Roof water harvesting in hills – innovations for farm diversification and livelihood improvement

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The north eastern region (NER) of India receives bountiful rains (>2000 mm) annually. However, there is extreme water scarcity during post- and pre-monsoon season (November–March). In such a situation, roof water harvesting (RWH) holds promise for multiple livelihood opportunities. RWH unit with polyfilm lined water collection tank of 37 m^3 storage capacity (i.e. 5.5 × 4.5 × 1.5 m^3) was demonstrated at 11 farmers fields mostly on hill tops in the Ri-Bhoi district (Meghalaya). The average demonstration area was 500 m^2/farmer in the vicinity of homesteads (kitchen gardens). Volume of water harvested in a collection tank was about 53 m^3 including about 16 m^3 harvested during dry season due to seasonal replenishment. The cost of water harvesting was estimated at about Rs 144 and Rs 119/m^3 considering lifespan of five and ten years respectively. Farmers used harvested water for diversified activities such as raising crops [maize, broccoli, French bean, laipatta (*Brassica juncea*), tomato, etc.] and livestock (pig or poultry) in addition to domestic use. The farmers without RWH could use land only during rainy season for crop cultivation. On an average, the net income from each RWH based model (500 m^2 demonstration area) was Rs 14,910 for crop + piggery and Rs 11,410 for crop + poultry farming which was 261 and 176% higher, respectively than the normal farmers' practice. Similarly, employment and water use efficiency enhanced by 221 and 586%; and 168 and 218% under crop + piggery and crop + poultry based farming respectively.

Keywords: Jalkund, multiple use of water, NER hills, rain water harvesting, silpaulin.

WATER is indispensable for virtually all human activities and for sustaining ecosystems upon which the present and future generations depend. There is an urgent need to realize that water is a finite and vulnerable resource which must be used efficiently and equitably. Per capita fresh water availability in the Himalayan region is estimated to range from 1757 m^3/year in Indus, 1473 m^3/year in Ganges to 18,417 m^3/year in Brahmaputra basins with an all India average of 2214 m^3/yr. Per capita availability of water is projected to be 1465 m^3 and 1235 m^3 by the years 2025 and 2050 respectively. As per the United Nations' standard, countries with annual per capita availability of <1700 m^3 are considered as water stressed and those with <1000 m^3 as water scarce. India would need 2788 billion cubic metre (bcm) of water annually by 2050 to avoid water stress condition and 1650 bcm to avoid water scarcity situation[1].

The north eastern region (NER) of India is endowed with enormous water resource potential that accounts for about 34% of country's total water wealth. The long-term average annual rainfall of NER is about 2000 mm and in Umiam, the study site, is about 2450 mm. The per capita and per hectare availability of water in NER is the highest in the country[2]. However, less than 5% of the existing potential of the region has so far been tapped for societal use. The net irrigated area in NER is less than one-fourth of the national average which currently stands at 43.2% (ref. 3).

Erratic distribution of rainfall (both in spatial and temporal dimensions) often makes NER suffer from severe water scarcity during pre- and post-monsoon months. Monsoon rains from June to September account for more than 70% of the annual rainfall. The pre-monsoon rainfall (March–May) accounts for 25% of annual rainfall and the post-monsoon and winter rainfall (October–February) are scanty (5%), limiting the agricultural activities during summer and winter seasons. On the other hand, extreme water scarcity during post-rainy season constraints the farmers' access to a reliable water source and to a meaningful economic activity at the farm. Delay in pre-monsoon showers and delay in the onset of monsoon lead to serious damages for agriculture[4]. Even drinking water availability is a serious problem especially for farmers residing on hills. Women and children walk miles to fetch water to meet their daily needs[5].

It is projected that by 2021, an additional 15 million population will be added to the current 45 million in the region. Consequently, the already low per-capita total utilizable water availability (1404 m^3) will further reduce to less than 1000 m^3 and the region will be pushed from already water stressed to water scarce zone. Trend analysis of long term rainfall data (1983–2014) for mid-altitude of Meghalaya (Umiam, 25°41′N, 91°55′E, 1010 m msl) using non-parametric Mann Kendall test, further revealed that contribution of monsoon months to total annual rainfall are declining marginally at the rate of 1.70 mm (ref. 6). Therefore, water harvesting and its efficient utilization is the major approach for enhancing its productivity in NER[7].

Water-surplus period is from May to October, while November–April is water-deficit period (Figure 1). During the post-monsoon months, acute water shortage was

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observed, mostly due to inadequate rainfall which cannot even meet 50% of the monthly potential evapotranspiration (PET) demand. This situation extended up to March (pre-monsoon). Similar trend of acute shortage of rainfall occurred during post-monsoon[7]. Hence, the present study focused on those months. During the last decade, the gap between rainfall and evaporation increased. Compared to the first five years (2005–09), the gap has increased in the latter half of the decade (2010–14) (Figure 2).

Sometimes during rainy season, early withdrawal of rain is common leading to drought-like situations. Droughts of 2006 and 2009 are some recent examples which resulted in reduction in productivity by 20–30% in the region as a whole[8]. Water poverty mapping based on household surveys in a typical hilly village in NER (Nagaland) showed that all households fared poorly in terms of most components of water poverty index[3]. In the valleys of NER, the collection of run-off water in macro-water harvesting structures (farm ponds, tanks, lakes, etc.) having reasonably large catchment area has proved successful, with adequate attention on designs, storage capacity, and soil type in addition to managing seepage

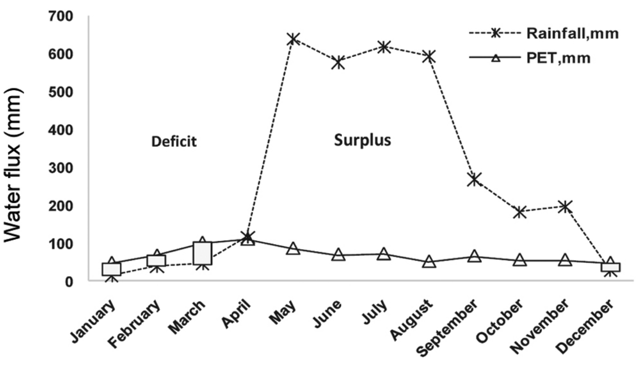

Figure 1. Climatic water balance [rainfall-potential evapotranspiration (PET)] 28 years average at Umiam, Meghalaya.

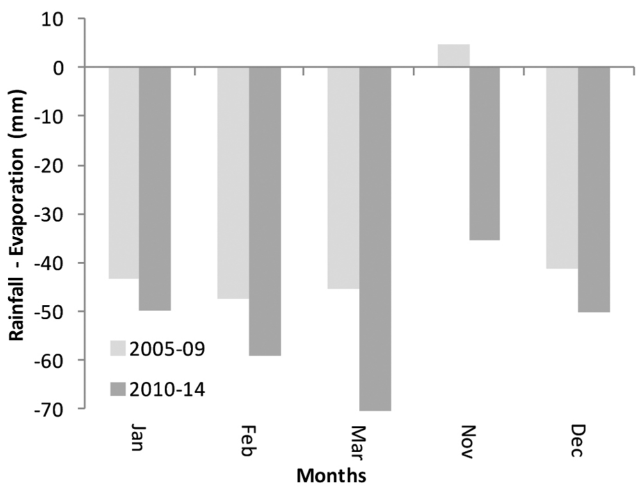

Figure 2. The gap between monthly total rainfall and evaporation.

loss[9]. However, for uplands and hills, construction of such structures is not feasible owing to high seepage loss, porous soil, steep slopes, etc. In such situations, rainwater harvesting in lined cost-effective micro-rainwater harvesting structures such as ‘jalkund’ is the right option[10]. Jalkund – a micro-rain water harvesting structure capable of storing about 30,000 l water in high density poly ethylene (HDPE) film-lined tank has been recommended for north eastern hills for diversified farming activities[5]. Lining of water harvesting structure is essential for retention of harvested water for the entire dry season, i.e. from November–March as seepage losses of 55 l/m^2/day have been reported from NER hills[11].

However, a constraint of such structure is the non-availability of catchment area in the hills. Further, allowing run-off into collection tank results in siltation and makes water dirty. All these problems can be overcomed through roof water harvesting (RWH). The quality of roof-top rainwater being good, could also be used for drinking purpose (with proper treatment) in addition to agriculture, domestic use, etc. RWH can diversify homestead farming by inclusion of remunerative and water efficient crops (broccoli, capsicum, tomato, etc.) and rearing of livestock (pig, poultry, duck, etc.) against the conventional practice of remaining idle or workless for want of water during post-rainy season[8]. Keeping this in mind, RWH in agri-film lined micro-rain water harvesting structure in hills has been evaluated and demonstrated in farmers’ fields. All aspects of water harvesting, including awareness programme, design requirement, demonstrations on fitting of guttering, size and capacity of rain water collection tanks, water loss, longevity of lining material, water productivity and diversified use of stored water have been dealt with.

Surveys and meetings were conducted to select different villages of Ri-Bhoi district of Meghalaya for implementing the programme. The objectives, goal and importance of such programmes were highlighted during the meetings. A total of 11 farmers’ fields were selected for demonstration of RWH system in the district. The geographical coordinates (latitude, longitude and elevation) of the demonstration sites are provided in Table 1.

A typical rooftop rainwater harvesting system comprises (Figures 3 and 4): roof catchment, gutters, down pipe and first flush pipe, polyethylene sheet (silpaulin, 250 μ thickness) and storage tank.

Roof of the house served as the catchment area for harvesting rainwater. Roofs were of galvanized iron (GI) or asbestos sheet or concrete. If the house had thatched roof, it was covered by HDPE sheet to generate more run-off and to get clear water. The amount of rain falling on the roof was channelized through guttering and pipe system to a storage tank or recharge tank. The horizontal area, not the inclined area, of the roof was considered to calculate the amount of run-off. In case of RWH the amount of run-off was taken as 75–90% of the total rainfall[10]. It was

Table 1. Geographical coordinates of the demonstration sites

Name	Village name	Latitude (N)	Longitude (E)	Altitude (m)
Ms Belma Tamu	Kyrdem	25°41.532	092°04.415	883
Mr G Marwein	Sohkyndur	25°42.330	091°53.122	937
Mr Shalan Sylliang	Nongrah	25°43.154	091°59.072	900
Mr L. Umdor	Sohkyndur	25°42.316	091°53.750	940
Mr Elvit Mukhim	Nongpyrdet	25°40.604	092°03.864	888
Mr M Lamare	Umeit	25°42.598	091°57.068	913
Ms Filisha Rani	Mawlein Mawkhan	25°42.868	091°54.387	994
Ms Banrilang Maring	Sohrublei	25°41.329	092°04.731	898
Mr R. Kharsati	Kdonghulu	25°44.710	092°04.427	905
Ms Mariam Saring	Nongthymmai	25°41.397	092°04.115	883
Ms Seplina Masharing	Wahrnai	25°41.569	092°04.485	881

Figure 3. Accessories for roof water harvesting.

Figure 4. Guttering in roof and lining jalkund with silpaulin.

considered that 10% of rainwater would be lost through splash, leakage, overshoot from gutters, evaporation, etc.

Gutter (Figure 4) collected roof water and conveyed it down the pipe and channelized to the collection tank. Gutter is a semi-circular channel which can be fabricated from plain galvanized sheet. Plastic gutters were preferred as plastic is corrosion resistant. Length of the gutter required was kept equal to the running length of all sides of the roof. Diameter of gutter was calculated based on the amount of run-off to be conveyed through it. Maximum rainfall intensity was considered for calculating the size of the gutter. Accordingly, guttering gradient was adjusted. Gutters were fixed below the roof sheet along its length to receive run-off. A gentle slope of about 0.5% towards the outlet was provided along the gutter.

Run-off collected from gutters was conveyed down to a storage tank on the ground through down-pipes. Diameter of a down-pipe was 150 mm. An inlet screen (wire mesh) was fitted at the junction of gutter and down-pipe to prevent the entry of dry leaves and other debris. A valve or 90° elbow was fitted at suitable location in down-pipe to flush out initial run-off which might contain impurities like dust, bird droppings or toxic substances. Plastic pipes were used to avoid rusting and to reduce the cost[10].

To check foreign materials from entering the storage tanks, a 'sand filter' was fitted inside the pipe network before the storage tank. 'Sand filter' was cheap and suitable for relatively bigger foreign particles[11].

For the present study, earthen rain water collection tank (5.5 m × 4.5 m × 1.5 m) lined with 250 μ polyethylene sheet (silpaulin) was provided to the farmers along with guttering systems and other accessories for harvesting roof water. Size of the tank depended on water yield from the roof catchment and water demand[10]. To make the collection tank leak proof, its walls were lined with brickwork or concrete masonry, cement plaster or with any other membrane material[11]. The collection tank was covered to protect stored water from contamination and evaporation by constructing a roof, made of thatched material, corrugated iron or other suitable material.

About 37,000 l of rain water was harvested by farmers in collection tanks (at one point) which was recycled for diversified farming and domestic uses. The actual quantity of water harvested was about 53,000 l owing to replenishment during winter rains. The harvested water was used for cultivation of *rabi* crops like broccoli, cabbage, cauliflower, French bean, capsicum, etc. Even during *kharif* season, water was used for life saving irrigation of vegetables and maize whenever there were dry spells. Water was also used for livestock (pig and poultry) and domestic use (Figure 5). It was earlier reported that about 30,000 l of stored water could irrigate 250 m^2 area for vegetable production and rear five piglets and 50 poultry birds during dry season (November to April)[5].

A tullu pump (1 HP along with 30 m plastic pipes 2.5 cm dia), a sprayer and a rose-can were provided for efficient use of harvested water and plant protection measures. Seeds of high yielding varieties of vegetables such as broccoli, okra, lettuce, tomato, etc. were distributed for cultivation with harvested water to enhance water productivity. A small poultry unit (broiler 25 no./batch) or piggery unit (2 piglets) was integrated with RWH system for increasing productivity, employment and income. A starter feed was given to each farmer for managing poultry (50 kg/farmer) and piggery (100 kg/farmer) units. Later the farmers managed poultry/piggery on their own with locally available resources such as kitchen waste, farm waste, along with some concentrate feed like maize grains, etc. For pigs, in addition to kitchen wastes, farmers used tuber crops (colocasia, sweet potato, etc.) and local grasses. Nutrient management in crops and vegetables was done mostly through organic manure and on-farm residue recycling.

Production data of all crops/livestock was recorded from individual farmer's field. Revenue generated from crops as per the prevailing market price was considered as gross return and the difference between gross return and cost of cultivation was net return. The benefit : cost ratio (B : C ratio) was computed by dividing gross return with cost of cultivation.

Water use efficiency (WUE), water productivity (WP) and maize equivalent yield (MEY) were computed using following formulae.

$$\mathrm{WUE} = \frac{\text{seed yield or economic yield (kg ha}^{-1}\text{)}}{\text{rainfall (mm)}},$$

WP was estimated as

$$\mathrm{WP} = \frac{\text{maize equivalent production (kg)}}{\text{water used (m}^3\text{)}}.$$

Total production of the system indicates the total economic product (e.g. maize yield + pea yield + vegetable yield, etc.).

In case of more than one crop or commodity in a system, yield from each component is multiplied with its respective per unit price and divided by the unit price of maize to obtain MEY of the system and for comparison of two or more production systems.

The net return obtained from RWH based crop + piggery system was Rs 14,910 and crop + poultry system was Rs 11,410 compared to Rs 4130 from farmers' conventional practice at the same area (Table 2). Higher net returns with pig-based farming system than that with poultry-based farming has also been reported by Saha *et al.*[5]. MEY from an average area of about 500 m^2 under RWH with crop + piggery component was about 3167 kg (63.34 t/ha) and crop + poultry was about 1467 kg (29.34 t/ha) compared to only 586 kg (11.72 t/ha) from conventional practice (Table 3). Due to rain water

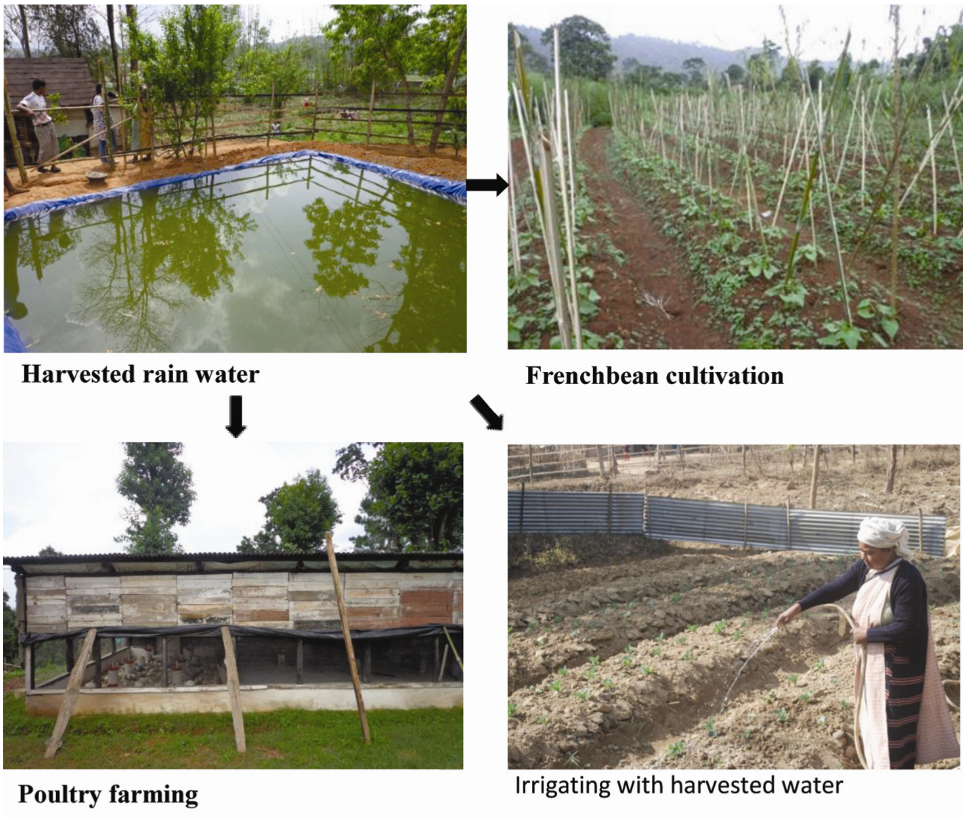

Figure 5. Diversified use of harvested rain water.

Table 2. Production, employment and income from various components of roof water harvesting based model

Particulars		Area allotted (sq. m)	Production (kg)	Employment (Man days)	Cost involvement (Rs)	Gross return (Rs)	Net return (Rs)
Multiple use of harvested water							
Crop component							
Kharif/pre-*kharif*	Frenchbean	200	128	7	800	2560	1760
	Bhindi	100	61	4	500	1220	720
	Pumpkin, bottle gourd, cucumber, etc.	100	90	4	500	900	400
Rabi crop	Broccoli	150	88	6	700	1760	1060
	Cabbage	100	69	4	500	690	190
	Carrot	100	76	4	500	1520	1020
	Laipatta, lettuce, etc.	50	38	2	200	360	160
Livestock component							
Livestocks	Poultry (Broiler)	25 nos. in each batch (4 batch/year)	130	20	6900	13,000	6100
	Piggery	2 piglets	171	30	28,900	38,500	9600
Total	Crop + poultry	500	–	51	10,600	22,010	11,410
	Crop + piggery	500	–	61	32,600	47,510	14,910
Farmers' practice							
Kharif/pre-*kharif*	Ginger	200	460	12	2050	4600	2550
	Frenchbean	100	43	3	300	860	560
Rabi crop	Laipata	50	26	1	150	720	570
	Lettuce	100	25	3	300	750	450
Others	Unused land	200	–	–	–	–	–
Total		500	–	19	2800	6930	4130

Table 3. Maize equivalent yield and water productivity in roof water harvesting system

Farming practice	Maize equivalent yield (kg)	Water use efficiency (kg ha^{-1} mm^{-1}) Yield/rainfall	Water productivity kg m^{-3}	Water productivity Rs m^{-3}	B : C ratio
Roof water harvesting and its multiple use					
Crop + poultry	1467	11.98	27.68	415	2.1
Crop + piggery	3167	25.85	59.75	896	1.46
Farmers' practices	462	3.77	–	–	2.5

Table 4. Economics of roof water harvesting for multiple use (estimate for 5 years and 10 years)

Particulars	Dimension specification^{-1}	Rate unit^{-1} (Rs)	Amount (Rs)/ Water (m^3)
Digging charges for collection tank	5.5 m × 4.5 m × 15 m	100 m^{-3}	3700
Silpaulin for lining	33′ × 27′ (250 GSM)	9000	9000
Guttering materials	Pipe, half round pipe, elbow, joint bracket, adjustable rafter, running outlet etc (one complete set)	–	16,000
Fencing	20 bamboo	50	1000
Labour charges for fitting guttering, lining the tank	13.2 m length and 7.2 m breadth	–	1500
Plastering and cushioning collection tank	–	–	1000
Maintenance cost (5% of gross cost) for 2nd to 5th years	–	1500 year^{-1}	6000
Total cost for first 5 years			38,200
Silpaulin replacement in 5th year	20% higher price	10,800	10,800
Maintenance cost (5% of gross cost) for 6th to 10th years	20% enhancement over previous 2 years	1800 year^{-1}	9000
Miscellaneous	–	500/year	5000
Total cost for 10 years	–	–	63,000
Economics of water harvesting			
5-year period			
Total water harvested	–	53 m^3 year^{-1}	265 m^3
Cost of water harvesting (Rs m^{-3})	–	–	144
Cost of water harvesting (Rs l^{-1})	–	–	0.14
10-year period	–	–	
Total water harvested	–	53 m^3 year^{-1}	530 m^3
Cost of water harvesting (Rs m^{-3})	–		119
Cost of water harvesting (Rs l^{-1})	–	–	0.12

harvesting and its efficient recycling, WUE enhanced substantially under crop + piggery (25.85 kg/ha/mm) and crop + poultry (11.98 kg/ha/mm) compared to normal practice (3.77 kg/ha/mm) (Table 3). Employment generation under crop + piggery and crop + poultry was 61 and 51 man-days respectively, compared to only about 19 under conventional practices, thus enhancing employment by 221 and 168% respectively. Multiple use of water helped farmers to get year round employment and income. It also helped in increasing farm productivity and WUE and thus, has been widely reported[7,9]. For efficient use of water, innovative delivery mechanisms were developed by farmers. Plastic buckets were used instead of metallic ones to avoid damage to lining materials. Some farmers siphoned water from collection tank using electric tullu pump. Some others used gravitational force to divert water to crop fields. Some farmers cultivated climbing crops such as chow-chow (*Sechium edule*), bottle gourd, etc. over collection tanks using a bamboo made structure. Such innovation not only efficiently utilized space but also enhanced income and reduced evaporation from collection tanks during dry season[9].

The approximate cost involved in RWH system including silpaulin lined earthen collection tank (5.5 × 4.5 m × 1.5 m) from an average GI sheet roofed house (12 m × 6 m) was Rs 32,200 in first year (Table 4). The life span of guttering materials is generally about ten years and silpaulin about 5 years. Hence, in 10 years' time, two silpaulin sheets would be required for lining the jalkund. Surface area for rain water harvesting included area of collection tank (25 sq. m) and roof area. The actual roof area of an average sized house of 13.2 m × 7.2 m was about 95 sq. m including increase in area due to plinth area of about 60 cm in each side along the length and breadth of the roof. Thus, the total surface area of RWH was 120 sq. m. The potential for rain water harvesting from 120 sq. m area was about 294 m^3 considering the average rainfall of 2450 mm in study site. However, at one point, volume of the collection tank under demonstration was only 37 m^3, which was just about 12.6% of the potential harvested water that was utilized. During dry months of November–March, about 130 mm of rainfall was received in the study sites which amounted to about 16 m^3 water over 120 m^2 collection area. During winter months, farmers began to recycle the harvested water for multiple uses and the water level came down. Hence, an additional amount of 16 m^3 could be stored due to periodical replenishment by winter rains. Thus, the actual amount of water harvested in the collection tank was 37 m^3 during rainy season and an additional 16 m^3 during dry season totalling to 53 m^3. As a result, the collection tank actually harvested 40% higher amount of water above its storage capacity. For a 10-year period, the total rain water harvested would be around 530 m^3. The approximate cost involved for harvesting water for ten years was estimated at Rs 63,000. Thus, for this much period, the cost of water harvesting would be Rs 119/m^3 or Rs 0.12/l. Productivity of water due to its multiple use in agricultural activities was estimated at Rs 896 and 415/m^3 water under crop + piggery and crop + poultry systems respectively (Table 3), which was almost 7.52 and 3.5 times higher than the cost incurred in RWH (Rs 119/m^3) (Table 4), i.e. the B : C ratio were 7.52 : 1 and 3.5 : 1 under two farming systems respectively. The economics may vary depending on the cost of materials involved in developing a RWH unit, farming components, productivity and market price of the produce. The net annual income of Rs 2965–9495 from about 30,000 l of harvested rain water in polyfilm lined pond had been reported by Saha *et al.*[5].

From eleven RWH systems, a total amount of 583,000 l (583 m^3) water was harvested annually which otherwise would have gone waste as run-off. Adoption of RWH system resulted in saving of farmers' time in their daily activities such as cleaning and giving water to their livestocks for which, earlier they had to walk down hills or distant places to fetch water. The nutritional security and livelihood of hill farmers enhanced substantially due to year round availability of crops and vegetables and higher farm income.

G. Marwein from Sohkyndur village, Ri-Bhoi District, Meghalaya, a beneficiary of RWH technology narrated: 'I am very much happy that I got a RWH unit installed in my home since water scarcity is the major problem in our locality during dry season. The technology brought water to our doorstep and saved time and energy that we used to spend on collecting water from distant places for agricultural practices. Before, we used to cultivate kitchen garden crops only in the rainy season and water scarcity was a major problem to leave land empty during dry season. Now we can cultivate vegetable crops such as cabbage, broccoli, French bean, etc. during winter/dry season that fetch high price in the market. Most importantly we can even manage to rear livestock such as poultry, pigs, etc. due to water availability at doorstep.'

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