DOMESTIC ROOF WATER HARVESTING

IN THE HUMID TROPICS

CONCEPT OF WATER SECURITY ENTAILING DOMESTIC ROOF WATER HARVESTING

PREPARED

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1.0 Introduction

The Domestic Roof Water Harvesting (DRWH) Study supported by the European Union has four research components. Low cost technology, Health Aspects, Institutional aspects and water security. Latter is the responsibility of the Lanka Rainwater Harvesting Forum (LRWHF), who has been conducting research during the past year to establish water security at household level. DRWH study has milestone reports to denote the end of specific time periods. For water security, it has six milestone reports, of which the first milestone report entitled "Household Water Security in Sri Lanka using Domestic Roof Water Harvesting" was presented in December 1998. The current report entitled "Concept of Water Security Entailing the Use of Domestic Roofwater Harvesting" is the second in the series of six reports. The final outcome of the study will be a book entitled "Domestic Roofwater Harvesting prospects and Problems in the Humid Tropics".

The present study component, attempts to understand and introduce the concept of household water security, mainly based on research conducted in rural communities where water is a scarce resource. Also these households use multiple water sources to satisfy their water needs. Rainwater Harvesting is only one option among many, used by these families.

This report consists of ten chapters. The first three deals with the introduction, background and the definitions of water security. Fourth to eighth chapters' deals with the research study, which includes study sites in different environments, methodology, water security modeling and studying water security under different scenarios. The last chapter deals with the continuation of research on water security and closing remarks of the milestone report two.

Though the concept of water security was introduced through this report, a more detail understanding of the subject will be presented in subsequent reports. It is expected to field test the water security model established in this study before household water security using DRWH is introduced into the wide range of water research.

2.0 Background

World Water Situation and Water Scarcity

The world population is expected to reach 8 billion by the year 2020 (UNFPA 1997). Food as well as water will be in high demand with increasing population. While much is debated about the worlds ability to feed the rising population, relatively less attention has been paid to population growth and household water security, specially in developing countries.

Since 1970, global demand for water has increased at approximately 2.4% per annum (Clarke 1993). Rapid urbanization and industrial development in developing countries will exert more pressure on water supply, where the majority share is allocated for irrigation. It is estimated that 1.2 billion people in 20 developing countries have no access to “Safe Water”. (WHO 1998). These countries have been identified as “Water Scarce” (Renewable water resource < 1000 m^3 per capita per annum), and the projections are that by year 2020 the number of countries in the water scarce category will increase to 30, of which 21 will be in low income, food deficit nations (Rosegrant 1997). Hence, the challenge for the future will be to ensure adequate access to safe water for the poorest households in these countries.

At a global level water withdrawals are expected to increase by 35% by the year 2020. (ibid 1997). The per capita water availability, on the other hand has declined by approximately 40% in Asia and by 50% in Africa (Ayibotele 1992). While large sums of funds are allocated annually to improve water supply and sanitation, number of people facing water insecurity remains above 1 billion and is on the increase (Economist 1998).

One of the reasons for inadequate water supply coverage in most developing countries is the investment decisions in most poor countries are directed towards large-scale dam construction and/or Hydro power development, neglecting the poor communities who suffer without safe water supplies. Sri Lanka is an ideal example for this situation where 84% of the countries power supply is covered by large scale Hydro power stations and 70% of lands are irrigated with large-scale irrigation systems. While this is abundant proof for availability of water resources in Sri Lanka, it has failed to provide safe drinking water to 40% of her population by 1999.

Sri Lanka's per capita annual water resources stands at 2802m^3 (as at 1991 census). This is expected to decline to 1928 m^3 by year 2025 (Amarasinghe and sally 1999). These amounts far exceed the per capita water resources of "water stress" countries (Table 1).

Table 1 : Counties Facing Potential Water Insecurity in Year 2000 According to the Water Stress Index' [1/].

Country[2/]	Population in 2000	Water Availability	
		Internal renewable fresh water availability	Water resources including river flows from other countries
	(millions)	(m^3 per capita)	
Egypt	62.4	29	934
Saudi Arabia	21.3	103	103
Libyan Arab Jamahiriya	6.5	108	108
United Arab Emirates	2.0	152	152
Jordan	4.6	153	240
Mauritania	2.6	154	2843
Yemen	16.2	155	155
Israel	6.4	260	335
Tunisia	9.8	384	445
Syrian Arab Republic	17.7	430	2008
Kenya	34.0	436	436
Burundi	7.4	487	487
Algeria	33.1	570	576
Hungary	10.1	591	11326
Rwanda	10.4	604	604
Botswana	1.6	622	11187
Malawi	11.8	760	760
Oman	33.3	880	880
Sudan	33.1	905	3923
Morocco	31.8	934	943
Somalia	10.6	1086	1086

1 Water stress : internal renewable fresh water availability between 1,000 0 1,667 cubic meters/capita/annum, water scarcity ; internal renewable fresh water availability < 1,000 cubic meters/capita/annum

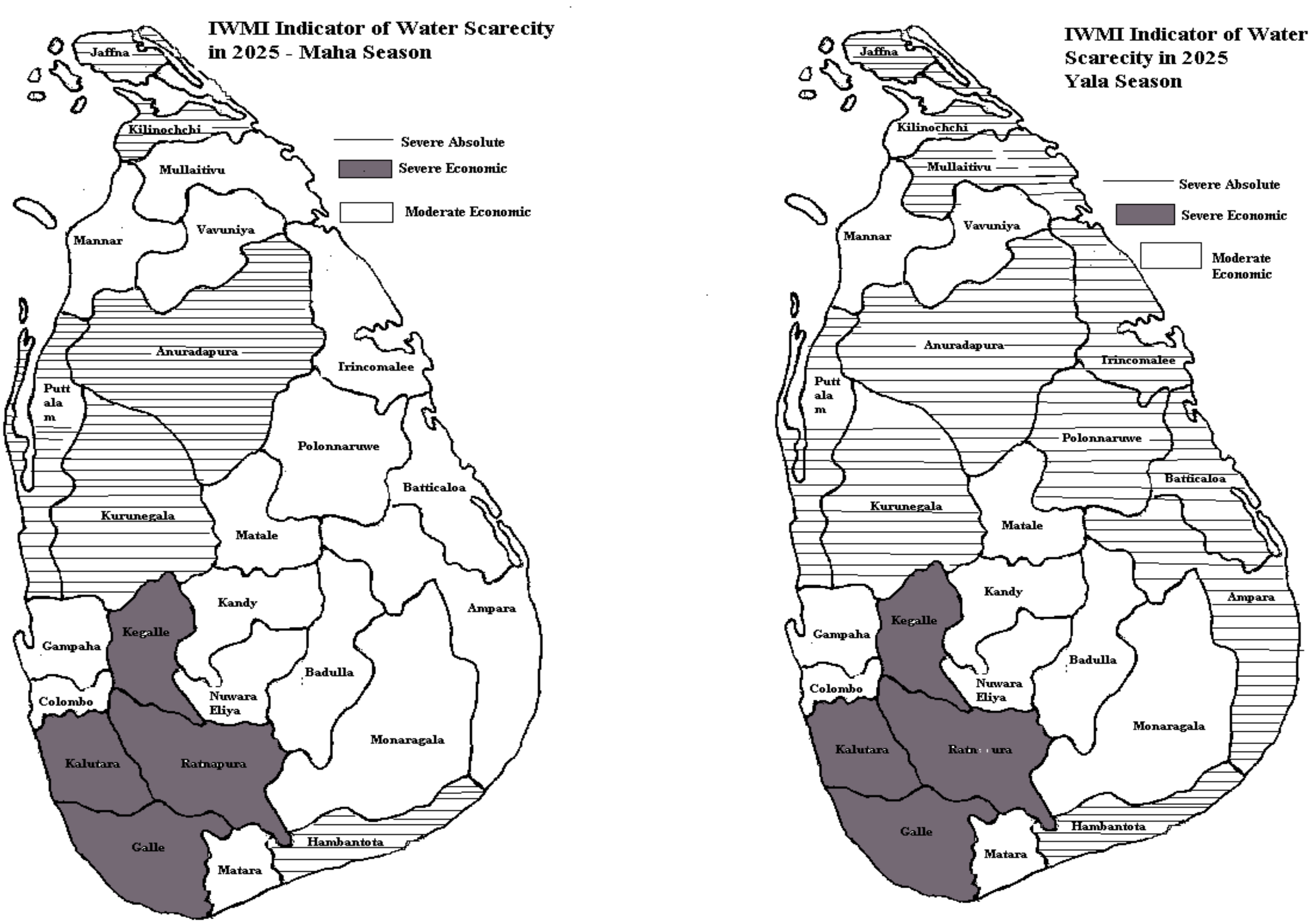
2 A number of other countries with smaller populations, e.g. Barbados, Cape Verde, Kjibouti, Malta, Qatar and Singapore are also included in the water-scarce category.

Source : Adapted from Webb and Iskandarani (1998)

According to these statistics, Sri Lanka can be categorized as a country with moderate or little or no water scarcity. However, what is apparent is that these aggregated macro level statistics do not reflect the actual seasonal and spatial variations in water supply and demand. As such, aggregated statics give a misleading indicator of water scarcity. A recent study conducted by Amarasinghe et al in 1999 has clearly indicated the high degree of seasonal and spatial variations of water supply and demand. Based on these studies Sri Lankan has been divided into absolute water scarce districts and economic water scares districts depending on the seasonality. Absolute water scarcity in this instant has been defined as when total water withdrawals are more than 50% of the available water resources. According to this classification almost all dry zone districts in Sri Lanka faces either seasonal or year round absolute water scarce conditions on the other hand economic water scarcity is defined in terms of the magnitude of future development needs. If the future demand is less than 50% of the total available water resources, but is more than twice the level of current withdrawals, then it is considered to be in sever economic water scarce condition (Figure 1). Masking of sub-national water demand by national statistics is also apparent in the Indian context. India as a whole has adequate average water supplies of 2500 m^3 per capita, but the state of Rajastan has access to only 550 m^3 per capita of water (Webba and Iskandarani 1998). Similar examples have been sited from China and parts of Mexico (ibid 1998).

In Sri Lanka, the total water demand for the three sectors, agriculture, domestic and industrial were considered for assessing water scarcity. Though no water scarcity at national level is indicated at present or in the near future, at sub-national level, large variations in water scarcity have been reported. The demand for quantity and quality of water is expected to increase in future with countries aspiration for greater degree of industrialization. Hence, meeting increasingly competing demand will require innovative technical and organizational approaches to water resource management, backed by an effective institutional and policy environment (Amarasinghe and Sally 1998).

Figure 1: IWMI Indicator of Water Scarcity for Sri Lanka in the year 2025



3.0 Definition of Households Water Security

Water security, unlike food security is still not very clearly defined or adequately researched to understand the dynamics of it. Water in this context is not only a commodity but also a natural resource and a perceived human entitlement. While much is known about food security and environmental security, little is known about the appropriate mixes of policies, institutions and market mechanisms that could help achieve household water security in water stressed environments. (Webb and Iskandarani 1998). Water security can be broadly defined as access by all individuals at all times to sufficient safe water for a healthy and a productive life (ibid 1998). However, the concept of "Safe Water" in the definition is not well understood because it has multiple standards, safe water can mean, clinical safely, cultural safely, perceptional safely, minimum pollutant standard etc. Hence, the word "Safe Water" is still been used losely in context.

3.1 Genesis of Household Water Security (HWS) Definition under the DRWH Study.

At the beginning of the DRWH study, there was no clear understanding of the definition of water security. One of the earliest attempts to define HWS by Ariyabandu and Dharmalingam (1997) states that, "Water security is to have an adequate domestic water supply, so that the productive livelihood of peasants can be sustained".

This definition was further refined by Thomas. (1998). He defined WS as Absolute Water Security and Design Water Security (or design achievement). In the former case he defines WS as the quantity of water reliably supplied to perform culturally normal life. In the latter case, WS is defined as the quantity of water reliably supplied to achieve the design daily requirement of water.

Han Heijnen (1998) in personnel communication with Lanka Rainwater Harvesting Forum (LWHF) defines WS as the ability to ensure that the household has access to water of adequate quality and quantity for human consumption, hygine and other household and (possibly) minor economic activities.

Hence, the need for WS expresses itself in

- Access to (natural) water sources near by the house
- Assured access to such sources at any time of need (time of day/season of the year)
- Access against a reasonable effort in time of collection or energy (spent collecting).

Thus, it may be necessary to construct facilities at household level to enhance household water security. This may include household level storage, closed tanks for drinking water and open tanks or ponds for other uses. Storage tanks should be designed to ensure HWS for a specific period of time base on environment and consumer parameters.

At times WS was understood to be as the simple ratio of water supply to water demand or water available to water desired or required. However, this misunderstanding was rectified later by enlightening the complexities of HWS, which includes qualitative determinants like accessibility, predictability affordability quality etc. Since, the definition on water security has changed and taken a more holistic approach which includes both qualitative and quantitative measures in determining household water security.

After working on the DRWH study for nearly one year, Ariyabandu (1999) along with other researchers have defined household water security as "**Accessibility, reliability and timely availability of adequate safe water to satisfy, basic human needs".**

This however could still be debatable, because basic human needs (BHN) can be subjective depending on the environment and specific community behavior with regards to water use. "Basic Human Need" of water, as defined by (Gleick 1996), refers to four basic human needs, drinking water for survival, water for human hygiene, water for sanitation services and modest need of water for household food preparation. After conducting extensive literature survey on water use patterns of communities both in developed and developing countries, Glecek recommends a 50 lpcd as the standard BHN and states that there should be a guaranteed access to this quantity independently of an individuals economic, social or political status. Gleicks recommendation of 50 1pcd consist of 5 lpcd for drinking, 20 1pcd for sanitation, 15 1pcd for bathing and 10 1pcd for food preparation.

If we accept Gleicks argument of BHN of water, we can establish 50 1pcd as the minimum requirement to satisfy household water security. However, what is not considered in his analysis is the time and energy expended in collection of water, quality preference, reliability of sources and direct and opportunity cost of water transport. In a typical rural setting in the developing world, the above mention factors can be major determinants in deciding the water security of rural communities.

An Alternative Expression of Household Water Security

Household water insecurity can be simply expressed as the difference between water deficit at household and water available for household use. This can be expressed as;

Water Insecurity = Water Deficit in a Household > Available Supply at Household

Household water deficit means, the water needed over and above what is available at home in order to provide adequate water for all members of a household at all times to live a normal life.

Household water deficit is a result of water consumption requirement at household level, water supply at household, distance to fetch water and availability of water carriers. Each of these factors can effect the household water security either positively or negatively. However, impact of these factors on household water security depends on household size, number of growing children, type of work done by householders, health of water carriers, old people at household etc.

In the context of our research, household water deficit could be fulfilled by constructing a rainwater harvesting tank. However, this would have a cost (or a value). Hence, the value of the deficit would be;

- Cost of constructing a rainwater tank and operation and maintenance

  or

- Cost of a 45 gallon drum to collect rainwater
- Cost of hiring somebody to bring water

  or

- Paying for water bowsers on a regular basis

4.0 Studying Water Security in Different Environmental conditions

The foregoing discussion has established a basic understanding of household water security, specially among rural communities in Sri Lanka. In an attempt to establish our hypothesis on household water security, we have selected four study locations based on Agro-ecological zones. The selected locations represent the wet, intermediate and the dry zone. The study locations during the reference year (1998) received 1936 mm, 961-1348 mm and 765-913 mm of rainfall respectively. The socio-economic statuses of the sample householders vary from casual daily wage earners to small-scale tea landholders. However majority are small-scale farmers by profession. Monthly income of the sample population varies from less than Rs. 1500 (£ 13) to Rs. 10,000 (£ 88) per month depending on the profession of the householders. The three agro-ecological zones were selected to assess the water use pattern of households living primarily in different rainfall regimes and to understand the multiple water source use by rural communities. While the dry zone study locations are situated in the south east, flat terrain comprising mainly of Reddish Brown Eath (RBE) soils the wet and the intermediate zone study locations are situated in hilly undulating landscape with lateratic soil formation. Most parts of the study locations are made of crystalline hard rock with low water baring capacity. Hence, the natural recharge of domestic wells in this area is low and during the dry season from June to September most natural springs get reduce to a trickle.

The purpose of studying water security in different geographical and climate conditions is to study the water user behavior patterns in different conditions. We were interested in finding the implication of energy spent in fetching premium quality water for drinking and probably cooking rather than the distance travelled. In the flat terrain dry zone, it would be the distance to fetch water but in the wet zone in southern Sri Lanka the hill-terrain makes travelling much difficult with water containers than doing the same in the dry zone. In the intermediate zone, the sample was located in a manner that had a mixture of long distances and hill-terrain to climb. The comparative water use data and behavioral information from wet zone tea small holders, daily wage earners from the intermediate zone and small-scale farmers from the dry zone would give us the relative importance of direct costs and opportunity costs of fetching water under different economic conditions.

Another aspect we anticipate to study in varying conditions is the perceptional quality of drinking water. This has a direct relationship to rainfall intensity and flowing water in different locations. Among rural communities in Sri Lanka water quality perceptions have been a strong deterrent to drinking water security. Most households do not drink rainwater not because of the absolute poor quality of water but because of the perception that rainwater harvested from rooftops is inherently poor. Other reasons contributing to this situation are the absence of filters and first flush systems, contaminated roof run off with organic pollutants like leaf mater and bird droppings. Hence, lack of technological innovations have also effected drinking water security in few locations.

5.0 Methodology

To establish meaningful results in household water security, daily household water use patterns should be collected at least for two hydrological cycles. For the purpose of this report we have collected daily water use data for three months, from March to May which was the end of the wet season in most locations. Daily water use data includes, disaggregate water for drinking, cooking, personnel washing, toilet purposes, washing cloths and other activities. Water uses for each of these activities were recorded daily by the householders themselves on a given format.

This format captures water use from rainwater tanks and as well as what is brought from other sources. To compare the difference in water use by rainwater tank beneficiaries and non-beneficiaries, same quantitative data was collected from a equal number of sample households who do not have rainwater harvesting tanks. The quantitative data was supported by qualitative information collected from the same respondents regarding their water use behavior pattern. This set of qualitative information includes, but not restricted to the following aspects.

1. General socio-economic information from respondent households.
2. Distance people travel to fetch water and time taken
3. Responsibility in fetching water
4. Water quality perceptions
5. Managing household water

6. Reliability of other water sources
7. Direct and opportunity cost of time in fetching water
8. Preference and importance given to different water sources
9. Operation and maintenance of water sources
10. Use of filters and first flesh systems in relation to quality of rain water

All information from respondents were collected by trained graduate field assistants. The qualitative information was reported in biweekly field reports which included behavioral change of water users and any other important changes that could contribute to rural community water use pattern

The quantitative data was analysed to compare water use pattern for different months for each water use activity (i.e. drinking, cooking etc). These data were normalized to cumulative membership in order to compare the water use pattern for different months. The mean values for each activity in each month were used in the fuzzy set theory to establish the water security model.

5.1 Limitations

1) One of the major limitations of the present approach is lack of time series data on water use pattern to use in establishing water security.

2) Quantitative data collected provides provision for only rainwater and one other source of water. The data collection format does not give adequate space to accommodate different sources of household water and also to accommodate number of same source during water scarce periods.

3) As recording ones own water use over along period is monotonous and non-rewarding reliability of the data can only be about 65-70%.

4) Frequent turn-over of field assistants due to the nature of the job (non permanent contract) disrupts the continuity in data collection.

5) This report only present data from two study locations as there were data gaps in the other two locations due to field assistance leaving for other jobs. A more complete analysis is expected in Milestone report 3.

6) Only applicability of the water security model is discussed in this report. Use of actual field data in the model will be given in Milestone report 3.

6.0 Household Water Security under Two Scenarios

This section presents two scenarios of water security in southern Sri Lanka. Two villages with different characteristics were selected for the study.

	Village A (Deiyandara)	**Village B (Palathugoda)**
Village economic	Small-scale farming and casual labors	Small-scale tea land holders government permanent workers
Rainfall	Approximately 1900 mm per annum	Approximately 800-1000 mm per annum
Ground water	Good, drinkable	Poor saline water
Relief	Steep and undulating	Relatively flat
Proximity to the nearest town	16 km	4 km
location	wet zone	between wet and dry zone

Both villages use roof water for domestic use for different reasons. Village A uses roof water due to transport difficulties in fetching water for household use. Village B, uses roof water as the ground water is too saline to use for any kind of household use.

6.1 Village A - Deiyandera

6.1.1 Water Sources for Domestic Use

Villagers in Deiyandera has two primary sources of water. Dugwells and roof water harvesting. Under existing relief formation it is not possible to construct personnel or group dug wells as and where required. At present there are dug wells used separately for drinking and bathing purposes. These wells are located at the valley bottom where water transport becomes extremely difficult and during the dry season water transport time becomes a significant factor in household time budget.

Roof Water Harvesting is of two types

a) Using temporary gutters to collect rainwater into open rectangular tanks.

b) Collecting roof water to Brick dome/Ferro-cement tanks of $5m^3$ capacity constructed under the community water supply sanitation project (CWSSP). This system uses more permanent gutters and the water tanks are more robust and have a life span of 10 years.

6.1.2 Uses of Roof Water

The rainwater collected in small rectangular tanks (2800 liters) is open at the top, hence subjected to contamination. Maintenance is minimum in these tanks, thus, water can be used for about week after each rainfall. Householders use this water only for personnel washing and toilet use immediately after rains.

Tanks constructed under the CWSSP are more durable, covered from the top, hence water can be used for a long period of time. Householders use this water for all household purposes, including drinking (occasionally) and cooking.

6.1.3. Drinking Water Security

Villagers in Deiyandera use dug well water for drinking. However, they have two types of wells. Drinking water wells and bathing water wells. People use a strict criteria in selecting drinking water wells.

i) Drinking water wells should not be used for bathing

ii) Surroundings of drinking water wells should be cleaned

iii) These well should always have flowing water

iv) It should be used by number of families

v) Distance to the drinking water wells

vi) Ownership of the well

There are at least 5-6 drinking water wells according to these criteria in Deiyandera. However during the dry season water level in most of these wells deplete making water fetching difficult. Another common problem is lack of able labour to fetch water from these wells. Usually male children and adult males are involved in fetching water. If they have to leave the house for few days they fetch adequate to compensate for their absence. When water carriers fall sick or the only male in the family is old, the household faces a situation of water insecurity.

Rainwater Harvesting beneficiaries, use rain water after boiling to over come the drinking water insecurity period. However, they use rainwater directly for drinking during the rainy season. This ensures a better quality of water during continuous rain. Apart from roof water harvesting few households use directly harvested rainfall for drinking. However, only small quantities of rain water can be harvested in this manner and only small vessels found in the kitchen are used for this purpose. Thus, harvesting rain water has increased the drinking water security of these peasants.

6.1.4. Cooking Water Security

Rainwater tank beneficiaries use stored water for cooking, especially during rainfall periods. However, few days after cessation of rainfall, people discontinue using rainwater due to change in colour of water, smell and sometimes due to mosquito larvae. However, if good quality well water can not be found due to non-availability or due to lack of labour, people restore to rainwater even if the quality is not premium. In such situations, secondary quality of stored rainwater is used for washing vegetables and rice before using premium quality well water for actual cooking.

6.1.5 Toilet Water Security

Water for toilet use is predominantly stored rainwater. When the rainwater tank water level recedes, people bring a bucket of water for toilet use whenever they visit a well for any other purpose. However, when supplying water is extremely difficult, they use pit toilet instead of water-seal type toilets.

6.1.6 Bathing Water Security

Specially identified dug wells are used for bating. These wells do not have a parapet wall and fertilizer residues from cinnamon plantations often contaminate water. Wells are sometimes located in their own compound, in such event the distance they have travel vary from 100-150 meters. However, when they do not have wells in the compound, they could be travelling as much as 1½ km to bathing wells. However, when there is adequate rain, specially women bath with stored rainwater or when householders have to bathe in the night after days work, they often restore to use stored water. In both situation these people have improved their bathing water security due to the presence of stored rainwater.

6.1.7 Water Security for Washing Cloths

There is no prioritization of water for washing cloths. However, people do not use well water for washing cloths if the water is contaminated and the colour of water is muddy or brown. In such situations they use wells with clear water. People of Deiyandera can use muddy water for bathing but refuses to use for washing cloths. Those who own rainwater tanks, always use stored rainwater for washing cloths but in reducing water conditions, they conserve the rainwater and use bathing wells and drinking water wells for washing cloths.

6.1.8 Animal Husbandry/Home Gardening Water Security

Though animal husbandry is not common in Deiyandara, they use predominantly stored rainwater for tea seedlings and other household foliage and flowering plants.

6.1.9 Water for Religious Activities

One of the most important security measures adopted by rainwater users is preserving stored rainwater for cultural activities. In this village a household performed an entire religious function by preserving rainwater for the occasion.

A subjective judgment to assess the household water scarcity offered by stored rainwater (in a multiple water source situation), can be presented as below.

Activity	Subjective Judgement
Drinking	40%
Cooking	60%
Bathing	20%
Washing Cloths	50%
Toilet Use	80%
Animal Husbandry/ Home Gardening	80%
Cultural Activities	90%

Hence under the existing environmental conditions water requirement for the last three categories are almost secure with stored rainwater. In the first four categories stored rainwater could only provide less than partial security. Hence, other sources of water are required to fulfill the demand. However, the total water security of a household under these circumstances depends on other qualitative factors like;

1. Distance to travel to fetch water and energy spent
2. Availability of transport
3. Household economy
4. Availability of water carriers
5. Age of water carriers
6. Opportunity/direct cost of retching water
7. Quality of water

A schematic diagram of water use pattern under different water sources is given in figure 2a and 2b.

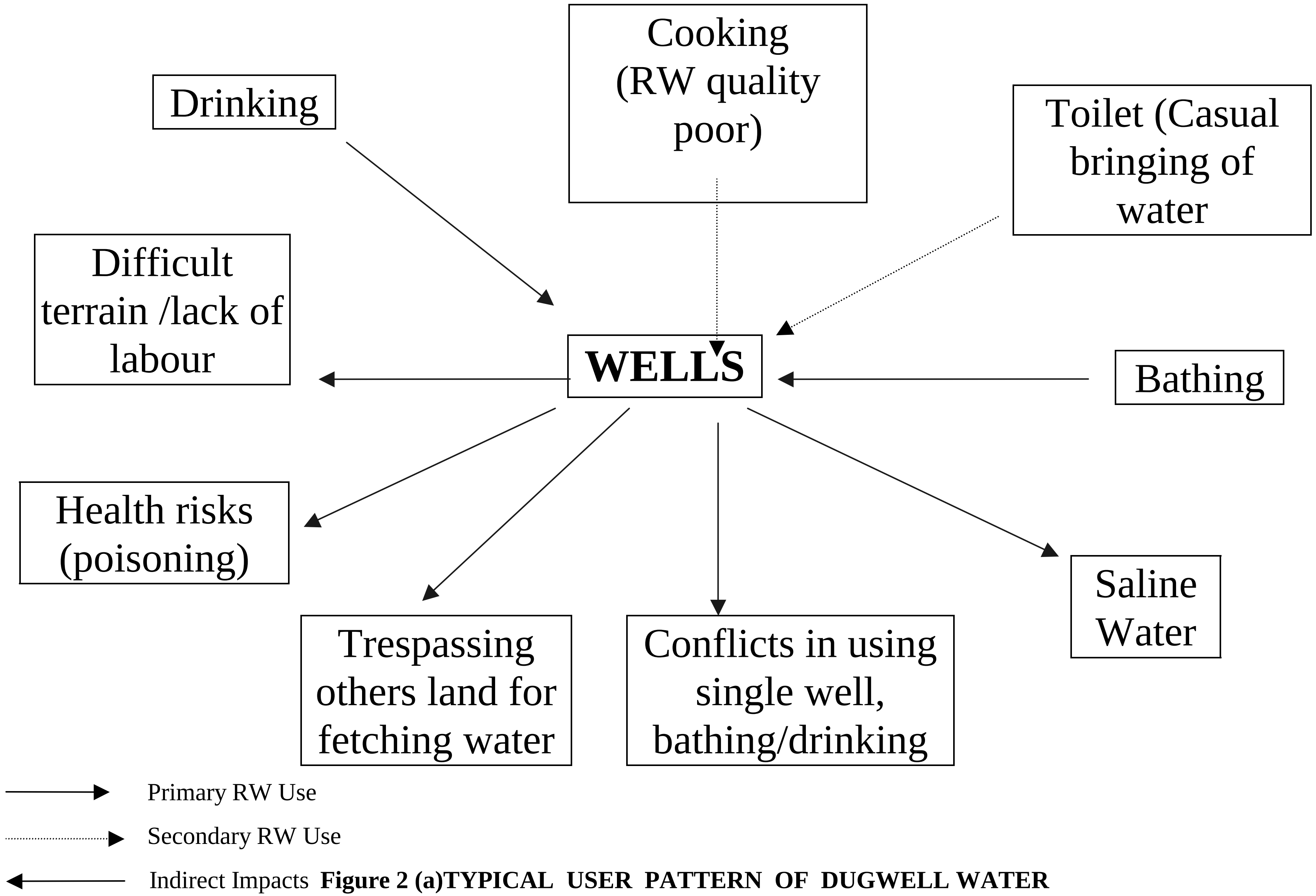


Figure 2 (a)TYPICAL USER PATTERN OF DUGWELL WATER DEIYANDERA HOUSEHOLD RESPONSE

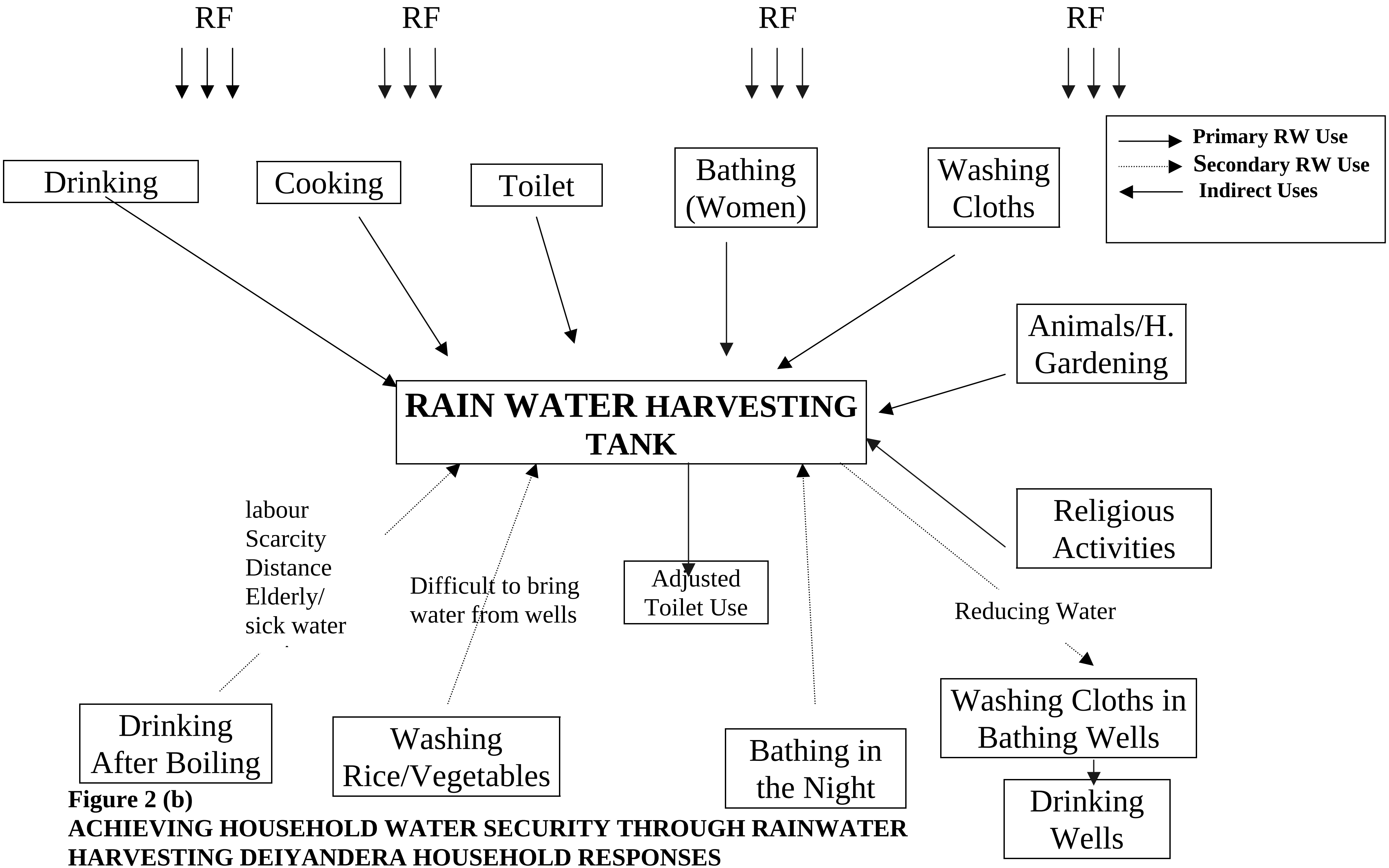


Figure 2 (b)
ACHIEVING HOUSEHOLD WATER SECURITY THROUGH RAINWATER HARVESTING DEIYANDERA HOUSEHOLD RESPONSES

6.2 Village - B Palathugoda

6.2.1 Water Sources for Domestic Use

There are four types of water sources used by people in this village. The first source of water is stored rainwater collected during rain, secondly well water from outside the village where water is not saline and drinkable. Thirdly town water supply where wealthy people fetch only for drinking. Finally the saline water wells found in the village which people use under difficult conditions. Rainwater Harvesting is of three types, collecting rainwater into small vessels during rainfall. Collection under this system can be used for short duration and collected quantities are small. There is no system of storage under this method. Harvesting roof water into more permanently built brick-motor tanks. This system collects more water for future use though water is subject to contamination. The third method is harvesting rainwater from tree-trunks, which incidentally is a traditional method practiced in Sri Lanka, under water short situations.

6.2.2 Drinking Water Security

As the ground water is saline to drink, Most people either collect rainwater through roof run off or bring water from wells located outside the village, which are not saline. If these sources fail, those who are economically sound bring water from the Tangalle town supply. Those who collect rainwater into permanent tanks are people who are employed and have no time to fetch water nor do they have excess labour to carry water. Some of these people have spent up to Rs. 30,000 (£ 263) for constructing rainwater tanks of about 6 m^3 capacity. All rainwater harvesters have permanent tile roofs indicating a high social status in the village. These people prefer rainwater for its taste and convenience.

However, most people in the village still depend on well water brought from out side the village. These wells are either public wells or privately owned wells. People go to these wells because the quality of water is better, not too far away and can obtain a continuous supply. However, during the dry season people have to walk up to about 4 km at times due to depleting of drinking water wells. Water is usually fetched by females in a household but if the distance is more than a kilometer, males perform this function. Bicycles are also use it for fetching water. In rural Sri

Lanka both men and women use bicycles to bring water. However, the decision as to who should fetch water depends on the type of occupation, distance to travel and availability of bicycles.

As stated before, few people (wealthy) travel to the Tangalle town center to bring water when both the above options fail. However only premium quality drinking water is brought from the town supply and usually it is adequate for 2-3 days. Bringing water from the town supply has a cost. If they use a motobicycle they spend Rs. 20 (US cents 30) per trip for fuel. The trip may take from 20-30 minutes. If a two-wheel tractor is used, it takes 40-60 minutes and cost Rs. 40 (US cents 60) per trip. If however, a bicycle is used there is no cost.

Those who can not afford to bring water from the town supply, have to track long distances in small footpaths to collect water. That too they collect into small containers, as they are unable to own large enough containers to store more water. Hence, the certainty of having drinking water under water stress situations depends to a great extent on individual household economy.

6.2.3. Cooking Water Security.

People use water from three sources for cooking. Rainwater is the most important source of water for cooking. People prefer this water due to the absence of salinity. When water is scares, they use saline water from wells but only to wash vegetables and rice. Cooking is always done with either rainwater or well water, which are non-saline. Use of coconut in Sri Lankan cooking makes this activity more rainwater friendly. Squeezing coconut can not be done in saline water because high salt water tends to curdle (coagulate) the coconut milk. However, when stored rainwater is in short supply and if they do not have labour to bring water from out side the village, people restore to using saline water for cooking. However, they boil the water before using for cooking.

6.2.4 Water for Toilet Use

All toilet water requirements is satisfied with saline well water. People bring water from other non-saline water wells only if saline water is not available. Hence, saline water provides a complete water security for toilet use.

6.2.5 Bathing Water Requirement

Water for regular bathing is a problem. This particularly true for women who do not like to use saline water for bathing due to their long hair. When saline water is used for bathing hair gets stiff and it becomes difficult to comb. Therefore women travel 2-3 km to bathing water wells or use the river running across the village. Sometimes the river water too gets saline due to salt water intrusion from the sea under such situation women are left only with fresh water wells. In any event they have to travel few kilometers that takes time. Hence the degree of bathing water security depends on the distance they have to travel and relative importance given to this activity as a social event among women. Usually it is common to observe groups of women go for bathing at any given time.

6.2.6 Water for Washing Cloths

People use stored rainwater and river water for washing cloths. However people prefer using rainwater for washing as it does not contain any salts and it is easy to apply soap with rainwater. Also when there are infants in the households, washing is exclusively done by rainwater. Through some people go to the river to wash cloths, they avoid washing white cloths when the river water is muddy or saturated with silt. Hence, washing water security is partly satisfied with stored rainwater.

6.2.7 Water Requirement for Animals and Home Gardening

The total water requirement for animals and home gardening is met with saline well water. Some believe that saline water is preferred by animals than non-saline fresh water. Stored rainwater is never used for this purpose.

In this village water for cultural functions are brought by bowsers from the town. They could pay any thing between Rs. 250, - 500 per bowser of water.

During high rainfall periods people use rainwater for all activities including bathing, washing of cloths and personnel washing. However with cessation of rainfall people use rainwater only for drinking and cooking and with the increasing in water stagnation period, people decide the use of rainwater depending on the quality of water. What usually happens is with increasing stagnation time people tend to stop drinking rainwater. However under extreme drought conditions, people restore to drinking rain water mainly due to increasing travel distance for good quality water, lack of able labour to bring water and due to the absence if any other viable alternative. If water is brought from out side sources under these conditions it is used only for drinking and cooking.

A subjective judgement of household water security using stored rainwater in this village - Palthugoda, under multiple water source situation, can be presented as below.

	Activity	**Subjective Judgment**
-	Drinking	30%
-	Cooking	80%
-	Washing Cloths	70%
-	Bathing	20%
-	Toilet Use (Sanitation)	-
-	Animal Husbandry	
	Home Gardening	-
-	Cultural Activities	-

This description gives the usual water use pattern of an average village household. Accordingly, rainwater is used mainly for cooking and washing cloths. For drinking and bathing less than partial water security is met by rainwater. Last three items in the above list do not use rainwater at all. Thus, other sources of water can fully satisfy the water need of these items.

However, the water use pattern of village-rich can be different to the above description. In this case they use more rainwater say, 75% for drinking and more than 80% of rainwater for other uses. Under extreme conditions they can bring water from the Tangalle town supply only to satisfy the drinking water requirement. However this depends on the economic situation of the households. A schematic diagram of water use under varying water source is given in figure 3a and 3b.

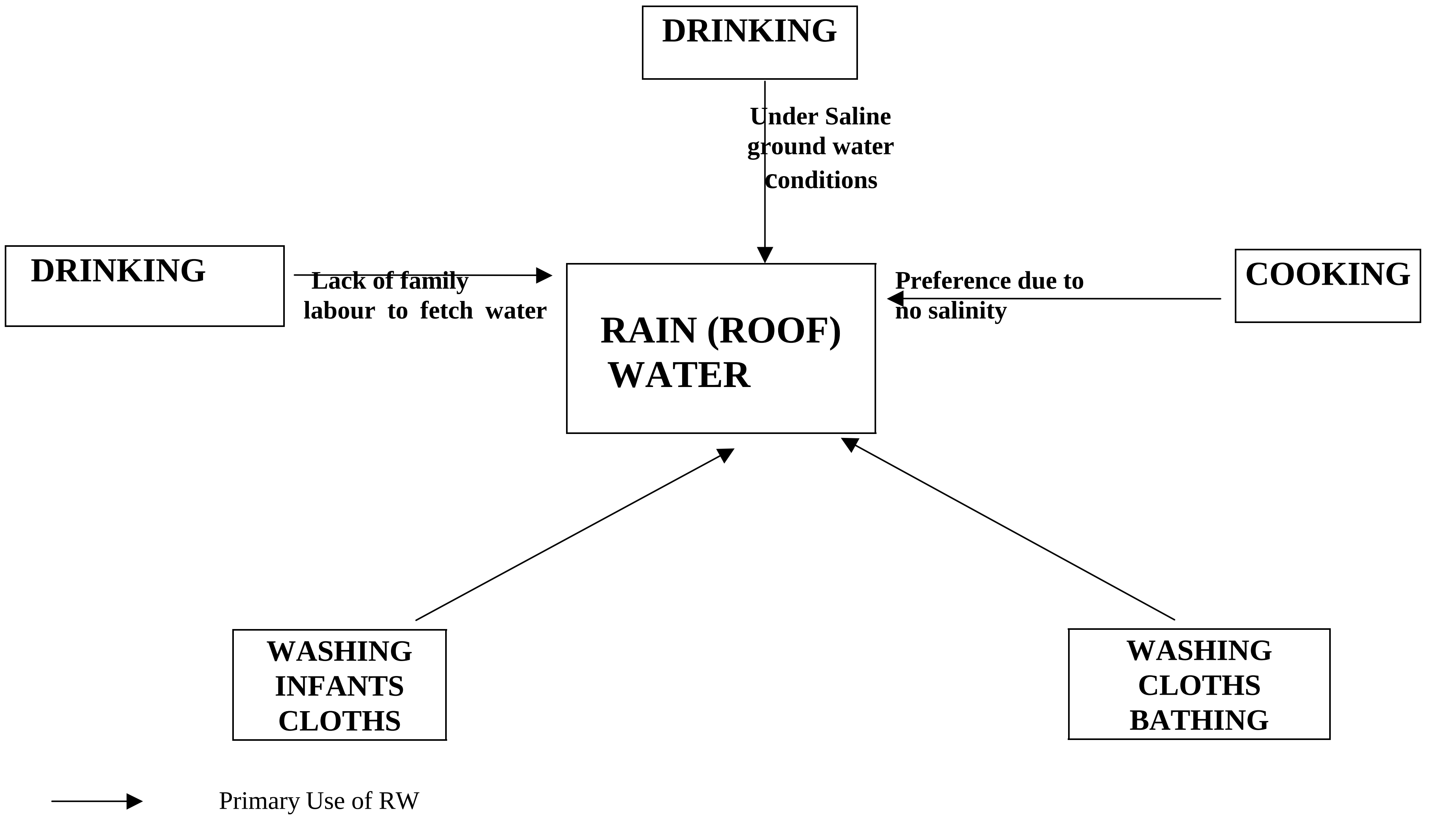


Figure 3 (a) **USE OF RAIN (ROOF) WATER BY PALATHUGODA HOUSEHOLDS**

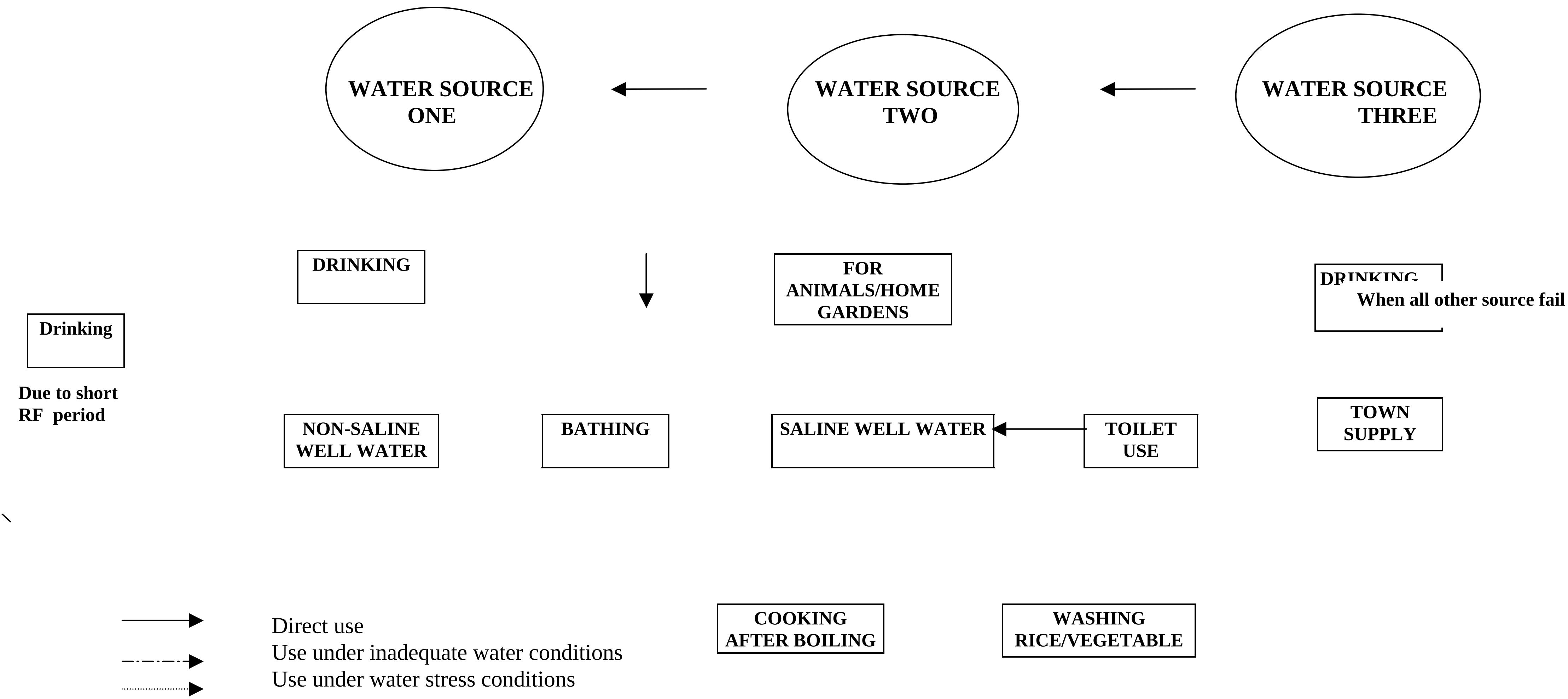


Figure 3 (b) **WATER USE PATTERN WITH OTHER WATER SOURCES PALATHUGODA HOUSEHOLDS**

WATER USE PATTERN UNDER BRACKISH WATER CONDITIONS (Days after Rains)

Rain	**1 - 8 Days**	**8 Days - 1 ½ Months**	**1 ½ Months - 2 Months**	**2 Months - Next Rain**
Well Water Use	* For drinking * Washing Cloths * Cooking *Washing Utensils * Washing Face	*Not taken for drinking * Washing Cloths (to about 30 days) * Washing vegetables (except for squeezing coconuts) * Toilet use * Washing face etc.	*Not taken for drinking *Not taken for washing cloths * Washing vegetables * Toilet use * Washing utensils	*Personnel washing * Toilet
Rainwater Tank Use	* Washing face etc. * Uses as a buffer security	* Used for drinking * Used for squeezing coconut * Washing of infant cloths * Controlled use of Rainwater	* Used for drinking * Cooking * Washing cloths (Sometimes)	* Used for drinking after boiling * Cooking
Water brought from outside village	No	* Once a week from a well in the area	* Twice a week from TOWN	* Once in two days from TOWN
Bathing	* Make use of dug wells	* Visits streams * Washes cloths in the stream	* Visits streams * Washes cloths in the stream	* Visit streams

7.0 Water Quality and Drinking Water Security

Quality of any water directly determines the drinking water security of a community. In the two study locations too, it was the physical quality of water that decided whether the water was good for drinking or not. This theory applies to both stored roof water and dug well water. In this respect, it was easy to assess the physical quality of water in a roof water tank than in a dug well. Thus the latter has a defacto advantage over rain water. The criteria generally used by these communities to assess the quality of water are as follows;

1. Colour of water
2. Taste of water
3. Presence of mosquito and other types of larvae
4. Odour of water

The community perceptions of drinking water are governed by these factors. Besides these physical characters of water, selection of dug wells for drinking water also depends on the depth of wells, flowing water in wells and number of users per well. People always prefer to use wells used by a larger number of families rather than few families. This implies that larger the number of users better the quality of water.

According to community perceptions, lack of filters and non-adherence to first flush of water makes stored water unfit for drinking. As a result of this situation, decaying leaf litter and other organic derbies are common in most rainwater harvesting tanks. People also judge the quality of water depending on the level of water in the tank or period of continuous stagnation without any replenishment from rainfall. People in the two study locations firmly believe that water begins to deteriorate when rain water tank water level is down to ¼ of the tank. This implies that continuous stagnation of water over a long period encourages water quality deterioration. While the same community would use stored rainwater even for drinking, during and immediately after rains. This implies that people believe that quality of rainwater is good for drinking when it is fresh but contaminates over time. This perception of people do not change whether the storage tank is underground or above ground. Hence, the drinking water security of rural households depend on intensity and duration of rainfall with respect to stored rainwater. In this context drinking water security is a function of quality perception.

To substantiate the water quality perceptions of the community, water samples from underground rainwater tanks were tested for its physical and biological quality.

When water sample were tested on 26th June after month of no-rain period, 6 out of 8 tanks had good quality water with no indication of E-coli. The two tanks with no tank covers recorded an E-coli count of 100/100 ml. In one of these tanks, water was extracted using a bucket, which could be a source of contamination. When the same sample was tested on 18th August after rains, all tanks except one indicated the presence of E-coli. In the first instance the tanks were half filled with water while in the second instance the tanks were less than quarter filled with water. The change in quality of water can be attributed two reasons.

1. Since non of the tanks had a first flush system washing of birds and possibly rat and Bandicoot/Polecat droppings would have contributed to the presence of E-coli in water samples immediately after the rains.
2. When water is stored for a long time (as in the earlier case) with out any new replenishments, absence of sunlight and minerals can impede bacterial growth and also could lead to elimination of existing bacteria. This could have been the reason for non existence of E-coli in the water samples taken on 26th June.

This analysis indicate that what people in Deiyandera consider as good quality water after rainfall could be contaminated and water that is considered as bad when tank water stagnates could be good with respect to absolute quality of water. This leads to an interesting scenario, where drinking water security of people in this community is a manifestation of their own perceptions and not of absolute quality of water. However, what matters is what people believe. Fortunately there is no reports of children or people falling sick after consuming water from any of these sources. Table 4 indicates the physical and biological quality of water used for domestic purposes in the study locations.

Physical and Biological Quality of Water in the Study Locations

Date of Sampling	Location	Source of Water	No. of Samples	PH	Turbidly (NTU)	Conductivity/Hardness	E-coli Counts/100 ml
26.06.99	Deiyandera	Rainwater tank	8	> 8.2	< 5.0	20 - 40 mg/l $caco_3$	0-5, 108, > 1000
26.06.99	Deiyandera	Well	4	>8.2-6.8	< 5.0	20 - 40 mg/l $caco_3$	16 - 70
18.08.99	Deiyandera	Rainwater tank	6	7.7-9.0	< 5.0	30 - 100 µc/cm	0 - 79
18.08.99	Deiyandera	Well	2	5.5	< 5.0	40 - 70	190, > 2000
26.06.99	Tangalle	Rainwater tank	1	7.8	< 5.0	20 mg/l $caco_3$	100
26.06.99	Tangalle	Town supply	1	7.8	< 5.0	20 mg/l $caco_3$	0
26.06.99	Tangalle	Well	1	6.0	< 5.0	820 mg/l $caco_3$	16

Source : Field Site Measurements 1999

8.0 Water Security Modelling

Introduction

Water needs for domestic and agricultural purposes of the rural, peri-urban and urban communities depend on water availability and water use. Urban communities depend to a greater extent on pipe borne purified water, supplied by the National Water Supply and Drainage Board (NWS&DB). Metered supply is provided to households while free standpipes and bousers are available for low income urban communities. Urban communities experience water cuts during relatively short dry weather periods due to low flows in major tributaries. However, they have shown resilience to such situations by obtaining water from other sources and by reduced water usage. Urbanisation has taken place in cities located mainly in the wet and intermediate zones, with significant rainfall distributed throughout the year. Though there exists a high potential to use harvested rainwater, provision of high quality water at low cost has discouraged initiating such endeavours.

The peri-urban communities largely depend on groundwater, obtained through large diameter wells. Households either have their own wells or have access to a private/or a public well. Wells identified exclusively for drinking provide good quality water and are protected from contamination. The amount of water available for domestic use cannot be defined in a conventional manner since a higher percentage is re-used after percolation. In such instances, a high water security is maintained while maintaining a high consumption level.

Rural communities mainly rely on surface and ground water bodies to meet their domestic requirements. Their use includes water for animals and home gardening. During extended dry weather periods, quality water is not available nearby, and has to be obtained from distant sources. This has resulted in more time being spent on collecting, transporting and storing water, reducing the overall productivity of a household.

Household Water Security should reflect the community's ability to access required quantity and quality of water for consumption, hygiene, other household needs and for minor economic activities. Water available may have its short term variations due to hydrological changes as well as long term effects, resulting from socio-economic stresses, affecting households, communities, a country, or a region.

Household Water Security can be expressed in terms of water availability *(WA)* and overall water use, $\sum_{1}^{n} W_i$ (in litres per capita per day (lpcd)), as:

$$WS_{1,2,,n} = \frac{WA}{\sum_{1}^{n} W_i} \qquad (8.1)$$

where water requirement can be identified as drinking, W_1 , cooking, W_2 , washing, W_3 , toilet needs, W_4 , bathing, W_5 , and others, W_6.

The Overall Water Security defined in equation (1) can also be evaluated by combining water security values obtained for individual attributes such as:

for drinking: $WS_1 = \frac{WA_1}{W_1}$ and for cooking: $WS_2 = \frac{WA_2}{W_2}$ etc.

where the Overall Water Security Index can be `weighted' to reflect the relative importance.

Household Water Security evaluated based on simple mathematical models such as those discussed above has inherent limitations such as:

a) the state of knowledge concerning water availability and water use is imprecise.

b) The complexities in water use arising due to human perceptions (such as taste, cultural values) cannot be easily quantified.

Models based on Fuzzy Set Theory can be used to express both qualitative and quantitative data and the results obtained for individual water uses can be integrated to give an Overall Water Security Index.

Fuzzy Mathematics

Fuzzy mathematics was first introduced by Lotfi A. Zadeh (Zadeh, 1965) and is extensively used in analysing non-deterministic problems such as in the evaluation of slope failure potential (Juang et al., 1992). Fuzzy models 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).

Fuzzy mathematics uses Fuzzy Sets to model the relative values of attributes and their relative importance expressed as fuzzy `ratings' and `weights'. They are qualitatively expressed in linguistic terms characterised by fuzzy functions normalised to the domain ranging between 0 to 1 (refer Figure 8.1). As an example, the attribute Average Household Drinking Water Requirement (lpcd) for a given month can be `Medium'. The establishment of maximum and minimum limits is explained in Section 9.

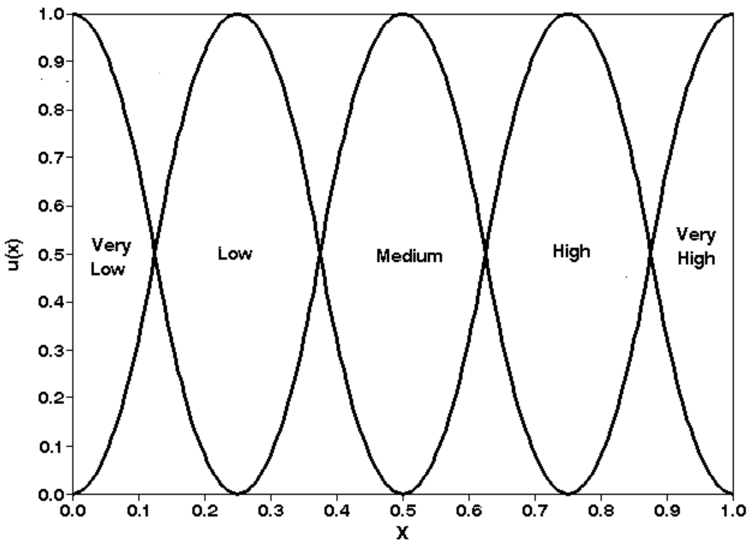


Figure 8.1: π curve representing the five linguistic variables.

Decision Tree Analysis

A `Decision Tree' represents the hierarchical structure which establishes the overall attribute; in this case the Overall Water Security Index. The proposed model uses a decision tree consisting of a single level, i.e. primary factors and their respective weights, which are integrated to yield the Overall Water Security Index. It is assumed that the factors at these levels have an independent contribution towards the final result.

Evaluation of Household Water Security Index *(WSI_h)*

The process of combining of membership functions representing relative ratings and weights is termed Fuzzy Integration. The combined rating of the failure potential, *R*, based on a weighted average of all factors on a given branch of the evaluation tree is expressed as:

$$R = \left[\prod_{j=1}^{n} \left(r_j \right)^{w_j} \right]^{\beta}$$

(8.2)

r_j, rating of failure potential according to factor j; w_j, weight of factor j as compared with other factors on the same branch (level) of the evaluation tree; n, number of factors in the given branch of the evaluation tree, and $\beta = \frac{1}{\sum_{j=1}^{n} w_j}$

The overall fuzzy distribution function is obtained by using the same approach, repeatedly, at each level of the decision tree. This can be directly evaluated using conventional arithmetic using the extension principle and its inferences or by using the Monti-Carlo Simulation Technique as suggested in Juang et al., 1992.

The Water Security Index (WSI_h) obtained may be evaluated to show the daily, monthly, or annual variations observed in a representative community sample. However by extending the decision tree, this could serve as an input to determine the overall water security of a community, a district, a province, a country or a region.

9.0 Evaluation of Household Water Security using Fuzzy Sets

Research Study

In establishing an Overall Water Security Index, household water use patterns with respect to drinking, cooking, washing, bathing, toilet use and other uses are studied identified by agro-ecological zones, carried out through at least one hydrologic cycle.

Data on water use for study areas Matara and Tangalle will be used to construct a Water Security Model. The average household per capita per day use for drinking, cooking, washing clothes, washing face, toilet use and other uses for months March through May will be established.

The sources are identified as:

(a) households using only spring/ground water,

(b) households using only harvested rainwater,

(c) households using spring/groundwater and harvested rainwater.

The variation in water use for a given attribute can be identified as very low, low, medium, high and very high, depending on their relative importance. As an example if the average household drinking water requirement varies between 3 to 7 litres per capita per day, the said categories can be arbitrarily (not necessarily so) decided as:

very low	< 3	lpcd
low	3 - 4	lpcd
medium	4 - 5	lpcd
high	5 - 6	lpcd
very high	6 - 7	lpcd

The above values can be normalised with respect to the variation in water use as:

$$\frac{WaterUse - MinimumUse}{MaximumUse - MinimumUse}$$

to yield a normalised Fuzzy Set (refer Figure 8.1) over the study period.

The average Household Drinking Water Requirement (obtained above) will be weighted. to represent the security (or insecurity) involved in obtaining water.

Criteria governing the relative importance of each attribute will be established based on qualitative data collected during the study and will reflect the following:

i) The difficulties in hauling water from a distance source (may involve climbing, travelling etc.).

ii) The quality and preference of water (biological, hardness, taste, colour etc).

iii) Reliability of source (if recharge rate is slow).

iv) Even the direct cost and opportunity cost (may require to pay, loss of productive time etc).

The Water Security with respect to drinking is expressed as: $r_d^{w_d}$, where r_d being the linguistic rating and w_d the linguistic weight.

Water Security with respect to other attributes can be found by adopting a similar approach.

Having performed the above, one has to ascertain the degree of relative importance of the above factors on overall water security. As an example drinking may be “very important” compared to bathing “medium importance”. This is very subjective and may vary from place to place. Therefore careful consideration has to be given in determining the relative importance of primary attributes.

The attributes and their weights are combined to give the Overall Water Security Index (refer equation 8.2).

10.0 Concluding Remarks

An attempt taken to establish household water security using Roof Water Harvesting has been successfully demonstrated. However, due to inadequate time series data, household water security analyses had to be restricted to three months quantitative data. Nevertheless, the current experiment will be conducted over at least two hydrologic cycles to establish household water security more firmly. Once the water security model has been establish, it will be tested with rural communities using rainwater and other water sources. Once the field testing of household water security is completed, an attempt will be taken to establish water security with semi urban or peri-urban water uses. Subsequently, the model will be tested in India (possibly in Maharastra) under similar conditions. Inclusion of household water security into a wider water sector research will be done only after the household water security concept is more thoroughly understood through experiments conducted in south Asia.

An experiment conducted so far indicates that drinking water security can be considerably enhanced if the physical quality of water can be increased. Contamination of stored rainwater with leaf litter is an important deterrent which influences users to avoid rainwater for drinking. Presence of biological fauna and poor maintenance of roof surfaces are other reasons that keep users out of rainwater. Introduction of filters and proper use of first flush system along with awareness programmes can influence a change in water user attitudes towards improving household water security.

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