and weights for Sources 1 & 2		Tertiary Factors and weights	
Distance travelled	A	D = 1-50 m and h = 0-10 m	A
		D = 50-100 m and h = 0-10 m; D = 1-50 m and h = 10-50 m	B
		D = 100-200 m and h = 0-10 m; D = 50-100 m and h = 10-50 m	C
		D>800 m and h = 0-10 m; D>200 m and h = 10-50 m; D>50 m and h> 50 m	D
		D>800 m and h = 0-10 m; D>200 m and h = 10-50 m; D>50 m and h> 50 m	E
Taste	A	Ordinary water	A
		Harvested rainwater	C
		Brackish water / saline water	E
Purity (Processing)	A	Pure and clear water	A
		Water contains plant matter and dust. Needs filtering	B
		Water needs boiling and / or filtering.	C
		Water contains cement dust, bird droppings, worms and larvae	E
In an emergency	B	Neighbours help	A
		Consumption is reduced	B
		Use stored water	C
		Use water used for cooking	D

Table 2: Water for Cooking; Secondary and Tertiary Factors and their respective Weights.

Secondary Factors and weights for Sources 1 & 2		Tertiary Factors and weights	
Distance travelled	A	D = 1-50 m and h = 0-10 m	A
		D = 50-100 m and h = 0-10 m; D = 1-50 m and h = 10-50 m	B
		D = 100-200 m and h = 0-10 m; D = 50-100 m and h = 10-50 m	C
		D>800 m and h = 0-10 m; D>200 m and h = 10-50 m; D>50 m and h> 50 m	D
		D>800 m and h = 0-10 m; D>200 m and h = 10-50 m; D>50 m and h> 50 m	E
Taste	A	Ordinary water	A
		Harvested rainwater	B
		Brackish water / saline water	E
Purity (Cooking)	A	Pure and clear water	A

		Water contains plant matter and dust. Needs filtering	B
		Water contains cement dust, bird droppings, worms and larvae	E
Purity (Washing)	B	Pure and clear water; contains plant matter and dust. Needs filtering	A
		Water contains cement dust, bird droppings, worms and larvae	E
In an emergency	B	Neighbours help; use stored water	A
		Consumption is reduced	B

Table 3: Water for Washing Face; Secondary and Tertiary Factors and their respective Weights.

Secondary Factors and weights for Sources 1 & 2		Tertiary Factors and weights	
Distance travelled	B	D = 1-50 m and h = 0-10 m	A
		D = 50-100 m and h = 0-10 m; D = 1-50 m and h = 10-50 m	B
		D = 100-200 m and h = 0-10 m; D = 50-100 m and h = 10-50 m	C
		D=200-800m and h=0-10m; D=100-200m and h=10-50m; D=0-50m and h>50m	D
		D>800 m and h = 0-10 m; D>200 m and h = 10-50 m; D>50 m and h> 50 m	E
Hardness	A	Ordinary water; Harvested rainwater	A
		Brackish water / saline water	E
Purity	B	Pure and clear water; water contains plant matter and dust. Needs filtering	A
		Water contains cement dust, bird droppings, worms and larvae	E
In an emergency	C	Neighbours help; use stored water	A
		Consumption is reduced	B

Table 4: Water for Washing Clothes; Secondary and Tertiary Factors and their respective Weights.

Secondary Factors and weights for Sources 1 & 2		Tertiary Factors and weights	
Distance travelled	A	D = 1-50 m and h = 0-10 m	A
		D = 50-100 m and h = 0-10 m; D = 1-50 m and h = 10-50 m	B
		D = 100-200 m and h = 0-10 m; D = 50-100 m and h = 10-50 m	C
		D>800 m and h = 0-10 m; D>200 m and h = 10-50 m; D>50 m and h> 50 m	D
		D>800 m and h = 0-10 m; D>200 m and h = 10-50 m; D>50 m and h> 50 m	E
Hardness	A	Ordinary water; Harvested rainwater	A
		Brackish water / saline water	E
Purity	A	Pure and clear water; water contains plant matter and dust. Needs filtering	A
		Water contains cement dust, bird droppings, worms and larvae	E

In an emergency	B	Neighbours help; use stored water	A
		Consumption is reduced	B

Table 5: Water for Toilet use; Secondary and Tertiary Factors and their respective Weights.

Secondary Factors and weights for Sources 1 & 2		Tertiary Factors and weights	
Distance travelled	A	D = 1-50 m and h = 0-10 m	A
		D = 50-100 m and h = 0-10 m; D = 1-50 m and h = 10-50 m	B
		D = 100-200 m and h = 0-10 m; D = 50-100 m and h = 10-50 m	C
		D>800 m and h = 0-10 m; D>200 m and h = 10-50 m; D>50 m and h> 50 m	D
		D>800 m and h = 0-10 m; D>200 m and h = 10-50 m; D>50 m and h> 50 m	E
In an emergency	A	Neighbours help; use stored water	A
		Consumption is reduced	B

Table 6: Water for other uses; Secondary and Tertiary Factors and their respective Weights.

Secondary Factors and weights for Sources 1 & 2		Tertiary Factors and weights	
Distance travelled	A	D = 1-50 m and h = 0-10 m	A
		D = 50-100 m and h = 0-10 m; D = 1-50 m and h = 10-50 m	B
		D = 100-200 m and h = 0-10 m; D = 50-100 m and h = 10-50 m	C
		D>800 m and h = 0-10 m; D>200 m and h = 10-50 m; D>50 m and h> 50 m	D
		D>800 m and h = 0-10 m; D>200 m and h = 10-50 m; D>50 m and h> 50 m	E

Table 7: Tertiary Factors and their respective Weights for Households.

Use	Secondary Factors	**Household No. 38**				**Household No. 39**				**Household No. 41**				**Household No. 52**			
		Season (Wet, Dry)				**Season (Wet, Dry)**				**Season (Wet, Dry)**				**Season (Wet, Dry)**			
		W	W	D	D	W	W	D	D	W	W	D	D	W	W	D	D
		Source 1	Source 2	Source 1	Source 2	Source 1	Source 2	Source 1	Source 2	Source 1	Source 2	Source 1	Source 2	Source 1	Source 2	Source 1	Source 2
Drinking	Dist. travelled	D	—	D	—	D	D	A	—	E	A	E	—	A	—	A	—
	Taste	A	—	A	—	A	A	A	—	A	A	A	—	A	—	A	—
	Purity (Processing)	B	—	A	—	A	A	A	—	A	A	A	—	A	—	A	—
	Emergency	A	—	A	—	A	A	A	—	A	—	A	—	A	—	A	—
Cooking	Dist. travelled	A	A	A	A	A	D	A	A	A	A	E	A	A	—	A	—
	Taste	B	A	B	A	A	A	A	B	B	A	A	A	A	—	A	—

	Purity (Cooking)	B	B	B	E	A	B	A	A	A	A	B	B	A	—	A	—
	Purity (Washing)	B	B	B	D	A	B	A	B	B	A	B	B	A	—	A	—
	Emergency	A	A	B	E	A	A	A	A	A	A	B	B	A	—	B	—
Washing Face	Dist. travelled	A	A	D	A	C	C	A	A	B	A	C	A	A	—	A	—
	Hardness	A	A	A	A	A	A	A	A	A	A	B	A	A	—	A	—
	Purity	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Emergency	A	A	A	E	A	B	A	C	A	A	A	A	A	—	A	—
Washing Clothes	Dist. travelled	A	A	D	A	A	C	A	A	A	A	C	A	C	—	C	—
	Hardness	A	A	A	A	A	B	A	A	A	A	A	A	A	—	A	—
	Purity	A	A	A	A	A	A	A	B	A	A	A	A	A	—	A	—
	Emergency	A	A	B	A	A	A	B	B	B	A	B	A	B	—	C	—
Toilet Use	Dist. travelled	A	A	D	A	A	A	A	A	A	A	A	A	C	—	C	—
	Hardness	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Purity	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Emergency	A	B	B	B	A	B	—	B	A	B	A	B	A	—	A	—
Other uses	Dist. travelled	A	A	D	A	B	D	A	A	A	A	C	A	C	—	C	—
	Hardness	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Purity	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Emergency	A	B	A	B	A	A	B	B	A	B	A	B	A	—	B	—

Simplified Method

A simplified method based on Microsoft Excel spreadsheet is proposed to evaluate the WSI with respect to the activities considered in this study. The simplified version is contained in the file SIMPLE.XLS.

The method requires qualitative representation of water use and the weights in linguistic terms. This can also be used as a simulation tool to assess the state of water insecurity and to see how it can be improved.

The user is required to input primary ratings (which reflect the actual water use for different activities obtained from different sources), Secondary weights (decided by users and planners based on their perceptions) and Tertiary weights (which reflect the quality and the difficulty in obtaining water).

Figure show below gives the HWS indices with respect to the activities used in this study.

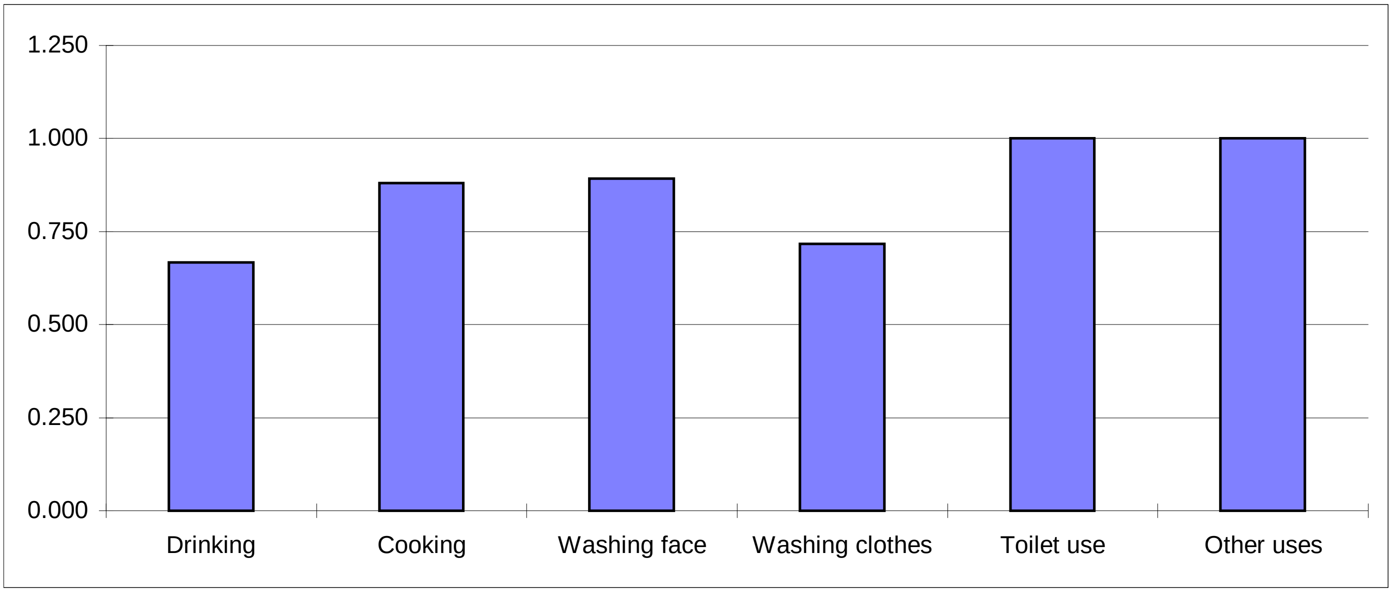

Figure showing HWS indices for different activities

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