Feasibility Study Of Rainwater Harvesting Techniques In Bangladesh

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Abstract

Some rural areas (around 52 districts) in Bangladesh, there is a serious arsenic problem in ground water and in some urban areas like Dhaka, the capital of Bangladesh has also scarce of safe drinking water. Rainwater might be a good solution for both of the cases i. e., alternate source of the above mentioned problems. In this regard, this research explored the possibility of harvesting rainwater in rural communities of Bangladesh as well as densely populated city like Dhaka, using simple and low cost technology. In this connection, rainwater has been experimentally harvested at Bangladesh University of Engineering and Technology (BUET) in the monsoon using a small catchment area (15' x 15') made of water proof cloth and a ferro-cement storage tank having capacity of 3200 liters for 05 members' family and the rainwater was stored for 04 months. Additionally, the research also looked at the quality aspect of the stored rainwater including color, total solids, total dissolved solids, lead, turbidity, hardness, acidity, pH, nitrate, fluoride, total coliform, fecal coliform, COD, and BOD. Initial test results indicated that the stored rainwater had a slightly higher pH value (8.1 to 8.3) and presence of coliform bacteria (when water is stored for more than three months) also detected. The traditional filtering system removed contaminants completely and coliforms were removed up to 60% of the total. Depending upon the location, this combination of rainwater harvesting and indigenous filtering system was likely to be a better and cheaper alternative to extracting water from surface water sources.

Key words: Rainwater harvesting, initial flushing device, low cost.

Introduction

Bangladesh is located between latitude 20° 34′ to 26° 38′ N and longitude 88° 01′ to 92° 41′ E and has tropical monsoon with high rainfall from April to September (125 cm to 500 cm). Rural water supply in Bangladesh was based on groundwater, as it is free from pathogenic microorganisms and available in adequate quantity in shallow aquifers. But in the coastal belt because of high salinity in surface and groundwater, in the hilly areas due to absence of good groundwater aquifers as well as difficulties in tubewell construction in stony layers were the main constraints for the development of a dependable water supply system. In the north and north-western region of Bangladesh due to heavy extraction of groundwater for irrigation, groundwater depletion continues during summer and was a main constraint for the development of a dependable water supply system.

Arsenic content in alluvial sediments in Bangladesh was usually in the range of 2 - 10 mg/l; which was slightly greater than that in typical sediments (BGS and MML, 1999). Arsenic concentrations in soils as high as 51 mg/l in Faridpur and 83 mg/l in Comilla had been reported (Ulla, 1998). Arsenic in shallow tubewell water had been found in 211 thanas out of 460 thanas (BGS and MML, 1999). In acute arsenic problem areas, more than 75 percent of the shallow tubewells were contaminated. In Bangladesh about 33,000 tubewell water samples had so far been examined for the presence of arsenic, of which 9,000 have been analyzed in laboratories adopting approved Standard Methods (APHA, AWWA & WEF, 1998) and the remaining 24,000 had been tested by less reliable field kits. It was observed that 51 percent of the shallow tubewells were producing water with arsenic content more than the WHO Guideline value of 0.01 mg/l and 35 percent more than 0.05 mg/l, the maximum acceptable concentrations in Bangladesh (WHO, 1993). An estimated 20 million people were exposed to the risk of arsenic related ailment through drinking of arsenic contaminated water (BGS and MML, 1999). It had been considered to be the most serious drinking water arsenic related problem in the world in terms of population exposure. About 7,600 arsenic affected patients had so far been identified in arsenic affected areas. The magnitude of groundwater contamination and population affected were yet to be assessed by a national survey. At present, the presence of high arsenic concentration in shallow ground water aquifer was also a main constraint for the development of a dependable water supply system.

At first rainwater harvesting was practiced for irrigation purpose only. Now-a-days it is practiced for irrigation as well as drinking and domestic purposes in many countries of the world. Normally it was harvested from rooftop. In Texas and California of USA, Philippine, Germany and Japan, harvested rainwater was being used as drinking, domestic and as well as in irrigation purposes (Internet, 1999). In Canada, up to 50% of harvested water was used for lawn and irrigation purposes (WCWWA, 1993).

The Government of Maldives provided High Density Polyethylene (HDPE) tanks to store the rainwater for the communities free of charge and to individual households on cost recovery basis with financial support from UNICEF (Fattah, 1999). The system of rainwater harvesting for water supply was being used in many arid and semi-arid countries of the world like Tanzania, Morocco, Kenya, Thailand, India, Nepal, Maldives etc.

In Bangladesh, different forms of water harvesting techniques were used in hilly and flat areas. In hilly areas, for household purposes many indigenous techniques were used namely Jhurjhuri, Phor and Thagalok-kum systems. For irrigation purposes, indigenous cross-dam and retention ponds were used in Kaptai and Banderban. Godha method was used for navigation in different areas of Chittagong Hill Tracts (Kabir et al, 1999). Flat land inhabitants had used various forms of water harvesting both in small and large scale. These methods were small ditches in agricultural fields, harvesting in ponds etc. Small ditches, haors and beels were used to hold water from rainfall for supplementary irrigation. There were about 1.76 million ponds in Bangladesh where water was collected from rainfall and seepage (BBS, 1997). In some areas with a high salinity problem, about 36 percent households had been found to practice rainwater harvesting in the rainy season for drinking purpose (Hussain et al, 1989).

The average annual rainfall in Dhaka City is shown in **Figure 1**, ranges from about 2157 mm for the last 16 years since 1980 to 1996 (BBS, 1997). Theoretically 20% of the total rainfall might satisfy almost the whole of the Dhaka City's demand, collected during the monsoon (Kabir et al, 1999). A total of 228 nos. of rainfall stations and 54 nos. of automatic rainfall recorders were surrounded over Bangladesh (BWDB, 1999). Those rainfall stations were giving the rainfall records everyday.

OBJECTIVES OF THE STUDY

The objectives of the study were as follows:

- To develop a feasible rainwater harvesting techniques.

- To monitor the quality of harvested rainwater and to suggest a guideline for long-term use.
- To assess the present water use rate and acceptability of rainwater use for domestic purposes.

METHODOLOGY

The method of the experiment described step by step in a brief as follows:

- The rainfall analyses were done for the last 40 years (from 1957 to 1996) rainfall data, and 7-day and 10-day period of minimum dependable (90%) rainfall of Dhaka City were calculated.
- The site selection was done according to some specific design criteria.
- The volume of storage tank was determined using the Area consumed (Ac) - volume consumed (Vc) relation method which is shown in Appendix A.
- A ferrocement rainwater-harvesting tank as shown in **Figure 2** was manufactured according to the required design steps.
- Fabrication of initial flushing device: This flushing device was designed and fabricated during the study in order to flush the roof or catchment. It prevented the contamination that resulted from first rain that was mixed with leaves, birds dropping and other dirt. To fabricate the initial flushing device a plastic pot (volume app. 8 liters), two PVC pipes (3" dia.) of one-foot length each, one steel sheet, one spring etc. were necessary.

How does it work? A movable cover was set on the outlet pipes. This cover was attached to the plastic pot by a spring. One pipe diverted clean water to the storage tank and another diverted dirty or first flush to the plastic pot. Initially when rain started, the clean water inlet pipe should be closed and the dirty water drained to the plastic pot. This pot was attached to the pipe covered by a spring. This spring beard the load of a significant portion of first flush water. This significant portion of water means the amount of water needed to flush the catchment and this amount was approximately 8 liters. When the spring exceeded the load then it pulled the cover and closed the dirty water inlet pipe to allow the clean water entered into the storage tank. The completion of rainwater collection after each and every shower, the movable cover must be closed the inlet pipe of the storage tank manually.

- Cost Effectiveness analysis was done using water demand and corresponding size of the storage tanks as shown in **Figure 3** for different purposes such as (i) drinking, (ii) drinking and cooking, (iii) drinking, cooking and dishwashing, as shown in **Figure 4,** (iv) drinking, cooking, dishwashing and bathing, (v) drinking, cooking, dishwashing, bathing and cloth washing was determined from the survey which was done during this research. The cost of different sizes of storage tanks (made of ferrocement) was estimated. A graphical representation of demand and storage tank area was established. Also demand versus cost of construction was plotted. Considering the cost (dwellers willing to pay for this system), optimum demand/size was determined from the curve. Based on the market price, the cost effectiveness of optimum size of the constructed (ferrocement) tank was analyzed in comparison to plastic and GI tanks.
- Water Collection Procedure: Rainwater has virtually no bacterial content. With few exceptions, the quality of rainwater prior to interception is more consistent than that of other water sources. When the construction of storage tank was completed, a cloth catchment was tightened above the tank. The parachute cloth catchment was used because of its non-toxic character. An initial flushing device and a plastic net were attached at the inlet of the storage tank. Some dirt, bird's dropping etc. may drop on the catchment that may contaminate the water. When the rainfall started the initial

flushing device diverted the dirty water that cleaned the catchment (for avoiding contamination) automatically and the clean fresh water was stored in the storage tank. The rainwater collection procedure was started in the middle of the September 1999. This time period was at the end of the monsoon. The storage tank was filled within 10 - 12 days. When the storage tank was filled by water, the excess water was drained out automatically.

- Stored rainwater quality monitoring: Ahmed (1999) stated that the following quality tests have to be conducted for stored rainwater at a regular interval of 15 days, for a period of four months:

Physical and Chemical Tests	Microbiological Tests
Color, Total Solids, Total Dissolved Solids, Lead, Turbidity, Hardness, Acidity, pH, Nitrate, Fluoride.	Total Coliform, Fecal Coliform, COD, and BOD.

  The above mentioned tests were performed in the Environmental Engineering Laboratory, Department of Civil Engineering, BUET, Dhaka. Everyday around 25 liters of water were drained out as because of a family having 5 members (water requirement with a minimum of 2 liters/day/person for drinking purposes (Kanagarajan, 1995) and 16 liters/day/family for cooking and dishwashing purposes) would consume that amount of water per day, when the tests were continuing.

- Filtration of the Stored Rainwater: The harvested rainwater in the storage tank was stored for around 4 (four) months and its quality was monitored in 15 (fifteen) days interval. During stored period there were found some total coliform. But it is known from literature that 3 in occasional but not consecutive samples are acceptable, 10 for unpipped water supply but should not occur repeatedly also acceptable (ITN News letter, 1999). For avoiding and reducing this total coliform, a sand filters having three layers of different depths of sand such as 12", 18", 24" were made. A layer of coarse aggregate was placed at the bottom, sand layer in the middle and coal layer at the top of the filter. Coal was used to avoid the bad smell of water. Sand was used to reduce total coliform. After filtering, filtered water of 3 different sand layers were tested in the laboratory. From the result it was clear that 12" sand layer reduced 30% total coliform, 18" layer reduced 40% and 24" reduced 60%. From literature it is known that a sand filter having 1 m of sand layer may remove around 95% to 98% of the total coliform.
- A questionnaire survey was done in 4 slum areas (Kathakbagan, Namapara, Rahmatganj and Nakhalpara) of Dhaka city to collect information about the slum dwellers acceptability, willingness etc, on the rainwater harvesting system.

Result Analysis and Discussions

To obtain accurate authenticated and representative data, the water samples were collected only once after 15 days from the storage tank to the Environmental Engineering Laboratory, Department of Civil Engineering, BUET, Dhaka. The results of different test parameters are shown in the **Table 1** below.

Table 1: Quality test results of harvested rainwater stored in a ferrocement tank for 4 months (from September to December, 1999).

Tests name with unit	Accep. range	1st	2nd	3rd	4th	5th	6th	7th	8th
Color, TCU	15	30	15	12	10	10	10	12	12
Total Solids (Suspended solids), m/l	10	15	10	6	6	6	6	7	7
Total Dissolved Solids,	1000	80	80	75	68	72	75	78	78

m/l								
Turbidity, NTU	10	0.83	0.82	0.81	0.80	0.82	0.81	0.82	0.82
Hardness as $CaCO_3$, m/l	200-500	16	18	15	17	15	15	16	16
pH	6.5-8.5	8.1	8.2	8.2	8.2	8.1	8.1	8.1	8.1
Nitrate, m/l	10	0.2	0.22	0.23	0.22	0.2	0.2	0.21	0.2
Fluoride, m/l	1	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Lead, m/l	0.05	0.032	0.028	0.028	0.029	0.027	0.029	0.03	0.03
COD, m/l	4	1.5	1.5	2	2	2	2	2	2
BOD, m/l	0.2	0.05	0.05	0.05	0.045	0.05	0.052	0.05	0.05
Fecal coliform, N/100ml	0	0	0	0	0	0	0	0	0
Total coliform, N/100ml **	0	0	0	0	0	0	8	9	11

** 3 in occasional but not consecutive samples, 10 for unpipped water supply but should not occur repeatedly.

The tests were conducted from the storage tank and total 8 (eight) samples were once analyzed. The water samples were collected during the monitoring period of September - December 1999. From the above table it was clear that the test parameters result were all within the acceptable range. But in first two test results were higher than acceptable range (15 TCU) because of mixing of color of the parachute cloth to the rainwater. Next six test results were within the acceptable range. Total solids, Total dissolved solids, Turbidity, Hardness, pH, Nitrate, Fluoride, Lead, COD, BOD and fecal coliform all were within the acceptable range without total coliform. After 3 months the test results of total coliform shown approximately 10/100 ml. This total coliform might enter in the storage tank by inlet pipe with mixing of air.

Cost Effectiveness Analysis: Two types of cost effectiveness analysis were done for the experiment such as (i) for materials and costing of storage tank and also (ii) systems for existing and ferro-cement storage tanks. These analyses can be shown in Table 2 & 3 below:

Table 2: Cost of storage tank considering present market price and construction cost (1999).

Materials	Capacity (m^3)	Total cost (Tk.)	Per m^3 cost (Tk.)
Ferrocement molded tank	3.2	8000	2500
Ferrocement wire framed tank	10	14040	1404
Ferrocement bamboo reinforced tank	4.5	6660	1480
Cement jars	2.0	2800	1400
Cement ring tank	5.0	6330	1266
Brick reinforced tank	5.0	16500	3300
Steel sheet tank	3.2	9000	2812
Steel sheet tank	5.0	12000	2400
Plastic tank	1.0	6000	6000

Table 3: Cost Effectiveness Analysis for two systems

Rainwater Harvesting Technique	**Existing Water and Sewerage Authority (WASA) water**
Cost: Total construction cost Tk. 8,000. Maintenance cost Tk. 200/year (including cleaning by chlorine and repairing if any leakage detected) Economic life = 15 years	***Cost (water scare areas):*** Connection cost = Tk. 7,000/connection (WASA, 1981) Water use rate = Tk. 0.15 to Tk. 0.25/liter.

Therefore, total cost = (8,000 + (200 x 14)) = Tk. 10,800 Annual payment = (10,800/15) = Tk. 720 Cost/liter = (10,800/26 lit x 365 days x 15 years) = Tk. 0.07/liter	Total cost = (Tk. 0.15 x 26 liters x 365 days x 15 years) + 7,000 = Tk. 28,350. Annual payment = (28,350/15) = Tk. 1425.

Left column showed the cost of rainwater harvesting system and right column showed the WASA water cost which considered as benefits if rainwater harvesting system is used.

Net Present Value (NPV):

We know that NPV = $(B_0\text{-}C_0)/(1+d)^0 + (B_1+C_1)/(1+d)^1 + (B_2+C_2)/(1+d)^2$ + --- --- + $(B_n+C_n)/(1+d)^n$

Where, C = The value of costs incurred in time n, B = The value of benefit incurred in time n, d = Discount rate (0.05) and n = economic life in years.

Year	Cost (C), Tk. (RWHT)	Benefit (B), Tk. (WASA)	(B – C), Tk.	$(B_n – C_n)/(1+d)^n$ Tk.
1	8000 (const.)	7000+(.15*26*365)=8424	424	404
2	200 (mainte.)	(.15*26*365)= 1424	1224	1110
3	200 (mainte.)	(.15*26*365)= 1424	1224	1057
4	200 (mainte.)	(.15*26*365)= 1424	1224	1007
5	200 (mainte.)	(.15*26*365)= 1424	1224	959
6	200 (mainte.)	(.15*26*365)= 1424	1224	913
7	200 (mainte.)	(.15*26*365)= 1424	1224	870
8	200 (mainte.)	(.15*26*365)= 1424	1224	829
9	200 (mainte.)	(.15*26*365)= 1424	1224	789
10	200 (mainte.)	(.15*26*365)= 1424	1224	751
11	200 (mainte.)	(.15*26*365)= 1424	1224	715
12	200 (mainte.)	(.15*26*365)= 1424	1224	682
13	200 (mainte.)	(.15*26*365)= 1424	1224	649
14	200 (mainte.)	(.15*26*365)= 1424	1224	618
15	200 (mainte.)	(.15*26*365)= 1424	1224	589
				Total = 11,942

According to Sassone (1978), “the higher its NPV, the better is a project”. From the above analysis it was shown that NPV was equal to Tk. 11,942, which was higher than WASA. So, the project was better.

Feasibility Analysis: The feasibility can be determined by three constraints: technical, economical and social (UNDP – World Bank, 1990).

(a) Technical: The initial consideration of the feasibility of rainwater harvesting system concerned water availability as compared to its use or demand. The supply of the system depends how much rain falls during the year and the variability of rainfall. The demand imposed on the system depends on water use. If the supply exceeds the demand, then the rainwater harvesting system is feasible from a technical point of view (UNDP – World Bank, 1990). From Figure 3, it was clear that supply exceeded the demand (supply 1896.39 mm and demand 1113.25 mm in an average per year). So, the rainwater harvesting system was technically feasible.

(b) Economical: From Table 3, it was reveled that the construction cost of ferrocement tank having capacity 3200 liters was Tk. 8,000. The economic life of a ferrocement tank is 16 years (UNDP – World Bank, 1990). The maintenance cost per year of the tank was Tk. 200 (including cleaning of the tank by chlorination, repairing if any leakage detected etc.). So the total cost was ((8,000 + (200 X 14)) = Tk. 10,800. Analyzing this cost considering 15 years of economic life of a ferrocement tank, the price of rainwater was Tk. 0.07/liter. On the other hand, WASA's present (1999) water use rate Tk. 0.15 to 0.25/liter excluding fixed cost Tk. 7,000/connection. The rainwater use rate was 3 times less than WASA's water use rate. So, the rainwater was more economic. Without it the quality of rainwater was better, by using this rainwater health of the family members was improved, medical cost was reduced, carrying of heavy loads for water collection from far away will be reduced, water carrier will be freed for productive work, if the storage tank was on the ground surface then no energy cost was needed to operate the system etc. was added benefit for the use of rainwater. Considering the above factors it was clear that the rainwater harvesting system was feasible.

(c) Social: Bangladesh Rural Advancement Committee (BRAC) constructed two types of rainwater harvester in Sonargaon and Jhikargachha area of Bangladesh. It was observed that although people were happy with the quality of rainwater the cost was prohibitive. Also in every case, the rainwater harvester was used by more than one family so the stored rainwater only lasted for a limited period (maximum one month), not long enough to cover the full dry period (BRAC, 2000). So, it was clear that the people of those area were accepted the system. From the questionnaire survey report it was also clear that people were known about the quality of rainwater and they were willing to pay to install this system as because of their limited scope. Some of the people were experienced because of NGO activities and constructed materials were available and cheap to develop rainwater harvesting system. So, it was clear that this system was socially feasible.

Considering the above mentioned three constraints it was clear that rainwater harvesting system was feasible in the context of Bangladesh.

Conclusions

From the above research it was clear that for the water scarce areas and the arsenic contaminated areas, the rainwater harvesting was a very useful and acceptable as low cost rainwater harvesting techniques. In the arsenic contaminated areas, this source might be an alternate option of water source. Also in the scarce safe drinking water areas like Dhaka, it might be very useful. The water quality was acceptable as safe drinking water in Dhaka areas up to four months and it was applicable only for this area, because the other cities, the air quality might not be the same, so the rainwater quality might differ.

For the further development of the study the more care should be taken when the water was stored in the storage tank and the inlet of the tank may close carefully, so that the total coliform bacteria can not enter and grow in the tank up to whole year or the water can use up to whole year as safe drinking water.

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Appendix A

Calculation of Ac-Vc relation method:

In this method critical catchment area per person (m^2/capita) and minimum storage volume provided per person serviced (m^3/capita) was determined based on the following equations:

(1) $A_{c1} = A_{c\ min} = (C * month)/(f * R_{a\ min})$, m^2/capita

Where,

$A_{c\ min}$ = Minimum catchment area, m^2/capita

C = Monthly demand per capita, liters/month {(2.2+2+1.2)=5.4*30=162 liters}

f = Runoff coefficient, 0.75 (Schiller, 1990)

$R_{a\ min}$ = Lowest annual rainfall over the observed period, mm/year (1500 mm)

So, $A_{c1} = (162 * 4)/(0.75 * 1500) = 0.576\ m^2$/capita

(2) $R_{c1} = \{C/(f * A_{c1})\} = \{162/(0.75 * 0.576)\} = 375$ mm/year

(3) $D_{c1} = \{A_{c1} * F * (R_{c1} * Nc - \sum R_i)\}/1000$

$= \{0.576 * 0.75 * (375 * 4 - 300)\}/1000 = 0.5184\ m^3$/capita

Where, $\sum R_i$ = rainfall in the dry period

(4) $V_{c1} = [D_{c1}/\{1 - (1/Lc * 0.5 * Nc)\}]$

$= [0.5184/\{1 - (1/12 * 0.5 * 4)\}] = 0.62208\ m^3$/consumption

From equation (1), Ac1 = 0.576 m^2/capita, So, for 5 members, (0.576 * 5) = 2.88 m^2

Again from equation (4), Vc1 = 0.62208 m^3/consumption,

So, for 5 members, (0.62208 * 5) = 3.11 m^3

Now making repetition the above equation by adding 1 with the value of equation (1),

i. e., $A_{c1} + 1 = A_{c2} = 2.88 + 1 = 3.88\ m^2$

Solving again the above equations we get, V_{c2} = 2.84 m^3

In this way the calculated area and volume was recorded.

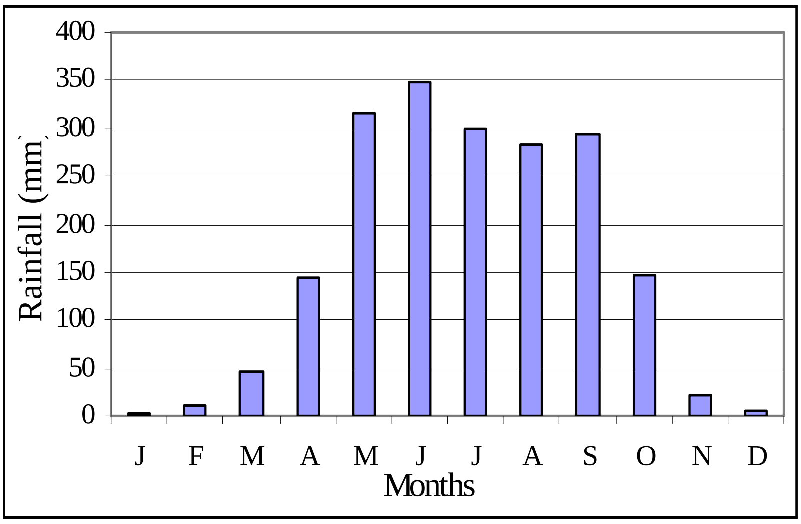

Figure 1: Average rainfall pattern in Dhaka City.

Figure 2: Ferro-cement storage tank (capacity 3200 liters).

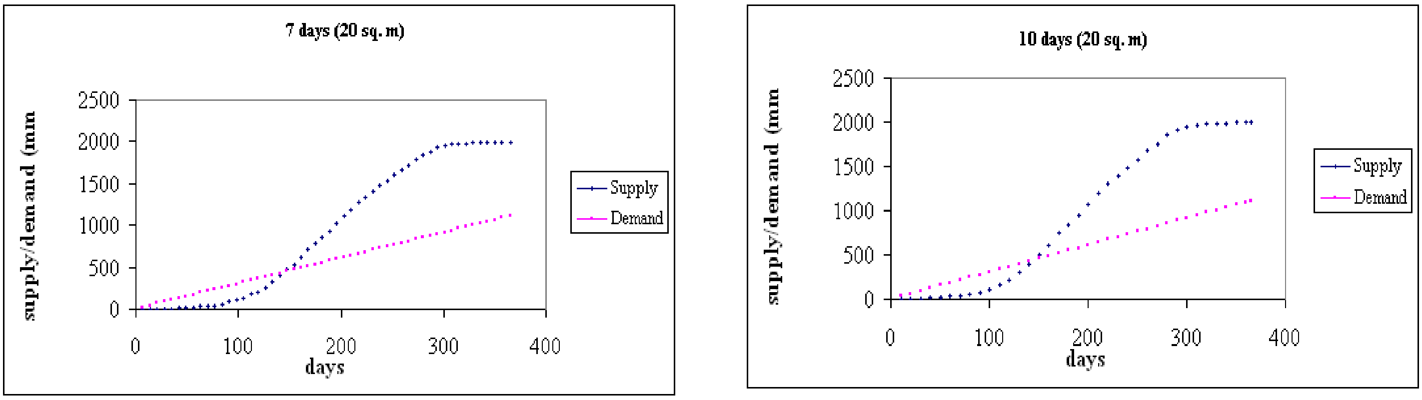

Figure 3: Storage volume required (7-day, 10-day period) for catchment area of 20 sq.m.

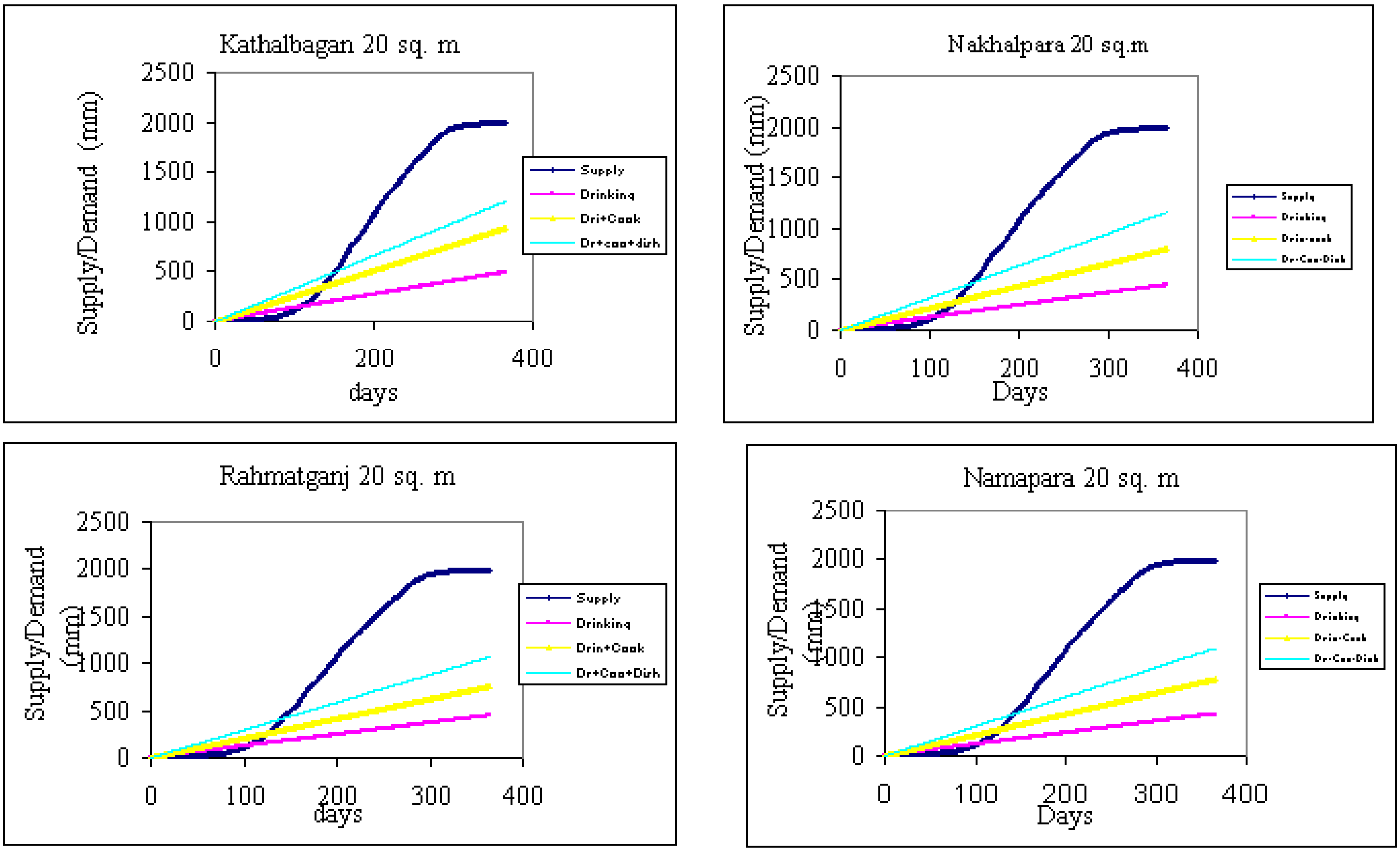

Figure 4: Volume required for differentFigure 4: Volume required for different water use components for four study sit water use components for four study sites.