# Water Quality Study and Cost-Benefit Analysis of Rainwater Harvesting in Kuttanad, India

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# Abstract

Clean water access is a basic human right. However, at present, about 1.9 million children die, 20% from diarrheal disease in India per year. In India, 1 person dies from water-related disease every minute and 4 people die across the globe (UNICEF 2005). Eighty percent of the 700,000 citizens of Kuttanad, a region in the coastal state of Kerala in India, have no access to clean water. In the Kuttanad region of Kerala, intensive untreated human sewage and agricultural activities have caused severe surface water contaminations. At the same time, other sources of fresh water are unreliable for drinking: ground water is acidic due to the soil conditions and iron leaching; fresh water from public tap is infrequent; and water supply from private vendors is extremely expensive. Of all water sources, rainwater alone satisfies the WHO Guidelines for drinking-water quality. Using both primary and secondary data from water samples and community surveys, this study analyzes the costs and benefits of rainwater harvesting in the Kuttanad region of Kerala, India. The major costs include the initial construction cost of rainwater harvesting system and the maintenance costs. The major benefits include an increase in household dispensable income, time and energy saved from collecting water, and reduction of epidemic outbreaks and associated medical costs. The objective of this thesis is to ascertain the net benefits or costs from rainwater harvesting under a variety of scenarios for households in different existing water supply conditions. It is concluded that households with different existing water consumption pattern will benefit positively in various degree from investing in domestic rainwater harvesting systems. Continuous data collection and research are needed to validate the benefits and costs of rainwater harvesting in Kuttanad.

# Motivation

In my sophomore year, I took a seminar with seven Luce International Environmental Fellows from Brazil, Cameroon, China, India, Nigeria, Sudan and Tanzania respectively with Professor Steven Hamburg. At the end of the semester, I applied to the Luce Undergraduate Fellowship to work with the Indian Fellow, Dr. Anil Kumar. Dr. Kumar introduced me to Dr. A.P. Thomas (Director), Dr. C.M. John (faculty member) and Mr. V.P. Sylas (PhD Candidate) of the Mahatma Gandhi University School of Environmental Sciences (MGU SES) in Kottayam, India.

Throughout the summer, under the guidance of Dr. Kumar and faculty members from the MGU SES, I sampled water and conducted community surveys. During one of the first visits to the villages, I saw a dead rat carcass floating in the canal, and twenty feet away in the same canal, a woman brushing her teeth and another woman washing her dishes. In my study area, known as Kuttanad in the State of Kerala, women and children are spending up to several hours every day to fetch water for their families. This is time that could be spent on childcare, income generation, or education.

The water that they spend hours collecting is still polluted, and it causes epidemic outbreaks in the villages. In addition, a family has to spend USD 36 to buy drinking water from private vendors every year on average. This is a significant amount considering that the State's average GDP per capita is only USD 667 (Kerala Planning Board 2006). Traditional methods of rainwater harvesting with poles and cloths or plastic sheets are common in the villages. There are no cultural nuisances in consuming rainwater in Kuttanad. The constraints of such a traditional method of rainwater harvesting are the small storage capacity and the non-watertight system. The limited capacity of containers such as plastic jars or cans make it impossible to store water sources from the monsoon season to the dry season. The non-watertight design exposes the water to possible contaminants from disease vectors, such as mosquitoes, rats or bird droppings, when it is stored over time.

During one of our community surveys, I met Ms. Suma Chisol. Ms. Suma is a mother of two children and the secretary of the village women's self-help group. She has a masters degree from a local college, yet she lacks the financial capability to solve the water scarcity problem. When her two children grow older, they will have to help her carry water too. Listening to her story and other villagers' experience compelled me to bridge the gap between academic research and community development- we decided to return to the Achinakom Village and presented the water quality findings and community survey's results.

In August 2007, before I left Kerala, we presented the research results at the Achinakom Village community meeting attended by around 200 villagers. At the end of my presentation, one woman stood up and asked, "Now that we know the water is dirty and it causes illnesses, we want clean water. What is the next step and what will you do?"

I was surprised by her question- I thought my role as a student researcher was only to present the water quality result and make a recommendation to the villagers. Motivated by the villagers' feedback, we also went to meet with the members of the Vechoor District Panchayath[1] the next day, before I left India. The Panchayath said they were excited to receive a scientific study and promised actions to install rainwater harvesting systems.

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[1] Panchayath is a basic administrative body of the village level in India. Panchayath members are elected by the villagers to represent them.

I returned to Brown and kept in touch with Dr. Kumar and Mr. Sylas from MGU SES. Since then, it has been over a year and no large-scale rainwater harvesting scheme has happened in the Achinakom Village. Recalling the water scarcity faced by the community in Achinakom, I returned to Kerala and began to form a collaborative effort known as *Rainwater for Humanity* in December 2008.

In January 2009, with the help of 55 college students and women volunteers, we canvassed the entire Achinakom Village and collected information on the financial, technical and environmental feasibility of adopting rainwater harvesting (see Section **3.3 Achinakom Village Survey** for details). Back in the States, since February 2009, ten students from Brown Engineers Without Borders and the RISD Architecture Department joined forces to optimize the rainwater harvesting system design. Other Brown students joined *Rainwater for Humanity* to fundraise and develop a business plan. Locally in India, we are collaborating with an 8,000-members-strong women self-help group to develop a training program of rainwater harvesting for its women members. Hence, *Rainwater for Humanity* is an international partnership with a local women's self-help group known as Asparawa Screwpine Society, with a reputable South Indian non-profit MS Swaminathan Research Foundation, with Mahatma Gandhi University, Brown University and the Rhode Island School of Design (see **Figure 1** for the overview of Rainwater for Humanity's structure).

By building rainwater harvesting structures and training women to be the entrepreneurs, *Rainwater for Humanity* harvests rain to improve community health and empower women in Kuttanad, India. *Rainwater for Humanity* aims to equip women entrepreneurs with the masonry and marketing skills to build and sell rainwater harvesting structures. The present women's self-help groups provide women with the social network they need, and this project will expand the entrepreneurial platform to harness economic and community health returns. The project's mission encompasses and extends beyond the goal of finding clean water. As the community gains the confidence and technical capability to invest in one resource, they will be able to move on and gain many more. Thus, this project harvests rain to conserve water, boost community health, and empower women in Kuttanad, India.

After I graduate, together with several *Rainwater for Humanity* student members at Brown, I plan to return to Kerala and work with our local partners. Interacting with supportive faculty members and students over the past four years has motivated me to reach out of my comfort zone and, to believe that "citizens who channel their passion into action can do almost anything".[2] The birth of *Rainwater for Humanity* was based on research. I hope this thesis will substantiate the economic arguments of adopting rainwater harvesting in Kuttanad (see **Figure 2**).

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[2] Ashoka Foundation. What is a social entrepreneur? http://www.ashoka.org/social_entrepreneur

# Part I: Background & water scarcity in Kuttanad

The State of Kerala is located on the south-west coast of India. Kerala has the second highest population density among all states in India (Kerala Government Census 1991). Kuttanad is a region located in the coastal low-land of Kerala, well known for its scenic backwaters and agricultural fields. It is one of the lowest regions in India, with 500 $km^2$ of the area below sea level (Mathews 2003) (See **Figure 3**). Intercepted by lagoons, rivers and canals, Kuttanad forms one of the world's largest and most complex backwater systems. Most of the area is under water throughout the year.

Despite progress made in human development, Kerala currently faces an increasing potable water scarcity due to pollutions. In Kerala, open wells serve as the traditional major fresh water source for domestic and irrigation purposes. More than 70% of the population in Kerala depends on open wells for meeting their domestic water requirements (James 2004). However, pollution and unscrupulous urban planning have severely deteriorated the quality and quantity of Kuttanad's fresh water supply in recent decades. The fresh water supply is hugely defective due to urban encroachment, land reclamation for agriculture and tourism, fragmentation by transportation routes, untreated human sewage from dense settlements, and intensive agricultural run-offs including fertilizers and pesticides (Reddy 2006).

### *Barrage construction*

The Thaneermukkam barrage, constructed in 1975, provides an example of poor water management and planning. **Figure 3** indicates the location of the barrage, which was constructed to impede salt water intrusion into Vembanad Lake to allow the growth of a second rice crop in Kuttanad. The barrage has greatly obstructed the waterway and created a stagnant water body which has led to a number of severe environmental problems. These problems include eutrophication, decline in backwater fish yield, siltation, loss of biodiversity and water borne diseases (Mathews 2003 and Kumar 2007). The barrage caused a shift of salinity gradient towards the north, and an increase in occurrence of fish diseases, and an explosive growth of alien aquatic weeds. The siltation also poses dangers of flash flood to the community, especially during the monsoon seasons (Kumar 2007). In addition, the obstructed waterways and the continuous fallow of rice fields have created breeding grounds for disease vectors such as mosquitoes and rodent respectively (MSSRF 2007).

### *Failure of pipe water supply*

According to surveys conducted by the Center of Water Resources Development and Management (CWRDM), more than 80% of the people in Kuttanad rely on contaminated canal water for their daily water requirements. Meanwhile, governmental efforts to supply water via pipes and public taps have failed to meet the population’s demand (Joseph 2003). First, the public water supply is highly irregular. In Kuttanad, the public taps supply water up to several times a week, and often for an hour during evening times (Suchitra 2003). The officials at Kuttanad Water Supply Scheme call and inform the community leaders when water is being released into the pipes. The community leaders then pass the messages to households in the villages. It is usually the women or children in a household who hurry towards the public water taps and fill their pots until the taps run dry (Suchitra 2003). As women and children are responsible for collecting sufficient water for household consumption, the insecure water provision imposes a disproportionately large social burden on them. Second, the public water supply network has limited coverage due to the difficulty of laying pipes across wetlands and paddy fields. Most pipes and public taps are also poorly maintained. Official estimates state that between 50%-70% of these rural water systems are in a state of disrepair (Singh 1993). Due to poor installation and lack of maintenance, pipes often leak, are common, wasting valuable fresh water and increasing risks of contamination to the fresh water supply. Third, the quality of the public water is highly inconsistent and unreliable. The analytical results of public tap water samples presented in the subsequent section show a disturbing picture. Five out of ten tap water samples is contaminated, the *E. coli* levels ranging from 40 to 460 per 100 ml of water, far exceeding the WHO Drinking water standard of 0 *E. coli* per 100 ml of water.

### *Economic burden of purchasing private vendor water*

With limited to no public water supply and contaminated ground water, households located in rural areas are forced to purchase water from private vendors. According to the Kerala Water Authority (KWA), the extent of water supply coverage is 78% for the urban population and 54% for the rural population in 1991. In Kuttanad, it is reported that pipe water only reaches 25% of the population (MSSRF 2007). Most households located in rural areas are low income families involved in the agricultural sectors. On the other hand, middle-class households which reside in urban areas have proper connection to pipe water. The KWA's pipe water bill for 5,000 liters consumption is Rs 20 (or USD 0.4) per year (KWA 2008). Whereas, an average household in rural area without pipe water connection spends Rs 1,800 (or USD 36) per year to purchase water from private vendors (See **3.3.2 Survey Results** for details). The poorest households, on average, pay 900 times more money on water than the upper socio-economic classes. The lack of clean water supply in rural areas means that the poorest households pay the most to purchase water from private vendors, further widening the income gap and quality of living. In addition, there is an inverse relationship between the cost of supply and the ability to pay (Gould 1999). Due to the cost of laying pipes over long distances and across different topographic areas, it is increasingly expensive to provide water to smaller and remoter settlements. At the same time, the economic opportunities for remote households are limited to subsistence farming or simple manufacturing activities, for example. Therefore, the water scarcity in Kuttanad is a community health hazard, women's and children's social burden and a socio-economic problem.

# Part II: Water Quality Study

## *2.1 Introduction*

In this study, the objective of collecting and analyzing water samples is to determine the water quality from a variety of sources in the North Kuttanad region. The water quality study will inform the second part of this thesis in which the cost and benefits of rainwater harvesting will be investigated. There is a difference between “pure water” and “safe drinking water.” Pure water does not contain any minerals or chemicals, and does not exist naturally (EPA 1999). Safe drinking water may contain naturally occurring minerals and chemicals such as calcium, potassium, sodium or fluoride which are actually beneficial to human health (UNEP 2008). In general, good quality drinking water is “free from disease-causing organisms, harmful chemical substances and radioactive matter, tastes good, is aesthetically appealing and is free from objectionable color or odor” (Life Water Canada 2007).

Thirty seven water samples were collected in fifteen villages: Nagampadam, Aalummoodu, Chengalam, Thiruvarppu, Parripu, Pulikkuttisserry, Maniyaparambu, Kumarakom, Ithikayal, Cheepumnkal, Achinakom, Kudaveehur, Edayazham, Perumthuruth and Kaipuzha. The samples were collected from a variety of sources including river, ponds, wells, public taps and rainwater tanks. A handheld GPS and visual observations were used to mark the coordinate of each sample. The locations of the sampling sites and sources are presented in **Figure 4** and **Figure 5** in the Appendix. Water samples were collected in sterilized plastic bottles, and were immediately stored in the coolers with cold packs after collection. Using the Mahatma Gandhi University School of Environmental Sciences laboratory facilities, the samples were analyzed within one to ten days after the collection. In order to acquire a complete data set of the water quality, the water samples were analyzed for the following parameters:

- Chemical Content: pH, Nitrate, Phosphate, Total Hardness, Calcium, Magnesium, Chloride, and Sodium
- Physical Content: Total Dissolved Solids and Conductivity
- Biological Content: *E. coli* and Total Coliforms

The following sections will include the background, methodology and result for each analyzed parameter.

### ***2.1.1 pH***

*Background*

The acidity of a solution is expressed as the pH which is defined as pH= -log[$H^+$]. In other words, the concentration of hydrogen ion [$H^+$] in a solution determines the pH value. As the pH value is the negative exponent to the base 10 of [$H^+$], there is an inverse relationship between [$H^+$] and the pH value. The lower the pH, the more acidic is the sample; the higher the pH, the more basic.

In natural water bodies, [$H^+$] usually comes from carbon dioxide in the air dissolving in the water, forming carbonic acid. The reaction is shown in the following equation, $CO_2 + H_2O = H_2CO_3$. Acidity can also be caused by acid rain from industrial pollutants, such as sulfur dioxide emissions from power plants (Eby 2004). On the other hand, alkalinity is the solution's capacity to resist changes in pH. This capacity is commonly known as "buffering capacity." When acid is added to a solution, the presence of hydroxide ($OH^-$) absorbs the excess $H^+$ ions and inhibits a rapid decrease in the solution's pH. Alkalinity of natural water is determined by the soil and bedrock in contact with the water. The main sources for natural alkalinity are bedrocks which contain carbonate, bicarbonate and hydroxide compounds such as limestone. A pH of 6.5 - 8.5 is the range with the maximum environmental and aesthetic benefits (EPA 2008).

*Method*

1. The pH meter was calibrated each time before usage. The calibration was done by setting the meter to two known standard buffer solutions of pH 7.4 and pH 9.2 respectively. The calibration was repeated until readings were within ± 0.05 pH units of the known buffer value (EPA 1982).
2. After each measurement of samples, the probe was rinsed with distilled water to wash away any remnants of the samples being measured. Any remaining distilled water was absorbed by a clean paper towel to prevent dilution of subsequent samples.
3. When not in use, the probe tip was kept moist at all times.

### *2.1.2 Total Hardness*

*Background*

Total hardness is an expression for the total amount of the calcium and magnesium cation concentration in a solution. While a high level of total hardness can cause nuisances to water users, water hardness itself is not a safety issue for human consumption (Wilson 1999). Due to the calcium or magnesium deposits on items such as plumbing and sinks, hard water decrease the life of plumbing systems and water appliances. In addition, the cations form insoluble salts with soap, hence decreasing the soap’s cleaning performance and adding difficulty to cleaning and laundering tasks.

A widely practiced method to determine water hardness is to perform a complexometric titration using a standard ethylenediaminetetraacetic acid (EDTA) solution (EPA 1971). The EDTA complexes with calcium and magnesium in a one-to-one molar ratio (Harris 2003). $Ca^{+2}$ and $Mg^{+2}$ ions are the major causes of hardness in water. They form a soluble chelated complex with EDTA. The polyvalent ions of some other metals such as strontium, iron, etc are also capable of precipitating the soap and thus contributing to the total hardness of water. The Eriochrome black T is used as an indicator. When the indicator is added to hard water at pH of 10.0 ± 0.1, the solution becomes wine red in color. This is due to the formation of a complex between metal ions and indicator**,**

$M^{+} + I$ (indicator) $\rightarrow MI^{-2}$ (wine red complex)

When EDTA is added to the solution, colour changes from wine red to blue at the end point. This is because EDTA breaks up the wine red complex ($MI^{-2}$) and chelate with divalent cations, releasing the free indicator molecules. The complex formed between divalent cations and EDTA is blue in color between pH 7 and 11. Therefore, the solution turns blue at the end point, as shown in the following equation,

$MI^{-2} + EDTA \rightarrow [M.EDTA]$ (blue complex) $+ I^{-2}$

*Method*

1. 25 ml of the well-mixed water sample was measured into a conical flask
2. 2 ml of buffer solution and a pinch of eriochrome black T were added.
3. If the sample turned to blue in color immediately, then no measurable magnesium and calcium was present. However, if the sample turned into wine red in color, magnesium and calcium was present. In the latter case, the solution would be titrated against 0.01 M EDTA until the wine red color turned to blue.

4. A blank titration was also carried using distilled water.
5. The total hardness of the sample was calculated by the following equation,

$$\text{Total hardness}\left(\frac{\text{mg}}{\text{L}}\right) = \frac{(A - B) \times 1000}{\text{Volume of sample (ml)}}$$

Where, A = volume of EDTA consumed for sample, ml
B = volume of EDTA consumed for blank, ml

### *2.1.3 Nitrate*

*Background*

The primary source of nitrate in water systems usually comes inorganic fertilizer and animal manure (Nolan 2002). Other sources of contamination include deposits from airborne nitrogen compounds emitted by industry and automobiles (Nolan 2002). In developing countries, inorganic fertilizers, septic tanks and domestic animal manure from feedlots are the common forms of nitrate contamination. Nitrate does not pose threat to an adult’s health in general. However, excessive ingestion of nitrate by infants can cause low oxygen levels in blood and is potentially fatal (EPA 2006). Excess nitrogen and phosphorus in surface waters also spurs sudden algae growth, causing eutrophication. The decaying of algae rapidly depletes the dissolved oxygen in water, usually resulting in massive fish kills and repulsive odors, making the water bodies unpleasant to use for consumption or recreational use. The US EPA has set the Maximum Contaminant Level (MCL) for nitrates at 10 ppm, and for nitrites at 1 ppm (EPA 2006). The EPA approved method for testing nitrate is based upon the reaction of the nitrate ion with brucine sulfate in a sulfuric acid ($H_2SO_4$) solution at a temperature of 100°C (EPA 1971). The color of the resulting complex is measured at 410 nm by a spectrophotometer.

*Method*

1. The test for ‘blank’ (distilled water) and the standards were carried out with the samples at the same time. First, 10ml of each sample was measured and poured into a test-tube. Due to the slight salinity in the samples, 2ml of 30% sodium chloride (NaCl) was added into each test-tube to adjust the pH.
2. 10ml of 4:1 $H_2SO_4$ solution was added to the solutions using a pipette. The test-tubes were placed in a rack and swirled in a cold bath at around 10°C to ensure the mixing of the solutions.
3. After the temperatures of all solutions were stabilized, 0.5ml of brucine-sulfanilic acid reagent was added to each test-tube.
4. The test-tubes were boiled in a water bath at 90 - 95°C for 20 minutes.
5. The test-tubes were taken out of the boil and immersed in a cold-bath to cool the solutions to around 10 - 20°C.
6. The absorbance of each solution was measured at 410nm in a spectrometer.
7. A standard curve with the absorbance of standards against mg $NO_3$-N/L (nitrate-nitrogen per liter) was plotted.
8. The nitrate levels of the samples were identified using the respective absorbance level correlated their $NO_3$-N/L on the standard curve.

### *2.1.4 Phosphate*

*Background*

In natural water system, phosphorus is gradually released from rocks due to weathering. Phosphates generally exist in three forms: orthophosphate, metaphosphate and organically bound phosphate. The primary sources of phosphate from anthropogenic activities are sewage, agricultural run-offs and detergents (Wangsness 1994). Phosphorous is a growth limiting nutrient for plants. Therefore, similar to nitrate, excessive phosphorous in natural water bodies often spurs rapid algae growth, resulting in eutrophication. If ingested in extremely high volume, phosphate might cause digestive problem (Wangsness 1994). Phosphate is generally, however, not toxic to human beings or animals.

*Method*

1. 50 ml of water sample was measured and poured into a 125ml conical flask.
2. One drop of phenolphthalein and several glass beads were added to help stabilize the solution in the subsequent boiling.
3. A few drops of 20% NaOH drop was added until a pink color was developed in the solution.
4. A few drops of 9N $NH_2SO_4$ was added to decolorize the solution. Afterwards, 0.5g ammonium persulphate was added to digest the organic and inorganic forms of phosphates present in the solution into orthophosphates
5. The flask was covered with aluminum foil and boiled gently for 30minutes.
6. Distilled water was added to each solution, and the final volume of each solution did not exceed 40ml.

7. The samples were cooled to room temperature and one drop of phenolphthalein indicator was added.
8. The solutions were neutralized by adding 20% NaOH. Then, 1ml of 9N $H_2SO_4$ was added to discharge the pink color.
9. 4 ml of ammonium molybdate was added to form molybdophosphoric acid.
10. The solutions were then reduced by adding 0.5ml of stannous chloride, represented by the blue color developed in the solutions.
11. After 10 to 12 minutes, the color's intensity was measured at 690nm using a spectrophotometer.
12. The concentration of phosphate was then determined from the standard curve.

### *2.1.5 Chloride*

*Background*

The primary sources of chlorides in water bodies include bedrocks containing chlorides, oil refineries, industrial waste water discharges and effluent from treatment plants (Smith 1987). Sodium chloride may affect the taste of water, imparting a salty taste at a concentration of 250 mg/L (Smith 1987). However, chlorides are usually not harmful to people. A high level of chlorides disrupts fresh water system, threatening fresh water aquatic organisms. As salinity is one of the characteristics for coastal and brackish water systems. Therefore, salinity is not considered as a pollutant in the study area of this paper, Kuttanad. The seasonal saline intrusion is a natural phenomenon in the Kuttanad backwater systems. In fact, before the construction of the Thaneermukkom barrage, the saline intrusion cleanses out the water systems in many ways, preventing the growth of fresh water aquatic weeds (Kumar 2007).

*Method*

1. 50 ml of sample was measured and poured into a conical flask, and the pH was adjusted to a range of 7 - 10 using 0.1M NaOH.
2. 2 to 3 drops of potassium chromate ($K_2Cr_2O_4$) was added into the solution.
3. The solution was titrated against the 0.0141M silver nitrate ($AgNO_3$) solution. And the end-point on the burette was noted when the solution turned from yellow to brick-red in color. A blank titration was also carried out using distilled water.
4. The chloride concentration in mg/L was then determined by the following equation,

$$\text{Chloride}\,\frac{\text{mg}}{\text{L}} = \frac{(A - B)\,\text{x Normality of Silver Nitrate x } 35.45 \text{ x } 1000}{\text{Volume of sample}}$$

Where, A = volume of $AgNO_3$ consumed for sample (ml)

B = volume of $AgNO_3$ consumed for sample (ml)

### 2.1.6 Sodium

*Background*

Sodium is the most common nontoxic metal found in natural waters. It does not exist naturally in its own free state. Therefore, it is usually combined with other materials. Sodium salts are highly soluble, and are leached into the water from soil and bedrocks. Sodium salts are used in various industries and are found in significant quantities in industrial wastes. A high concentration of Na imparts a bitter taste to the water. The contribution of sodium in water to the average daily intake for a human being is relatively small. The National Academy of Sciences suggests a standard for public water allowing no more than 100 mg/l of sodium. As a high concentration of sodium is hazardous for people suffering from cardiac and kidney ailments, the American Heart Association (AHA) suggests that the 3 percent of the population who must follow a severe, salt-restricted diet should not consume more than 500 mg of sodium a day (Bradshaw 2002). The EPA's draft guideline of 20 mg/L of sodium in water protects people who are most susceptible (Bradshaw 2002). Cases in developing countries might be different from the standards set in the U.S., as people in poverty might be prone to sodium deprivation instead of excessive intake. A high concentration of Na in irrigation water also reduces the soil permeability, thus affecting the growth and yield of crops.

*Method*

1. The digital flame photometer was used to measure concentrations of sodium. A blank and a series of standard solutions were tested in the flame photometer. A calibration graph was obtained by plotting the respective emission against the known sodium concentrations.
2. The emissions of the subsequent samples were then plotted in the calibration graph, and the respective sodium concentrations identified.

### *2.1.7 Total Dissolved Solids and Electrical Conductivity*

*Background*

Total dissolved solids (TDS) include dissolved, suspended and settleable solids in water (EPA 2006). In fresh water, dissolved solids usually consist of calcium, chlorides, nitrate, phosphorus, iron, sulfur, and other ions particles that is small enough to pass through a filter with pores of two microns width (EPA 2006). Particulate matter such as silt and clay particles, plankton, algae, and fine organic debris will not pass through a 2 micron filter (EPA 2006). TDS is an important water quality parameter in regions with discharges from sewage treatment plants, industrial plants or extensive crop irrigation. The common sources of TDS include industrial discharges, sewage, fertilizers, road runoff and soil erosion.

Electrical conductivity (EC) is also known as specific conductance. It is a measure of the solution's ability to transmit electrical current. EC in water is closely related to the concentration of ionized substances. Ions that have a major influence on the conductivity of the water are $H^+$, $Na^+$, $K^+$, $Ca^{2+}$, $Mg^{2+}$, $Cl^-$, $SO_4^{2-}$ and $HCO_3^-$. Other ions such as $Fe^{2+}$, $Mn^{2+}$, $Al^{3+}$, $NO^-_3$, $HPO_4^{2-}$, $H_2PO_4^-$ and dissolved gases have a minor influence on the conductivity. Conductivity increases with increasing mineral content of a water sample.

There are three major reasons to analyze total dissolved solids content. First, the concentration of total dissolved solids affects the water balance in the cells of aquatic organisms (EPA 2006). Due to water potential gradient, an organism in water with a very low level of solids will swell up because more water will move into its cells relative to the quantity of water moving out. Similarly, an organism in water with a high concentration of solids will shrink due to a larger quantity of water moving out from its cell. As a result, the TDS will affect aquatic organism's ability to maintain the proper cell density, and hence disturbing its position in the water column. Aquatic organisms might not survive if it cannot adapt to a different water pressure. Second, toxics can easily attach to suspended solids. A higher concentration of suspended solids implies that there are more solid particles to serve as "toxics carriers" (EPA 2006). Due to the intensive agricultural practices in Kuttanad, it is especially important to analyze the TDS. A high

TDS level also poses risk of clogging irrigation pipes and lowering wastewater treatment plant efficiency. Third, a high TDS level makes drinking water unpleasant and unsuitable for human consumption. With higher TDS, less sun-light can penetrate through the depth of water, reducing the rate of photosynthesis by aquatic plants. As a result, TDS also leads to less dissolved oxygen supply in the water. EPA recommends drinking water to have a TDS level no more than 500 mg/L (EPA 2008).

*Method*

The TDS and electrical conductivity were measured using a digital TDS – Conductivity meter. The instrument was first calibrated using 0.01M potassium chloride. The TDS and conductivity levels in the water samples were then indicated by the machine.

### *2.1.8 E. coli and Total Coliforms*

*Background*

This is the one of the most important tests in this study, as pollutions from human sewage or animal waste are extremely severe in Kuttanad (Joseph 2003 and Kumar 2007). In 2002, there were 23,214 reported cases of diarrheal diseases in the Alappuzha District in Kuttanad (Gregory 2003). Coliform bacteria are common in the environment and are generally not harmful (EPA 2006). It is often used as an indicator of the water possibly containing other germs that can cause disease. *E. coli* are bacteria that indicate the presence of disease-producing organisms that normally live in the intestinal tracts of human or warm-blooded animals (EPA 2006). The major types of pathogenic organisms that can affect the safety of drinking water are bacteria, viruses, protozoa and worm infections. Typhoid, cholera and dysentery are caused by bacteria and protozoa. Diseases caused by viruses include infectious hepatitis and polio (WHO 2003). Specific disease-producing organisms are difficult to identify in water. Therefore, while total coliform and aerobic/anaerobic bacteria are not harmful, their presence implies that bacterial contamination from either human or animal fecal sources may be present.

The traditional laboratory tests for *E. coli* and Coliforms require the inoculation of media containing lactose, incubation and examination of gas bubbles under carefully controlled environment (EPA 2008). This study adopted a new approach approved by the EPA, known as the technology of the Coliscan MF medium developed by the Micrology Lab (Micrology Lab 2005). It is approved for use in National Primary Drinking Water Regulation compliance monitoring by the EPA. Coliscan makes use of "two special chromogenic substrates which are acted upon by the presence of the enzymes galactosidase and glucuronidase to produce pigments of contrasting colors" (Micrology Lab 2006). General coliforms produce the enzyme galactosidase and the colonies that grow in the medium will result in a pink color. *E. coli* will produce both the galactosidase and glucuronidase, therefore resulting in a dark blue color. It is relatively simple to count the dark blue colonies which indicate the number of *E. coli* per sample volume. The total of the pink and the blue colonies is the number of total coliforms per sample volume.

*Method*

1. The Coliscan medium was poured into a sterilized petri dish. Each petri dish was labeled with the code of sampling site and the quantity of sample water used from each site. Depending on the predicted quantity of *E. coli* in the samples, different quantities of water would be measured and applied onto the petri dishes. For example, only 0.2ml of samples collected from the river was applied onto the petri dishes; whereas, 5ml of samples collected from the public taps was

measured and applied onto the petri dish. The reason for varying the volume of sample applied onto the petri dish was to avoid an explosion of bacteria colonies on the petri dish from very polluted sources, making the count impossible.

2. An appropriate volume of water from the sampling bottle was measured and transferred onto the petri dish using a sterilized pipette.
3. The water sample was swirled around the petri dish, ensuring level distribution.
4. The petri dish was covered with lid and set aside in room temperature until the solution solidified.
5. After repeating the above procedures for all the samples, the petri dishes were incubated at 37°C for 24 hours.
6. The petri dishes were then taken out from the incubator. All the developed dark blue and pink colonies were counted separately.
7. Finally, calculations were done in accordance to the volumes used for the experiment, so to report the *E. coli* or total coliform count per 100ml. **Figure 6** in the Appendix showed examples of colonies developed on the petri dishes after incubation.

## *2.2 Results and Discussions*

The sampling results and the standards set by the Bureau of Indian Standards, WHO and EPA were shown in **Figure 7**. The result of the analysis indicated that microbial contamination, specifically the coliform bacteria, was the most prevalent contaminant amongst the tested parameters. Aside from the rainwater sample, all the remaining sampled sources failed to satisfy the *E. coli* count under the drinking water standards. The pH levels of the remaining water samples were also slightly acidic, due to iron leaching from soil in the region. In general, the water samples satisfied the standards in parameters including total dissolved solids, conductivity, hardness, calcium, magnesium, chloride, sodium, nitrate and phosphate. Due to the severity of microbial contamination demonstrated in the water samples, this section will focus its discussions on microbial contamination.

### *2.2.1 Contaminations and waterborne diseases*

The extent and implication of *E. coli* contamination are multi-folded and far-fetched. The river samples contain 1,600 *E. coli* per 100ml of water on average, with one of the river water samples containing 3,000 *E. coli* per 100 ml, far exceeding the WHO and EPA drinking water standard of 0 *E. coli* per 100ml of water. The WHO and the EPA set the maximum permissible level of *E. coli* bacteria to be zero per 100 ml for water directly intended for drinking or treated water in a public distribution system (WHO 2006 and EPA 2008). However, some standards such as the Bureau of Indian Standards allows drinking water to have 10 *E. coli* per 100 ml of potable water (BIS 1991).

It might be argued that the river water was not regularly used for direct consumption by the local population. The local inhabitants avoid consuming the river water when cleaner alternatives such as tap or well water are available, as shown in the subsequent survey result. However, due to limited supply of well or public tap water, river water has to be used for bathing or washing clothes. In a survey conducted in Kuttanad in 2002, 7% of households still report drinking from the river, which is not even suitable for bathing (Gregory 2003). The water samples in this study were collected during the monsoon season, hence the result presented was a “diluted” representation of water quality. Local academia mentioned that the *E. coli* level increased to over 10,000 per 100ml during the dry season from February to April.

A more conservative measurement to interpret the river water samples is the bathing water guideline (WHO 2003). The guideline states that the most frequent adverse health outcome associated with exposure to fecal contaminated bathing water was gastroenteritis. Based on the results from precedent epidemiological studies, WHO identified a cause-effect relationship between fecal pollution and acute febrile respiratory illness (AFRI), which is a more severe health outcome than gastroenteritis (WHO 2003). The no-observed-adverse-effect level (NOAEL) for AFRI is less than 40 intestinal enterococci per 100 ml, with less than 1% chance of contracting gastroenteritis illness risk and <0.3% contracting AFRI risk. The risk increases incrementally with higher concentration of intestinal enterococci in the water. At a concentration of more than 500 intestinal enterococci, there is a greater than 10% chance of contracting GI illness risk per exposure, and the AFRI illness rate is approximately 1 in 25 exposures (WHO 2003). While there is a lack of studies to derive a cause-effect relationship between *E. coli* and GI or AFRI, the health impacts of fecal contaminated water demonstrated in WHO study were alarming. The WHO Guidelines determine that usable and safe bathing water can have a maximum of 500 Coliforms per 100 ml. The water samples from Kuttanad contained an average of over 1,600 *E. coli* which has not included the count for other coliforms. In addition to GI and AFRI, specific waterborne diseases namely Enteric Fever, Typhoid, Hepatitis, Jaundice, Weil’s diseases (Leptospirosis), Cholera, Japanese Encephalitis and Amoebiasis have been cited as frequent epidemics in the Kuttanad region (Padmakumar 2007 and Gregory 2003). These are diseases caused by fecal-oral contaminations or via vectors such as mosquitoes or rats. The health impacts of using such water for bathing and in some cases drinking in Kuttanad are disturbing.

### *2.2.2 Differences between ground and surface water qualities*

**Figure 8** and **Figure 9** show the levels of *E. coli* in the river and the well water systems in the survey region respectively. The region in the darkest shade indicates areas with the highest *E. coli* count. For the river system in North Kuttanad, the major *E. coli* hotspots are the city center Kottayam and the down stream area of the Meenachil River known as Kumarakom. The belt region extended from Kottayam to Kumarakom shows a relatively high *E. coli* level at over 2,000 *E. coli* per 100 ml when compared to the 800 to 1,000 *E. coli* per 100 ml in the upper northern region. Kottayam and Kumarkom is a major city center and tourist attraction respectively. This condition suggests a possible correlation of population density and *E. coli* levels. *E. coli* level peaks in Kumarakom due to a number of hotels and tourist houseboats congregated in the area, releasing untreated sewage in the canals illegally (MSSRF 2007). In Kottayam, municipal and hospital wastes are the major source of untreated sewage (MSSRF 2007).

In Figure 4, the levels of *E. coli* in well water system, shows a very different pattern when compared to the river system in the same region. The hotspots of the *E. coli* contaminations in the well systems are concentrated in sampling site 3 Chengalam and sampling site 4 Parripu. Studies that have compared the surface water and groundwater samples collected in the up and the down gradient from *E. coli* sources respectively, such as a Concentrated Feeding Animal Operation (CAFO), detected elevated levels of fecal indicators in water collected in the down gradient from a polluting source compared with water collected from the up-gradient sampling sites (Sapkota 2007). Sampling sites 3 and

5 have a relatively low topography, they are located at the bottom of a valley. Their down gradient geographic locations suggest that sewage leakages from septic tanks have polluted the ground water, affecting the well water quality. A survey of 217 families in Kuttanad finds that 31% of the families have no special arrangement of waste disposals; they either litter the wastes on the premises or discard them into the river (Gregory 2003). In addition, only 53% of the families have septic tanks, 38% have other kinds of latrine facilities, and the remaining 9% of families have no latrine facilities at all (Gregory 2003). The well water in Sampling Site 5 contains 1,400 *E. coli* per 100 ml of water, and the river water from the same sampling site contains 1,050 *E. coli* per 100 ml of water.

Despite the general trend of river water being the most polluted, in some localized regions as shown in sample site 5, the well water is actually more polluted than the river water. Neither of them comes close to fulfilling the drinking water standards, however, with no other alternatives, it is better to consume the water source with the least amount of fecal contaminants and bacteria. The differences in seasons, water sources availability and geographic topography in Kuttanad suggest the importance of empowering local villagers to monitor their own water resources. The local villagers residing in the area will be the most familiar with the water resources available in their village. A water testing kit with users-friendly testing equipment of *E.Coli* and pH should be distributed to each village to allow villagers to monitor the water quality and adjust their consumptions accordingly. For example, when the water test shows that well water has a higher *E.Coli* count than river water, the villagers will have the instant access to information to switch from using the well water to river water.

### *2.2.3 Implications and remediation*

Remediating water pollution in Kuttanad should be a priority, studies have shown that *E. Coli* bacteria have demonstrated an increasingly high level of resistance to antimicrobials commonly used to treat diarrheal, namely tetracycline, amoxicillin and ampicillin (Sapkota 2007 and Ram 2008). One possible reason of such a resistance development is the lack of medical resource in developing countries. Most diarrheal diseases are treated without first identifying the pathogen causing the illness, and the prescribed antimicrobials are of inadequate quantity (Ran 2008). Drug resistance is easily developed under low levels of antibiotic treatment. This is because only a portion of the infection-causing microbes will be killed after the treatment, but not all of it. The remaining microbes which survive will have the most resistant straits and a higher chance to contain the natural immunity to the medication. Without competition from other microbes, the surviving microbes will be able to rapidly reproduce. As a result, all the reproduced microbes will now have the strongest strait and immunity to the medication. In addition, there is an increasing trend of nontherapeutic use of antibiotics in most animal feeds (Sapkota 2007). The leakages from septic tanks in CAFOs mean that the antibiotic resistance animal enteric bacteria are now polluting the ground water. The emergence of *E. Coli* resistance to a wide spectrum of antimicrobials is making the clinical management of waterborne epidemic outbreaks in the future more ineffective (Ram 2008). Given the emerging challenge, it is essential to prevent susceptible populations from *E.Coli* exposure. The most direct measure is to provide clean water and sanitation.

The local conditions in the Kuttanad area, as shown in the water quality result, pose complications to water quality remediation. The average annual rainfall of Kuttanad is over 2,900mm (Mamcompu Meteorological Station 2008). The region is regularly flooded at a level of 30 cm above ground level during the peak of monsoon season every year. Epidemiologic studies have indicated that extreme environmental factors, such as heavy rains, favor epidemic outbreaks (Corwin 1996). There is no viable method of protecting natural fresh water from storm water pollution. As a result of flooding, fecal waste is likely to mix with river water or other protected water sources (Corwin 1996).

WHO recommended that "guideline values should be interpreted and modified in light of regional or local factors" (WHO 2003). The factors to be considered include the "nature and seriousness of local endemic illness, population behavior, exposure patterns, and sociocultural, economic, environmental and technical aspects, as well as competing health risk from other diseases that are not associated with recreational waters" (WHO 2003). The majority of India's population is dependent on processed or unprocessed surface waters for drinking (Ram 2008). In addition, defective water distribution pipelines, insufficient treatment, and malfunction sewage collection structures have led to contamination of fresh water by fecal matter and other pathogenic bacteria (Brick 2004 and Ram 2008). The Kuttanad population relies heavily on canal water while no alternative water source is available. With over 20,000 cases of acute diarrheal disease every year, effective remediation strategies must be put in place immediately.

## *2.3 Conclusion*

The present study on water quality in the Kuttanad region has certain limitations due to the sampling size and unavailability of specific epidemic outbreaks data in correlation with the water quality in the region. In addition, due to the limited number of installed rainwater harvesting tanks in the region, only one rainwater sample has been collected. Further verification is needed to ensure the accurate representation of water quality in the region. However, the study does reveal the urgency of water scarcity and sheds light on the potential remediation strategies. The rainwater sample demonstrates a consistently low level of contaminants in all tested parameters. For the tested parameters in this study, rainwater is the only water source that satisfies all the respective drinking water standards set forth by the WHO and the Bureau of Indian Standard (WHO 2006 & BIS 1991).

# Part III: Economic Evaluation of Rainwater Harvesting

The abundant annual rainfall, scarcity of potable surface and ground water, frequent epidemic outbreaks and burden of collecting water or purchasing water suggests that rainwater harvesting has a huge potential to solve fresh water scarcity. The following cost benefit study of a household rainwater harvesting system aims to inform the economic returns of domestic rainwater utilization in Kuttanad, and contribute to a larger effort in solving drinking water scarcity. The following sections will present the current rainwater harvesting technology, discuss preceding economic valuations of drinking water, and present the method and result of economic valuation of rainwater harvesting in Kuttanad.

## *3.1 The potential of rainwater harvesting technology*

A rainwater harvesting system usually consists of three basic elements: the catchment system, the conveyance system, and the storage system. Catchment systems can vary from the rooftop of a domestic household to a large ground surface catchment area that recharges an impounding reservoir. The classification of rainwater harvesting systems depends on factors like the size and nature of the catchment areas and whether the systems are in urban or rural settings (UNEP 2000). This study will focus on the domestic rainwater harvesting system in a rural setting, which is the most appropriate system in the Kuttanad region.

The appropriate storage capacity of a rainwater harvesting system depends on the amount and distribution of rainfall. For example, in a region with abundant rainfall year round, a small tank sufficient to hold a few days of rainwater will be enough to meet the water demand for most of the year. On the other hand, drought-prone regions will need a significantly larger catchment area and storage tank to meet the water demand. Based on the rainfall distribution and pattern, there are elaborate calculation methods to model an appropriate storage capacity in a given region. In Kuttanad, with an average of 2,900 mm per year, a 6,000 liter storage capacity will be sufficient for an average household of 5 members (Mamcompu Meteorological Station 2008). More specifically, domestic rainwater harvesting system is composed of the catchment surface, piping, storage structure, filter system, overflow, and outlet. The materials and the degree of sophistication of the whole system largely depend on the initial capital investment. Ferro-cement technology has been widely cited as the most cost effective storage system (Gould 1999, CWRDM 2006, Socio Economic Unit Foundation 2006, MSSRF 2007). In most rural areas, with minimum air pollution, the harvested rainwater is suitable for drinking after filtering. In cases of households with limited construction space, a community rainwater harvesting system can be built and shared among several households. The cost per unit of water will be cheaper for a community tank than for a single-household tank. However, there will be more complications in the management aspect of a community tank. Measures need to be introduced to ensure equal sharing and proper maintenance of the system. In houses without an impermeable rooftop as catchment area, Silpaulin plastic sheets can be installed during the monsoon season (Gould 1999).

Rainwater harvesting systems have a number of advantages when compared to other water supply and purification methods. First, rainwater harvesting is decentralized and provides water near the point where it is consumed. The close proximity of water catchment and consumption allows the systems to be owned and maintained by the users themselves. This is important in ensuring sustainability in developing countries for the following reasons. 1) Local governments in developing countries often lack the funds or incentives to maintain public infrastructure to provide regular water service; and 2) Significant portions of the populations in developing countries reside in rural or inaccessible areas which are flood-prone, mountainous or without road access. The vast spatial areas to be covered mean that a centralized water supply scheme will be extremely expensive to construct and maintain afterwards. In Kuttanad, water pipe leakages are prevalent. When public taps or outlets are broken or missing, villagers often uses a bamboo or wooden shoot to plug the outlet loosely. When water comes through, most of it is leaked and drained into the adjacent canal, causing waste of precious fresh water. This is an example of the tragedy of commons when the governments are not in a financial position to closely monitor and maintain the public infrastructures. Therefore, in order for the rainwater harvesting system to function sustainably, it is essential to enable villagers residing in rural communities to maintain and, to a certain degree, repair the systems by themselves (Rondinelli 2006). A rainwater harvesting system does not require expensive tools or a high level of skill for maintenance; it is an appropriate system which can be maintained by its users in developing countries.

Second, rainwater harvesting systems utilize existing structures such as rooftops, playgrounds or ponds to capture rainwater. They have few negative environmental impacts compared to other technologies such as dams and reservoirs (UNEP 2000). Third, rainwater's quality is usually acceptable for human consumption with little treatment (Malanadu Development Society 2004). The physical and chemical properties of rainwater are generally superior to sources of groundwater that are subject to contamination (Malanadu Development Society 2004). Fourth, rainwater harvesting is energy efficient. Unlike some water purification methods such as UV light, rainwater harvesting does not require electricity or diesel to operate. As electricity outages are frequent in Kuttanad, a water supply system that does not rely on electricity to run is more appropriate. Fifth, there is a negligible maintenance cost. The users should wash the filter and storage tank once per year. The only replacement needed is the carbon in the filter unit. The carbon is made out of burnt coconut shells which are common and extremely affordable in Kuttanad. Sixth, rainwater harvesting systems can be established within a few days by local labor. This suggests an additional benefit of capability building within the communities. In addition, as the systems are constructed by local labor, skilful personnel will be in close proximity to provide maintenance needed throughout the systems' lifetimes.

## *3.2 Economic Framework of water*

### *Economic Valuation of Water*

There is generally no established market for fresh water, therefore its shadow price has to be estimated (Boardman 2006). A variety of methods have been devised to estimate the value of water in different quality levels or the benefits of improvements in water quality. Such methods include the travel cost method, contingent valuation surveys, the market analogy method, the intermediate good method, and the defensive expenditures method. Specifically, this study utilizes the reported payment to private vendors as the lower bound of willingness to pay. The travel cost model can also be used to monetize the time value that households spent on fetching water.

There is usually an inverse relationship between the cost of supply and the ability to pay. It is increasingly expensive to provide supplies to smaller and remoter settlements and homesteads, while the economic opportunities for remote householders decrease at the same time (Gould 1999).

### *Economics of rainwater harvesting*

Most rainwater harvesting cost-benefit analyses that have been conducted thus far focus on the impacts on agricultural productivity and returns (Senkondo 2004, Goel 2005, Ngigi 2005 and Haitbu 2006). Other research includes the valuations of spring cleaning efforts and introduction of handpumps as an alternative to water private vendors, both conducted in Kenya; and a feasibility study of low cost roofwater harvesting in East Africa. This section will discuss the relevant findings from the literatures reviewed.

Kremer's valuation on spring cleaning efforts in Kenya indicates that a pareto improvement relative to the status quo will be possible under the condition that landowners continue to provide households' access to unprotected spring water while charging their access to protected spring water (Kremer 2008). In addition, the study shows that the stated preference method tends to exaggerate households' willingness to pay for environmental amenities, and that revealed preference approach yields less variable valuations. Comparing the stated preference and the revealed preference to pay for rainwater harvesting is an important task for the rainwater harvesting system cost benefit analysis. The payment to purchase water from private vendors can serve as a lower bound of willingness to pay in this thesis.

A prevalent phenomenon and source of acquiring water in developing countries is from private water vendors. Whittington has investigated the operation and economics of water vending systems in Kenya. In his study area, 64% of water consumed is purchased from water vendors, and each household spends about 9% of their income on purchasing water. As water vendor activities are significant in the Kuttanad region, his paper has provided insights into thinking through the economic valuation and implications of water vending activities. Mainly, the significant portion of income spent on purchasing water suggests that households might be willing to pay substantial amount of money for water.

Goel studies the economic returns of rainwater harvesting in terms of wheat and maize production. The study calculates the net present annual return (PAR) per hectare of land by considering the increased yield, procurement prices of crops, input costs such as fertilizers and irrigation, construction cost of harvesting structures, and the maintenance cost. Finally, the PAR values of two different lifetimes and three sizes of rainwater harvesting structures are compared. The study results in benefit/cost ratios that range from 0.41 to 1.33. As a project is considered to be economically viable if its benefit/cost ratio is more than one, this study shows the significance of taking into consideration the different lifetimes and sizes of harvesting structures. Similarly, in Senkondo's study, he concludes that rainwater harvesting enables farmers to switch to high value crops, resulting in significant improvement of incomes and thus livelihoods. The maize production shows a consistent result across all indicators- a positive NPV, a larger than 1 benefit/cost ratio, and an internal rate of return of over 50%.

Ngigi has conducted a hydro-economic evaluation of rainwater harvesting for Kenyan farmers located in semi-arid regions (Ngigi 2005). Hydro-economic analysis considers 1) the reliability of rainwater harvesting to store adequate runoff to meet supplemental irrigation requirement to bridge dry spells and mitigate the impacts of persistent droughts; 2) the risk of the drought impacts on soil moisture and hence crop production; and 3) the profitability and cost benefit analysis of rainwater harvesting in terms of increasing crop production and stabilizing yields. It is a comprehensive study that bridges environmental science and economic analysis, with the objective of providing recommendations to farmers for deciding agricultural investments under drought risks and uncertain production. While the agricultural return assessment is irrelevant for my study, an aspect that my thesis can build on is the drought severity index. Drought severity index can be used to evaluate the reliability of rainwater harvesting during dry spells.

Haitbu’s study on rainwater harvesting for crop enterprises in East Africa has shown that rainwater has led to an increase in US$8 return per labor per day (Haitbu 2006). His study concluded the optimal increase in water availability for agriculture will be a combination of rainwater harvesting with improved roads drainage. The study’s conclusion is an important reminder to consider possible holistic approach which might yield a higher NPV in fresh water supply. The economic incentives of rainwater harvesting play an integral role on whether the local villagers will adopt rainwater harvesting system or not.

## *3.3 The Achinakom Village Survey*

### *3.3.1 Context & data*

The Achinakom Village is located in the North Kuttanad region; its coordinates are 76° 25’ 35.5” East and 9° 39’ 17.2” North. The Achinakom Village is also included in the aforementioned water quality study as water sampling site number 3. Achinakom Village is a typical village in the Kuttanad region with a total of 141 households (See **Figure 10**).

Local knowledge and word-of-mouth are the two criteria for mobilizing community participation in developing countries. The data collection of this thesis and the subsequent rainwater harvesting systems construction project of *Rainwater for Humanity* depend heavily on the community's active participation. Therefore, Achinakom Village was chosen due to a friendly relationship with the Secretary of women's self help group, Ms. Suma Chisol since August 2007. In January 2009, with the assistance of 55 volunteers from the Mahatma Gandhi University School of Environmental Sciences (MGU SES), the National Service Scheme of St. Xavier's College and the Achinakom's women self-help group, we canvassed the Achinakom Village. As the local dialect in Kerala is Malayalam, the survey was translated by Dr. C.M. John, a faculty member at MGU SES and Mr. V.P. Sylas, a PhD candidate of Environmental Sciences at MGU SES. Prior to the survey, two orientation workshops were held to familiarize the volunteers with the objectives and contents of the survey. There was a question-and-answer session after each orientation to ensure that the volunteers understood the survey. We conducted the survey on January 7, 2009 which was a local public holiday. The surveys were distributed to the volunteers who visited 141 households in total. The volunteers were divided into 17 teams with 3 to 4 members in each team. In each team, there were 1 to 2 MGU SES masters student(s), 1 St. Xavier's College student and 1 women's self-help group member. The motivation behind this arrangement was to leverage the expertise of different members. The MGU masters students had a firm grasp of the technical and academic objectives of this survey, and hence were able to fill out the survey as accurately as possible and answer technical questions from the villagers. The women's self-help group members were extremely familiar with the Village conditions. Aside from the local knowledge, they also brought credibility to the survey team as the villagers knew each other well. The St. Xavier's College students provided logistical support.

In addition to the purpose of data collection, the survey acted as an educational opportunity and awareness building campaign for all the parties involved including the student volunteers, the women's self-help group volunteers and the village interviewees. Discussing the questions related to the possibility of rainwater harvesting implementation has raised the villagers' awareness and knowledge of this topic. At the same time, student volunteers mentioned that from visiting and talking to the villagers personally, they have become more familiar and sympathetic towards the water scarcity situation in Kuttanad. During the debriefing after the survey, some student volunteers shared that they would become more active in pursuing solutions for the Kuttanad community.

### *3.3.2 Survey Results*

A total of 141 households were surveyed. However, only 114 data points were analyzed due to reasons such as the interviewees' unwillingness to disclose information and recording or translations errors by the interviewers. The survey also recorded the gender of the member(s) that was/were representing the households when answering the survey questions. As men and women often demonstrate different priorities in household resource allocations, this information allows further investigation into that area in the future (Pitt 1998). The survey demography shows that 65% of the interviewees are women. The top occupation reported by the interviewees is housewife (40%) followed by daily wage worker (21%), coir making (10%) and fishermen (4%). Most interviewees were adults and the average household size were 4.4 members (See **Figure 11**).

For drinking and cooking water, the survey shows that most households use water from private vendors during the summer season and rainwater during monsoon season (See **Figure 12**). On average, each person consumes 15.5 liters of water during summer and 10.3 liters during monsoon. On the other hand, most households rely on the canal for bathing and washing purposes (See **Figure 13**).

For evaluating the villagers' opinion towards rainwater harvesting, various questions were asked. When asked if they were supportive of bringing rainwater harvesting to the village, 99% of the interviewees said "yes." However, when asked if they were willing to share a community rainwater harvesting system with neighbors, 71% of the interviewees stated that they were not willing to share a community system. This specific question had not stated clearly that a community water tank is cheaper per unit of water than an individual household tank, and hence, it is normal to observe villagers' preference to own their individual assets, especially when water is a scarce good. Nonetheless, the response raises attention to the implementation aspect of rainwater harvesting system which will be discussed in the subsequent sections.

Lastly, the survey collects information on the existing conditions of time and money that the villagers spent on collecting water from wells, public taps or private vendors. The survey finds that on average, each household spends Rs 1800 (USD 36) to purchase water from private vendors per year. The entire village spends Rs 216,510 (USD 4,353) to purchase water from private vendors per year. This is a significant amount considering the fact that the per capita Gross Domestic State Product (GSDP) in Kerala is only Rs 32,852 (USD 667) (Kerala Planning Board 2006). This reported payment to private vendor per year also serves as the lowest bound of the households' willingness to pay for rainwater harvesting system. In terms of time cost, each household spends 2.4 hours every week to collect water from private vendors. Due to the differences of the households' locations from the main road, there is a wide distribution of the reported time spent (See **Figure 10** for households distribution in the Achinakom Village). Four households have reported spending over 7 hours per week to collect water. Assuming that the time opportunity cost is Kerala's minimum wage, the collection time will translate into Rs 13.47 per day.[3] (Assumptions will be discussed in detail in **3.4.3 Assumptions**) The time value is comparable to the average amount of money spent on private vendors per day, which is Rs 13.95.[4]

The subsequent cost benefit analysis (CBA) utilizes the data points collected for each household and analyzes the net benefits or costs in investing in a domestic rainwater harvesting system.

## *3.4 Valuation Method*

### *3.4.1 Classification of households*

As shown in the survey results, the sources of water consumption vary across seasons and households. For drinking water, most hosueholds use rainwater during monsoon and purchase water from private vendors during the summer. Some households also supplement their water consumption from different payment-free sources including well water, pipe water and pond water.

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[3] Kerala's daily minimum wage is Rs 107.78, assuming eight hours of working per day. The average collection time per day will be 1 hour. Hence, the time value is 107.78/8 = Rs 13.47.

[4] The average per person drinking/cooking water consumption during summer is 15.5 liters. The average household size are 4.5 members.The average price of water is Rs 0.2 per liter. Therefore, the daily amount spent on purchasing water from private vendor is 15.5*4.5*0.2 = Rs 13.95.

The Achinakom survey shows that there is a distinct water consumption pattern for each household in terms of water sources across different seasons and in terms of the amount of water used per member in different households. Therefore, this study clusters households into 14 groups according to their baseline water consumption sources. **Figure 14** shows the classification of Achinakom households into these 14 groups. The costs or benefits of rainwater harvesting depend heavily on the gains or losses compared to the status quo. Hence, the classification of households according to their current water consumption sources will illustrate the varying degrees of costs or benefits. Household Groups E, F, G3, H, I, J1 and J2 only have 3 or less data points. They are excluded from the cost benefit analysis. Given their small sample sizes, the results generated will not be representative.

### *3.4.2 Expected net benefits*

The expected net benefits [E(NB)] of a domestic 6,000 liter capacity rainwater harvesting structure for household *i* is shown as:

$$E(NB)_i = - C_0 + \sum_{t=0}^{19} \frac{1}{(1+r)^t} \ [E(B_t)_i - E(M_t)_i],$$

where $C_0$ = the material and labor cost of a 6,000 liter capacity rainwater harvesting system in Year 0, r = the discount rate, $E(B_t)$ = the estimated benefits from rainwater harvesting in year t and $E(M_t)$ = the expected maintenance cost of rainwater harvesting.

In order to account for the risks associated with utilizing rainwater harvesting, the probabilities of “work” [Pr (work)] and “not work” [Pr (not work)] are factored in:

$$[E(B_t)_i - E(M_t)_i] = E(B_{ti} - M_{ti} \mid \text{work}) \cdot \Pr(\text{work}) + E(B_{ti} - M_{ti} \mid \text{not work}) \cdot \Pr(\text{not work})$$

$$= NB_{ti}^{w} \cdot p + (0 - M_{ti})(1-p)$$

$$= NB_{ti}^{w} \cdot p - M_{ti}(1-p)$$

The probability implies that a rainwater harvesting system either remains completely intact or fails. In particular, this study defines that a rainwater harvesting system “works” when it is completely water-tight and preventive of any disease vectors from contaminating the water stored. A system is defined to “not work” when leakages develop and allow storm water to contaminate the storage tank or diseases vectors to enter the system. In reality, components of a rainwater harvesting system can be easily replaced and hence the system seldom fails beyond the point of repair. This study aims to present the most conservative estimation of benefits, and hence it is reasonable to assume that the system fails permanently in this analysis.

Given that a rainwater harvesting system fails, there will be no benefits associated with it. Hence, there are no benefits in the “not working” scenario. It is also assumed that the users will continue to maintain the system without the knowledge that the system is not working. Therefore, it is assumed in the analysis that the household will continue to incur the maintenance cost. In reality, users will be educated to monitor their system regularly. For the purpose of a conservative study, the worst case scenario is used. There might be extreme conditions such that the stored water is of very bad quality as the system fails, therefore, the benefits could actually be negative. It is impossible to quantify the particular negative effects in this case due to numerous unobservable variables. The discussion section should discuss the possible inadvertent negative effect of water supply intervention in community's health.

The following equation shows the detailed calculations of (B-M) for a single year from Year 1 till Year 20 for a single household. The following equation is used for Household Group B (see **Figure 14**). Household Group B includes households purchasing water from private vendors in both the summer season and the monsoon season. The initial investment cost (C) of a rainwater harvesting system is not included in the following equation as it is factored in Year 0.

$$B\text{-}M = 365^* [n^* j^* 0.5 (q_s + q_m) + v^* (t_p - t_r)] + v^* w^* (0.5^* d + e) + n^* I_h - M$$

Where,
$B$ = benefits
$M$ = maintenance cost
$n$ = number of individuals per household
$j$ = price of water sold by private vendors (Rs/liter)
$q_s$ = average quantity of water consumed per capita per day during summer season
$q_m$ = average quantity of water consumed per capita per day during monsoon season
$v$ = opportunity cost of time per day
$t_p$ = time spent collecting or buying water from private vendors per day
$t_r$ = estimated time spent collecting water from rainwater harvesting structure per day
$e$ = no. of members earning income or attending school in the household
$d$ = no. of child carer in the household
$w$ = extra productive days due to less water-related disease
$I_h$ = income save from less healthcare cost per capita per year
$C$ = construction cost of rainwater harvesting structure

Note: The detailed explanation of the equation and assumptions behind each variable are included in the following sections

### *3.4.3 Assumptions*

*Overall assumptions*

The choice of a discount factor is one of the most important decisions in this study. The discount rate can determine whether a rainwater harvesting system in Kuttanad will have positive or negative expected net benefits. Discounting is needed as it is generally accepted that resources available in the future are worth less than the resources available now. It is also necessary because through investment, resources available now will grow and transform into a greater amount in the future. This study has looked into a wide range of social discount rates that can be derived from rates observable in markets. There are several observable discount rates: private sector investment, social marginal rate of time preference, government's borrowing rate, and a weighted average of these three, interest rate of micro-credits given out by Kuttanad's non-profits, and local commercial banks' interest rate (Boardman 2006). There are numerous debates surrounding the selection of each of the aforementioned discount rates. For example, if the private sector investment rate is used, there will be concerns whether the private sector investment rate reflects how individual households weigh present consumption versus future consumption. In addition, each investment is different with specifics of how it is being financed, and the form and the time frame of return. Two projects might yield different short or long term health or environmental impacts. Given such a case, the choice of a discount rate will affect the final net present values. Specifically, a low discount rate favors projects with the highest total benefits. On the other hand, a large discount rate gives less weight to future returns. Hence, a high discount rate will weaken the NPV for projects which are back-end loaded and favor projects which are front-end loaded. The goal of this thesis is to evaluate whether the investment in a rainwater harvesting system will yield a positive return (net benefits) for a single household on average. The scope of ranking and comparing rainwater harvesting systems with other water supply alternatives is beyond the scope of this project. Therefore, in order to avoid the trap of discount rate debates, this thesis decides to encompass the plausible discount rate range of 0% to 30%. Two CBA are conducted, one with a zero discount factor, and another one discounted by 30%.

Aside from making assumptions for variable, it is essential to make general assumptions about the implementation of rainwater harvesting system in the Achinakom Village. Based on the survey, all but one of the 114 households have impervious rooftops. All of the surveyed households also have rooftop surface areas which are large enough to act as catchment areas. Therefore, it is technically feasible to construct rainwater harvesting systems that capture sufficient rainfall in the Achinakom Village. In addition, this cost benefit analysis considers that the rainwater harvesting system will provide sufficient water for human consumption including cooking and drinking. However, as mentioned in the Part 1 Water Quality Study, there is still a high risk of contracting water-related diseases from bathing and washing clothes in the canal water. The sanitation issue of canal water is beyond the scope of this thesis' CBA. The risks that water supply interventions inadvertently discourage community sanitation will be discussed at the end of the thesis.

The demand for private vendors during the summer is higher than in the monsoon season. Of the 114 households, 106 households purchase water from private vendors during the summer while only 23 households purchase water from a private vendor during the monsoon season. Hence, there might be a chance that queuing time during the summer is longer than during monsoon season. It is assumed that the private vendors will increase the quantity and frequency of water deliveries by tanker lorries during the monsoon season to take advantage of a higher demand. In respect of this, this study has classified the households into groups according to their consumption patterns. The cost-benefit equation will be slightly modified depending on the water consumption pattern of each household group. For example, in household group D1, as the households capture rainwater using cloths and buckets on their own household compound during monsoon season, no additional benefits of collection time saved from having a rainwater harvesting system during monsoon is factored in the analysis equation. Due to a difference in status quo, as shown in the, Household Group D1 has a lower average expected net benefits than Household Group B or Household Group C (see details at **3.6 Result Section**)

*Variables and assumptions used in the analysis*

This study bases its variables on an evaluation by the World Health Organization (WHO) on the costs and benefits of water and sanitation improvement (Hutton 2004). The WHO study is also used as a major source for monetizing non-monetary benefits and costs. The WHO analysis was conducted at the country level. The results are weighted by the country's population size and aggregated to give a regional average. Specifically, my study uses the regional index including India, known as the South-east Asia epidemiological pattern D (SEARO-D).

The index in the WHO's study accounts for the benefits from a simultaneous improvement of water and sanitation facilities services. As rainwater harvesting system only addresses the water facilities aspect, this thesis lowers the "amount of income saved due to averted cases of water related disease" provided by the WHO's study. It is assumed that there is a larger synergistic effect when water supply and sanitation are improved concurrently. Therefore, specifically, this thesis only uses a value which is 1/3 of the WHO’s reported health benefits. In addition, a sensitivity analysis is conducted to demonstrate the changes of the expected net benefits under all plausible values of uncertain parameters

For this thesis, the costs include the full investment and annual maintenance costs of a rainwater harvesting system. The benefits include time savings with better access to water, the gain in productive time due to less time spent ill, and the medical costs saved due to less treatment of diseases. The following sections are detailed discussions of the variables and their assumptions. The list of variables and their assumptions are also summarized in **Figure 15**. All of the stated assumptions will be tested rigorously in the subsequent sensitivity analysis.

### *Benefits*

The benefits can be categorized into health benefits and non-health benefits. For health benefits, the benefits are the reduction in incidence rates (number of cases reduced per year. Over the past decades, compelling academic studies have shown that beneficial health impacts are associated with improving water and sanitation facilities (Hutton 2004).

### *Health Benefits-* $I_h$ *(Income saved from less healthcare cost)*

Cost savings in health care are mainly related to the reduced number of treatments of diarrheal cases (Hutton 2004). In this study, the averted costs of medical treatments and hospitalization days are considered as the health benefits from using a rainwater harvesting system. Due to a lack of studies presenting data on the number of hospital visits per case of diarrhea, the WHO’s study assumes that a diarrheal case visits a health facility once, with a range of 0.5 to 1.5 visits. Once hospitalized, the length of stay is assumed to be 5 days on average. The hospitalization costs include the consultation, medication and overheads charges. Based on the WHO report, the annual patient treatment costs saved from providing access to water and sanitation services is USD 134 per capita. Due to reasons discussed in **Section 3.4.3 Assumptions**, this study assumes the averted patient treatment costs to be 1/3 of WHO’s USD 134, which is USD 44.67.

*Non-health Benefits – $j*q$(income saved from private vendor payments), $t_p$-$t_r$ (time saved from collecting water), and $v*w*(0.5*d +e)$ [(working/schooling/childcare days from less disease)]*

The non-health benefits include both costs reductions and additional benefits resulting from the intervention (Hutton 2004). They are the indirect economic benefits related to health improvements and the non-health benefits related to water improvements. The non-health benefits in my study include the income saved from payment to private vendors, time cost saved from collecting water, income gained from productive days from less disease, more school days from less disease, and more childcare days from less disease.

There are many and diverse potential benefits associated with improved water supply services, ranging from the easily identifiable and quantifiable to the intangible and difficult to measure (Hutton 2004). The aim of this thesis is to capture the most tangible and measurable benefits, and identify whether the installation of rainwater harvesting structures will bring about positive or negative net impacts to households. Therefore, this cost benefit analysis intentionally chooses to include only the identifiable and quantifiable costs or benefits. The omitted benefits variables will be discussed in the Results & Discussions session.

For j*q (income saved from private vendor payments), j is the price per liter of water sold by the private vendor and q is the drinking and cooking water consumed per person in the household. There are no assumptions involved with these two variables. The j and q inputs for each household are reported by the household's interviewee(s).

For $t_p$-$t_r$ (time saved from collecting water), $t_p$ is the time needed to collect water from private vendors, well or pond; $t_r$ is the time needed to collect water from a rainwater harvesting system. The variable $t_p$ is reported in the survey; it is the reported time spent on collecting water per day from each household. As the rainwater harvesting system will be constructed in the household compound itself, this study assumes that $t_r$ will be minimal, taking up two minutes per day. In addition to the health benefits and less medical costs associated with averted cases of disease, an extra benefit is the gaining of income forgone from working days lost otherwise. The daily minimum wage in Kerala is Rs 107.78. Assuming that there are 8 working hours per day, the minimum wage is used to monetize the value of time gained (Hutton 2004). Kerala has a long history of left and labor union movement. Peasant associations and labor unions have been central to the design and implementation of minimum wage legislation, welfare program and bargaining procedures that empowered the lower castes (Heller 1996). Though the labor unions have separated into different branches since 1960s, the presence of active labor unions and high literacy rate implies that the minimum wage is enforced more easily than other States in India. The enforcement of minimum wage is also verbally verified by local academia namely Mr. V.P Sylas and Dr. C.M John. They reported that the normal daily wage that an agricultural worker receives in Kuttanad is around Rs 100. One of the most common crops grown in Kuttanad is rice. There is a varying level of labor demand dependent on the seasons of rice crop schedule throughout the year. As a significant number of households are engaging in agricultural activities, the fluctuation of agricultural labor demand will affect the income generated by each household. The effects of seasonal agricultural labor demand will be discussed and taken into account in the sensitivitey analysis.

Aside from extra working days, the minimum wage is also used to monetize the extra days for schooling and childcare (Hutton 2004). The WHO's study reasons that the impact of illness is school absenteeism, which has a negative impact on the children's future human capital. For this reason, time not spent at school by children of school age is also valued on the basis of the minimum wage (Hutton 2004). The State of Kerala provides universal education for every child. The median number of schooling years is 10.3 years for the 20-24 year-old age group in 1998-99 (Chandrasekhar 2001). The survey data categorizes household members into three age groups, below 17, 17-50, and over 50. This CBA is monetizing both the schooling days and the working days equally with the Kerala minimum wage. Therefore, the ambiguity of whether adolescents between age 14-17 are attending school or working is resolved. Due to a uniformed monetization figure, the classification will make no difference in the numerical result of the expected net benefits.

. For extra child caring days, this study monetizes the child caring days gained due to averted illnesses at 50% of the minimum wage. The number of household members providing child caring service in a household is estimated in households with at least one child, by either the reported occupation "housewife" and/or adult member(s) from 17 to 50 years old in a household without occupation(s). Though grandparents may often provide childcare, they are also more likely to be ill, and hence have to be cared for. Therefore, elderly was not included due to the opposite effects of providing and receiving services counteracting and cancelling each other out.

### *Costs*

The associated costs with a rainwater harvesting system include the investment and the recurrent or maintenance costs. The investment costs (C) of a rainwater harvesting system includes the planning and implementation cost, tools and materials used to construct the system, and education materials on proper maintenance and health information (Huffon 2004). On the other hand, the recurrent costs (M) include the materials needed to maintain and repair any components of the rainwater harvesting system, the replacement of carbon in the filter, the washing of storage tank and the time of controlling the first flush system.

According to the WHO's report and other rainwater harvesting literatures, the average lifetime of a rainwater harvesting system is 20 years (Gould 1999 and Huffon 2004). The upper bound of investment costs for a rainwater harvesting system in Kuttanad is Rs 13,500. This figure is extracted from the interviews conducted with non-profits operating in Kuttanad and the Panchayath members. The WHO's study estimates that the operation, surveillance, and maintenance cost for rainwater harvesting to be 10% of the investment costs. Hence, the recurring cost over a structure's life time will be Rs 1,350.

Thus far, this section, **Figure 15** has summarized the variables' definitions, assumptions and the predicted bias towards the estimated net benefits/costs. In addition, the table presents the estimated magnitude of bias for each variable towards the net benefits/costs. It is impossible to quantify the bias magnitude with a numerical figure. Therefore, the magnitude scale only serves as a comparison amongst the variables, categorized into small, medium and large scale.

## *3.5 Sensitivity Test*

The purpose of the sensitivity analysis is to acknowledge the underlying uncertainty in this cost-benefit analysis (CBA). The monetary values and magnitudes assigned to each variable vary in reality. The sensitivity analysis will demonstrate how sensitive the expected net benefits are to changes in assumptions. If the expected net benefits remain positive under all plausible values of the uncertain parameters, then this CBA will have a higher confidence to conclude that the investment in rainwater harvesting is worthwhile. The large number of combinations with different assumptions and values makes it impossible to conduct analysis with each of them and analyze the results thoroughly. Therefore, there are a few more manageable approaches to conduct a sensitivity analysis which include partial sensitivity analysis, worst- and best-case analysis, and Monte Carlo analysis (Boardman 2006).

This thesis conducts the base- and worst- case analysis, which is more appropriate than a worst- and best-case analysis. The base-case assumptions generally assign the most plausible numerical values to unknown variables according to the researchers' best guess. Hence, a most representative net benefits figure will be generated from a base-case analysis based on the researchers' judgment. However, it is reported that there are often "cognitive limitations and bureaucratic incentives to generate optimistic forecast" (Boardman 2006). Therefore, a worst-case scenario analysis serves as a useful check against these unobservable biases. A worst case scenario is especially useful when the CBA presents a positive result. Similarly, a best-case scenario is useful when the CBA presents a negative result. Conducting a worst-case scenario also helps the researchers to gage the magnitude of difference needed in the variables to modify the outcome.

The changes in assumptions used in the sensitivity analysis are summarized in **Figure 16**. The worst-case scenario continues to adopt a discount rate of 30% which is the highest interest rate offered in Kuttanad by a local women's self-help group to their members. Second, the income saved from decreased healthcare cost has been reduced to 1/5 of the WHO's recommended figure instead of 1/3 used in the base-case scenario. The further reduction is to account for possible risks of inadvertent behavior, worsening the sanitation conditions when water supply intervention such as a rainwater harvesting system is introduced. In addition, the extra productive days gained (w) is also reduced from two days per year to one day per year.

Third, the monetization value of time has been reduced. This is to account for scenarios of unemployment or underemployment faced by the working members in a household. In Kuttanad, rice is cultivated in two seasons: summer (November to February) and monsoon (July to October) (Kurup 2002). The breakdown of agricultural labor costs shows that harvesting has the highest demand for labor, followed by land preparation. Therefore, October to February and July to October are the labor intensive seasons. The window from February to July, which is 1/3 of the year is the low labor demand period. As a result, the opportunity cost of carrying water during this time period is lower. The worst-case scenario assumed that the working members in a household will not be generating any income from February to July. Therefore, only 1/3 of the minimum wage is used to monetize the water collection time and extra productive working days gained from owning a rainwater harvesting system in the worst-case scenario.

Lastly, in terms of the functioning of the rainwater harvesting system, both the system's lifetime and the probability of "working" are drastically reduced. As the lifetime and proper functioning of a rainwater harvesting system depend heavily on its users' operation and maintenance, the system's lifetime is not completely guaranteed. The base-case scenario assumes that the lifetime of a rainwater harvesting system is 20 years, as stated by most of the rainwater harvesting literature. Fresh water is highly valued in Achinakom; the Achinakom community has also demonstrated a high interest (99% of the households support rainwater harvesting) in rainwater harvesting. Therefore, the base-case scenario assumed proper maintenance of the structure throughout its lifetime. The worst-case scenario will be a lack of proper maintenance and/or accidents happened that causes the system to develop leakages. The worst case scenario assumes that the system's lifetime is only 5 years, with a probability of 50% failing.

### *3.6 Results*

All the expected net benefits are positive under the three scenarios: 1) Analysis without discount rate, 2) Baseline scenario with a 30% discount rate, and 3) Worst case scenario or sensitivity analysis (see **Figure 17**). The relative increases in expected net benefits among household groups are mostly uniform across the three scenarios. Household Group B shows the largest expected net benefits [E(NB)] across the three scenarios. Group G1 shows the smallest E(NB) in the first two scenarios. This is within expectation due to the fact that Household Group B purchases water from private vendors in both the summer and monsoon seasons. Whereas, Household Group G1 consumes water from a combination of private vendors and other payment free sources of water during summer, and only consumes water from payment free sources such as well, pond, and rain during monsoon.

Household Group D2 has shown a significant drop in its average E(NB) from Rs 21,839 in the base-case scenario to Rs 61 in the sensitivity analysis. Household Group D2 does not rely on private vendors at all. Therefore, the major benefits of adopting rainwater harvesting will be the potential health benefits and the time costs savings. In the sensitivity analysis, as the monetary value of time or extra productive days are reduced significantly, the effects are especially pronounced in Household Group D2.

Household Group D1 has a slightly smaller average E(NB) than Household Group D2 in the first two scenarios. This is most probably due to the fact that Household Group D2 is consuming water from well during monsoon. Owning a rainwater harvesting structure will allow Household Group D2 to gain the time value forgone from collecting water from well originally over Household Group D1.

Household Group C has the second highest average E(NB) and Household Group G2 has the third highest average E(NB). Household Group C consumes water from private vendor in both seasons, supplementing consumption by capturing rainwater during the monsoon season. For Household Group G2, they only purchase water from private vendors to partially fulfill their water needs during the summer. Therefore, Household Group C will have a larger return than Household Group G2. This is because Household Group C will gain the money saved from water payment to private vendors in both seasons. Meanwhile, most of the benefits gained for Household G2 will only be the time value.

Lastly, the standard deviation of E(NB) across households is also computed using the following equation,

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2},$$

where Xi is the E(NB) for each household. The standard deviation results are shown in **Figure 17.** The E(NB)s from the same Household Group have a relatively wide distribution. It will be discussed in the following section

## *3.7 Discussions*

The results of the CBA show that there are positive E(NB)s for all of the households under all of the three scenarios. While these results further validate the precedent claims of rainwater harvesting, this CBA has simplified several conditions in Achinakom in hindsight.

First, the households have highly differentiable water consumption patterns. These varieties might be due to households' decisions, or the households might be constrained by their physical environments and locations. For example, the adjacent Panchayath provides public taps. Therefore, the Achinakom households which were located in close proximity to the neighboring village could afford the time cost to walk over and collect water. Such an option, however, is not available to all the households in Achinakom. Households located on the other side of the Village would not be able to afford the huge time cost and, hence, cannot choose public tap.

Second, this CBA has adopted the WHO's health benefits figure and applied it across all the Household Groups to value the health benefits from rainwater harvesting. Each Household Group is classified according to the baseline conditions of the households' existing water sources. The fact that certain households choose to pay a premium to private vendors for drinking water reveals a difference in the conceivable health benefits among water from private vendors, ponds, wells or public taps. Due to the various levels of water qualities, the health benefits of switching their existing water sources to rainwater harvesting will be different as well. Therefore, the uniformed value of health benefits applied onto households already paying private vendors to avoid diarrheal cases have resulted in an over-estimation of health benefits. However, due to the villagers' imperfect information of the sources' water qualities, it is unsure how large this overestimation is. As shown in the water quality results in Part 1, in some locations, the canal water actually has a higher quality than the well water. The fact that household members still choose to spend more time to collect water from a well than using the adjacent canal implies that the households have limited knowledge of their available water sources. In this case, if the actual water qualities do not vary significantly across different water sources, then a uniformed value of health benefits will not result in a gross over-estimation. Understanding how and what causes households to decide on using a water source will be instrumental in solving the possible errors of over-estimating health benefits.

Third, there are a number of benefits that were not included in the CBA due to a variety of reasons. For example, there is a certain non-use value intrinsic to improvements in water supply. Non-use value includes the option value, bequest value and the existence value. Option value means the possibility that the household may want and can use it in the future. Bequest value is the households' wants for future generations to enjoy the rainwater harvesting system. Existence value is that the household values that the environmental good exists, independence of whether they are utilizing it or not. These values are not directly applicable to rainwater harvesting system as a rainwater harvesting system has very limited contribution to existence value and option value. The non-use values are also very difficult to measure. The CBA will be more rigorous without including a benefit with huge degree of uncertainties.

Fourth, this study raises several questions on the implementation aspect of rainwater harvesting systems. It is clear that households prefer cleaner water and is willing to pay at least the payment to private vendors for cleaner source of water and/or the time value that they are investing in walking longer distances to collect water. Due to a lack of perfect information, it is unclear whether the water that they spend extra money or time to collect is actually of a superior quality. *Rainwater for Humanity* intends to implement the rainwater harvesting systems by providing microcredit in the forms of rainwater harvesting system materials to the villagers, the villagers will then repay the loan over several years. The major objectives of giving out microloans to the villagers are 1) to create a sense of ownership and proper maintenance of the system, and 2) to increase the affordability due to a high upfront cost of rainwater harvesting systems and aid the smoothing of consumption curve over time.  As a result, it is essential to clarify and validate 1) how villagers value water, 2) hence deciding the actual value of clean water from the households' perspectives, 3) how a rainwater harvesting system will benefit the households, and 4) determine the harvesting system's price that will yield positive net benefits to the villagers. Such information will be essential in deciding the price of a rainwater harvesting system, the level of subsidies, and the amount of microloans to be dispersed. To allow for uncertainty and unobservable factors, the price of the rainwater harvesting system should be set well below the expected net benefits that a household will enjoy from a rainwater harvesting system.

Fifth, due to a high degree of uncertainty, there are often unforeseeable challenges and risks when implementing community projects in developing countries. Thus far, this thesis has assumed that the sanitation service is beyond the scope of the CBA. In reality, water supply service ties intrinsically to the social activities and environmental services including sanitation conditions, traditional habits, and cultural nuisances. A study conducted in the Philippines have shown that a water supply intervention project have inadvertently worsened community sanitation (Bennett 2008). With an expansion of the city's municipal piped water, the drinking water source is no longer tapped locally. Hence, after the implementation of the water supply project, the increasing public defecation and uncontrolled garbage disposal have deteriorated the sanitation conditions. The paper concludes that “due to the large health externalities of sanitation, the impact of declining sanitation may overwhelm the benefit of receiving clean water.” This serves as a vivid example of the unforeseen negative impacts of a well-intended community project.

Lastly, during the community survey, I recalled several households stating that they were not willing to boil the water before consuming it as “boiled water tastes differently and cannot quench our (their) thirst.” Due to a different lifestyle, some households are reluctant to boil water. However, boiling water for 10 to 20 minutes is enough to remove most biological contaminants. This is especially important when most water sources are contaminated in the area. This further amplifies the importance of education and distributing information that is understandable by the local users.

### *3.8 Conclusion*

The analytical process and the results of the water quality study and the CBA have been extremely informative. The water quality results have shown that rainwater is the only water source that satisfies the drinking water standards. All the other water sources are contaminated with high levels of *E.Coli*. The CBA results have demonstrated that the average estimated net benefits from all household groups are positive. Though the CBA study has simplified the conditions in Kuttanad, it provides a good starting point to investigate the economic valuations of clean water in Kuttanad. The polluted environmental conditions and acute water scarcity in Kuttanad have been heavily studied by local academia and non-profits in the past decades. However, this study is the first of its kind to take on a potential solution to water scarcity and investigate its net benefits/costs compared to the status quo, using the economic perspective of a domestic household.

The following is a verse from a successful social entrepreneur, Martin Fisher who has co-created a company called Kick Start. By selling portable hand pumps for irrigation since 1991, Kick Start has since lifted 411,000 people out of poverty and created 58,000 new waged jobs in Kenya (Kick Start 2008).

> "A very poor family is very unlikely to spend the money to dig their own household well -- even if they have to walk 10 km to fill their jerry cans every day. Unless they have a good way of making money the opportunity cost of the saved time is simply too small. And even the purest drinking water from a protected well will have little health impacts if the family does not have enough water for

> basic sanitation. If you don't have enough water to wash your hands it is very hard to stay healthy. But give the family an economic incentive to dig a well (use the water to irrigate crops for sale and increase your income), and they will find a way to dig the well, get water to grow food and make money, have enough water to wash their hands, etc. more often and have more and cleaner water to drink."
>
> -Martin Fisher, Co-Founder & CEO of KickStart

Martin's comment addresses the area of this thesis' CBA that needs to be refined- other than the health and non-health benefits derived from clean water, what is the overall impact of a rainwater harvesting system on a houehold's livelihood? As mentioned, there might be hidden risks that a water supply intervention leads to exacerbated garbage disposal and hence a worse health outcome. More research needs to be done to understand the economic incentives of clean water. In addition, this study reveals the importance of collecting data collection before and after the implementation of rainwater harvesting systems. Over time, such data will provide valuable information on 1) the overall impact of rainwater harvesting system on health such as the changes in the cases of diarrheal disease, 2) the performance of the rainwater harvesting system, 3) how the households allocate the extra income and time saved, and 4) how the households respond to such information.

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# Appendix

**Figure 1.** The overview of *Rainwater for Humanity's* structure. *Rainwater for Humanity* adopts a collaborative and entrepreneurial approach.

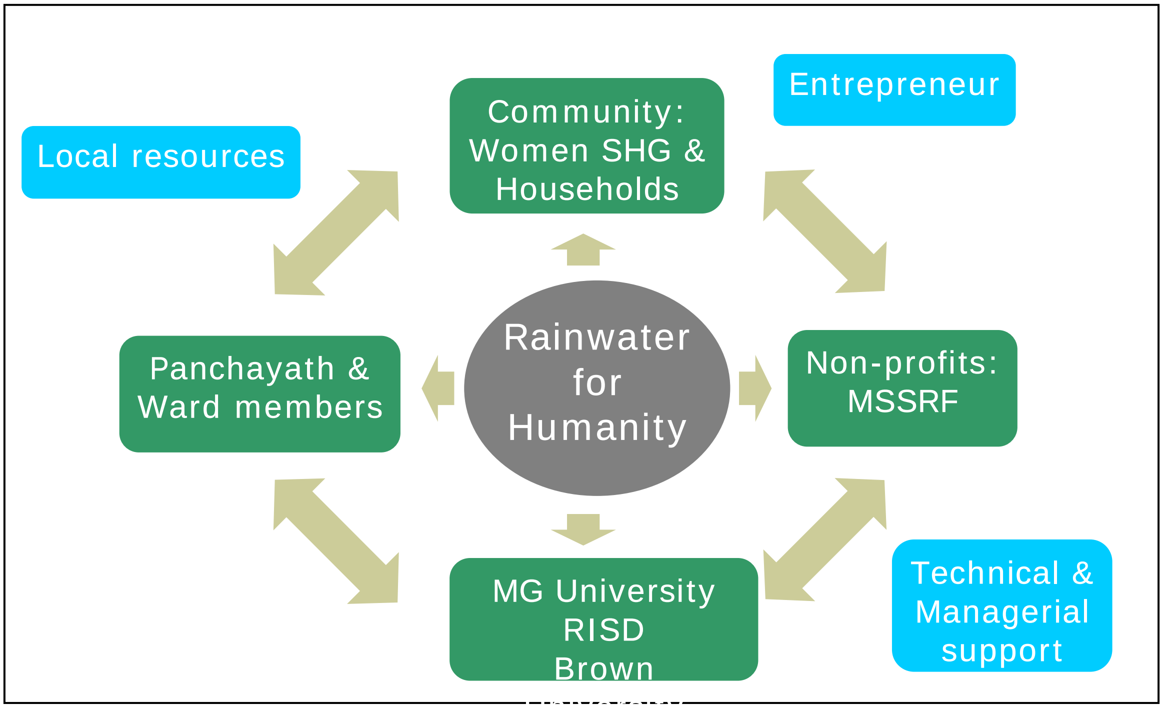
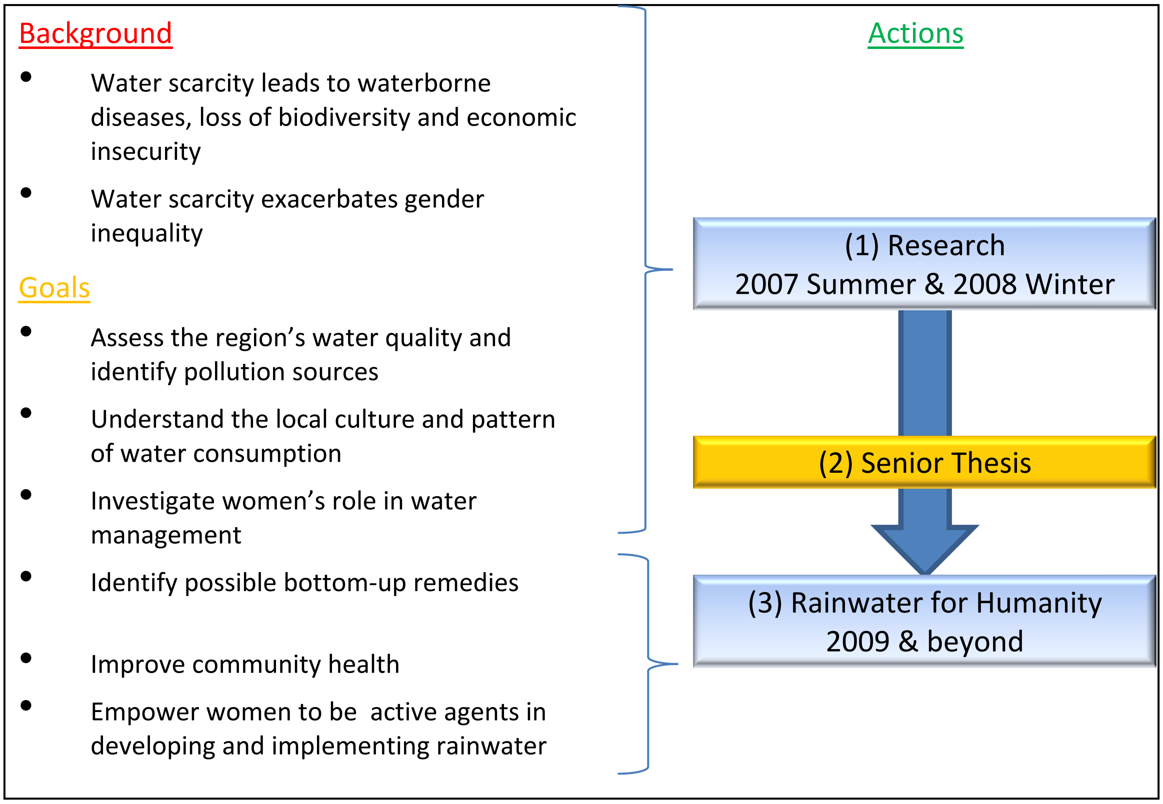


**Figure 2.** The thesis role and function of a larger effort known as *Rainwater for Humanity*



Background

- Water scarcity leads to waterborne diseases, loss of biodiversity and economic insecurity
- Water scarcity exacerbates gender inequality

Goals

- Assess the region's water quality and identify pollution sources
- Understand the local culture and pattern of water consumption
- Investigate women's role in water management
- Identify possible bottom-up remedies

- Improve community health
- Empower women to be active agents in developing and implementing rainwater

**Figure 3**. *The Kuttanad Waters Region in Alleppey District of Kerala.* The Thaneermukkam Barrage was constructed 30 years ago to increase rice production, with the additional pressure of agricultural land-use change, and human pollutions, the ecosystem in Lake Vembanad is disrupted with frequent eutrophication, invasion of alien species and spreading of water-borne diseases. Source unknown.

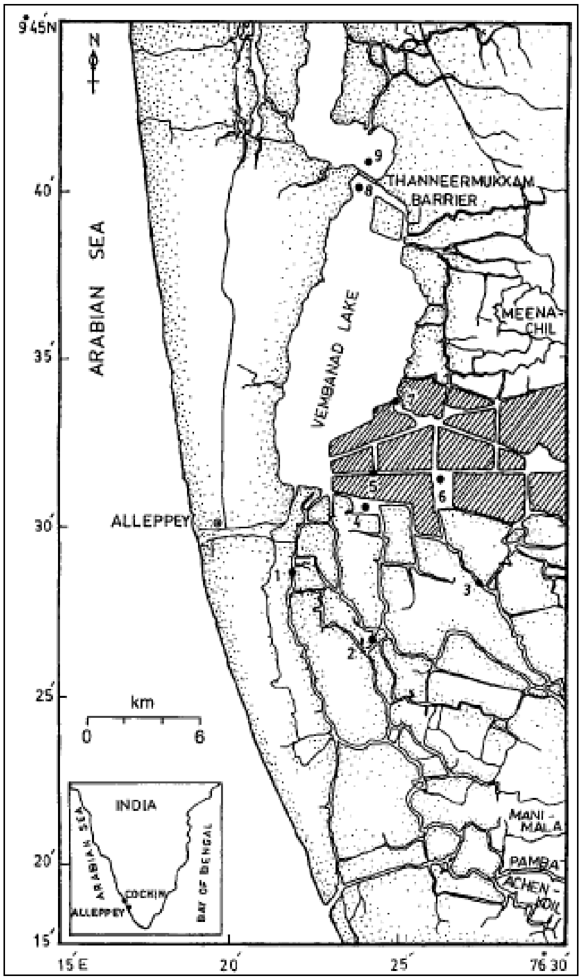


**Figure 4**. A total of 37 water samples were collected from a variety of sources including river, ponds, wells, public taps, and rainwater storage tank. There is a huge variety of available water sources amongst villages. The availability of water sources in each village were identified by observation or surveying the villagers.

| Sample Code | Site Name | River or Canal | Well | Tap | Pond | Rainwater |
|---|---|---|---|---|---|---|
| 1 | Nagampadam | R1 | W1 | T1 | / | / |
| 2 | Aalummoodu | R2 | W2 | / | / | / |
| 3 | Chengalam | R3 | W3 | T3 | / | / |
| 4 | Thiruvarppu | C4 | W4 | / | / | / |
| 5 | Parripu | C5 | W5 | T5 | / | / |
| 6 | Pulikkuttisserry | R6 | W6 | / | / | / |
| 7 | Maniyaparrambu | C7 | W7 | / | / | / |
| 8 | Kumarakom | R8 | W8 | T8 | / | / |
| 9 | Ithikayal | C9 | / | T9 | P9 | / |
| 10 | Cheepumnkal | R10 | / | T10 | / | RW10 |
| 11 | Achinakom | C11 | W11 | T11 & T11 GW | / | / |
| 12 | Kudaveehur | / | W12 | T12 | / | / |
| 13 | Edayazham | / | W13 | / | P13 | / |
| 14 | Perumthuruth | / | W14 | / | / | / |
| 15 | Kaipuzha | / | W15 | T15 | / | / |

**Figure 5.** The geographic locations of the 15 sampling sites. The sampling sites are clustered around the watershed of the Minachil River draining the North Kuttanad region.

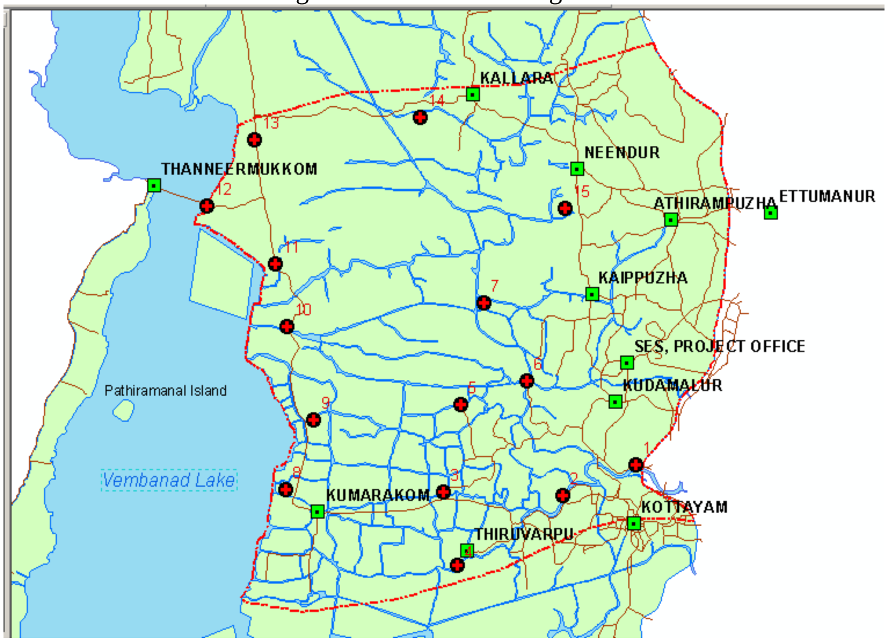


**Figure 6.** Two of the results of Coliform and/or E. coli colonies developed after 24 hours of incubation. On the left is the result of E. coli count for tap water from site 8 (T8). On the right is the result of E. coli count for river water from site 10 (R10). Though the colonies are denser in T8, due to the difference in water applied onto the petri dish, 5ml versus 1ml, the river sample actually contain more E. coli. In the cases of extremely dense colonies, the petri dishes were divided into four sections for ease of counting.

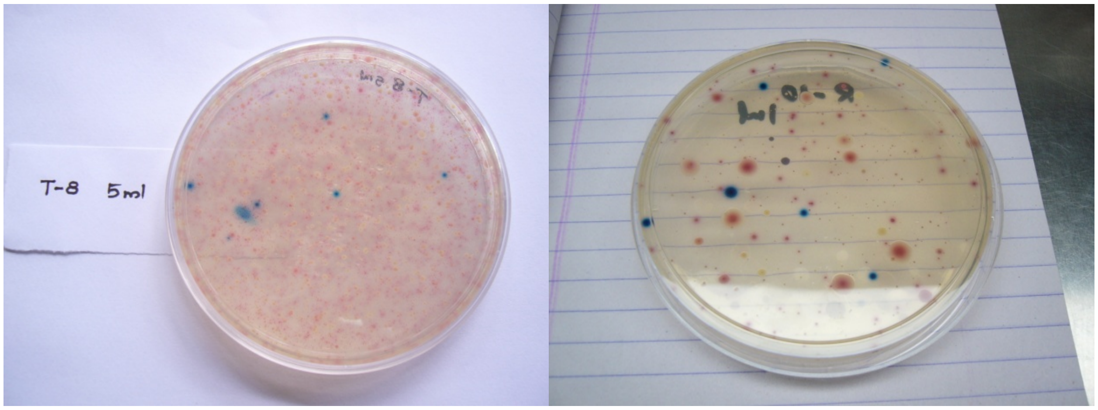


**Figure 7.** The analytical results of the 37 water samples. River water samples indicate a very high level of E. coli, with an average of 1,600 E. coli in 100ml of water. Over half of the well and tap water samples, which are commonly used as potable water, also show significant E. coli levels. The water samples from river, wells and taps are slightly acidic. It might be due to the iron leaching from the soil. The rainwater pH is alkaline, most probably due to the reaction of water with the mortar, which is the inner lining of the water storage tank. Aside from the E. coli and pH parameters, the water samples satisfy the other parameters' standards set forth by the WHO and the Bureau of Indian Standard.

| **Standard / Sample** | **pH** | **TDS (ppm)** | **Conductivity (us)** | **Hardness(mg/L)** | **Ca (mg/L)** | **Mg (mg/L)** | **Cl (mg/L)** | **Na (mg/L)** | **N (mg/L)** | **P (mg/L)** | **E. coli (per 100 ml)** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **WHO** | **6.5-9.2** | **500.0** | **/** | **500.0** | **100.0** | **150.0** | **500.0** | **200.0** | **45.0** | **/** | **0.0** |
| **EPA** | **6.5-8.5** | **500.0** | **/** | **/** | **/** | **/** | **250.0** | **/** | **10.0** | **/** | **0.0** |
| **BIS** | **6.5-8.5** | **500.0** | **/** | **300.0** | **75.0** | **30.0** | **250.0** | **/** | **45.0** | **/** | **10.0** |
| R1 | 5.8 | 13.9 | 29.5 | 10.0 | 2.4 | 7.6 | 16.0 | 3.7 | 1.6 | 0.1 | 2550.0 |
| R2 | 6.0 | 15.8 | 31.2 | 18.0 | 3.2 | 14.8 | 16.0 | 3.7 | 1.0 | 0.1 | 2000.0 |
| R3 | 5.8 | 16.0 | 33.4 | 12.0 | 1.6 | 10.4 | 13.0 | 3.1 | 1.4 | 0.0 | 2000.0 |
| R4 | 6.1 | 14.0 | 29.6 | 6.0 | 4.0 | 2.0 | 17.0 | 3.6 | 1.9 | 0.2 | 2000.0 |
| R5 | 5.9 | 24.2 | 50.3 | 14.0 | 3.2 | 10.8 | 15.0 | 5.5 | 1.1 | 0.1 | 1050.0 |
| R6 | 5.9 | 21.5 | 43.5 | 14.0 | 3.2 | 10.8 | 14.0 | 3.9 | 0.9 | BDL | 950.0 |
| R7 | 6.0 | 21.7 | 44.5 | 14.0 | 3.2 | 10.8 | 12.0 | 5.2 | 0.2 | 0.1 | 2000.0 |
| R8 | 6.1 | 24.3 | 51.3 | 14.0 | 2.4 | 11.6 | 18.0 | 5.7 | 0.4 | 0.1 | 3000.0 |
| C9 | 6.0 | 33.1 | 69.1 | 20.0 | 3.2 | 16.8 | 15.0 | 8.9 | 0.7 | 0.1 | 1000.0 |
| R10 | 5.9 | 31.6 | 64.7 | 18.0 | 4.8 | 13.2 | 23.0 | 7.6 | 0.4 | 0.1 | 750.0 |
| R11 | 5.3 | 133.0 | 266.0 | 42.0 | 6.4 | 35.6 | 55.0 | 30.8 | 0.4 | 0.5 | 800.0 |
| W1 | 5.6 | 30.6 | 60.6 | 30.0 | 7.2 | 22.8 | 20.0 | 3.5 | 0.7 | 0.5 | 100.0 |
| W2 | 6.0 | 144.0 | 300.0 | 82.0 | 21.6 | 60.4 | 39.0 | 20.6 | 9.7 | 0.2 | 0.0 |
| W3 | 6.0 | 148.0 | 311.0 | 80.0 | 18.4 | 61.6 | 48.0 | 28.5 | 1.7 | 0.1 | 1650.0 |
| W4 | 6.0 | 141.0 | 294.0 | 102.0 | 22.4 | 79.6 | 31.0 | 22.4 | BDL | 0.1 | 700.0 |
| W5 | 6.4 | 127.0 | 262.0 | 102.0 | 42.1 | 59.9 | 21.0 | 9.3 | 2.5 | 0.0 | 1400.0 |
| W6 | 5.6 | 113.0 | 231.0 | 48.0 | 12.0 | 36.0 |  | 20.0 | 1.1 | 0.1 | 600.0 |
| W7 | 6.1 | 98.0 | 202.0 | 48.0 | 12.8 | 35.2 | 33.0 | 25.1 | BDL | 0.1 | 750.0 |
| W8 | 6.8 | 480.0 | 982.0 | 276.0 | 73.7 | 202.3 | 240.9 | 73.7 | BDL | 0.1 | 90.0 |
| W11 | 6.0 | 75.7 | 147.0 | 72.0 | 20.0 | 52.0 | 14.0 | 5.7 | BDL | 1.2 | 50.0 |
| W12 | 6.4 | 120.0 | 233.0 | 104.0 | 37.7 | 66.3 | 27.0 | 10.6 | 1.1 | 0.2 | 500.0 |
| W13 | 6.4 | 123.0 | 239.0 | 92.0 | 32.9 | 59.1 | 29.0 | 13.4 | 8.8 | 0.0 | 0.0 |
| W14 | 4.8 | 64.1 | 125.0 | 20.0 | 4.8 | 15.2 | 38.0 | 28.2 | 8.4 | 0.0 | 0.0 |
| W15 | 5.4 | 46.1 | 89.2 | 22.0 | 6.4 | 15.6 | 19.0 | 8.6 | 7.1 | 0.2 | 0.0 |
| T1 | 6.4 | 21.3 | 45.2 | 26.0 | 4.0 | 22.0 | 19.0 | 3.7 | 0.0 | 0.1 | 0.0 |
| T3 | 6.5 | 27.2 | 57.0 | 16.0 | 3.2 | 12.8 | 17.0 | 6.1 | 0.7 | 0.1 | N/A |
| T5 | 4.9 | 84.3 | 171.0 | 38.0 | 6.4 | 31.6 | 36.0 | 16.5 | 22.2 | 0.1 | 460.0 |
| T8 | 4.5 | 44.5 | 93.0 | 20.0 | 3.2 | 16.8 | 28.0 | 9.1 | 0.7 | 0.1 | 0.0 |
| T9 | 6.6 | 96.0 | 203.0 | 56.0 | 16.0 | 40.0 | 39.0 | 17.6 | 2.9 | 0.0 | 140.0 |
| T10 | 6.6 | 146.0 | 302.0 | 66.0 | 16.0 | 50.0 | 56.0 | 31.8 | 0.7 | 0.8 | 40.0 |
| T11 | 7.3 | 408.0 | 749.0 | 196.0 | 31.3 | 164.7 | 140.0 | 78.7 | 0.2 | 0.6 | 20.0 |
| T11 | 6.3 | 143.0 | 222.0 | 94.0 | 10.4 | 83.6 | 26.0 | 19.1 | 2.0 | 0.5 | 0.0 |
| T12 | 7.3 | 402.0 | 814.0 | 102.0 | 24.8 | 77.2 | 32.0 | 80.2 | 2.2 | 0.7 | 0.0 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| T15 | 6.0 | 84.5 | 169.0 | 44.0 | 12.8 | 31.2 | 25.0 | 13.6 | 7.0 | 0.5 | 50.0 |
| P9 | 5.5 | 34.7 | 71.8 | 16.0 | 3.2 | 12.8 | 10.0 | 8.5 | BDL | 0.2 | 0.0 |
| P13 | 5.7 | 58.8 | 116.0 | 32.0 | 8.8 | 23.2 | 30.0 | 12.7 | 2.4 | 0.2 | 450.0 |
| RW10 | 8.4 | 27.2 | 57.7 | 32.0 | 9.6 | 22.4 | 12.0 | 1.3 | 2.7 | 0.0 | 0.0 |

Sources: World Health Organisation; US EPA; Bureau of Indian Standard

**Figure 8.** The E. coli distribution in the river system of North Kuttanad. The major E. coli hotspots were the city center Kottayam and the down stream of the river in Kumarakom. The belt region from Kottayam to Kumarakom showed a relatively high E. coli level when compared to the northern region. As Kottayam is a major city center and Kumarkom is a major tourist attraction, the condition suggests a correlation of population density and E. coli level. E. coli level peaks in Kumarakom due to a number of hotels and tourist houseboats congregated in the area, releasing untreated sewage in the canals illegally.

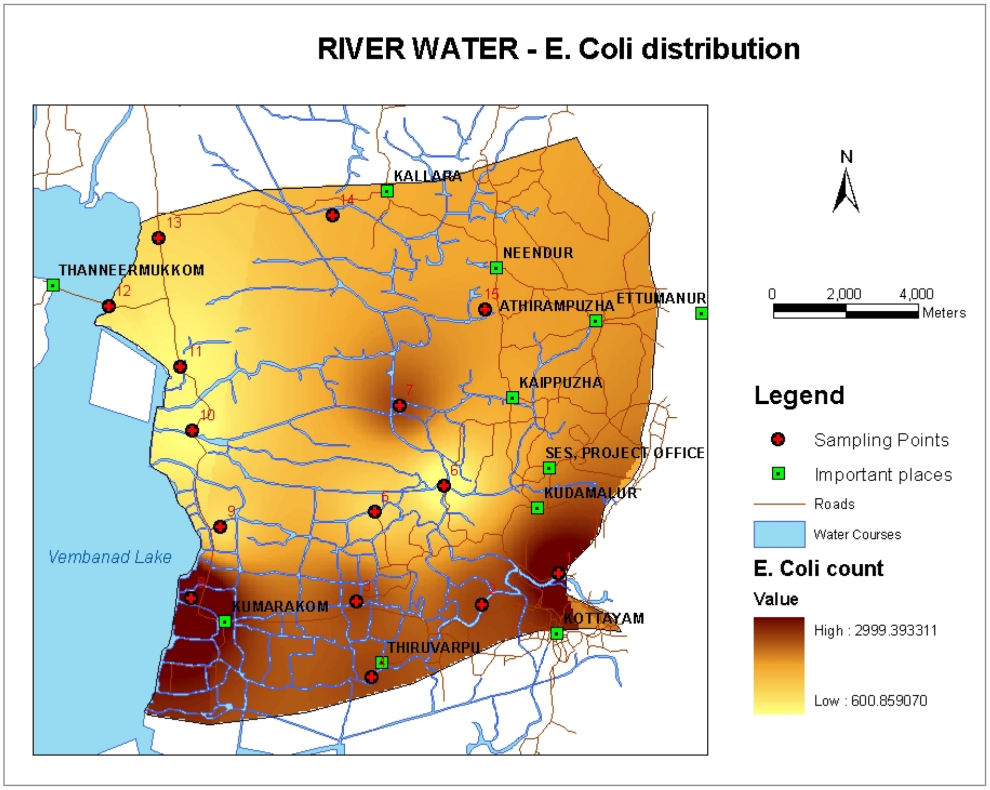


**Figure 9.** The E. coli distribution in the well water system of North Kuttanad. The well water pattern of E. coli levels is very different from the river water quality pattern. Sampling site 3 Chengalam and site 5 Parripu contain the highest levels of E. coli in the region’s well water. The relatively low topography of site 3 and site 5, situated in the down gradient of underground water flow, implies that underground septic tank leakage might be present.

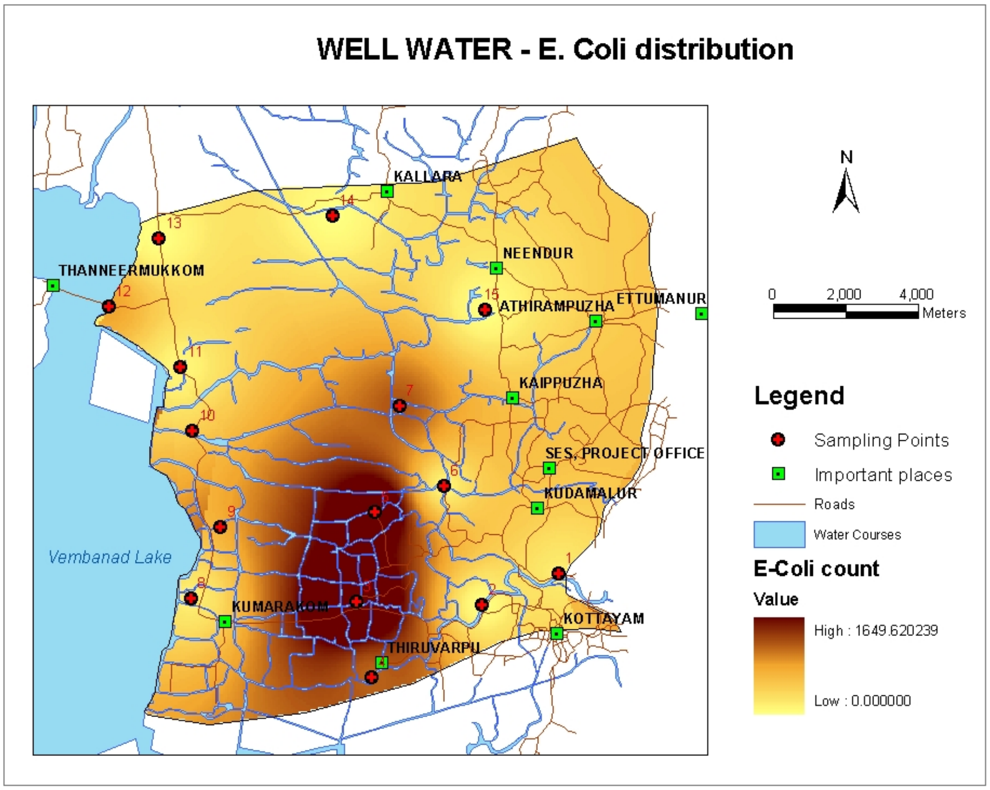


**Figure 10.** The canvassed village known as the Achinakom. It is located in North Kuttanad, with over 141 households.

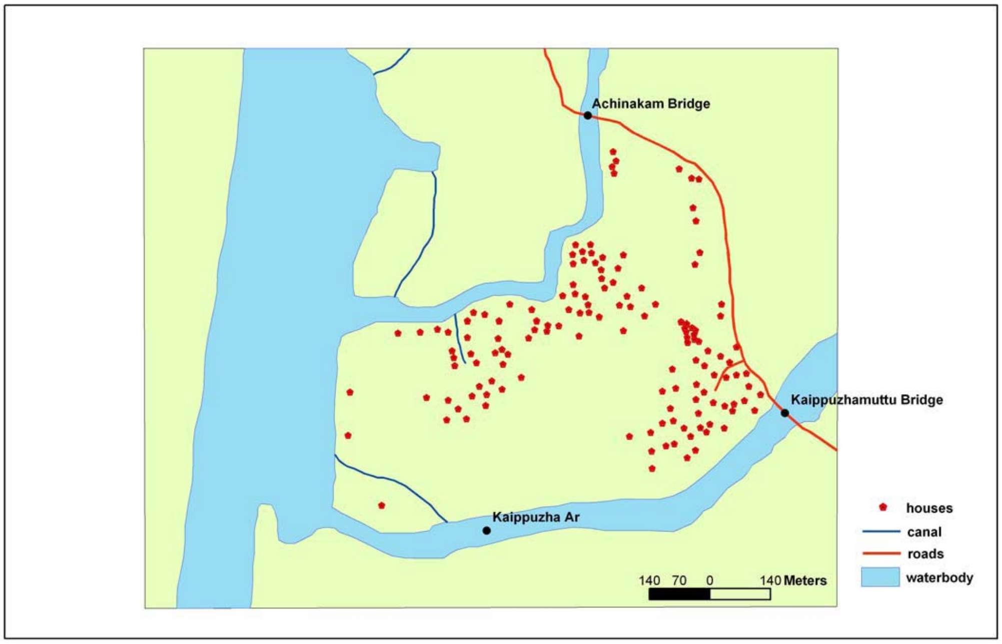


**Figure 11.** The Achinakom Survey Demography

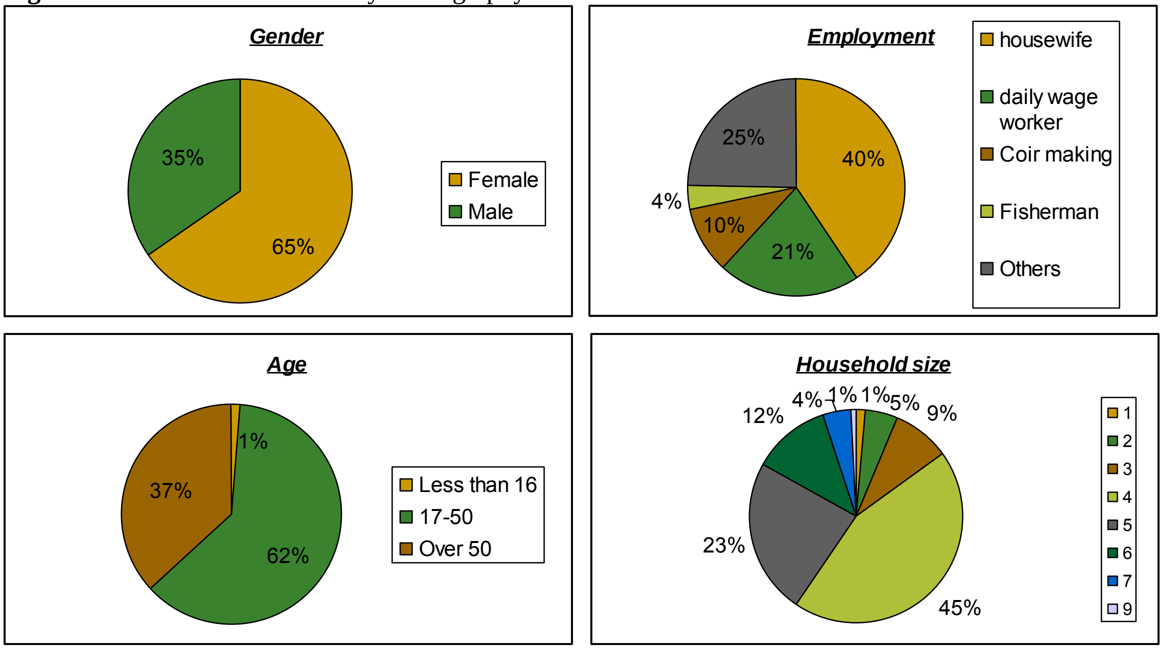


**Figure 12**. The drinking and cooking water sources during the summer season and the monsoon season

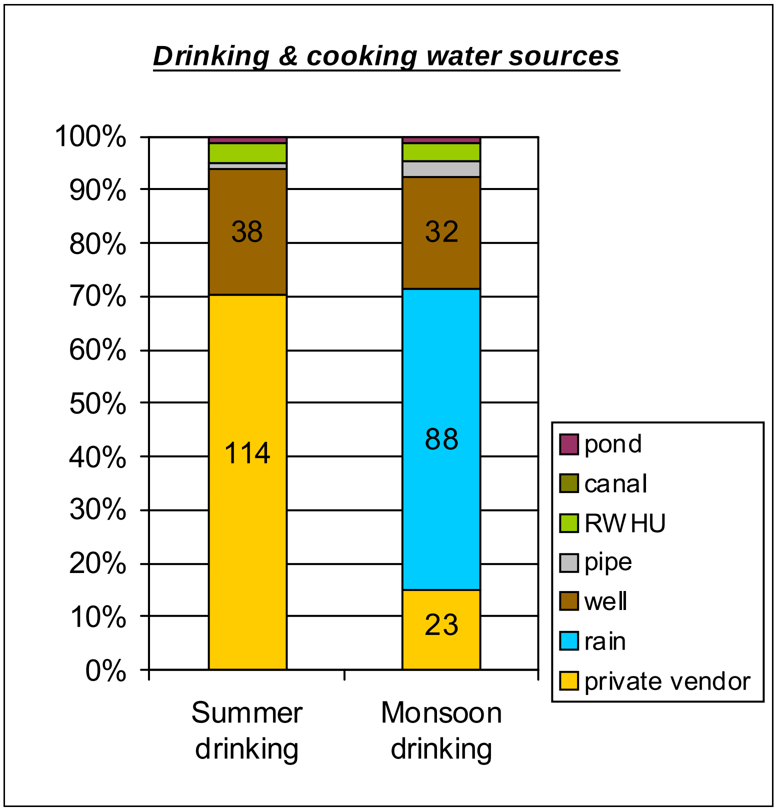


**Figure 13.** The average per capita water consumption during summer season and monsoon season

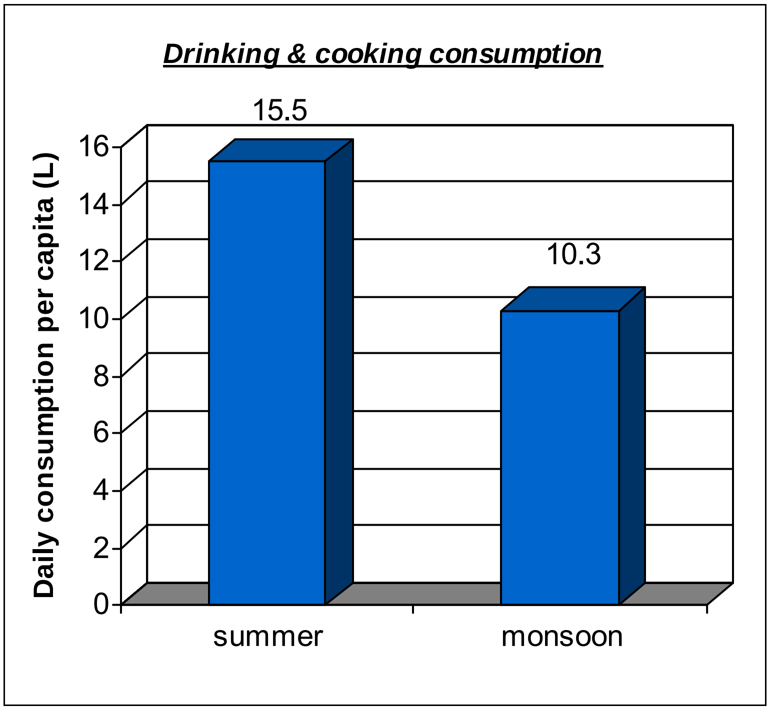
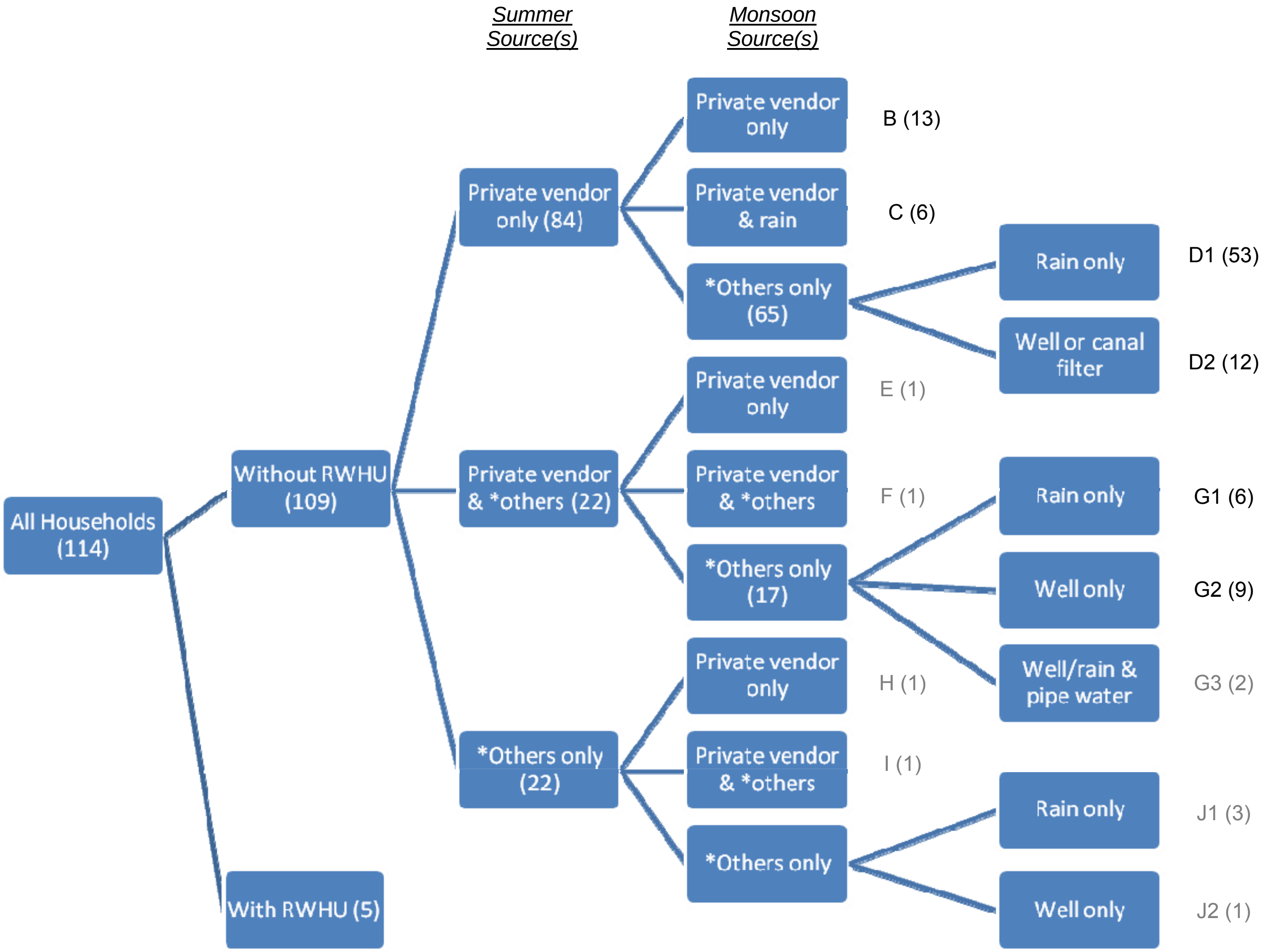


**Figure 14.** Classification of Achinakom's households according to their water sources. Due to limited sampling size, household groups with less than three data points are not included in the cost benefit analysis.



*Others = payment free source including well, filter canal water, cloth & bucket rain collection

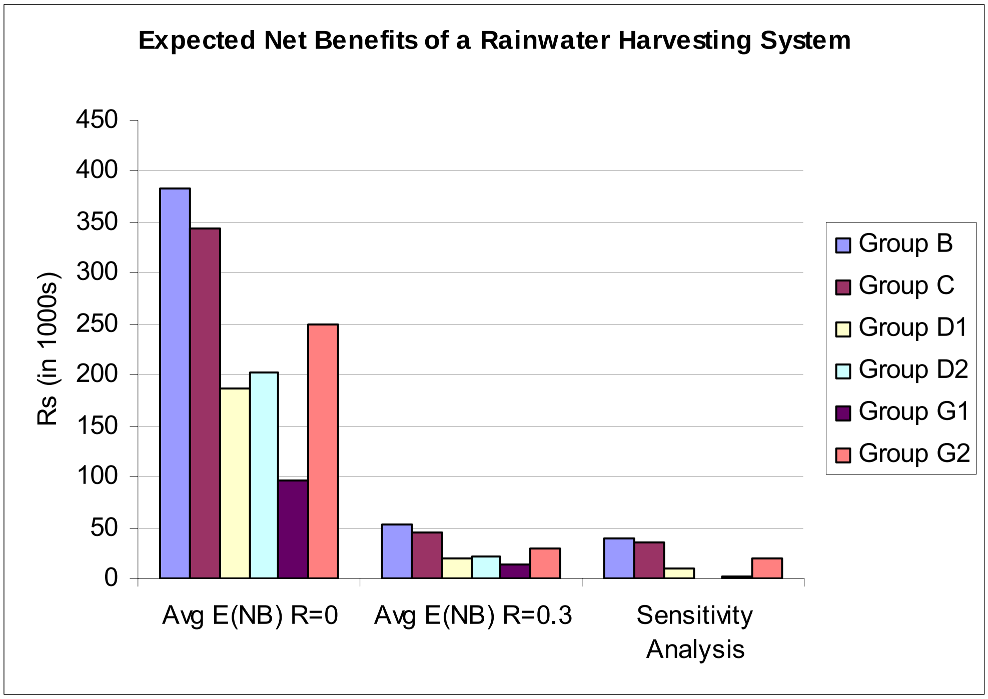
**Figure 15.** Assumptions of variables and direction of bias towards net benefits

| Variable | Definition | Assumption | Direction of bias towards NB | | Magnitude | | |
|---|---|---|---|---|---|---|---|
| | | | Positive | Negative | Small | Medium | Large |
| ***Health Benefits*** | | | | | | | |
| $I_h$ | Income saved from less healthcare cost per year | 1/3 of World Bank regional estimation | ● | | | | ● |
| j*q | Income saved from private vendor payments= j (price per liter of water sold by the private vendor)* q (drinking and cooking water consumed per person in the household) | Survey data. No assumptions involved | ● | | | | ● |
| $t_p$-$t_r$ | Time saved from collecting water = tp (time needed to collect water from private vendors, well or pond water) - tr (time needed to collect water from a rainwater harvesting system) | Time saved is monetized by the value of time (see assumption for v) | ● | | | ● | |
| v | Value of time | Value of time is the daily minimum wage in Kerala. Assumed 8 working hours per day, and minimum wage is fully enforced. Assumed full employment throughout the year. Seasonal fluctuations in labor demand will be reflected in sensitive analysis | ● | | | ● | |
| w | Extra producitve days and increased productivity without disease | No. of diarrhoeal cases averted and hospitalized days averted per capita; increased producitivity due to better health | ● | | | ● | |
| e | No. of members employed and/or attending school (below 17 years old) in the household | Each working and school day lost will lead to income forgone and diminished human capital respectively | ● | | | ● | |
| d | No. of childcarers in the household | Each childcarer day lost is equivalent to 0.5 of Kerala's minimum wage | ● | | | ● | |
| ***Costs*** | | | | | | | |
| M | Annual maintanence cost from Year 1-19 | 10% of the rainwater harvesting system initial investment cost | | ● | ● | | |
| C | Capital cost of RWH structure | Highest cost found from Kuttanad non-profits and Panchayath | | ● | | ● | |
| p | Probability that the RWH will function properly and provide sufficient water for the household consumption throughout the year | 14 years of rainfall data in Kuttanad is taken into consideration. A rainwater harvesting unit will be able to suffice all years aside from the driest year of the past 14 years. Estimation of drought will then be 1/14. Other risks such as contaminations, leakage, poor maintenance lead to an addition 0.2 chance of failure | | ● | | | ● |

**Figure 16.** Variables' input assumptions in different discount rate scenarios and a discounted cashflow.

| ***Input*** | ***R= 0*** | ***R=0.3*** | ***Sensitivity Analysis*** |
|---|---|---|---|
| **$I_h$** | 2233 | 2233 | 1340 |
| **$t_r$** | 0.0042 | 0.0042 | 0.0042 |
| **v** | 107.78 | 107.78 | 71.85 |
| **w** | 2 | 2 | 1.0 |
| **M** | 107.78 | 107.78 | 107.78 |
| **C** | -13,500 | -13,500 | -13,500 |
| **RWH system lifetime** | 20 | 20 | 5 |
| **# of days** | 365 | 365 | 365 |
| **Seasons** | 0.5 | 0.5 | 0.5 |
| **Parameter of child caring service in terms of minimum wage** | 0.5 | 0.5 | 0.5 |
| **p (work)** | 0.73 | 0.73 | 0.50 |
| **r** | 0 | 0.3 | 0.3 |

**Figure 17.** Estimated Net Benefits and in bracket, standard deviation of the Achinakom Village from utilizing the rainwater harvesting system.



| Group | Avg E(NB) R=0 | Std Dev | Avg E(NB) R=0.3 | Std Dev | Sensitivity Analysis | Std Dev |
|---|---|---|---|---|---|---|
| **B** | 383608 | 313578 | 52232 | 51905 | 39997 | 51840 |
| **C** | 343385 | 182384 | 45574 | 30189 | 35099 | 30759 |
| **D1** | 187231 | 324899 | 19726 | 53779 | 9321 | 53488 |
| **D2** | 202691 | 162420 | 21839 | 27091 | 61 | 21078 |
| **G1** | 95400 | 87863 | 13539 | 11414 | 2224 | 7501 |
| **G2** | 249394 | 322310 | 30016 | 53351 | 19795 | 51206 |