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Research Article

Productive Use of Natural Resources for Promotion of Horticultural Crop Production through Rooftop Rainwater Harvesting in Rain-Fed Hilly Areas of Punjab

Abid Hussain*, Sidra Majeed, Muhammad Z. Khan, and Waqas Farooq

Social Sciences Research Institute, National Agricultural Research Centre, Islamabad, Pakistan

Abstract: Rainfall variability often results in low crop and fruit productivity in rain-fed hilly areas. Rooftop Rainwater Harvesting (RTWH) Technology can play a promising role in achieving agricultural production potential in these areas. Its adoption makes the supply of water sustainable for vegetables, fruit, and crop farming as well as domestic use. According to key informants, RTWH is being adopted in the study area on technical lines since the early 1990s. However, the availability of literature about economic aspects of the technology in the context of Pakistan is quite limited. This study is an effort to document the economic aspects of the technology including cost structure, potential benefits, net returns, and returns on investment. Thus, the study is based on a purposively selected sample of thirty farmers from Kotli Sattian and Murree tehsils of Rawalpindi district having operational RTWH systems installed at farms. The data have been analyzed for descriptive statistics and financial evaluation. Moreover, technical discussions with key informants and a detailed review of literature have also been made to substantiate the findings of the study. In the study area, farming families have diversified income sources with a considerably low share of agriculture in family income (19.5%). The mean command area of the RTWH systems at sample farms was 0.33 acres, which is allocated to different vegetables, and mainly to guava & citrus orchards. Benefit-cost ratios of vegetables and fruit farming through RTWH is 1.16, with returns on investment of 15 %, and a rate of return to labour of 0.95 in the first year of installation. Thus, technology is economically viable in the study area. Moreover, the financial gains of RTWH can be improved by enhancing storage capacity and increasing the command area.

Keywords: Rooftop Rainwater Harvesting, Vegetables, Fruits, Adoption, Irrigation, Benefit-cost Ratio, Hilly Areas, Punjab

1. INTRODUCTION

Rainfed agriculture plays an important role in global food production. Its importance can be gauged from the fact that it constitutes 80% of the world's cropland and produces 60% of the global cereal grains [1]. While, rainfed areas are also the hotspots of poverty, food insecurity, malnutrition, poor physical & financial infrastructure, and severe land degradation [2]. In these areas, smallholder subsistence farming systems have limited opportunities to cope with ecosystem changes [3]. Water is a vital ingredient of every living thing on the earth and a basic need for every creature. The minimum domestic water requirement per capita per day is about 50 liter, including water for drinking, cooking, and washing, etc. Considering the national average household size of 6.39 members [4], the daily water requirement of an average-sized family is about 320 liter. However, water required for food production is much more e.g. on average to produce one kg cereals crops (wheat & rice) and pulses it requires about 1000 liter of water [5].

Pakistan is one of the world's most water-stressed countries [6]. The national annual per capita availability of water is below 1000 cubic meters, which is an internationally recognized threshold of water scarcity [7]. Pakistan extracts three quarters (74.3%) of its freshwater annually

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*Corresponding Author: Abid Hussain <abid.parc@gmail.com>

thereby exerting tremendous pressure upon renewable water resources [8]. In this scenario, maintaining water security which is defined as 'the sufficient availability and equitable access to water as an input to agricultural production and associated human well-being' is much essential [9].

The core of rainwater harvesting interventions is to reduce the effects of temporal rainfall shortages for domestic and productive uses. The water thus obtained may improve access, agricultural production, sanitation and health status of people. Ultimately all such improvements may lead to poverty reduction [10]. While rainwater harvesting (RWH) creates synergies between good ecosystem management and human well-being. It is also very useful for soil conservation which would otherwise erode due to the flash flow of rains [3]. Adoption of water harvesting improves resilience to drought and dry spells that result in both risk reduction and yield improvement [11]. RWH is an important source of domestic water in many rural areas of the developing world. It provides all or a portion of domestic, commercial, and agricultural water needs. Thus, RWH is considered the most promising source for supplying fresh water. The technology is being reflected in the water policies of many developing countries [12]. In this context, it is stated that improvements in rainwater harvesting techniques due to recent technological developments may guarantee the availability of food for the growing population [13].

RWH techniques have long been implemented around the world to cope with inter and intra annual variability in precipitation and maintain human well-being. Various studies professed RWH as an effective source of drinking water, livestock watering, and irrigation in drought-prone and rural areas viz. [12, 14, 15]. Moreover, in rural and hilly areas, high costs and low success rates make it difficult, time-consuming, and expensive to provide water supply schemes. Though RWH systems provide impressive results their adoption is much less widespread and slow than the potential to improve the livelihood of land-poor farmers [16]. The main reason is the risk involved in making agricultural investments in semi-arid environments that can be attributed to poverty and bad experiences. While researchers and development agents, more often share with farmers the positive aspects of technology and rarely highlight related risks and constraints [15].

Foregoing these facts in view, it has been endorsed that rainwater harvesting technology is the most appropriate and feasible approach for hilly areas of Pakistan [6]. According to key informants in a hilly tract of Kotli Sattian and Murree tehsils of Rawalpindi district of Punjab province, the rooftop rainwater harvesting (RTWH) technology was introduced by UNDP and IUCN in the 1990s. Many household-based productive activities viz. kitchen gardening, livestock raising, and micro enterprises are dependent on adequate supplies of domestic water [17]. While links between various activities further enhance farming income e.g. waste products from food-based micro-enterprises are used for livestock rearing.

It helps to overcome water stress periods due to changes from wet to dry season, or during within seasonal droughts through supplemental irrigation [3]. The use of RWH makes possible sowing of the crop at the desired time by providing a sufficient supply of water. Alternatively, crop selection should be made keeping in view the availability of irrigation water [18]. Moreover, RWH helps adapt the production of high-value crops through timely nursery sowing of vegetables and planting of fruit plants. High-value crops mostly make a considerable share in farmers' income and result in very high returns for them [19].

In the preview of increasing pressure on existing water resources, there is a need to reconsider actual and potential rainwater harvesting levels, as a viable alternative solution for water shortage [20]. Despite the importance of rainwater harvesting in the socio-economic development of communities, the availability of information about socio-economic aspects of technology adoption in the existing literature is quite limited. RWH technology has the potential to increase crop productivity and reduce the risk of crop failure. Moreover, it saves energy and farm maintenance costs [21]. RTWH being the most commonly used technique among RWH technologies in Makueni County and the vicinity of Nairobi city, capital of Kenya to overcome water scarcity as well for supplemental irrigation [22]. It is considered one of the potential water harvesting techniques for agricultural purposes in West Aisa and North Africa. Similarly, it has been adopted at a building scale in Nairobi and in many cities of Australia, North America, Europe, and Asia to meet household water demand [12].

In Pakistan, Earthquake Reconstruction and Rehabilitation Authority (ERRA) executed a development project in earthquake-affected areas of Khyber Pakhtunkhwa and Azad Jammu and Kashmir to construct forty thousand houses and 400 public/ community institutions equipped with RTWH. The average annual rainfall in areas affected by the earthquake of 2005 is 1500 mm. Thus, RTWH was promoted as an alternative method to preserve natural rainwater [23]. Few researchers including declared RTWH suitable for Islamabad and Lahore, respectively [24 , 25]. It is stated that 22 percent of the yearly household demand for water in the capital city can be met by using RTWH. It is found that RTWH is economical, environmentally friendly, and easy to install the system. It is declared as the best functional technique to avert the present and future water crisis in Pakistan [25].

A generic rooftop rainwater harvesting system as shown in Figure 1 contains several components e.g. the catchment of RTWH is the roof surface that directly receives the rainfall and provides water to the system. Gutter lines are used around the boundaries of a slanted roof to gather and transport rainwater to the storage tank. Conduits are pipelines that drain rainwater from the catchment or rooftop area to the harvesting point. The most commonly used conduit materials are polyvinyl chloride (PVC) and galvanized iron (GI). Another important segment of the RTWH system is the filter that functions to confiscate pollutants from harvested rainwater over the roof before it reaches the storage chamber. According to space and requirement, cemented tanks/ pools, plastic tanks, and buckets are used for storage of the harvested water [26].

The technology has been promoted in the study area through a research and development project that was executed by Climate Change, Energy and Water Resources Institute (CEWRI), NARC in collaboration with the ICARDA-Pakistan office from 2014 - 16 by organizing farmers field days for knowledge dissemination, providing them with technical support, convincing them for the adoption, as well as logistically supporting them in the installation of RTWH systems. Thereafter, from 2017 to 2018, few of the area farmers also adopted it on small scale on their own. However, the rate of adoption is still low and there is a knowledge gap about utilization, economic gains, and up-scaling potential of the technology for the production of vegetables and fruit crops in the study area.

2. MATERIAL AND METHODS

The study is based on a purposively selected sample of thirty farmers from Kotli Sattian and Murree tehsil of Rawalpindi district of Punjab with

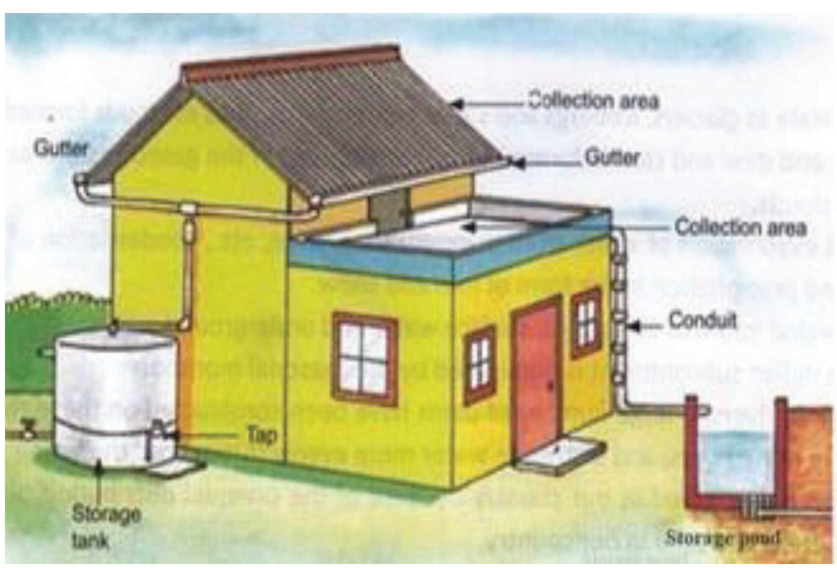

Fig. 1. Rooftop rainwater harvesting system (Adopted with the addition of few details from the website of IndiaMART: an Indian customer to customer sales services providing company)

operational RTWH systems installed at their farms. Thus, lists of such farmers were obtained from NRSP, Kotli Sattian. Moreover, a detailed review of cutting-edge published literature has also been made to substantiate the findings of the study. A field survey for the study was conducted in January-February, 2018. A comprehensive questionnaire was used to collect primary data that contains details about socioeconomic attributes, technology awareness, suitability, detailed cost of installation, and benefits. The questionnaire was pretested and then a formal survey was carried in the field area. Besides a formal survey of thirty farms with RTWH systems in operational conditions, focused formal and informal discussions were also held with key informants from National Rural Support Programme (NRSP) & Climate Change, Alternate Energy & Water Resources Institute (CAEWRI), and farmer respondents to obtain necessary complementary information. Selected areas were Bhagaand Nomal-Arokus valleys and adjoining areas of Kotli Sattian and Murree tehsils of Rawalpindi district, respectively.

Since the RTWH systems are integrated into existing buildings, the costs of land and roof were not included in the analysis. The key aspects considered are the roof gutters (collection), pipes and fittings (convey-ance), overhead /overground/ underground storage tanks, water filters, system maintenance, design life, and running cost. The variable cost of RTWH includes land preparation cost (tractor or manual), seed/ seedling cost, sowing cost, fertilizer cost, and farmyard manure (FYM), and labour cost to perform farm operations to grow the vegetables/ fruits and repair and maintenance cost of the system.

The primary data collected for the study were analyzed by using Statistical Package for Social Sciences (SPSS-22) for descriptive statistics, estimation of cost of the system installation and production of vegetables & fruits, and financial analysis; gross & net returns, benefit-cost ratios, and rate of return to labour. It is worth mentioning here that the financial benefits of RTWH as a single entity are minimal [27]. Thus, investigating the feasibility in monetary terms may provide a shortsighted perspective. Even when the economic feasibility of RWH does not lead to a favorable conclusion, a casual consideration of the non-monetary benefits can alter the conclusion. Non-monetary benefits associated with RTWH include simplicity of operation, low energy requirement, increased crop yield (> 30%), reduced emission of CO_2 increased infiltration & groundwater recharge, and reduced soil erosion [28].

The monthly volume of water that is fetched through the adoption of RTWH is also estimated, by considering the mean catchment area of roofs and using expression (1) that was also applied by [14, 29 - 32]. Water availability through the system has also been compared with the standard per capita daily water requirement of 48 liters (excluding two liters for drinking purposes) on monthly basis for the entire calendar year.

$$VR = I \times Har \times Cr \qquad (1)$$

Where VR =Average volume of rainwater harvested in an hour through roof-top system
I = Rainfall intensity (mm)
Har = Water harvesting/Catchment area (m^2)
Cr = Coefficient of runoff

The coefficient of runoff for any catchment is defined as the ratio of the volume of water that run off to the volume of rain that falls on the surface [33], it depends on the dimensions of the roof as well on the material used [29], and is given by expression (2).

$$C(r) = Vr/Vw \qquad (2)$$

Where Vr= Volume of runoff
Vw = Volume of rainwater that falls on the surface

The runoff coefficient for the study area has been taken as 0.8 which is taken as a standard for the designing of roof catchment systems [33]. Although, it may range from 0.8 to 0.9 for roofs made with tiles, and from 0.7 to 0.9 in the case of roofs made with corrugated metal sheets [34]. The rate of return to labour (RRL) is determined by expression (3). The benefit-cost ratio (BCR) of vegetables and fruit farming through RTWH is calculated by expression (4).

$$RRL = (GR-TEL)/TCP \qquad (3)$$

Where GR = Gross Revenue
TEL = Total cost excluding labour

TCP = Total cost of production

BCR = REV/TC (4)

Where REV = Total revenues

TC = Total cost

3. RESULTS AND DISCUSSION

3.1 Climate and Farming System

Rooftop rainwater harvesting (RTWH) has the potential to be adopted in rain-fed hilly, semi-hilly, plain, and desert ecologies [12]. In rain-fed areas of Pothwar, specifically in the study area with the humid environment, the technology has good potential to be adopted by farmers. Murree and KotliSattian area are situated in a subtropical highland climate zone, with mean annual precipitation of 1,440 mm in Murree and 990 mm in Kotli Sattian. Thus, the mean annual rainfall in the study area is 1215 mm. The temperature ranges from 0°C to 35°C, with an average of 26°C at Murree and from -4°C to 47°C, with an average of 22°C at Kotli Sattian [35].In the study area, crop and livestock farming, which was the main livelihood earning activity in the past has now been taken as secondary sources of income due to change in resource endowment of the people and availability of employment opportunities in non-agriculture sectors. With time area people have entered both public & private sector services, small businesses, and unskilled/ skilled labour markets. Specifically, in Muree tehsil tourism and hoteling opened up new earning avenues for the people.

Wheat is the main Rabi season crop which is generally followed by maize crop. Sample respondents told that loquat, apricot, peach, walnut, guava, plum, lemon, jamen, persimmon, orange, pear are the fruits grown in the area. Cropping mainly depends on rains as there are few seasonal springs and farmers use the water for watering livestock and raising crops. Crop productivity in the study area is low, the average yield of wheat and maize crops are 12 and 24 mounds per acre, respectively. Lower than recommended use of inputs is the reason for low crop productivity. Most people keep livestock to meet their household milk needs. Similarly, [36] stated that crop and livestock productivities are quite low in the study area. It is reported that milk productivity of dairy animals is low, with average daily milk productions of buffaloes, cows, and goats of 8.0, 4.0, and 0.75 liters, respectively. It is further stated that women of the area are actively involved in farming and allied activities. Women grow vegetables, hoe, and harvest crops. Moreover, livestock management is the complete responsibility of the womenfolk. Foregoing this in view, it is stated that RTWH technology is much compatible with existing crop and livestock farming systems in rain-fed hilly areas of Punjab.

3.2 Characteristics of Sample Households

Technological advancements, economic conditions, institutional support, and human-specific factors are the determinants of the adoption of agricultural technologies and practices in developing counties [37]. Socioeconomic characteristics of sample adopter farmers of rooftop rainwater harvesting (RTWH) are presented in (Table 1, Section-I). The adopters were in the late adulthood group, with mean age and formal education of 51.8 and 8.4 years, respectively. They were well experienced in crop farming with a mean experience of 22.6 years. The study area has hilly topography, where crop farming is practiced generally on terraces, with small landholdings. The mean operational landholding of sample farmers was 2.1 acres. Which is predominantly rain-fed. Similarly, due to the limitation of land, fodder supplies are much limited resulting in small livestock holdings. Mean livestock holding in the study area was 3.6 animals per farm, with one to two cows and two three goats. Farming households in the study area have diversified income sources with very limited dependency on crop and livestock farming. Crop and livestock income shares were 13.7 and 5.8 % in the household income, respectively (Table 1, Section-II). Non-farm income shares more than one-third of the household income (35.9%). Small enterprises and remittances share 26.7% and 17.9% in the income of farming households respectively.

3.3 Awareness of the Technology, Access to Materials and Support Services

Availability of effective information as characterized by [38] to be accurate, timely and relevant, reduces the uncertainty of the user and results in the best choice among the alternates available to him. While, adoption of water harvesting for supplementation irrigation depends on observed risk reduction of crop failure and economic benefits for farming households as was evident in Burkina

Table 1. Demographic characteristics of adopter farmers

Farmers' Characteristics	Mean	Standard Deviation
Age of the farmer (Year)	51.8	13.6
Education of the farmer (Year) Farming	8.4	2.1
experience (Year)	22.6	21.3
Family size (Number)	6.2	2.7
Total Operational holding (Acre)	2.0	1.2
Livestock holding (Number)	3.6	3.3
Household Income Sources (Rs./ annum)	**Mean**	**Percent**
Crops	41100	13.7
Livestock	17400	5.8
Small enterprises & trade	80400	26.7
Remittances	54000	17.9
Job/ Non-Farm	108000	35.9
Total	309000	100.0

Faso, Kenya. [39]. Similarly, diversification of the cropping system causes the adoption of RWH and supplementation of irrigation [19]. In agreement with this, it stated that a one-unit increase in diversity of irrigated crops, especially high-value crops, increases the chances of adoption of RWH technology by 6.98 units (about seven times) [40].

Similarly, successful experiences with the RTWH technology have been reported by [40] from China and [41] from Rwanda. In the study area, rainwater harvesting is the indigenous practice as people store rainwater in small ponds, ditches, and tanks for household use for generations. In the study area, RTWH technology was introduced by UNDP and IUCN in the 1990s, thus twenty percent of the sample farmers reported having knowhow about it for more or less 25 years. While out of the remaining (80%), forty percent each were apprised about the technology and its benefits by technical personnel of CEWRI, PARC-NARC, and by their fellow farmers, each. Similarly, market access is a key factor to improve the productivity and selection of product portfolios. Better market access results in the adoption of new beneficial production technologies and techniques. One-half of the farmers reported that materials required for installation of rooftop water harvesting systems are available in local markets on an average at two locations to them. While remaining half reported purchasing it from non-local markets in Bhara Kahu, Islamabad, and Raja Bazar, Rawalpindi at an average distance of 42 km from their farms.

Adoption of rainwater harvesting depends on educational status, number of active family labourers, contact with extension agents, participation in public sector initiatives, and optimistic attitude toward the technology. These are reported to have a statistically significant positive effect on the adoption by [40]. Other factors that facilitate the process of the adoption include farmers' assets holding and practical training [22], technical support [39], membership to a community/ farmer organization [42], and access to credit [43]. While it is also stated that RWH techniques require a considerable amount of economic and physical resources, which are often inaccessible to specific farm households having small landholdings in rain-fed areas, thus makes it an unaffordable venture for them. [39] Sixty percent 60% of the sample farmers reported that technical services for installation of RTWH systems and repair and maintenance were available in their vicinity to a sufficient extent. Eighty percent of them were of the view that educated and illiterate people in their localities have the almost same level of understanding about technology. Similarly, eighty-three percent of the farmers were of the view that technology is beneficial, and if materials required for installation are made available in their area it will accelerate the adoption. Eighty-seven percent 87% of the adopter farmers reported getting training about the technology installation, repair, and maintenance from PARC-NARC and NRSP. While thirteen percent of the farmer reported adopting the technology on their own as it is indigenous and quite easy to install.

In the study area, people use rooftop harvested water for livestock watering, household uses, crop and fruit farming, etc. The majority of the sample farmers (75%) reported having access to credit mainly provided by NRSP. However, none of them reported obtaining a loan from NRSP for investing it in rooftop rainwater harvesting infrastructure. NRSP provides individual loans of just Rs. 5000 with annual charges of Rs.1000 (20%). Which is quite insufficient to meet the installation cost of the system.

3.4 Potential of Rainwater Harvesting & Utilization

RTWH results in the availability of a sufficient quantity of water for household consumption. Rainfall water harvesting potential through RTWH in the study area is presented in Table 2. The mean annual rainfall in the study area is 1215 mm. This results in monthly water availability of 4072 to 43552 liter per household by considering the average roof catchment area of 221.3 m^2 and coefficient of runoff of 0.8. In the study area, the average monthly water availability through the system is 17926 liter. Daily water availability per capita ranges from a minimum of 22 liters in November to a maximum of 231 liters in August. Thus, RTWH provides a sufficient quantity of water to meet daily household water needs from January to September. While during October to December rainfall water harvesting through the system is less than the standard per capita daily water requirement of 48 liters by nine-liter in October to the highest gap of 26 liters in November. However, in the winter season decrease in requirements of water for both household use as well crop production occurs. Hence it can be stated that rainfall in the study area is sufficient to meet the water requirement of the people for household use if it would be attached with double storage capacity than the current level averaged at 360 ft^3 (10,194 liters). However, farmers are unable to enhance storage capacity due to resource constraints. Similar, findings of inadequate storage capacity of tanks for rainwater harvesting and its use for domestic water supply are reported by [20] from the Edo State of Nigeria. It was stated that the majority of people got empty tanks mid-way into the dry season. Thus, the water supply for production for the production of vegetables and fruits can be stabilized by increasing the water storage capacity.

3.5 Cost-benefit Analysis of RTWH for Kitchen Gardening

Economic benefits of rainwater harvesting depend on the amount of rainfall and its timings, as well as on the construction design i.e. catchment area, water storage capacity, and irrigation facilities [41]. Similarly, these factors play important role in determining the costs of installation of the RTWH

Table 2. Rainfall water harvesting potential through RTWH

Months	Rain Fall (mm per month)			Monthly water Availability per household (liter)	Daily water availability per capita	Daily excess (+)/ deficit (-) in per capita water requirement* (liter)
	Kotli Sattian	Murree	Mean			
January	62	103	83	14694	79	31
February	72	107	90	15934	86	38
March	97	130	114	20183		61
April	70	105	88	15580	84	36
May	50	76	63	11154	60	12
June	57	98	78	13809	74	26
July	201	285	243	43021		183
August	201	290	246	43552		186
September	90	125	107	18943		54
October	32	50	41	7259	39	-9
November	19	27	23	4072	22	-26
December	34	44	39	6905	37	-11
Total	985	1440	1215	215104	-	-

system. On sample farms, crop operational area was ranged from about one to four-acre, with a mean of 2.1 acres. The catchment area of the RTWH systems was ranged from 121.4 to 526.1 m^2, with a mean of 221.3 m^2. Command area of the system at sample farms, averaged at 0.33 acres (16.7% of the operational area), ranged from 0.06 to 2.50 acres. Cost and benefit analysis of RTWH on an average farm basis with a command area of 0.33 acres is presented in Table 3.

The fixed cost of the rooftop rainwater harvesting system includes the cost of gutter pipes, conduits, and filters. Which is found to be about Rs. 10,000. The annual fixed cost of installation of the system was Rs.1764 by considering the life of the system 5.75 years, thus it shares 9.22 % in the total cost of vegetable/ fruit production through the RTWH system. Twenty-five percent of the sample farmers reported having sand filters installed with the system for water cleaning and quality improvement. Half of them (50%) reported practicing manual cleaning of systems on annual basis, while the remaining (25%) responded not to clean the systems at all. Fixed cost of water storage tank (concrete or plastic) is averaged at Rs. 9933, by considering operational life of 8.67 years, it shares 5.69 percent in the total cost of production. Thus, the fixed cost of the RTWH system shares 14.91 % in the total cost of production of vegetables and fruits.

RTWH systems are used to irrigate vegetables and fruit orchards mostly in the vicinity of homes. Vegetable production is economically more viable due to higher returns and shorter growth periods and high demand in semi-arid environments [15]. Sample farmers reported a growing variety of vegetables, including garlic, onion, turnip, radish, spinach, peas, fenugreek, carrot, coriander, cucumber, gourds, and okra. Sample farmers reported using harvested rainwater for irrigation of fruit plants (guava and citrus). However, the whole of the fruit production is consumed at home or gifted to relatives and friends. Considering the cost of family labour at prevailing wage rates, the total variable cost was Rs.16087 per annum (84.99% of the total cost).

Total revenues from produce per annum (including the value of products used at home or gifted at retail market prices) were Rs.21920. Net revenue from the RTWH is Rs.2992 per annum by considering the cost of family/shared labour at prevalent market rates thus, the benefit-cost ratio (BCR) of crops and fruit farming through RTWH systems was 1.16 with a return on investment of 15%. The rate of return to labour cost was 0.95. This is quite substantial considering limited employment opportunities specifically for women folk in rain-fed hilly areas of Punjab. The results are in line with [44], as the BCR of RWH ranges from 1.0 to 1.6 in semi-arid areas of Tanzania. It is stated that RWH improves gross margin as well as returns to labour. A review of the literature revealed that BCR greater than 1.0 is considered a feasible goal for RWH [45-47].

The impact of RTWH for rural communities in India has been studied and it is reported economically viable, with a positive impact on the productivity, employment, and income of the rural poor households [48]. Farmers having RTWH systems installed at their farms in the study area obtain economic gains from the adoption despite the subsistence level of farming. It also provides partial employment opportunities for people in general and women in specific. Financial gains could be improved further by enhancing storage capacity, increasing command area under RTWH, selecting crops with water requirements process that coincides with water supply through the system, or through the adoption of high-efficiency irrigation systems like drip, drip-bucket, and sprinkler, etc. Similarly, the making of micro-catchments around fruit plants can also help to minimize the effect of water stress [49]. Likewise, the use of harvested rainwater can be made more economical if used for multiple purposes like kitchen gardens, livestock and household uses to reduce water hauling cost/ utility bills. It is reported that it resulted in increased annual income of rural households in India [50]. In the study area, RTWH results in net revenue of Rs.14385 per annum without including the opportunity cost of family labour, with a substantial benefit-cost ratio of 2.91.

Water is considered the most important factor limiting agricultural production in rain-fed hilly areas. Increasing water scarcity is also mounting pressure on other natural resources. Thus, it is required to augment the water supply in these areas through accelerated adoption of RTWH by exploring feasible sites. Moreover, farmers are

Table 3. Cost and benefits of adoption of rooftop rainwater harvesting system (Rs. per farm)

	Units	Quantity	Price	Value	Life (years)	Cost annum^{-1}
A. Fixed Costs						
i. Water harvesting						
Conveyance component Gutter lines	feet	35.0	65.5	2643	5.75	460
Conduit	feet	15.0	413.3	6200	6.67	930
Water quality improvement component Coarse mesh/ valve/ filters	No.	0.33	600.0	200	1.0	200
Installation cost	M/day	1.0	1000.0	1000	5.75	174
Sub total				10043	-	1746 (9.22%)
ii. Storage component Tank (Concrete/plastic)	No.	1.0	9933.3	9933.3	8.67	1077
Sub total				9933.3	-	1077 (5.69%)
Total (i+ii)	**Rs.**	**-**	**-**	**19975.8**	**-**	**2841**
B. Variable costs						
Cleaning of tank by using fami ly labour	M/day	0.25	600	-	-	150
Slaked lime for cleaning of tan k	Kg	2.5	30	-	-	70
Land Preparation (tractor)	Hours	2.3	728	-	-	1699
Land preparation (manual by family labour)	M/day	0.7	600	-	-	413
Seeds/Seedlings	Rs.	850	-	-	-	850
Sowing by using family labour	M/day	2.25	600	-	-	1350
Fertilizer	Kg	27.5	30	-	-	825
FYM	Trolle	0.5	1500	-	-	750
Family labour for other farm operations (hoeing/weeding, irrigation, FYM &	M/days	15.8	600	-	-	9480
Repair & maintenance hired labour	M/days	0.50	1000	-	-	500
Total						16087 (90.12%)
C. Total cost (A+B) by considering cost of family labour						**18928**
D. Total cost by excluding opportunity cost of family labour						**7535**
E. Revenues Vegetables						
Consumed at home/ gifted	kg	72.0	62.5	-	-	4500
Sold out	kg	228.5	70.0	-	-	15995
Fruits Consumed at home/ gifted	kg	12.5	50			625
Consumed at home/ gifted	dozen	10	80			800
Gross Revenue						**21920**
Net Revenue with the cost of family labour (E-C)						**2992**
Net Revenue without the cost of family labour (E-D)						**14385**
BCR with the cost of family labour (E/C)						**1.16**
BCR without opportunity cost of family labour (E/D)						**2.91**

needed to be sensitized about the water scarcity, the importance of saving rainwater through the adoption of technology, and judicious use of harvested water for household purposes i.e. abolition, bathing, house cleaning, animal watering, kitchen gardening, cloth washing, and toilet use, etc.

4. CONCLUSION AND RECOMMENDATIONS

Findings of the study are useful for key stakeholders as it provides necessary information of the relevant factors and conditions under which the technology performs the best. The technology is very cost-effective and can help decision-makers and water resource planners to meet water scarcity challenges in the region. The study revealed the huge potential of RTWH in hilly areas of Punjab, as these are humid areas with high rainfall and farmers are to face water stress in the summer season, particularly during April to June. Furthermore, this system is very suitable for hilly and scattered houses, where providing water through supply schemes is generally very costly. RTWH can add in household income by reducing food bills especially for vegetables and fruits which they usually buy from the market at high prices. Adoption of the technology saves the precious time of people which could be used productively elsewhere in other productive income-generating activities. It reduces their fatigue for water fetching for households as well as kitchen gardening. Most importantly use of the water harvested through the system is used to produce contamination-free vegetables and fruits with low use of synthetic fertilizers and hazardous chemicals. That is more fresh, healthy, and readily available to farm families than those supplied at high prices from distant wholesale markets. In the study area, farmers are resource-poor, and mostly take agriculture as a secondary business. Furthermore, great variations in rainfall have been reported from one location to another location. All these factors limit the adoption of the technology. Thus, a participatory promotion approach should be brought to the fore for the promotion of technology and improving subsistence food production. In this regard, increased awareness, capacity building, and collaboration among key stakeholders including subject specialists, researchers, technical experts, development partners, agricultural extension staff, and land users should be pursued. Similarly, farmers' skills regarding system installation, repair & maintenance should be enhanced. The public sector should come forward to up-scale the adoption through policy interventions about subsidies and access to loans. The technology should be given due coverage in the 'National Water Policy' and plans. Furthermore, climate change's impact on rainwater harvesting potential is also required to be researched as farmers reported great variation in rainfall patterns over time.

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6. CONFLICT OF INTEREST

The authors declare no conflict of interest.

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