Proceedings WARMICE-2012
Sudhir Kumar, et al. (eds)
I.A.H., 2012

Assessing the Potential for Rooftop Rainwater Harvesting: A Hope for Semi-arid Region in Haryana

Omvir Singh and Sushila
Department of Geography, Kurukshetra University, Kurukshetra- 136119, India

Abstract : Rainwater harvesting is one of the promising ways of supplementing the surface and underground scarce water resources in areas where existing water supply system is inadequate to meet the demand. Rainwater harvesting is being promoted as a panacea for the growing drinking water crisis in India and many underdeveloped and developing countries. The present study is, therefore, an attempt to find out the rooftop water harvesting potential at micro level in a semi-arid Dhani Mohabbatpur village of Hisar district in Haryana. A primary survey of 763 households was conducted to assess the water harvesting potential during February and March 2011. Potential of rainwater supply from the rooftops of the residents were estimated using the runoff coefficients for cemented and non cemented built up houses including public buildings namely, bus stand, panchyat ghar, child development centre, primary and high school of the village. The study revealed that the potential of rooftop water harvesting in the village are quite enormous and if this water is harvested, it will reduce the pressure on village public water supply and as well as on surface and groundwater resources in the water scarce region.

Keywords: Domestic use, Potential, Rooftop rainwater harvesting, semi-arid region, Water supply

INTRODUCTION

The world's single largest problem is water scarcity (Jury & Vaux, 2006). Water is essential to life and it works as a foundation stone for social and economic development of any country in the world. It is used mainly in the domestic, agricultural and industrial sectors. Moreover, food production is essentially a function of water availability at farm levels. Rising population and urbanisation coupled with climate change may reduce water supply globally during the 21st century (Murad et al. 2007; Wheida & Verhoeven, 2007). Environmental degradation in many countries of the world is reducing human access to safe potable water. Recent growth in the global economy is having far reaching impact on water resources and their uses. Interestingly, changes in lifestyle and changes in consumption rate of water are also leading to pressure on fresh water resources.

Rainwater harvesting via roof top and ground catchments is an ancient technique of providing domestic water supply in arid and semi–arid rural areas of India (Agarwal & Narain 1997). Table 1 highlights the availability of rainwater quantity from different size rooftop catchment depending on amount of rainfall. It can be found in the literature that rainwater is being used, for example, in hotels in China (Deng 2003), schools in Taiwan (Cheng 2003; Cheng & Hong 2004; Wung et al. 2006), houses and residential buildings in Germany (Herrmann & Schmida 1999), houses in Australia (Coombes et al. 1999) and in the UK (Fewkes 1999), amongst others. It is a best option and preferred as an alternative sources of domestic water supply where the ground water is inaccessible due to certain technological and environmental problems. State governments in India have been encouraging the people to adopt the domestic rooftop water harvesting through subsidized schemes. The water thus collected can meet the immediate domestic requirements. Rainwater harvesting has assumed overriding significance all the more in view of the depleting ground water levels during the recent droughts in various parts of India (Ariyabandu 2001). Rooftop rainwater harvesting systems have a relatively small irrigation potential for vegetable gardens (Pachpute et al. 2009). Rainwater harvesting can also be used to minimize water loss and to augment water supplies in any watershed systems (Sekar & Randhir 2007). Moreover, water stored from the house rooftop is presumed to be pure and potable.

In India, the per capita average annual fresh water availability has reduced from 5177 cubic meters in 1951 to 1820 cubic meters in 2001 and it is estimated to further come down to 1341 cubic meters in 2025 and 1140 cubic meters in 2050 (Kumar et al. 2005). Rainwater harvesting is one of the promising ways to meet the water demand in water scarce regions. It is an important technique to confront the increasing shortage of water and to manage the precious water judiciously. Also, it is one of the measures for reducing impact of climate change on water supplies. Agarwal (1998) envisages enormous potential of water harvesting in India, and emphasizes the importance of rainwater harvesting and its pivotal role in water management. Rainwater harvesting is playing a central role in the water supply for agriculture in arid and semi-arid regions of India like Gujarat and Rajasthan (Kolavalli & Whitaker, 1996).

Water scarcity in semi-arid region of Haryana is a tangible phenomenon and detailed information on rooftop rainwater harvesting potential at the individual household level as a specific case have not been undertaken so far in the state and as well as in the country. Therefore, the present research has been attempted to assess the quantitative availability of rainwater harvesting potential on rooftops in individual households of Dhani Mohabatpur village in semi-arid Hisar district of Haryana. Thus, this study contributes to improving the knowledge about the potential of rooftop rainwater harvesting systems at household level.

DESCRIPTION OF THE STUDY AREA

The present study has been carried out at micro-level in semi-arid region of Haryana in Dhani Mohabatpur village of Hisar district. The village is a part of Ghaggar-Yamuna alluvial plain and mark a gradual transition to the Thar Desert. The aeolian deposits comprising accumulation of sand blown from Thar Desert of Rajasthan are mostly confined in the village. These sand accumulations occupy vast stretches of land and occur in the shape of sandy flats, mounds and ridges at places attaining dunal shapes over the sandy flats. The active and moving sand dune generally occurs in the village. The vegetal cover in the village is scant and it resembles the treeless undulating desert. The village is situated at 29^0 13' N latitude and 75^0 26' E longitude in Adampur tehsil of Hisar district (Figure 1). It spreads over an area of about 230 ha. The village is almost a level plain with medium textured sandy and sandy loam type soils. Soils are poor in organic matter content and nutrients. Wheat and cotton are major crops grown in the village whereas bajra, moong, moth, jowar, mustard, and vegetables are minor crops. Buffaloes, cows, sheep and goats constitute the livestock of the village. The total population of the village is approximately 3800 (Field Survey, 2011). The village economy is primarily based on agriculture and livestock.

According to the Thornthwaite's classification (1948), the climate of the area can be classified as tropical steppe, semi-arid and hot. It is mainly characterized by dryness and extremes of temperature with except during south west monsoon period when moist air of oceanic origin penetrates into the region. More than 80% of rainfall is received during this period. Cyclonic rain is also received in the area during winter season (January to February). Mean monthly wind speed at Hisar varies between 2.5-10 km/h. Dust storms are experienced occasionally during summer months and hail storm during winter months. Fog generally prevails during December and January months. Thunderstorms occur throughout the year but the highest incidences have been observed during monsoon season. However, the region is regularly traversed by the recurring droughts, famines and scanty and erratic

Table 1.

Rainfall (mm)	100	200	300	400	500	600	800	1000	1200	1400	1600	1800	2000
Rooftop area (m^2)	Quantity of rooftop harvested water (m^3)												
20	1.6	3.2	4.8	6.4	8.0	9.6	12.8	16	19.2	22.4	25.6	22.8	32
30	2.4	4.8	7.2	9.6	12	14.4	19.2	24	28.8	33.6	38.4	43.2	48
40	3.2	6.4	9.6	12.8	16	19.2	25.6	32	38.4	44.8	51.2	57.6	64
50	4.0	8.0	12	16	20	24	32	40	48	56	64	72	80
60	4.8	9.6	14.4	19.2	24	28.8	38.4	48	57.6	67.2	76.8	86.4	96
70	5.6	11.2	16.8	22.4	28	33.6	44.8	56	67.2	78.4	89.6	100.8	112
80	6.4	12.8	19.2	25.6	32	38.4	51.2	64	76.8	89.6	102.4	115.2	128
90	7.2	14.4	21.6	28.8	36	43.2	57.6	72	86.4	100.8	115.2	129.6	144
100	8.0	16	24	32	40	48	64	80	96	112	128	144	160
200	16	32	48	64	80	96	128	160	192	224	256	288	320
300	24	48	72	96	120	144	192	240	288	336	384	432	480
400	32	64	96	128	160	192	256	320	384	448	512	576	640
500	40	80	120	160	200	240	320	400	480	560	640	720	800
1000	80	160	240	320	400	480	640	800	960	1120	1280	1440	1600
2000	160	320	480	640	800	960	1280	1600	1920	2240	2560	2880	3200
3000	240	480	720	960	1200	1440	1920	2400	2880	3360	3840	4320	4800

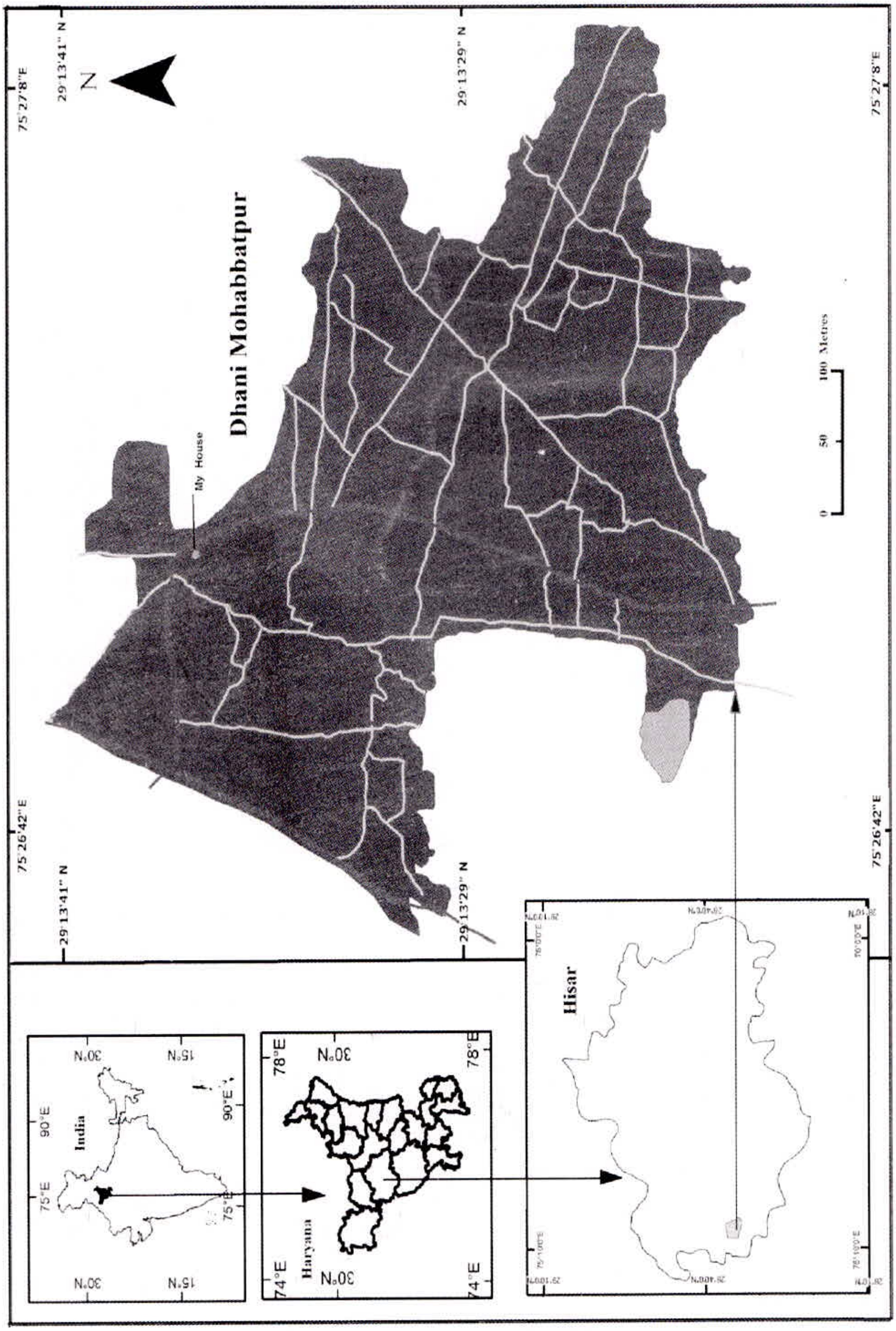
Dhani Mohabbatpur
My House
N
0
50
100 Metres
75°27'8"E
75°26'42"E
29°13'41" N
29°13'29" N
Hisar
India
Haryana
74°E
78°E
30°N
15°N
75°E
90°E

Fig. 1.

rainfall. The most noticeable famine in the district was recorded in the year 1783. The district has also noticeable severe droughts and famines during 1860, 1869, 1877, 1896, 1899, 1929, 1932, 1936, 1938-41 and 1987. The ground water in the village is very deep and it is available at more than 80 m depth from the surface. Moreover, it is saline and unfit for domestic and agriculture consumption.

METHODOLOGY

The present study is primarily based on both primary and secondary data. A primary survey pertaining to all 763 individual households of the village was conducted between late January 2011 and early March 2011. Greater time and effort were maintained by the researchers in this survey to maintain greater data accuracy and reliability. During the field survey, no explicit resistance was expressed by the households regarding their participation in the survey.

Measurement of rooftop area

The rooftop area of all the 763 individual households and common areas such as primary and high school, bus stand, panchyat ghar, child development centre and village ponds were measured by taking field measurements using a tape measure to estimate the rooftop water harvesting potential.

Collection of rainfall data

The Dhani Mohabatpur village has not its own rain gauge. Therefore, to determine the potential rooftop water supply in village daily rainfall data from the nearest stations with comparable conditions were collected for Hisar, Hansi and Adampur rain gauge stations from District Revenue Officer, Hisar for the period of 1980-2009. The amount and number of annual rainy days influences the need and design for rainwater harvesting. The fewer the annual rainy days or longer the dry period, the more the need for rainwater harvesting in a region.

Calculation of runoff coefficient

Runoff is the term applied to the water that flows away from an area after falling on its surface in the form of rain. Moreover, its yield varies with the size and texture of the catchment area. A runoff coefficient value of 0 would mean that no runoff occurs whereas a value of 1 would mean that all the rain falling on the catchment is translated into effective runoff. Moreover, runoff coefficients account for spillage, leakage, infiltration, catchment surface wetting, and evaporation (Gould & Nissen 1999). The coefficient of runoff (Cr) for any area (catchment) is defined as the ratio of the volume of water that runs off to the volume of rain that falls on to the surface.

$$(Cr) = \text{Volume of runoff} / \text{Volume of rain water that falls on the surface}$$

The runoff coefficients for Dhani Mohabatpur were considered as 0.8 for cemented roofs and 0.5 for non cemented roofs and ponds (Pacey & Cullis 1989; Leggett et al. 2001).

Calculation of rooftop potential supply

The total amount of water that is received in the form of rainfall over an area is called the rainwater endowment of that area. Out of this, the amount that can be effectively harvested is called the water harvesting potential. It was calculated as (Gould & Nissen, 1999):

$$S = R \times A \times Cr$$

Where, S = Water harvesting potential

R= Annual rainfall (mm)

A = Area of catchment (m^2)

CR= Coefficient of run off

RESULTS AND DISCUSSION

Rooftop rainwater harvesting potential from cemented houses

The analysis of rainfall data revealed that about 261.2 mm mean annual rainfall is available for rainwater supply in semi-arid Hisar district of Haryana (Table 2). The primary survey demonstrated that village has 763 households and the total population is 3803 persons. About 97% of the total households in the village have cemented roofs with an area of about 39424.8 m^2, which can be used for rain water harvesting. The cemented rooftop area of different households in the village varied from 15 m^2 to 182 m^2. The survey revealed that about 20% of the total cemented households in the village have rooftop area between 40 m^2 to 50 m^2, 19% between 30 m^2 to 40 m^2, 13% between 20 m^2 to 30 m^2, 12% between 50 m^2 to 60 m^2, 9% between 60 m^2 to 70 m^2, 7% between 70 m^2 to 80 m^2 and rest 20% in other categories. However, actual surface area of the rooftops was calculated under each rooftop class to avoid over and under estimation of the potential harvested water on cemented rooftops. Total rooftop area, potential rainwater supply and stored water were calculated for each rooftop area class. This analysis demonstrated that that about 8238 m^3 of water can be harvested on the cemented rooftops of Dhani Mohabatpur village (Table 3). The households having rooftop area between 40 m^2 to 50 m^2 have the maximum potential followed by 50 m^2 to 60 m^2. It was also observed during the survey that households with larger number of family members had larger rooftop area. According to United Nations (UN) and World Health Organisation (WHO), it is assumed that 20 liters/capita/day water is inevitable for the rural communities in the developing countries. The United Nation targeted it as minimum water requirement for all domestic requirements including personal hygiene also. Moreover, International Drinking Water Supply and Sanitation Decade (IDWSS) highlighted that out of 20 liters/capita/day water, 10 litres/capita/day is only for drinking, cooking and washing of utensils purpose. Therefore, if rooftop water harvesting is practiced in Dhani Mohabbatpur village, the availability of 8238 m^3 potential rooftop water can fulfil the domestic water demand of cemented household's population (3672) for 225 days during a year (approximately $7^1/_2$ months).

Rooftop rainwater harvesting potential from non-cemented houses

Out of 763 surveyed households in Dhani Mohabatpur village only 26 households (3%) rooftop area were found to be constructed with the sand and clay (non cemented) material which is locally available. It was observed that most of non cemented households pertain to lower economic group of the village. The rooftop area of various non cemented households varied from 15 m^2 to 56 m^2. The total rooftop area under these households was found to be 746 m^2 and only 131 persons reside in such houses. The rooftops constructed with sand and clay material generate low runoff coefficients and subsequently low quantities of water. Therefore, rooftop rainwater harvesting potential for these households has been considered very bleak. The analysis revealed that out of the total 26 non cemented households, 43 % households in surveyed Dhani Mohabatpur village have rooftop area less than 20 m^2, 15% each between 50 m^2 to 60 m^2, 30 m^2 to 40 m^2 and 20 m^2 to 30 m^2 and 12 % between 40 m^2 to 50 m^2. The calculations of rooftop area, rainfall and runoff coefficients demonstrated that about 972 m^3 of water can be harvested from the non cemented rooftops of Dhani Mohabatpur village (Table 4). The non cemented households having rooftop area between 50 m^2 to 60 m^2 have the maximum rainwater harvesting potential followed by > 20 m^2 rooftop area households. Therefore, if rooftop water harvesting on non cemented houses is practiced in Dhani Mohabbatpur village and 10 liters/capita/day water is required for drinking and cooking, then the availability of 972 m^3 potential rooftop water supply can fulfil the domestic water demand of non cemented household's population (131) for 74 days during a year.

Table 2.

Years	Hisar	Hansi	Adampur	Average (District)
1980	251.6	156.3	232.8	213.6
1981	276.8	301.8	249.4	276.0
1982	335.0	225.0	350.4	303.5
1983	440.2	267.0	502.0	403.1
1984	370.8	364.0	255.7	330.2
1985	302.8	304.0	159.0	255.3
1986	264.5	132.0	133.0	176.5
1987	132.1	161.0	86.2	126.4
1988	532.2	534.1	457.0	507.8
1989	148.5	126.4	104.0	126.3
1990	413.3	243.0	213.0	289.8
1991	345.7	169.2	78.2	197.7
1992	373.5	114.0	172.0	219.8
1993	284.8	441.0	147.0	290.9
1994	420.0	345.5	229.0	331.5
1995	481.5	391.0	365.5	412.7
1996	251.0	309.0	101.0	220.3
1997	469.0	465.0	186.0	373.3
1998	535.5	293.0	188.0	338.8
1999	335.2	174.5	104.0	204.6
2000	89.0	102.0	59.0	83.3
2001	435.5	344.5	255.0	345.0
2002	154.0	120.0	86.0	120.0

Table 3

Roof top area (m^2)	Number of households	Total roof top area (m^2)	Potential rainwater supply (m^2) (Catchment area x mean annual rainfall x coefficient of runoff)			Storage water (L)	Total storage water from non cemented houses (m^3)	No of days @ 10 L/ capita/day
50-60	4	206.5	206.5	261.2	0.5	26968.9	97236.9/1000 =97.2	10×131 =1310 =74 days
40-50	3	130.4	130.4	261.2	0.5	17030.2		
30-40	4	131.6	131.6	261.2	0.5	17187.0		
20-30	4	96.8	96.8	261.2	0.5	12642.1		
< 20	11	179.2	179.2	261.2	0.5	23408.7		
Total	26	744.5	744.5	261.2	0.5	97236.9		

Rooftop rainwater harvesting potential from primary and high school building

Dhani Mohabbatpur village primary school has 12 class rooms with one office building. Total rooftop area of the primary school comes around 1004.4 m². The calculations of rooftop area, rainfall and runoff coefficients demonstrated that about 210 m³ of water can be harvested through rooftop rainwater harvesting from Dhani Mohabbatpur village primary school building (Table 5). Total strength of students in the school is 389 along with 11 teachers, so there are 400 people in the school. If 2 liters/capita/day water is allocated to each student for their basic requirement in the school (Tapir, 1995), then daily water requirement in the school will come to 400 x 2 = 800 liters. Hence, the total potential water available from the primary school building for 262 days in a year. Therefore, the rooftop rain water harvesting from the school itself can fulfil the basic water requirement of the school for about $8^1/_2$ month during the water scarce period. Moreover, the number of water supply days may increase in the reference of the student strength, as the total strength of regular student is 70% and further if school holidays during a year are also taken into account then water harvested from the primary school rooftops will be surplus and subsequently it can be utilized for other purposes such as gardening related works in the school.

The high school of the village has 18 rooms including office building and their total rooftop area comes around 1506.6 m². About 315 m³ of water can be made available to school if rooftop water harvesting is practiced from the building. The availability of 315 m³ of potential rooftop water can fulfil the water demand of high school population for 428 days if 2 liters/capita/day water is allocated for their basic requirement in the school. The analysis revealed that high school building has surplus water throughout the year and it can be supplied for domestic use in the village.

Rooftop rainwater harvesting potential from bus stand, panchayat ghar, child development centre and ponds

Total rooftop area of Dhani Mohabbatpur village bus stand was measured as 90 m² and depending on the rainfall and runoff coefficients the total available water is about 19 m³ (Table 5). Therefore, if rooftop water harvesting is practiced in Dhani Mohabbatpur village bus stand, the availability of 19 m³ potential rooftop water can fulfil the water demand of bus stand visiting population (230 per day) for 41 days during a year if 2 litters/capita/ day water is allocated to the bus stand users to fulfil their basic requirement. Similarly, the quantity of water available due to potential harvesting from village panchyat ghar and child development

Table 4. Rooftop area for the non cemented houses and estimation of potential rainwater supply

Roof top area (m^2)	Number of households	Total roof top area (m^2)	Potential rainwater supply (m^2) (Catchment area x mean annual rainfall x coefficient of runoff)			Storage water (L)	Total storage water from non cemented houses (m^3)	No of days @ 10 L/ capita/day
50-60	4	206.5	206.5	261.2	0.5	26968.9	97236.9/1000 =97.2	10×131 =1310 =74 days
40-50	3	130.4	130.4	261.2	0.5	17030.2		
30-40	4	131.6	131.6	261.2	0.5	17187.0		
20-30	4	96.8	96.8	261.2	0.5	12642.1		
< 20	11	179.2	179.2	261.2	0.5	23408.7		
Total	26	744.5	744.5	261.2	0.5	97236.9		

Table 5. Rooftop area for the common buildings and Estimation of potential rainwater supply

Common Buildings	Total roof top area in (m^2)	Potential rainwater supply (m^2) (Catchment area x mean annual rainfall x coefficient of runoff)			Storage water (L)	Total stored water (m^3)	No of days @ 2L/capita/day
Primary school	1004.4	1004.4	261.2	0.8	209879.4	210	2×400=800=262 days
High school	1506.6	1506.6	261.2	0.8	314819.1	315	2×333=666=428 days
Bus stand	90.0	90.0	261.2	0.8	18806.4	19	2×230=460=41 days
Panchayat ghar	81.4	81.4	261.2	0.8	17009.3	17	2×25=50=340 days
Child development centre	124.9	124.9	261.2	0.8	26099.1	26	2×88=176=148 days
Total	2807.3	2807.3	261.2	0.8	586613.4	587	2×1076=2152=273 days

centre can fulfil the drinking water demand for 340 and 148 days in a year, respectively. Moreover, it was revealed from the analysis that the available potential rainwater from the rooftops of all common buildings of Dhani Mohabbatpur village can make the water available for 273 days during a year for the respective users (approximately 9 months).

Dhani Mohabbatpur village has three large size ponds with their total surface area of about 7500 m^2. The approximate depth of these ponds varies between 4 to 5 m. Depending on their surface area, depth, rainfall quantity and runoff coefficients these ponds of village can harvest about 979 m^3 of potential rainwater (Table 6). The water stored in the village ponds can be utilized for livestock and various non drinking purposes such as washing of clothes, gardening and flushing. Effective pond management through ground catchment harvesting will not only solve the water problem of the village but also it will recharge the groundwater quantities.

Water stored from the rooftops is presumed to be pure and potable as it does not flow on the ground and do not come into contact with any solid or liquid materials. However, its quality is altered when it passes through the gutters because water comes in contact with dust, debris and leaf litter which is collected on the roof and gutters. Therefore, it needs to be disinfected before use. This can be done either by boiling the water in a

Table 6. Surface area of the three village ponds and estimation of potential rainwater supply

Pond Number	Total surface area (m^2)	Potential rainwater supply (m^2) (catchment area x mean annual rainfall x coefficient of runoff)			Storage water (L)	Total stored water (m3)
1	3000	3000	261.2	0.5	391800	
2	2000	2000	261.2	0.5	261200	
3	2500	2500	261.2	0.5	326500	
Total	7500	7500	261.2	0.5	979500	979500/1000 = 979

vessel before consuming or by dissolving the bleaching powder to the water stored in the tank.

CONCLUSIONS

A close examination of the present research argues that rooftop water harvesting systems can prove the best alternatives to public water supply systems in semi-arid rural regions of India. In order to determine the potential of rooftop rainwater harvesting in semi-arid Dhani Mohabbatpur village of Hisar district in Haryana a 30 year rainfall data from three stations was obtained and analysed for inter annual and intra annual variations. The rainfall analysis of these stations revealed that mean annual rainfall in the region is less than 500 mm. Therefore, the management of the rainwater in the region is urgently required to meet the water demands and rooftop rainwater harvesting can be the effective alternative for water resource management. Effective decentralized management strategy for rainwater harvesting must be developed by community participation which will make the people self dependence for their fundamental requirement of drinking water. Rooftop rainwater harvesting and effective pond management through ground catchment harvesting will not only solve the drinking water problem in semi-arid areas of Hisar district in Haryana, but it will be highly practicable in other parts of the country facing similar situation. Moreover, rainwater harvesting usage will also promote significant water saving in the region if well harnessed. The problem of water shortage is being currently experienced in the village during the dry season will be solved using the sufficient rainwater in the wet season. However, the success of rainwater harvesting in the region will depend on the acceptability and affordability of the communities. Moreover, rooftop harvested water usage will reduce pressure on available fresh surface and groundwater resources in water scarce region.

REFERENCS

Agarwal, A. & Narain, S. 1997 Dying wisdom: rise, fall and potential of traditional water harvesting systems in India. Centre for Science and Environment. 4th Citizen's Report. New Delhi:

Agarwal, A. 1998 Rainwater harvesting in a new age: when modern groundwater and river exploitation has reached its limits. Water Harvesting, SIWI 1998 Paper No. 2, Stockholm, pp. 5–12.

Ariyabandu, R. D. S. 2001 Varieties of water harvesting. In: Making Water Everybody's Business: Policy and Practice of Water Harvesting. Centre for Science and Environment, Delhi.

Cheng, C.L. & Hong, Y.T. 2004 Evaluating water utilization in primary schools. *Building and Environment* **39** (7), 837–845.

Cheng, C.L. 2003 Evaluating water conservation measures for Green Building in Taiwan. *Building and Environment* **38** (2), 369–379.

Coombes, P.J., Argue, J.R. & Kuczera, G. 1999 Figtree Place: a case study in water sensitive urban development (WSUD). *Urban Water* **1**(4), 335–343.

Deng, S. 2003 Energy and water uses and their performance explanatory indicators in hotels in Hong Kong. *Energy and Buildings* **35** (8), 775–784.

Fewkes, A. 1999 The use of rainwater for WC flushing: the field testing of a collection system. *Building and Environment* **34** (6), 765–772.

Gould, J. & Nissen-Peterson, E. 1999 Rainwater Catchment Systems for Domestic Supply: Design, Construction and Implementation. International Technology Publications, London. pp 27-61.

Herrmann, T. & Schmida, U. 1999 Rainwater utilisation in Germany: efficiency, dimensioning, hydraulic and environmental aspects. *Urban Water* **1**(4), 307–316

Jury, W.A. & Vaux, H.J. 2006 The role of science in solving the world's emerging water problems. Proceeding of National Academy of Science USA. **102**:15715–15720.

Kolavalli, S. & Whitaker, M. L.1996 Institutional aspects of water harvesting: Khadins in western Rajasthan, India', Paper presented at the 6th Annual Conference of the International Association for the Study of Common Property, Berkeley, California, USA.

Kumar, R., Singh, R.D. & Sharma, K.D. 2005. Water Resources of India. *Current Science* **89** (5), 794-811.

Leggett, D.J., Brown, R., Stanfield, G., Brewer, D. & Holliday, E. 2001 Rainwater and greywater use in buildings: decision-making for water conservation. CIRIA report PR80, London.

Murad, A.A., Al Nuaimi, H. & Al Hammadi, M. 2007 Comprehensive assessment of water resources in the United Arab Emirates (UAE). Water Resources Management 21 (9), 1449–1460.

Pacey, A. & Cullis, A. 1989 Rainwater Harvesting: The Collection of Rainfall and Runoff in Rural Ar*eas*. International Technology Publications, London.

Pachpute, J. S., Tumbo, S. D., Sally, H. & Mul, M. L. 2009 Sustainability of rainwater harvesting systems in rural catchment of Sub-Saharan Africa. *Water Resources Management* **23** (13), 2815–2839

Sekar, I. & Randhir, T.O. 2007 Spatial assessment of conjunctive water harvesting potential in watershed systems. *Journal of Hydrology* **343** (1), 39–52.

Tapir, N. 1995 Improved Roof Rainwater Harvesting in Primary Schools. Presented at the 7th International Rainwater Catchment Systems Conference, Beijing.

Thronthwaite, C.W. (1948). An approach towards a rational classification of climate. Geographical Review 38 (1), 55-94.

Wheida, E. & Verhoeven, R. 2007 An alternative solution of the water shortage problem in Libya. Water Resources Management 21(6), 961–982.

Wung, T.C., Lin, S.H. & Huang, S.M. 2006 Rainwater reuse supply and demand response in urban elementary school of different districts in Taipei. *Resource Conservation and Recycling* **46** (2), 149–167.