C-3 Report by IIT Delhi, July 2000

WATER QUALITY IN DOMESTIC ROOFWATER HARVESTING SYSTEMS (DRWH)

ABSTRACT

The biological and chemical quality of water samples from experimental DRWH set up at IITD, New Delhi were analysed. Data reported in the literature on DRWH water quality were compiled by world region.

Based on experimental and compiled data it is seen that physico-chemical quality of water is generally acceptable and this can be easily monitored using field kits.

As for biological quality, there is a need for further discussions at global levels, on the indicator bacteria used for testing rain water. Under the current project, water quality from different types of experimental DRWH systems was tested by rapid field tests and compared with lab tests by standard procedures. H2S strip test is suitable at field level for detection of high level bacterial contamination. In 70% of the samples tested the bacterial content exceeded the potability standards. Avoiding the first 2 mm of rain as first flush was found to reduce contamination. It appears advisable to treat the water from DRWH before drinking.

Bacterial growth and decline, kinetics of bacterial decay, conditions for algal growth in water stored in DRWH, are also under study and preliminary results are reported herein.

CONTENTS

1 INTRODUCTION

1.1 Background

The sub-programme under the project on DRWH, namely, "Health issues related to DRWH" is led by I.I.T., Delhi. The focus is on the following issues:

1) To see if the quality of water in DRWH storage meets potable water standards.
2) To study various design parameters which influence the quality of water.
3) Suggest modifications and practices to be introduced to make the quality of water acceptable.
4) Suggest design modifications and practices needed for insect/mosquito control.

Early in the current year the C-2 report on "DRWH and insect vectors: A literature review" was submitted.

The following activities were taken up with respect to water quality:

a) The review of literature on "Water Quality in DRWH systems" was updated.
b) The efficacy of various measurement techniques for determining water quality was experimentally examined. The results for different types of tests were correlated.
c) DRWH systems with different design modifications were set up and water quality was monitored and related to design aspects.

The results of water quality tests are presented in this report (C-1). The water quality in DRWH as reported by different researchers from different countries is also recorded. Some additions and modifications have been made to this report based on additional information obtained in the current year. Experimental facilities were set up for rapid and in depth analysis of inorganic, organic and biological contaminants in water.

1.2 Water quality in DRWH

As seen from the literature survey the percentage of DRWH samples which meet potability standards vary from 10-70% in terms of bacterial quality. Thus in the worst case 90% of the samples do not meet the standards (Appendix I). Clearly in no case 100% of the samples were found to meet bacteriological standards. On the other hand chemical quality of DRWH samples were acceptable in majority of cases except in the of first flush, and also when toxic metals or chemicals from roof or the atmosphere, was there.

Hence, DRWH would be especially useful where the ground water is highly contaminated by chemicals such as arsenic, fluoride or other chemical contaminants, but the bacteriological quality would still require monitoring. In this context rain water harvested from the roof directly would indeed be a valuable source. It is relatively easy to eliminate bacterial contamination by boiling, but elimination of dissolved chemicals even in small concentrations is quite costly.

Under the project it was proposed to systematically test the biological quality of water from different DRWH systems, using different measurement techniques, and look for correlations. Among bacteriological contaminants, total and faecal coliform, faecal streptococci and E. coli are used as indicator bacteria for faecal contamination. H_2S producing bacteria can also be monitored. Details on H_2S strip tests, MPN and other standard methods were presented in Report C-1. In addition the following tests which are useful in the detection of biological contamination are available. Details of these are appended to report C-1:

i) Coliphage detection test
ii) β Galactosidase/enzymatic test
iii) Viral detection in water

The biological quality has to be tested immediately after sampling. In this regard rapid tests are very useful. Different authors have used different tests as were described in the Report C-1. Of these, the H_2S strip test is considered promising. In the present study, water quality as measured by the H_2S test was compared with results obtained by laboratory MPN method/plate count method. Based on this the reliability of the rapid test was examined.

1.3 WQ measurements in experimental DRWH systems

Various design parameters have been identified as contributing to the contamination of rain water. Specifically the effect of the following needs attention:
i) whether there is first flush diversion.
ii) the types of roof, gutter, tank, filter
iii) the nature of the roof's surroundings: e.g. overhanging trees, accumulation of leaves, animal and bird droppings

Five DRWH systems with varying design features were constructed on the I.I.T., Delhi Campus. The salient features of these systems are shown in Table 1.

2 BIOLOGICAL QUALITY OF WATER SAMPLES

2.1 Indicator bacteria and correlations between tests using them

It may be noted that the H_2S producing bacteria like *Clostridia perfringens* are normally present in faeces. Though in much smaller number as compared to *E. coli*, they can survive in water longer than coliform bacteria. The H_2S strip test depends on their presence. Although the H_2S strips have a good shelf life, it was noted that, while freshly prepared strips become black in 24 hrs in the presence of H_2S producing bacteria, in the case of shelf-stored strips an incubation of 48 hrs may be needed. Hence, while establishing a correlation between the results of H_2S strip tests and MPN tests, a time period of 48 hrs was chosen.

The ratio of faecal coliform to faecal streptococci gives an idea of the source of faecal contamination. If FC:FS < 1, it suggests that the contamination is of non-human origin i.e. animals and birds. But if FC:FS > 4, it is implied that faecal contamination may be of human origin, which could also be secondary. Primary contamination by human excreta may however be ruled out where the roof is inaccessible to humans. It may be noted that in stored water samples, streptococci can produce enough lactic acid and other organic acids from sugar fermentation that their medium becomes acidic and their growth is inhibited. This may lead to faster reduction in streptococci as compared to coliform, thus raising the FC:FS ratio for the stored sample above that in the fresh sample. Hence the time elapsed between water contamination and testing becomes crucial.

Water samples from each of the tanks were analysed at different times to see the water quality, with or without intermittent rains. The samples were drawn in sterilised bottles and tested for potability. A total of 54 samples were analysed. The results are compiled in tables 2A, 2B, 2C, 2D and 2E respectively for tanks MAA, MAP, BLC, BLT and MIC (the tank features are shown in table 1). Table 2F shows some rainfall data. The data for the first flush samples are shown in table 3A. As expected, the bacterial count in the first flush was very high.

H_2S strip test is an excellent test suitable for field level as it is easy, cheap and the villagers can see the black colour. MPN test is quantitative as it gives the most probable count of bacteria. The correlation between rapid H_2S strip test and various MPN test was examined (tables 3B-3F).

P_1 signifies a positive correlation when both the tests give negative results i.e. bacterial count below limits specified.
P_2 is a positive correlation when both the tests give positive results i.e. indicate bacterial counts above the limits specified.
N_1 signifies a situation where strip test does not give black colour in 48 hrs but MPN shows a bacterial count.
N_2 is signifies a situation where H_2S strip test gives black colour in 48 hrs but MPN does not give a bacterial count.
Thus N_1 and N_2 stand for negative correlation between the two tests.

Out of the total different samples analysed, 65-75% gave a positive correlation ($P=P_1+P_2$) between MPN and H_2S strip tests; the correlation is slightly lower where an MPN-FS test is used than when MPN-FC or MPN-TC is used. The correlation is generally higher at low levels of bacterial contamination, i.e. in most cases $P_2>P_1$.

In the remaining (35-25%) cases ($N_1 + N_2$), the two tests did not correlate (table 3B). Out of these 15-25% gave positive results for MPN but negative ones for the H_2S strip test (N_1) and ~15% gave negative results for MPN test but positive ones for H_2S (N_2). In other words in ~20% of cases even though the H_2S test shows that the water is potable this is really not so in terms of MPN. This negative correlation is more pronounced when bacterial counts are low. Roger Fujioka has evolved an MPN test based on H_2S strip method under the project. We will also evolve a MPN test based on H_2S and study the correlation with MPN for other bacteria.

Out of the water samples tested on the current project, only 13% of the samples met WHO standards for all the three indicator bacteria as well as H_2S test, and at best 25-30% samples met the relaxed standards (Table 3F). In a report (see idrc.ca/library document 008918) from International Development Research Centre (IDRC), the H_2S strip test and MPN tests with regards to total coliform and faecal coliform have been compared. The samples analysed in this report included rain water, shallow well water, pond water and deep well water. About 39% of the rain water samples were found to meet the potability standards, while for shallow well and deep well the potable samples were 3.4 and 83.3% respectively. Thus rain water was much better than shallow well water, whereas deep well water was the best. It is noted that contamination in case of rain water may be due to birds and rats. In this report correlations between H_2S and MPN tests are also presented. This varies with the type of water, i.e. shallow-well, deep-well or rain water, reflecting perhaps on the differences in the bacterial consortia present in the sample. Further work is needed in this direction.

2.2 Correlation between turbidity and number of bacteria

Pure E. coli was inoculated in 1,000 ml of sterile water and serial dilution of it was performed, as indicated in Table 4A. Each of the diluted samples (standard samples) and rain water samples were spread plated on nutrient agar plates and incubated at 35°C for 24 hrs. The number of colonies were counted in a cell counter. For the same samples turbidity was measured in a nephelometer.

As seen from the table, a rainwater sample with a low NTU of 1 had 1.632×10^6 bacterial colonies, whereas sterile water with a NTU of 1.5 had no colonies. This is because suspended colloidal particles and organic matter, contribute to turbidity besides bacteria. If turbidity was only due to bacteria even at 5 NTU the bacterial count could be greater than 3×10^7.

2.3 Decay rate of total coliform, faecal coliform and faecal streptococci in water samples stored in the tanks and in PET bottles

Three tanks were chosen from different locations having different number of initial bacterial count.

i) MIC, a cement tank with high bacterial count.

ii) BLT, a segmented cement tank at Institutional Area with high bacterial count.
iii) BLC, a cement tank at the Institutional Area with low bacterial count.
1,000 ml of samples were drawn from each into sterilised bottles.

66.6 ml of the sample was subjected to MPN test for detecting the presence of coliform group of bacteria and streptococci. The procedure was repeated everyday to observe the fall of bacteria with respect to time period. The results are shown in Tables 5A, 5B and 5C for MIC, BLT and BLC respectively. A decay rate curve was plotted between the time period (in days) and the MPN. It was observed that the total coliform and faecal coliform count fell in 20-25 days and faecal streptococcus fell in about 10-16 days. Therefore, on an average, the bacteria decay in 10-25 days of storage.

2.4 Decay rate of bacteria in the presence and absence of nutrients (Isolation of pure strains from rain water samples)

(a) Decay of faecal coliforms

Isolation of E. coli from rain water

33.3 ml of rain water was subjected to the MPN test to detect the presence of coliform in MacConkey Broth for 48 hrs at 35°C in the incubator. The tube with maximum growth was taken and presence of *E. coli* was confirmed by inoculating a loop full of bacteria into the Brillinat Green Lactose Bile Broth and further grown at 35°C for 24 hrs. From the BGLB tube 2 loops-full of bacteria was spread plated and streaked onto a series of nutrient agar plates and allowed to grow at 35°C for 24 hrs.

The growth of 2 types of colonies typical (nucleated with or without blue green metallic sheen) and atypical (opaque, un-nucleated, mucoid, pink) were observed. From each of these plates one or more well isolated *E. coli* colonies were picked up and transferred to series of nutrient agar and Eosin methylene blue agar plates to grow separate typical and atypical colonies at 35°C for 24 hrs. The process was repeated for a few generations to obtain a pure strain of *E. coli* and the presence was confirmed by performing MRVP test.

Inoculation of the pure strain of E. coli into samples with different nutrient level

Six loop fills each of the pure strain was first dissolved in 1 ml of sterile water and made up to a volume of 5 ml. This 5 ml of pure strain of *E. coli* was transferred into 1,000 ml each of (1) double distilled, sterile water, (2) rain water samples which was boiled to kill the micro-organisms and (3) rain water which was not boiled. Each of these samples were immediately subjected to MPN test and again at an interval of 4 hrs and subsequently every day to observe the bacterial decay rate with respect to nutrient availability. The data are shown in table 6A and 6B. It is observed that in complete absence of nutrient i.e. in sterilised water, the coliform bacteria survived for about 10-11 days. But in the presence of limited nutrition, the coliform bacteria decayed in 20-25 days.

(b) Decay of faecal streptococci

Isolation of faecal streptococcus from rain water sample

33.3 ml of rain water was subjected to MPN test to detect the presence of streptococcus by growing in Azide Dextrose Broth for 48 hrs at 35°C in the incubator. The tube with maximum growth was taken and a loop full of bacteria was transferred on to the PSE (Pfizer Selective Enterococcus) agar plates at 35°C for 24 hrs. A loop full of growth was used for generations in several plates of PSE agar to obtain a pure strain.

Inoculation of pure strain of streptococcus into samples with different nutrient levels

Six loop fulls each of the pure strain was first dissolved in 1 ml of sterile water and the volume was made to 5 ml. This was transferred into 100 ml each of (1) double distilled, sterile water (2) rain water after boiling to kill the micro-organisms and (3) rain water without subjecting to boiling.

Each of these samples were immediately subjected to MPN and again at an interval of 4 hrs and subsequently everyday to observe the bacterial decay rate with respect to nutrient availability. In case of the faecal streptococci the experiments indicated that in the total absence of nutrient i.e. in sterilised water, the streptococci count fell within 2 days. But in the presence of limited nutrition the streptococci count fell over 17-20 days approximately. The data are presented in Table 6.

(c) Decay rate constant

As discussed earlier the coliform group of bacteria decays at a slower rate as compared to the faecal streptococcus. It has been reported that the faecal streptococci when provided with sufficient nutrition grow abundantly and in this process the streptococci release toxins which inhibit the growth of their own kind. As a result, the decay rate of streptococci is much faster than the coliform group.

When the decay rate was studied for the same group of bacterium in the total absence of nutrient it was observed that due to self generated toxicity the streptococci count falls rapidly but the coliform group survive. In the presence of limited nutrition, both the bacteria fell at a slower rate as compared to the rate of decay in the total absence of nutrition. This trend was seen even on boiling the water and inoculating pure culture, the dissolved solids (nutrients) are not eliminated by boiling. The decay rate constant (often expressed as the generation/hour) was calculated.

In our experiments, the fall of bacteria under different conditions was studied and the decay was noted in (i) 1,000 ml of sterile water (ii) a sample of stored rain water from the storage tank MAP (iii) a sample of the same rain water, which was boiled to eliminate the existing bacteria (see table 6A & 6B). A graph was plotted between number of days (time period) and number of cells (MPN count). The rate constant/decay constant was found to approximately -1 generation/ day (see table 6C).

2.5 Testing for heterogeneity of the samples with respect to bacterial distribution

The following test was performed to see the distribution of bacteria on storage. Two types of samples were taken as described below:

i) Sample was kept standing for 24 hrs and water drawn from different heights/levels of the bottle.
ii) Sample was shaken vigorously and water drawn in triplets.

1,000 ml of rain water was collected and stored in two PET bottles up to a height of 18 cm in each case. Markings were made at distances 1 cm (L3), 8 cm (L2) and 16 cm (L1) respectively from the base. One of the bottle was kept standing. A 50 ml sample was withdrawn from different levels and taken into separate sterilised bottles. The second bottle of rain water sample was vigorously shaken and samples were randomly drawn from the PET bottle in triplets to observe the distribution of bacteria. All the samples drawn were subjected to the standard methods of MPN test and H_2S strip rapid test. The results are shown in table 7.

It was seen that on mixing the water by shaking, an average count of TC (46), FC (240) and FS (0) was seen. On the other hand on allowing the water to stand, there is a gradation in bacterial counts with more bacteria at the lower level closer to the base. But the gradation was not linear with depth. Further work is needed in this direction.

2.6 Water treatment methods

Since, it was observed that rainwater was found potable only 30% of times even with relaxed standards, the following physical treatments methods were applied to bring it to potable standards:

i) Heating the water at 100^{o}C or 60^{o}C
ii) Exposing the transparent storage bottles to sunlight and UV.

Rain water with a TC count of 1,000 and FC count of 240 from BLT-78 was used for the experiments for 15 minutes (table 8A). To see the effect of duration of heating, rainwater from the storage tank BLC was taken in 12 (200 ml each) sterile conical flask and subjected to different heating conditions i.e. boiling at 100^{o}C for 1, 5, 15 and 20 minutes and heating at 60^{o}C for 1, 5, 10, 15 and 20 minutes. Simultaneously, control was also taken where no heating was carried out. The water samples were subjected to H_2S strip test and MPN test for total coliform, faecal coliform and faecal streptococcus. The results (Table 8B & 8C) show that boiling even for one minute is sufficient to eliminate total coliform, faecal coliform and faecal streptococcus. The H_2S strip test which gave black colour in 24 hrs when no treatment was done, did not give black colour when the rainwater was boiled for one minutes. Heating at 60^{o}C for 1 minute eliminated total coliform and faecal coliform but faecal streptococci survived and were eliminated only on heating for 15 minutes. However, H_2S strip did not give black colour after 1 minute of heating at 60^{o}C.

In another treatment method the storage bottles were exposed to sunlight under different conditions. The samples from storage tank MAA was drawn 3.3.2000 and 11.4.2000 in sterile bottles of volume 200 ml, were kept in sun over for 16 hours over two days under the following three conditions. (a) covering the bottles totally with carbon paper, (b) covering them partially by carbon paper and (c) bottles were left totally transparent without any covering (d) Bottles kept inside with no treatment of sunlight were used as control.

The water samples were subjected to standard H_2S strip test and MPN test for total coliform, faecal coliform and faecal streptococcus. It was observed that covering the bottles partially with carbon gave good results (table 10) as it eliminated total coliform, faecal coliform and faecal streptococcus for both the samples drawn on 3rd March and 11th April. H_2S strip also gave negative test in these cases. In water samples from the bottle which was totally covered with black carbon in one case, the H_2S strip became black in 24 hrs. and TC, FC and FS persisted. In this case the temperature was only 27^{o}C. In the second case, the temperature in the bottle reached 45^{o}C. The H_2S strip gave negative result and only faecal streptococcus was seen. Transparent bottles showed better results than totally covered bottle. Thus the effect of sunlight depends on two parameters (a) heating and rise in temperature due to this and (b) exposure to UV rays. Partially covered bottles get heated and also receive UV rays of the sun, whereas the totally covered bottles get heated more but UV rays are blocked. SODIS (Solar Water Disinfection) has also been reported in the literature. Water is disinfected by radiation and by solar thermal water treatment by exposing small to full sunlight for 5 hrs or for 2 consecutive days even with 50% cloudy sky.

2.7 Algal growth in rainwater samples

It was observed that rainwater samples stored over a period of 3-6 months in transparent PET bottles and glass bottles, and exposed to sunlight supported algae growth, when sufficient nutrition was available. On the other hand sterile water (autoclaved) kept in transparent glass/PET bottles as control had no algal growth. Samples subjected to boiling were also devoid of any algal growth. When sample bottles were completely blackened by carbon paper there was no algal growth. The data are reported in Table 9. Thus both sunlight and nutrients are needed for algae to grow. To prevent algal infestation, the tanks must be kept closed without exposure to sunlight.

3 CHEMICAL QUALITY OF WATER SAMPLES

The essential chemical characteristics such as pH, EC (electrical conductivity) TDS (Total Dissolved Solids), TH (total hardness) and content of Ca^{+2}, Na^{+1}, NO^{-}_3 and Cl^- are reported for storage tanks labelled MAP, MIC, BLC and BLT and MAA respectively (tables 12A, 12B, 12C, 12D, 12E). These were measured by rapid method in kits and also detailed analysis was undertaken – see Tables 12A-12D. The two data are compared. Essentially the chemical water quality was acceptable. In all the cases no significant differences could be seen with material and design changes in roof, gutter and storage type.

Specifically the following conclusions were reached concerning the chemical/physical quality of stored roofwater:

- It was be seen that the collected samples were generally clear without colour. Only a few samples had a yellowish hue when contaminated due to leaves from overhanging trees. Odour and taste wise also the water samples were acceptable.
- The pH range of water samples measured by a pH meter was in the range 7-8.5 and the values obtained by rapid testing kit was also in range 7-8. Thus the pH was well within the acceptable limits.
- Chloride and total hardness measured by laboratory method and by testing kits were in agreement. The values were below limits allowed for potability within the experimental error.
- The TDS and all other cations/anions concentrations were within acceptable limits.
- On storage in ferrocement tanks, no significant change in TH/TDS/pH was observed.
- Out of five DRWH, only in one case, the first flush showed a high TDS/TH value. In the other cases, even the first flush had acceptable TDS.

Note: Detailed procedures for using laboratory and rapid tests are described in report C-1.

4 SUMMARY AND CONCLUSIONS

Analysis of literature data available on the quality of water stored in DRWH systems, field level survey as well as experimental work done under the current project, indicate the following:

1) Generally, the physico-chemical quality of water in terms of colour, odour and taste, pH, total dissolved solids (TDS) and total hardness (TH), meet the prescribed standards. Occasionally pH has been reported to be low (acidic) or high (alkaline).
2) Toxic metal ions and toxic chemicals are reported only in rare cases and may arise from material used for the roof or atmospheric pollutants adsorbed on dust.
3) Most of the material used for storage tanks e.g. cement, iron, wood and plastics do not negatively affect the physico-chemical quality, with a few exceptions.
4) The physico-chemical parameters can be tested easily by using available field kits.

On the other hand, the main problem with the quality of stored water in DRWH lies with its bacteriological quality. The following are the main issues:

1) Total coliform (TC), faecal coliform (FC) and faecal streptoccocus (FS) are used as indicators of faecal contamination. Total coliform test is rendered difficult in the presence of large counts of other bacteria. Hence, E. coli is considered a better indicator. All the bacteria can be quantified at the lab level by the most probable number (MNP) method and plating in specific media after micro filtration and counting the colonies. It is not easy to perform these tests at the field level. The rapid tests available at field level are essentially useful for indicating the presence/absence of bacteria. The H_2S strip test based on production of H_2S by sulphur reducing bacteria such as *Clostridum perfringens* is considered most useful as it correlates well with plate count or MNP test for faecal coliform.

2) Dust from the soil, and droppings of birds and animals can also be the source of contamination by the above bacteria. Thus, the indicator bacteria need not necessarily be of human origin. It is reported that faecal streptococcus is more in bird/animal dropping. Thus if FC/FS ratio less than 1, contamination may be of non-human origin, and if FC/FS is greater than 4, then contamination may be of human origin. However, it may be noted that on storing rainwater, FC & FS counts fall at different rates. As FS counts fall faster, FC/FS ratio may increase with storage.
3) In any case where first flush eliminating devices are absent, all the indicator bacteria are generally present in water samples in numbers beyond what is acceptable by any standards. First flush is invariably contaminated. Since bird dropping and dust particles do not depend on roof type, it is difficult to categorically state whether any one type of roof is better than the other. However, experiments under the current project show that contamination from brick tiled roof was more than with other kind roof, like plastic, metallic and asbestos roof. Also it is possible that a rough surface may carry more dust and thus cause greater contamination. Higher temperature reached by a metallic roof due to solar heating may lead to reduction in bacteria. However, it is difficult to rely on such issues in designing for water quality.
4) The same goes for the gutter materials. From the health point of view it is important to clean the gutter from time to time and ensure that water does not stagnate. This leads mosquito breeding.
5) Tree hanging in the vicinity, definitely enhances the possibility of contamination due to increased access of the roof to birds and animals. Also leaves contribute to organic loading of the water samples, which in turn act as nutrient for bacterial growth.
6) On storage, generally due to limitation of nutrients, bacterial count falls. Different indicator bacteria under study decay over 7-20 days depending on the initial amount of bacteria, nutrient availability and other storage conditions.
7) Increase of temperature due to sun's heat or exposure to UV radiation of sun, reduces and ultimately eliminates bacteria. However, exposure to sunlight in the presence of nutrients can lead to algal growth, especially when the storage is open.
8) Mosquito breeding generally occurs if mosquitoes are already available in the vicinity of storage. Water quality deteriorates with the breeding of mosquito. The only way to prevent mosquito in the tank is by covering the openings by appropriate screens. The holes in the mesh should be small enough not only for preventing access to mosquitoes, but also to mosquito eggs which could be washed off.

Thus the basic conclusion from the study, substantiated by actual experimentation under the project are that DRWH must be designed, taking the following into consideration:

i) Convenient first flush device must be integrated.
ii) Storage must be tightly lidded and all entry points must be closed by a mesh to prevent entry of mosquitoes and eggs.
iii) It is preferable to allow the water to stand for some time before drawing. The bacterial count is more at the bottom. Hence the water drawn may be from a higher level, e.g. with drawing water from an over flow system may be useful. The sediments accumulated may be removed from time to time. Thus, instead of one tank of large capacity, more tanks in a series may be used, but increase in total cost has to be considered.
iv) Some rapid testing methods like H_2S test methods are useful in the field for indicating presence of biological contamination. However even, when the indicator tests are negative, it is preferable that some treatment is given for elimination of bacteria, before drinking the water. The safest methods of treatment are exposure to UV & boiling. From the angle of design parameters, a slow sand filter at inlet or outlet could be used. It would be easier to use such a filter at the outlet. However, the sand filter should be maintained properly and kept clean.

5 FURTHER WORK PROPOSED

Further research is in progress under the project to determine the following:

1) What really constitutes the first flush i.e. how much water is needed for the roof to be completely washed clean so that the subsequent precipitation of rain is clear. The design and usefulness of first flush eliminating devices integrated with DRWH, will also be examined.
2) Whether storage will lead to total elimination of bacteria in the absence of nutrients in the rain, and render the water potable. It must be noted that bacterial decay patterns vary for different pathogens and indicator bacteria. Also, so far separate tests are not being conducted for virus in water. The absence of indicator bacteria is taken to signify the absence of human contamination including human viral contamination.
3) Further studies will be conducted on settling pattern of bacteria on storage, for deciding on suitable design inputs.

Acknowledgement

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TABLE 1: DESIGN FEATURES OF EXPERIMENTAL DRWH SYSTEMS SET UP AT I.I.T. DELHI FOR WQM

Tank No.	Tank label	Type of Roof	Type of Gutter	Type of Tank	Filters	Over-hanging tree?	Mosquito Breeding in the vicinity?	Location
1	BLT	Tin (CI)	Alumin'm	Segmented ferrocement (2,500 l)	Cement inlet	A tree at some distance	No	Block-IV, Institut'l Area
2	BLC	Cement (planar)	PVC	Ferrocement (2,500 l)	Cement inlet	Yes	No	Block-IV, Institut'l Area
3	MAP	Plastic roof corrug'd	Alumin'm	Sintex (300 l) (LDPE)	Earthen pot inlet	No	No	Resident'l Area
4	MAA	Asbestos corrug'd	PVC	Sintex (300 l) (LDPE)	Earthen pot inlet	No	No	Resident'l Area
5	MIC	Cement (planar)	Alumin'm	Ferrocement (500 l)	Cement inlet	Yes (number of trees)	Yes	Micro-model

Roof area: Actual/inclination/horizontal projection

TABLES 2A to 2F – WATER QUALITY IN DIFFERENT TANKS

Table 2A: WQM in tank MAA

Code	Date of sample with drawing	H_2S strip				Date for experim't for MPN	MPN for E. coli		MPN for faecal strepto-coccus FS
		Date of Experim't	24 hrs	48 hrs	72 hrs		Total coliform TC	Faecal coliform FC	
1 (14)*	06.08.99	06.08.99 11.08.99	- -	+ -	 -	11.08.99	4	0	0
2 (21)*	12.08.99	16.08.99	-	-	-	30.08.99	0	0	0
3 (31)	24.08.99	24.08.99	-	-	-	30.08.99	0	0	0
4 (35)*	06.09.99	06.09.99	-	+		07.09.99	≥ 1,100	11	4
5 (54)	27.09.99	27.09.99	-	-	-	27.09.99	93	93	20
6 (62)	25.10.99	25.10.99	-	-	-	25.10.99	≥ 1,100	28	15
7 (67)	09.11.99	09.11.99	-	-	-	09.11.99	≥ 1,100	0	210
8 (82)	11.01.00	11.01.00	-	-	-	11.01.00	≥ 1,100	≥ 1,100	460
9 (83)	17.01.00	18.01.00	-	-	-	18.01.00	210	210	9
10 (87)	01.02.00	02.02.00	+			02.02.00	460	240	9
11(90)	14.02.00	15.02.00	+			15.02.00	460	460	9

Table 2B: WQM in tank MAP

Code	Date of sample with drawing	H_2S strip				Date for experim't for MPN	MPN for E. coli		MPN for faecal strepto-coccus FS
		Date of Experim't	24 hrs	48 hrs	72 hrs		Total coliform TC	Faecal coliform FC	
1 (15)*	06.08.99	06.08.99 11.08.99	- -	+ +		11.08.99	≥ 1,100	43	4
2 (22)*	12.08.99	16.08.99	-	-	+	30.08.99	4	0	0
3 (32)	24.08.99	24.08.99	-	+		30.08.99	9	0	0
4 (37)*	06.09.99	06.09.99	-	+		07.09.99	460	43	4
5 (55)	27.09.99	27.09.99	-	-	-	27.09.99	93	9	20
6 (63)	25.10.99	25.10.99	-	-	-	25.10.99	≥ 1,100	3	15
7 (68)	09.11.99	09.11.99	-	-	-	09.11.99	0	0	4
8 (81)	11.01.00	11.01.00	-	-	-	09.0100	0	0	1,100
9 (84)	17.01.00	18.01.00	-	-	-	18.01.00	0	0	9
10 (88)	01.02.00	02.02.00	-	-	-	02.02.00	0	0	15
11 (91)	14.02.00	15.02.00	+			15.02.00	4	4	4
12 (95)	07.03.00	07.03.00	-	-	-	07.03.00	4	4	210

Table 2C: WQM in tank BLC

Code	Date of sample withdrawing	H_2S strip				Date for experim't for MPN	MPN for E. coli		MPN for faecal strepto-coccus FS
		Date of Experim't	24 hrs	48 hrs	72 hrs		Total coliform TC	Faecal coliform FC	
1 (2)*	20.07.99	20.07.99	-	+			-	-	
2 (3)	23.07.99	26.07.99	-	-	-	26.07.99	1,100	0	0
3 (9)	30.07.99	30.07.99	-	-	-	04.08.99	20	7	0
4 (19)*	06.08.99	06.08.99 11.08.99	- -	+ -	- -	- 11.08.99	- 75	- 4	- 0
5 (28)*	12.08.99	16.08.99	-	-	-	30.08.99	4	3	0
6 (34)	24.08.99	24.08.99	-	-	+	30.08.99	150	150	0
7 (41)*	06.09.99	06.09.99	+	-	-	07.09.99	210	43	0
8 (57)	27.09.99	27.09.99	-	-	-	27.09.99	4	4	0
9 (65)	25.10.99	25.10.99	-	-	+	25.10.99	150	0	0
10 (70)	09.11.99	09.11.99	-	-	+	09.11.99	93	21	9
11 (72)	16.11.99	16.11.99	+			16.11.99	39	23	7
12 (80)	11.01.00	11.01.00	-	+		11.01.00	43	23	0
13 (85)	17.01.00 (rained 14.01.00)	18.01.00	+			18.01.00	1,100	1,100	1,100
14 (86)	01.02.00	02.02.00	+			02.02.00	≥ 1,100	≥ 1,100	150
15 (89)	14.02.00	15.02.00	+			15.02.00	≥ 1,100	460	43
16 (94)	03.03.00	03.03.00	+			03.03.00	460	4	43
17 (97)	24.03.00	24.03.00	+			24.03.00	≥ 1,100	4	460

Table 2D: WQM in tank BLT

Code	Date of sample with drawing	H$_2$S strip				Date for experim't for MPN	MPN for E. coli		MPN for faecal strepto-coccus FS
		Date of Experim't	24 hrs	48 hrs	72 hrs		Total coliform TC	Faecal coliform FC	
1 (1)*	20.07.99	20.07.99	-	+					
2 (4)	23.07.99	26.07.99	-	-	-	26.07.99	0	0	0
3 (27)*	12.08.99	16.08.99	-	-	+	30.08.99	0	0	0
4 (33)	24.08.99	24.08.99	-	+		30.08.99	43	9	0
5 (40)*	06.09.99	06.09.99	+	-	-	07.09.99	≥ 1,100	240	4
6 (56)	27.09.99	27.09.99	-	+		27.09.99	39	4	9
7 (64)	25.10.99	25.10.99	-	-	+	25.10.99	93	7	150
8 (69)	09.11.99	09.11.99	-	+		09.11.99	1,100	23	1,100
9 (71)	16.11.99	16.11.99	+			16.11.99	1,100	1,100	1,100
10 (78)	07.12.99	09.12.99	-	+		09.12.99	1,100	240	93
11 (79)	21.12.99	21.12.99	+			21.12.99	240	0	43

Table 2E: WQM in tank MIC

Code	Date of sample with drawing	H$_2$S strip				Date for experim't for MPN	MPN for E. coli		MPN for faecal strepto-coccus FS
		Date of Experim't	24 hrs	48 hrs	72 hrs		Total coliform TC	Faecal coliform FC	
1 (8)*	30.07.99	30.07.99	+			04.08.99	≥ 1,100	≥ 1,100	1,100
2 (11)	03.08.99	03.08.99	-	+		04.08.99	240	4	9
3 (18)*	06.08.99	06.08.99 11.08.99	+ -	-		11.08.99	≥ 1,100	≥ 1,100	≥ 1,100
4 (38)	06.09.99	06.09.99	+			07.09.99	≥ 1,100	≥ 1,100	≥ 1,100
5 (66)	25.10.99	25.10.99	-	+		25.10.99	≥ 1,100	≥ 1,100	≥ 1,100

Table 2F: Rainfall during June, 99 - May, 2000

S.No.	Date	Type of rain
1.	20.06.99	1st rain (light)
2.	18.07.99	Heavy rain
3.	29.07.99	Rain
4.	5&6.08.99	Heavy rain
5.	11&12.08.99	Rain
6.	5&6.09.99	Heavy rain
7.	19.09.99	Rain
8.	30.09.99	Rain
9.	14.01.00	Rain
10.	12.05.00	Heavy rain

TABLES 3A to 3F - WATER QUALITY TESTS BY DIFFERENT METHODS

Table 3A: Biological quality of first flush

Code	Date of with-drawing sample	H_2S strip				Date for experim't for MPN	MPN for E. coli		MPN for faecal strepto-coccus FS
		Date of Experim't	24 hrs	48 hrs	72 hrs		Total coliform TC	Faecal coliform FC	
1 MAA-13 new roof	06.08.99	11.08.99	-	-	-	11.08.99	0	0	0
2 MAP-36	06.09.99	06.09.99	-	+		07.09.99	≥ 1,100	≥ 1,100	≥ 1,100
3 BLT-42	07.09.99	07.09.99	+			07.09.99	≥ 1,100	≥ 1,100	≥ 1,100
4 BLC-43	07.09.99	07.09.99	+			07.09.99	210	210	9

Table 3B: Correlation between H_2S strip test and MPN according to different standards

S.No.		Total Coliform (TC)				Faecal Coliform (FC)				Faecal Streptococcus (FS)			
		P_1 %	P_2 %	N_1 %	N_2 %	P_1 %	P_2 %	N_1 %	N_2 %	P_1 %	P_2 %	N_1 %	N_2 %
1.	*WHO standard* TC 0-10 FC 0 FS 0	24	46	26	4	24	46	26	4	24	41	28	7
2.	*Relaxed standard I* TC 0-50 FC 0-10 FS 0-10	26	39	24	11	39	35	11	15	32	24	19	26
3.	*Relaxed standard II* TC 0-100 FC 0-10 FS 0-10	35	39	15	11	39	35	11	15	31	24	19	16

Table 3C: Correlation between H_2S strip test and MPN test according to total coliform

	Total No. of samples	P_1		P_2		Total % $P_1 + P_2$	N_1		N_2		Total % $N_1 + N_2$
		Actual no.	%	Actual no.	%		Actual no.	%	Actual no.	%	
WHO TC: 0-10	54	13	24	25	46	70	14	26	2	4	30
Relaxed standard I TC: 0-50	54	14	26	21	39	65	13	24	6	11	35
Relaxed standard II TC: 0-100	54	19	35	21	39	74	8	15	6	11	26

Table 3D: Correlation between H_2S strip test and MPN test according to faecal coliform

	Total No. of samples	P_1		P_2		Total % $P_1 + P_2$	N_1		N_2		Total % $N_1 + N_2$
		Actual no.	%	Actual no.	%		Actual no.	%	Actual no.	%	
WHO standard FC: 0	54	13	24	25	46	70	14	26	2	4	30
Relaxed standard I or II FC: 0-10	54	21	39	19	35	74	6	11	8	15	26

Table 3E: Correlation between H_2S strip test and MPN test according to faecal streptococcus

	Total No. of samples	P_1		P_2		Total % $P_1 + P_2$	N_1		N_2		Total % $N_1 + N_2$
		Actual no.	%	Actual no.	%		Actual no.	%	Actual no.	%	
WHO FS: 0	54	13	24	22	41	65	15	28	4	7	35
Relaxed standard I or II FS: 0-10	54	17	31	13	24	56	10	19	14	26	44

Table 3F: Acceptable samples which fulfilled all the parameters for potability

S.No.	Standard	Total No. of samples	No. of samples acceptable	% of acceptable samples
1.	WHO TC: 0-10 FC: 0 FS: 0	54	7	13
2.	Relaxed standard I TC: 0-50 FC: 0-10 FS: 0-10	54	15	28
3.	Relaxed standard II TC: 0-100 FC: 0-10 FS: 0-10	54	16	30

Table 3G: Coliform and faecal coliform count in rain water as reported in IDRC report

No. of coliform per 100 ml of rain water	Total coliform count				Faecal coliform			
	MPN total coliform positive		Hydrogen Sulphide Test		MPN faecal coliform positive		Hydrogen Sulphide Test	
	No. of samples	%	+	-	No. of samples	%	+	-
Rain water (54 samples) 0 or < 2 = 0					17	32	10	7
0 - 10	21	38.9	11	10	5	10	-	-
11 - 100	15	27.8	-	-	16	30	-	-
101 - 2,400	18	33.3	11	22	16	30	-	-

Table 4: Correlation of turbidity and number of colonies

S.No./ Code No.	Bacterial dilutions (20 ml samples mixed as shown)		Turbidity* (NTU)	No. of colonies in 20 ml
	Bacterial solution ml	Sterile H_2O ml		
A (1)	0	20	1.5	0
M (2)	20	0	50.0	Non-countable - colonies forming a lawn
B (3)	0.5	19.5	2.0	5632×10^3
C (4)	1.0	19.0	3.0	5824×10^3
D (5)	2.0	18.0	4.4	27648×10^3
E (6)	3.0	17.0	5.9	53568×10^3
F (7)	4.0	16.0	7.0	Non-countable - colonies forming a lawn
G (8)	5.0	15.0	9.0	"
H (7)	6.0	14.0	10.0	"
I (8)	7.0	13.0	16.0	"
J (9)	8.0	12.0	20.0	"
K (10)	9.0	11.0	20.0	"
L (11)	10.0	10.0	25.0	"
(N) Bacterial (12) 1,000	Bacterial 1,000 NTU equivalent	-	200.0	"
Samples from rainwater tanks				
MAA-100			1.9	418×10^3
MAP-101			1.4	3024×10^3
MIC-18 (yellow & dirty water)			1.0	1632×10^3

* 10 NTU is the maximum permissible limit according to Rajiv Gandhi National Drinking Water Mission; 5 NTU is the maximum permissible limit according to WHO standards

Table 5A: Bacterial decay rate for water sample (MIC-66)

Days	Coliform		Faecal Streptococcus
	TC	**FC**	**FS**
1	≥ 1,100	≥ 1,100	≥ 1,100
2	≥ 1,100	≥ 1,100	≥ 1,100
3	≥ 1,100	≥ 1,100	210
4	460	240	75
5	460	240	28
6	460	210	-
7	240	93	-
8	240	93	3
9	240	93	11
10	93	43	11
11	93	23	7
12	93	9	4
13	150	9	0
14	93	4	0
15	75	9	0
16	75	4	0

Table 5B: Bacterial decay rate for water sample (BLT-71)

Days	Coliform		Faecal Streptococcus
	TC	FC	FS
1	1,100	1,100	1,100
2	≥ 1,100	≥ 1,100	93
3	≥ 1,100	≥ 1,100	150
4	≥ 1,100	≥ 1,100	14
5	≥ 1,100	≥ 1,100	23
6	≥ 1,100	≥ 1,100	23
7	≥ 1,100	≥ 1,100	43
8	1,100	1,100	43
9	1,100	1,100	43
10	1,100	1,100	7
11	1,100	1,100	23
12	1,100	1,100	23
13	1,100	1,100	23
14	1,100	1,100	23
15	460	460	23
16	460	460	9
17	240	240	4
18	240	240	-
19	240	240	-
20	210	210	-
21	210	210	-
22	93	93	-

Table 5C: Bacterial decay rate for water sample (BLC-72)

Days	Coliform		Faecal Streptococcus
	TC	FC	FS
1	39	23	7
2	75	23	9
3	43	23	9
4	39	4	4
5	43	9	4
6	43	9	4
7	43	23	0
8	23	9	4
9	15	0	9
10	7	7	4
11	0	0	0
12	4	4	0
13	4	4	0
14	4	4	0
15	93	4	0
16	9	3	-
17	4	0	-
18	4	0	-
19	4	-	-
20	4	-	-
21	4	-	-
22	9	-	-

Table 5D: Decay time constants derived from Tables 5A and 5B

(Time constant is the parameter *T* in the fit: *N* = K.exp(*D*/T) where *N* is MPN and *D* is time in days)

Tank	Measure	No of days	Time Constant in days	Correlation coefft R2
MIC-66	TC	14	5.31	0.86
MIC-66	FC	14	2.46	0.94
MIC-66	FS	12	2.28	0.51
BLT-71	TC	14	5.17	0.89
BLT-71	FC	14	5.17	0.89
BLT-71	FS	17	5.58	0.51

Table 6A: Decay rate of coliform group (E. coli) in absence and presence of nutrient

S.No.	Time	Sterile Water MPN	Tank Water MAP-95 MPN	Tank Water after boiling MAP-95 MPN
1.	Initial sample before inoculation of bacteria	0	4	0
2.	O minute. Sample immediately after putting the inoculum	≥ 1,100	≥ 1,100	≥ 1,100
3	4 hrs	≥ 1,100	≥ 1,100	≥ 1,100
4	1 day	≥ 1,100	≥ 1,100	≥ 1,100
5	2 days	≥ 1,100	≥ 1,100	≥ 1,100
6	3 days	≥ 1,100	≥ 1,100	≥ 1,100
7	4 days	1,100	≥ 1,100	≥ 1,100
8	5 days	1,100	≥ 1,100	≥ 1,100
9	6 days	460	≥ 1,100	≥ 1,100
10	7 days	210	≥ 1,100	≥ 1,100
11	8 days	93	≥ 1,100	≥ 1,100
12	9 days	93	≥ 1,100	≥ 1,100
13	10 days	9	≥ 1,100	≥ 1,100
14	11 days	9	≥ 1,100	≥ 1,100
15	12 days		≥ 1,100	≥ 1,100
16	13 days		1,100	≥ 1,100
17	14 days		1,100	≥ 1,100
18	15 days		460	1,100
19	16 days		460	460
20	17 days		210	240
21	18 days		240	210
22	19 days		93	93
23	20 days		93	93
24	21 days		75	93
25	22 days		43	43
26	23 days		23	15
27	24 days		4	9
28	25 days			4

Note: 'Time constant' (for exponential decay) is 1.44 times 'Decay Time' in days per gen.

Water	Measure	No of days	Time Constant in days	Correl coeft R2
Distilled water	E-Coli MPN	8	1.33	0.94
Tank water	E-Coli MPN	11	1.99	0.96
Sterilised tank water	E-Coli MPN	12	2.28	0.93

Table 6B: Decay rate of faecal streptococcus in absence and presence of nutrient

S.No.	Time	Sterile Water MPN	Tank Water MAP-95 MPN	Tank Water after boiling MAP-95 MPN
1	Initial sample before inoculation of bacteria	0	210	0
2	O minute. Sample immediately after putting the inoculum	≥ 1,100	≥ 1,100	≥ 1,100
3	4 hrs	≥ 1,100	≥ 1,100	≥ 1,100
4	1 days	1,100	≥ 1,100	≥ 1,100
5	2 days	4	≥ 1,100	≥ 1,100
6	3 days	0	≥ 1,100	≥ 1,100
7	4 days		≥ 1,100	≥ 1,100
8	5 days		≥ 1,100	≥ 1,100
9	6 days		≥ 1,100	≥ 1,100
10	7 days		≥ 1,100	≥ 1,100
11	8 days		≥ 1,100	≥ 1,100
12	9 days		≥ 1,100	≥ 1,100
13	10 days		1,100	≥ 1,100
14	11 days		1,100	1,100
15	12 days		1,100	210
16	13 days		210	93
17	14 days		43	93
18	15 days		93	75
19	16 days		9	93
20	17 days		4	43
21	18 days			43
22	19 days			23
23	20 days			4

Table 6C: Decay constant of bacteria

S.No.	Sample which was Inoculated with bacteria	Total no. of generation	Mean Decay Time	Rate Constant/ Decay constant
1.	Sterilised water	- 8.103 gen/2 days	- 1.78 hr/gen (or -0.073 day/gen)	- 0.56 gen/hr
2.	MAP-95 not boiled	- 8.103 gen/17 days	- 17.76 hr/gen (or - 0.74 day/gen)	- 1.34 gen/day
3.	MAP-95 (boiled)	- 8.103 gen/20 days	- 15.12 hr/gen (or - 0.63 days/gen)	- 1.58 gen/day

Table 7: Testing the heterogeneity of the stored samples

S.No.	Sample MAA-87	Coliform		Streptococcus	H_2S strip test
		TC	FC	FS	
1.	Shaking	460	240	9	Black in 20 hrs
2.	*L-1: 16 cm from base	240	15	0	Black in 20 hrs
3.	*L-2: 8 cm from base	1,100	1,100	7	Black in 20 hrs
4.	*L-3: 1 cm from base	1,100	1,100	9	Black in 20 hrs

* Sample was kept standing for 24 hrs and then the water drawn from different layers, L_1, L_2, L_3 . The water level is 18 cm from (above) the base.

Table 8A: A comparative study of standard treatment procedures

S.No.	Sample	Treatment	H_2S strip test	MPN for Coliform bacteria		MPN for Faecal streptococcus
				Total coliform	Faecal coliform	
1.	BLT-78* Initial	No treatment	Black in 48 hrs	1,00	240	15
2.	BLT-78-TS	Sunlight for 2 days (16 hrs)	No black colour	4	0	0
3.	BLT-78-TB	Boiling for 15 min	-do-	0	0	0
4.	BLT-78-TU	UV in laminar flow for 1 hr	-do-	43	0	4

* Sampling on 7.12.99

Table 8B: Treatment by boiling (100^{o}C) of stored tank water (BLC-94)

S.No.	Time (min)	MPN for Coliform bacteria		MPN for Faecal streptococcus	H_2S strip test
		Total coliform	Faecal coliform		
1.	0 (no heating)	460	4	43	Black in 24 hrs
2.	1	0	0	0	No black colour
3.	5	0	0	0	"
4.	10	0	0	0	"
5.	15	0	0	0	"
6.	20	0	0	0	"

Table 8C: Treatment by heating stored tank water (BLC-97) at 60°C

S.No.	Time (min)	MPN for Coliform bacteria		MPN for Faecal streptococcus	H_2S strip test
		Total coliform	Faecal coliform		
1.	0 (no heating)	≥ 1,100	4	460	Black in 24 hrs
2.	1	0	0	7	No black colour
3.	5	0	0	4	"
4.	10	0	0	4	"
5.	15	0	0	0	"
6.	20	0	0	0	"

Table 8D: Treatment of sunlight for 16 hrs

S. No.	Sample no.	Treatment of sunlight	Temp. in the bottle	H_2S strip test	MPN for Coliform bacteria		MPN for Faecal streptococcus
					Total coliform	Faecal coliform	
1.	MAA-94* initial	No treatm'nt by sunlight (control)	25°C	Black in 24 hrs	460	4	43
2.	MAA-94-ST	Transparent bottle kept in sunlight	27°C	No black colour	0	0	3
3.	MAA-94-SP	Bottle partially black	29°C	-do-	0	0	0
4.	MAA-94-SB	Bottle totally black	32°C	Black in 24 hrs	7	4	7
5.	MAA-99** initial	No treatm'nt by sunlight	39°C	No black colour	≥ 1,100	≥ 1,100	3
6.	MAA-99-TS	Transparent bottle	41°C	-do-	0	0	0
7.	MAA-99-PS	Bottle partially black	43°C	-do-	0	0	0
8.	MAA-99-BS	Bottle totally black	45°C	-do-	0	0	3

* MAA-94: Sampling on 3.3.2000
** MAA-99: Sampling on 11.4.2000

Table 9: Study of algal growth in rainwater sample under storage and different treatment procedures

S. No.	Sample	Description of sample	Date of sampling	Observation for algae (dates)			
				12.1.00	12.2.00	26.4.00	22.5.00
1.	BLT-78	100% storage tank water	7.12.99	+			
2.	BLT-78-A	(1:1) BLT-78: sterile H_2O	7.12.99	+			
3.	BLT-78-B	(1:3) BLT-78: sterile H_2O	7.12.99	+			
4.	BLT-78-C	(1:9) BLT-78: sterile H_2O	7.12.99	-	+		
5.	BLT-78-D	(1:99) BLT-78: sterile H_2O	7.12.99	-	-	+	
6.	BLT-78-TS	BLT-78 kept in sunlight (2 days)	7.12.99	++			
7.	BLT-78-TB	BLT-78 boiling for 15 min	7.12.99	-	-	-	-
8.	BLT-78-TU	BLT-78 kept in UV of laminar flow (1 hr)	7.12.99	+			
9.	Sterile H_2O	sterile H_2O	7.12.99	-	-	-	-
10.	BLC-94-SB	Kept in sunlight (2 days), totally covered with carbon	3.3.00	-	-	-	-
11.	BLC-94-SP	kept in sunlight (2 days), partially covered black	3.3.00			-	+
12.	BLC-94-ST	Kept in sunlight (2 days) in transparent	3.3.00	-	-	+	

TABLES 10 A to D – CHEMICAL QUALITY OF WATER IN RAINWATER TANKS

Table 10A: Chemical quality of water in storage tank MAP by laboratory method and Development Alternatives (DA) kit

Lab'y methods	PH meter	EC	TDS	Total hardness (ppm)	Ca as $CaCO_3$ (ppm)	Ca^{2+} (ppm)	Mg^{2+} (ppm)	NO_{3-} (ppm)	Cl^- (ppm)
MAP-15	7.6	1.36	101	40	16	6.4	5.8	20	14.2
MAP-22	8.23	0.49	36	20	9.5	3.3	2.5	9	14.2
MAP-32	7.7	0.86	64	44	17.6	7.04	7.6	5	11.3
MAP-37	7.2	0.41	30	16	4.8	1.92	14.1	2.2	8.5
*MAP-23	7.9	0.83	62	36	14.4	5.8	5.2	2	8.5
*MAP-36	8.45	0.54	40	16	6.4	2.6	13.4	2	23
MAP-55	7.4	0.54	40	16	11.2	4.5	11.5	3	14.2
MAP-87A	8.0	0.812	60	184	12.8	5.12	41.6	25	8.51
MAP-88	7.5	0.587	44	176	14.4	5.8	39.3	35.5	8.51
MAP-91	7.5	0.66	49	172	12.8	5.12	38.7	32.5	8.51

DA kit	pH (strip)	Turbidity	TH	Cl^-
MAP-15	7.0	~ 10 NTU	72	28
MAP-22	7.5	~ 10 NTU	44	17
MAP-32	7.0	~ 10 NTU	64	17.7
MAP-37	7.5	Nil	32	21.3
MAP-23	8.0	= 10 NTU	44	21
MAP-36	8.0	Nil	44	17.7
MAP-87	7.5	Nil	48	28.4
MAP-88	8.0	Nil	56	32
MAP-91	7.0	Nil	64	28.4

Table 10B: Chemical quality of water in storage tank MIC by laboratory method and Development Alternatives (DA) kit

Lab'y methods	pH meter	EC	TDS	Total hardness (ppm)	Ca (as $CaCO_3$) (ppm)	Ca^{2+} (ppm)	Mg^{2+} (ppm)	NO_{3-} (ppm)	Cl^- (ppm)
MIC-8	7.7	1.47	109	16	4.8	1.9	2.7	18	22.7
MIC-11	8.05	4.3	320	152	43.2	17.3	26	20	99.3
MIC-18	8.35	2.69	200	56	19.2	7.68	9	39	36.9
MIC-38	7.51	0.93	69	40	6.4	2.6	37.4	5	14.2

DA kit	pH (strip)	Turbidity	TH	Cl^-
MIC-8	7.0	Nil	44	33
MIC-11	7.0	Nil	160	141
MIC-18	7.5	Nil	76	76
MIC-38	7.0	Nil	40	17.7

Table 10C: Chemical quality of water in storage tank BLC by laboratory method and Development Alternatives (DA) kit

Lab'y methods	pH meter	EC	TDS	Total hardness (ppm)	Ca as $CaCO_3$ (ppm)	Ca^{2+} (ppm)	Mg^{2+} (ppm)	NO_{3-} (ppm)	Cl^- (ppm)
BLC-2	8.07	0.97	72	36	14.4	5.8	5.25	10.5	14.2
BLC-3	8.29	1.61	120	56	21	8.3	8.5	35.5	19
BLC-9	7.98	1.75	130	56	22.4	9	8.2	37.5	14.2
BLC-19	6.6	2.53	188	56	16	6.4	10	50	19.8
BLC-28	8.09	1.25	93	36	11.2	4.5	6.1	26.5	11.34
BLC-34	8.34	1.61	120	25	6.4	2.6	4.3	29	8.5
BLC-41	8.23	0.75	55.8	24	14.4	5.8	18.2	9	5.7
BLC-86	7.5	1.77	132	276	48	19.2	55.4	100	12.8
BLC-29	7.81	1.1	82	36	19.2	7.7	4.1	9.5	11.3
BLC-43	7.6	0.61	45	32	17.6	7.0	25	2.0	11.4
BLC-89	7.3	0.7	52	180	16	6.4	39.8	37.5	5.8

DA kit	pH (strip)	Turbidity	TH	Cl^-
BLC-2	7.0	Nil	64	33
BLC-3	6.0-7.0	Nil	88	38
BLC-9	7.0	Nil	96	70
BLC-19	7.0	Nil	64	17
BLC-28	7.5	Nil	58	21.3
BLC-34	7.5	Nil	60	17.7
BLC-41	7.5	Nil	36	17.7
BLC-86	7.0-8.0	Nil	164	32
BLC-29	7.0	Nil	64	21
BLC-43	7.0	Nil	60	17.7
BLC-89	7.0-8.0	Nil	68	30.1

Table 10D: Chemical quality of water in storage tank BLT by laboratory method and Development Alternatives (DA) kit

Lab'y methods	pH meter	EC	TDS	Total hardness (ppm)	Ca as $CaCO_3$ (ppm)	Ca^{2+} (ppm)	Mg^{2+} (ppm)	NO_{3-} (ppm)	Cl^- (ppm)
BLT-1	6.92	0.48	36	8	5.6	2.2	0.6	8	14.2
BLT-4	8.02	0.66	50	28	8	3.2	5	19	11.3
BLT-27	6.72	0.54	40	20	14.4	5.8	1.4	27	8.5
BLT-33	7.68	0.87	65	28	12.8	5.1	3.7	40	5.7
BLT-40	7.34	0.46	34	24	8	3.2	21	20	8.5
BLT-42	6.8	1.46	108	136	38.4	15.4	121	30	8.5
BLT-56	7.1	0.57	42	24	11.2	4.5	19.5	3	14.2

DA kit	pH (strip)	Turbidity (NTU)	TH	Cl^-
BLT-1	7.0	Nil	40	35
BLT-4	7.0	Nil	64	49
BLT-27	7.0	Nil	56	17
BLT-33	7.0	Nil	44	17.7
BLT-40	7.0	Nil	30	17.7
BLT-42	7.0	Nil	192	17.7

Table 12E: Chemical quality of water in storage tank MAA by laboratory method and Development Alternatives (DA) kit

Lab'y methods	pH meter	EC	TDS (ppm)	Total hardness (ppm)	Ca as $CaCO_3$ (ppm)	Ca^{2+} (ppm)	Mg^{2+} (ppm)	NO_{3-} (ppm)	Cl^- (ppm)
MAA-14	7.97	6.42	480	16	4.8	1.9	2.7	7	11.3
MAA-21	7.54	0.88	65	24	11.2	4.5	3.1	1.7	16
MAA-31	8.07	1.12	83	28	12.8	51	3.7	1.2	14.2
MAA-35	8.27	0.86	64	26	6.4	2.6	23	1.5	42.5
MAA-54	7.7	0.72	53	20	9.6	3.8	16.2	3.1	17.01
MAA-90	7.5	0.70	52	172	12.8	5.12	38.7	32.5	8.51
MAA-13	8.6	4.3	320	48	14.4	5.76	8.2	39	31

DA kit	pH (strip)	Turbidity (NTU)	TH (ppm)	Cl^-
MAA-14	7.0	10	20	19
MAA-21	7.5	10	44	17
MAA-31	7.5	Nil	40	21.3
MAA-35	7.5	Nil	44	16
MAA-13	7.0	10	84	75
MAA-90	7.5	Nil	56	24.4

APPENDIX I: WATER QUALITY IN DRWH SYSTEMS (data from the literature, by region)

A1 AFRICA

(a) Biological Quality

Country	Author	Total samples	Water quality	Ref.	Remarks
Botswana	J.E. Gould	-		J.E. Gould. Rain water catchment possibilities for Botswana. April, 84, pp 10-12. BTC (Botswana Technology Centre).	• Generally high quality of properly stored rain water is seen. Periodic chlorination is the most economical solution for maintaining water quality.
Botswana	J.E. Gould	13 roof tanks 8 ground catchments		J.E. Gould and H.J. McPherson. Bacteriological quality of rain water in roof and ground catchments system in Botswana. Water International 1987, 12, pp. 135-8.	• Rain water from corrigated iron roofs is of high quality.
Tanzania (Dares Salam)	Mayo & Mahuri	Oct. 1988 & Dec. 1989	86% samples were free of FC. 45% samples tested positive for TC. FS were obtained in 53% of samples.	A.W. Mayo & D.A. Mashauri. Rainwater harvesting for domestic use in Tanzania. A case study. University of Dar es salaam staff houses. Water International 16 (1991), pp 2-8.	
Kenya	Otieno			F.O. Otieno. Quality issues in rainwater collection. Raindrop, June, 94.	Need for maintaining water quality is stressed.
Kenya	Bambrah & Haq	Review of existing literature on rain water quality.	Guidelines for drinking H_2O quality and various physical & chemical treatments have been described.	Dr. G.K. Bambrah and Ms. S. Haq. Quality issues in rain water harvesting in Kenya. Proceedings of 8th International Conference on RWCS, April 25-29, 1997, pp 547-553.	Suitability of using untreated rain water for human consumption is discussed.
Kenya	Bambrah & Haq			Dr. G.K. Bambrah and Ms. S. Haq. Quality issues in rain water harvesting in Kenya. Proceedings of 8th International Conference on RWCS, April 25-29, 1997, pp 547-553.	

(b) Chemical Quality

Tanzania	Mayo & Mahuri	Samples from rain water cisters	pH, total hardness turbidity & colour were analysed	A.W. Mayo & D.A. Mashauri. Rainwater harvesting for domestic use in Tanzania. A case study. Universityof Dar es salaam staff houses. Water International 16 (1991), pp 2-8.	• pH range was 9.3-11.7 & was above standard limits • About 54% of consumers raised objections over taste of water

A2 N. AMERICA

(a) Biological Quality

USA	Roger S. Fujioka and Robert D. Chim	18 cistern systems 36 samples	First flush was not eliminated. FC was recorded in 34 out of 36 samples. FS were present in 16 of the 18 cistern. Chemical quality was also examined and was acceptable.	The microbiological quality of cistern waters in tantallis area of Honolulu Haiwa. Proceedings of the 3rd International conference on 'Rain water cisterm', Jan. 14-16, 1987, Khon Kaen, Thailand	More FS than FC indicating contamination is by birds rather than humans. Bacterial count was reduced in transit from storage tank to the bucket. Turbidity did not always correlate with indicator bacteria.
USA	Roger S. Fujioka, S.G. Insena and Robert D. Chim	15 cistern systems 28 water samples	Significant fraction of faecal coliform recovered from water sample is E. coli. Chemical quality was acceptable.	'The bacterial content of cistern water in Hawai'. Proceedings of Int. conference on rain water system, 1991, Taiwan.	Natural sunlight is an effective disinfectant. Indicator bacteria was not off the roof. Faecal indicator bacteria are present in soil house in to the roofs.
USA	E.W. Faisst and Roger S. Fujioka	Water samples from corrugated metal roof into four 55 gallon plastic cistern samples. 16 samples were analysed over an8 month period.		'Assessment of four rain water catchment designs on cistern water quality'. International Conference, 1994 proceedings of the 6th International Conference on rain water catchment system, Nairobi. Kenya, 1-6 April, 1993	H_2S strip test correlated with FC as compared to TC after a 24 hr incubation. H_2S producing bacteria are more likely to be found in cisterns with sediment build up sand/charcoal/gravel filter reduced bacteria, but still some samples did not meet US standards. The algae film inside cistern was indicated high nutrient level.

A3 S.E. ASIA

(a) Biological Quality
South-East Asia

Thailand	Komol Sivaborrorn	503 were analysed. Out of this 54 were rain water samples.	Bacteriological quality analysis was conducted by different methods	Final technical report submitted to ITRC on development of simple tests for bacteriological quality of drinking water (WQ) control for south east asia. Available on the web.	• H_2S strip test is an excellent test for it is easy, cheap & villagers can see the black colour. • β-galactosud showed good results. The method can be modified to use in the field. • Coliphage test was not so effective. • Out of 54 samples tested positive for coli, faecal coliform, E. coli counts.
Thailand	Appan	709 samples were collected from tiled roofs & gutters, containers located in homes, jars and the point of consumption		A. Appan, Roof water collection systems in some southeast Asian countries: Status and water quality levels. The Journal Royal Society of Health. October, 97, Vol. 117 No. 5, pages 319-323.	• More than 76% of the samples had values exceeding WHO standard • Samples other than those collected from the container showed an FC/ FS ratio of less than one. Possibly 79%-82% of the contamination could have emanated from animal droppings.
Phillipines	Appan	25 ferrocement tanks	24% of total samples had F. coli exceeding WHO guideline limit		
Malaysia	Appan	72 samples from 2 types of roofs in West Malaysia	F. coli values far exceeded the WHO value		
Singapore			• TC & FC values exceed guideline value		•
China	Xijing et al.	Total coliform become fewer in rain water contained in concrete cellais with tile surfaces			
Japan	Kita & Kitamura			Ichiro Kita and Kunihiko Kitamura. Fluctuation of the quality of container stored rainwater during storage. 7th International RWCS, Conference, June 21-25, 1995, Beijing, China, page 27-32.	• Results of coliform group of bacteria were positive throughout the periods.

(b) Chemical Quality

Thailand	Appan		Physico-chemical parameters performed were (pH, colour, turbidity, iron, manganese, lead & cadmium) More than 83% of the samples were satisfactory. However 43% of the samples exceedes the allowable limits of lead	A. Appan, Roof water collection systems in some southeast Asian countries: Status and water quality levels. The Journal Royal Society of Health. October, 97, Vol. 117 No. 5, pages 319-323.	

Indonesia	Appan				• Fish rearing within the tanks was tried.
Malaysia		72 samples were collected from 2 types of roofs in West Malaysia	pH value of rain water samples had a tendency to lie towards lower range of the guideline values		
Khon Kaen		709 samples were collected from tiled roofs & gutters containers located in homes, jars & the point of consumption	Only manganese (2-20% of the samples) and zinc (4-26% of samples) did not meet the guidelines levels		
Singapore		Roof water quality was monitored from a high rise building in Nanyange Tech. University for 6 years from May, 1989.	The values appear to be acceptable in all the physico-chemical parameters except pH which is low. Earlier field investigations have also shown that during January 1974 to July 1983, the range of pH in 11 monitoring stations distributed throughout Singapore was 4.8-5.5.		
China	Bo-ling		The alternative water source (rain water) which had normal fluoride levels was adopted to control fluoride endemics		
Japan	Tachi-Kawa		Metals (Fe, Zn, Pb) concentrations exceeded the standards in a study of rain water collected from roof tops		
Japan	Chiyuda Cets		1st flush of rain water after a 11 day dry spell was analysed. Physico-chemical (Fe, Cd, Cr, Cu, Mn, Ni, Pb, Zn) parameters are tabulated		• Initial rain fall upto 1.5 mm shows that the concentration of pollutants had accumulated on the roof for a 11 day dry spell
Japan	Nariyuki Inkano				• Tokyo International Rain Water Utilization Conference, Sumida city, Summer, 94, page 9-11. • Metals in rainwater in Tachikawa Saiwai-Cho Housing Complex • Quality of first flash of rainwater (Aug.-Sept., 86). • Prevention of mosquito breeding.
Japan	Kitamura		Stored rain water pH were almost constant except for the last 3 weeks duration Turbidity varied during first two weeks Ammonia nitrogen varied, decreasing on storage, which was probably caused by the bacterial activities	Kunihiko Kitamura, Ichiro Kita and Isao Minami. The effects of storage on rain water quality. Proceedings of the 8th International Conference on RWCS, April 25-29, 1997, Tehran, Iran, page 590-595.	• Bird dropping and insect caracasses were found in collected rain water (a sanitary problem)

A4 S & W ASIA

(a) Biological Quality

Srilanka	Heijen & Mansur			Han Heignen and U. Mansoor. Symposium on rainwater harvesting for water security, Feb. 28, 1998. "Rainwater harvesting in the community water supply and sanitation project".	• E. coli count was not high. Only 21% of samples showed 100 colonies/ 100 ml of TC
Srilanka	NWSDB			National Water Supply and Drainage Board, Sri Lanka. Chemical and bacteriological analysis report (15.10.98, 14.12.98 and 16.12.98).	• Bacteriological analysis (TC, EC & FS) was done and contaminantless was found. The board recommended boiling of water before consumption
Mitraniketan (Kerala)				All India Coordinated project report, sponsored by CAPART, Science and Society Division, Mitraniketan, Kerala.	• Bacterial examination was done on a few samples. The stored water had potable status.
Palestine (West Bank)	Sharekh		Level of total coliform contamination were found 27% > 0 coliform	M.S. Abu Sharekh. Rain water roof catchment systems for domestic water supply in south of West Bank. 7th International RWCS, Conference, June 21-25, 1995, Beijing, China, page 65-90.	• Rain water stored in cisterns was used for drinking & domestic purpose

A5 AUSTRALIA

(a) Biological Quality

South Australia	Fuller et al.	Vineyard & orchard areas - 7 cities Industrial areas - 4 cities Residential areas - 2 cities	• Coliform bacteria were present in 12 out of 41 tanks. Upto 500 coliform/ 100 ml were recorded • E. coli was detected in 6 tanks. 15% of 41 tanks levels upto 220 E. coli/100 ml were recorded. • Plate counts in most rain water tanks were in excess of 1,000/ml		C.O. Fuller, R.P. Walters and T.J. Martin. Domestic rainwater tanks working party, March, 81. Quality aspects of water stored in domestic rainwater tanks (a preliminary study).

(b) Chemical Quality

Australia	Ghafouri & Phillips			R.A. Ghafouri and B.C. Philips. Urban storm water re-use opportunities and constraints. Proceedings of 8th Int. Conference on RWCS, April 25-29, 1997, pp 554-565.	• Roof water is seen as one of the possible sources of collecting rain H_2O
South Australia	Fuller et al.	Water stored in domestic rain water tanks from 13 cities. Galvanised iron tanks in the range of 10,000-25,000 lit. were used.	A) Heavy metals Cadmium - one of the tanks reported relatively high cadmium concentration (0.018 mg/l) Lead - concentrations of lead in rain water from tanks were significantly higher (0.061 & 0.072 mg/l). This could be result of dust from surrounding country sides washed from roof tops with each rain fall. Zinc - zince concentrations were found to be in excess (15 mg/l) B) Pesticides were not detected in majority of the samples. C) Suspended solids - concentrations were negligible in all samples D) pH - range was 6.1-9.2 low pH values can accelerate corrosion problems in domestic appliances while high pH is an indication of under viable biological activity in the tank E) TDS - only samples taken from 2 rain water tanks had TDS concentrations in excess of 100 mg/ml (caused by sea spray)		

A6 EUROPE

(a) Biological Quality

Denmark	Per Jacobsen		Concentrations of lead (0.1 mg/l) & zinc (0.1-1.0 mg/l) exceeded the standards for drinking water in Denmak	Per Jacobsen. Metals in Rainwater in Denmark. Tokyo International Rainwater Utilization Conference, Sumida City, Summer, 94, page 9.	
Germany	Wilhelm Meemken		Parameters measured were pH, Fe, Mn, Cu, Pb, Zn, Ca, Mg, Na, K, NH_4^+, SO_4^{2-}, Cl^-, NO_3^- and electrical conductivity	Wilhelm Meemken. Quality examination of rainwater collected from roofs and stored in tanks. Tokyo International Rainwater Utilization Conference, Sumida City, Summer, 94, page 9-10.	• Rain water collected from the roofs could be used for flushing toilet washing cloths and watering plants without special treatment
Switzerland	Yakl Mason, Adrian A. Ammann, Andrea Ulrich & Laurasigg		Concentrations of Cr, Cu, Cd, Zn, Pb, Ca, Mg, Na, K, Cl, NH_4 were determined in rain water roof run off and in infiltrating water at various depths of soil.	Behaviour of heavy metals, nutrients & major components during roof run off infiltrat.	• The concentration of most parameter in roof run off were highest during the first flush at the beginning of rain events.