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Economic analysis of water harvesting in a mountainous watershed in India

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Abstract

Water management is an essential feature of any project related with overall development of agriculture. The Soan river catchment in the northwest Himalayas, is fed only by rainwater. Hence, a strategy of rainfed agriculture needs to be developed through water conservation and storage techniques. The Soan is an important river from a soil erosion and water management point of view and detailed economic analysis is needed for any proposal to be implemented in the field. The present study was undertaken to propose an economic analysis of water harvesting structures for the Soan catchment. The purpose of the investigation is to control erosion and conserve water to meet the requirements of supplemental and pre-sowing irrigation for major cereal crops in the area and to maximise agricultural productivity. Benefit/cost ratios ranging from 0.41 to 1.33 are obtained for water harvesting structures of different sizes with estimated life of 25 and 40 years respectively, by taking into account different crop return from maize and wheat.

Keywords: Benefit cost analysis; Irrigation; Reservoir; Storage of water; Water-harvesting structures

1. Introduction

The goals of rainwater management in an arid region include conserving moisture in the root zone, storing water in the soil profile, and harvesting of excess runoff for supplemental and pre-sowing irrigation of rainfed crops. Because only a portion of the rainwater is stored

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in the soil profile, the excess runoff water needs to be harvested in farm structures to meet the irrigation requirements of crops and other water needs in the area (Pillai, 1987; Natividad and Wooldridge, 1997). Water management is an essential feature of any project related with overall development of agriculture in arid watersheds. The Soan catchment is fed only by rainwater and hence, there is a need to develop economically viable and socially acceptable strategy of rainfed agriculture by conserving and storing available runoff for the well being of the poor farming community. The Soan, flowing from northwest to southeast and draining the Shivalik range of the Himalayas, is an important river from both soil erosion and water management perspectives. The Soan catchment is located between $75^{\circ}58'17''$E to $76^{\circ}23'13''$E longitude and $31^{\circ}17'30''$N to $31^{\circ}50'10''$N latitude. The catchment covers 1204 km^2 and is mostly hilly, with altitude varying from 340 m at Santokhgarh to 980 m above mean sea level at the Chintpurni temple. The soils of the area are formed of soft sandstones, brownish clay, conglomerates and river-derived alluvium that erodes easily. The badly truncated, steeply sloping, hilly terrain on both sides of the river causes rapid runoff into deep precipitous tributaries that drain into the Soan river. The areas under cultivation, forest, and pasture represent 27.8, 18.6 and 4.5% of the area of the watershed, respectively. Wheat and maize are the principal cereal crops and the average yields are 1.04 and 1.48 t ha^{-1}, respectively. The Soan catchment is divided into 32 sub-catchments, as demarcated under the Integrated Watershed Development Project for Rainfed Areas (IWDPRA) undertaken by the Department of Agriculture, Government of Himachal Pradesh, India.

Many researchers (Wiener, 1976; Nawalawala, 1994; Srivastava et al., 2000) have examined water development and water conservation strategies for improving water management in agriculture. In some areas, one application of 5 cm depth of pre-sowing irrigation of wheat increases yield from 2.05 to 3.55 t ha^{-1} (Singh and Bhushan, 1980; Sastry et al., 1985). Verma (1987) examined supplemental irrigation of maize and wheat, and computed the monetary return and benefit/cost ratio for an entire water harvesting tank irrigation system for Kandi area in district Hoshiarpur of Punjab state. The benefit/cost ratio varied from 1.13 to 4.56 depending upon the type of soil, assuming the life of the tank is 40 years. Other authors have encouraged the formation of water user associations, water pricing, conjunctive use of groundwater with surface supply and integrated watershed management (Anonymous, 2000a). In this paper, we examine site specific soil erosion based planning and analysis for the hilly region of northern India.

2. Materials and methods

The design capacity of a water harvesting structure normally is determined by the expected value of peak runoff for the anticipated life of the structure. The peak value is determined from historical records. In practice, especially in hills, it may not be possible to harvest all runoff from a catchment due to various reasons. The different reasons are unavailability of suitable sites for reservoirs in adequate quantity, scarcity of roads for carriage of heavy earth moving equipments in the hilly train, unwilling participation of local people, inequitable distribution of water, private ownership of land and paucity of funds, etc. Total runoff for the entire monsoon period is determined as 180 mm by summing runoff values for all active weeks (rainy season) i.e., 24th to 37th and has been considered as the annual runoff depth available for the purpose of water management planning (Kumar, 2002). The methodology for water management planning includes determination of the water harvesting catchment area (WHCA), the volume of water to be stored, evaporation and seepage losses, net available water (NAW), culturable command area (CCA) and the number of water harvesting structures for various sub-catchments of the Soan catchment. We estimate benefit/cost ratios for the entire watershed with different life and size structures and various crop returns.

2.1. Water harvesting catchment area

The water harvesting catchment area must be estimated when assessing the volume to be stored for irrigation and other purposes. It may not be possible to provide supplemental and pre-sowing irrigation in all of the Soan catchment area due to lack of suitable locations for water harvesting structures and other social and economic constraints such as private ownership, fragmentation of land holdings, disagreement among farmers about the location of the structure, non-availability of arable land on the downstream side of the reservoir, scarcity of roads and huge financial requirements. Hence, we determine the expected water harvesting catchment area for different sub-catchments. To reduce soil erosion, greater attention is needed in the area, which is highly eroded because severity of erosion also influences the size of the WHCA. We determine the volume of water to be stored in a particular sub-catchment by considering only a portion of the sub-catchment area and named here in as water harvesting catchment area. We conducted detailed discussions with the Divisional Soil Conservation Officer and field staff of Kangra Division of Soil Conservation, Department of Agriculture, Himachal Pradesh to determine appropriate proportions to use for estimating the WHCA. Consequently, proportion of 20, 15, 10 and 5% of the total sub-catchment area are assigned for WHCA for catastrophic, severe to catastrophic, medium to severe, and low to medium erosion levels, respectively.

2.2. Water to be stored, losses and net available

We compute the volume of water to be stored for a sub-catchment by multiplying the size of the WHCA by the estimated runoff value (180 mm) for the monsoon season. The volume of water requiring storage from the entire catchment area is determined by summing the volumes for all sub-catchments. Because wheat in the area is generally planted around the 44th standard week and pre-sowing irrigation is a prerequisite, the storage period is from the 27th–43rd week (119 days) for computing evaporation losses. To determine these losses, the area of pounded water surface when the reservoir is full to its maximum storage capacity has been considered as 5% of the catchment area. We estimate evaporation for different sub-catchments by multiplying evaporation during the entire period (average evaporation rate of 4 mm $day^{-1} \times 119$ days) by 5% of the WHCA for each catchment. This approach is consistent with seepage studies conducted by researchers for hilly areas of Himachal Pradesh (Sharma et al., 1986; Kumar et al., 1991; Kumar et al., 1993). Seepage losses are assumed to be 20% of the volume of water stored. Net available water is determined by subtracting evaporation and seepage losses from the volume of water stored.

2.3. Culturable command area and water harvesting structures

Considering one supplemental and one pre-sowing irrigation of 5 cm each for maize and wheat, the culturable command area is computed by dividing the volume of water available by the total depth of irrigation requirement (10 cm). Three sizes of water harvesting structures, small (0–10 ml), medium (10–50 ml) and large (50–100 ml) are considered. In the absence of topographical land use and ownership details, it is difficult to suggest the exact number and sizes of water harvesting structures for each sub-catchment. Therefore, a particular size of structure is suggested for the entire catchment area for storing available runoff water for planning purposes. The average capacities of small, medium and large reservoirs are taken as 5, 30 and 75 Ml, respectively (Samra et al., 1996). Thus the number of structures for a sub-catchment is determined by dividing the volume of available runoff water by the average capacity of the reservoir suggested for each sub-catchment.

The life of water harvesting structures also is a parameter value that is difficult to determine. Several workers have assumed the life of water harvesting structures to be in the range of 25–40 years (Joshi and Seckler, 1981; Kalra and Singh, 1985; Khybri, 1985; Verma, 1987; Anonymous, 2000b). Hence, we evaluate the economics of the proposed water management system for the study area for 25 and 40 years of life of water harvesting structures. The review of literature regarding supplemental and pre-sowing irrigation for maize and wheat crops reveals an additional increase in crop yields of 0.45 to 0.55 t ha^{-1} and 0.48 to 1.47 t ha^{-1}, respectively (Anonymous, 1992; Samra et al., 1996). Hence, we assume that yield will increase by 0.5 t ha^{-1} for maize and we consider three possible increases in yield for wheat of 0.5, 1.0 and 1.5 t ha^{-1}. For both maize and wheat, we consider one pre-sowing irrigation of 5 cm.

2.4. Economics of the water management plan

We analyze costs for the entire study area because land use and crop data are not available for sub-catchments. The cost of construction per unit capacity decreases as the size of a reservoir increases. Information describing the cost of construction and irrigation has been collected from field surveys and the Soil Water Conservation Wing of Department of Agriculture, Una, Himachal Pradesh. The cost estimates are based upon the recommendations of various research workers (Joshi and Seckler, 1981; Khybri, 1985; Agnihotri et al., 1989; Sharma et al., 1993; and Anonymous, 1995). The costs of constructing small, medium and large water harvesting structures are assumed to be $ 640, $ 560 and $ 480 (1 US$ = Rs. 50) per ml storage capacity of the tank, respectively. The current procurement prices for maize and wheat are $ 96 t^{-1} and $ 136 t^{-1}, as per the rates of the Food Corporation of India. As suggested by Joshi and Seckler (1981), Khybri (1985), Tung (1992) and Tiwari and Goyal (1998), the benefit/cost criterion is considered for evaluating the economics of the proposed plan. The costs and expected benefits are explained below.

2.4.1. Expected benefits

Normally, water management plans have a long life and the benefits occur during a long time span. Hence we must express our estimates of costs and benefits in terms of present values. In particular, we calculate the present annual return (PAR) per hectare for alternate water management plans.

The procurement prices of \$ 96 t^{-1} and 136 t^{-1} for maize and wheat, are fixed by the Agricultural Price Commission, Government of India. The recommended dose of fertilizer for irrigated wheat and maize in hills is 120, 60 and 30 kg ha^{-1} for nitrogen, phosphorus and potassium, respectively. Thus 260 kg of urea (46% N_2), 375 kg of single super phosphate (16% P_2O_5) and 50 kg of Muriate of Potash (60% K_2O) is needed if the crops are grown under fully irrigated conditions through out the growing period. Since only one irrigation is applied as pre-sowing/supplemental irrigation, the input cost of \$ 28 ha^{-1} for total application of 350 kg fertiliser at prevailing rate of \$ 80 t^{-1} has been considered assuming 50% application of recommended dose. We assume that maize yield increases by 0.5 t ha^{-1} $year^{-1}$ with one supplemental irrigation (Sastry et al., 1985). We examine three increases in yield for wheat: 0.5, 1.0 and 1.5 t ha^{-1}. The present value of the increase in yield over time is dependent on the effective life of the water harvesting structure. We examine useful life times of 25 and 40 years.

The present value of additional net revenue (PVANR) is determined by the following equation:

$$\mathrm{PVANR} = \sum_{t=0}^{T-1} \frac{\mathrm{AANR}}{(1+r)^t} \tag{1}$$

where AANR is the annual additional net revenue = annual return from crop − input fertiliser cost in nominal dollar ha^{-1}, r the discount rate, T the effective life of the structure in years.

In case of maize with present price of \$ 96 t^{-1}, an additional increase in yield of 0.5 t ha^{-1}, input cost of fertiliser as \$ 28 $ha^{-1}$and life of structure as 25 years, the present value of additional net revenue, with T = 25 and r = 0.1 is \$ 200 ha^{-1}.

The PVANR is \$ 215 ha^{-1} for maize with 40-year life of the structure. Similar calculations were done for wheat for which the PVANR is \$ 400, 800, 1200, and 430, 860, 1290 ha^{-1}, respectively for increases in yield of 0.5, 1.0 and 1.5 t ha^{-1} considering the life span of structures to be 25 and 40 years.

2.4.2. Cost involved

The estimated costs of construction are \$ 640, \$ 560 and \$ 480 Ml^{-1} capacity for small, medium and large reservoirs, respectively (Agnihotri et al., 1989; Anonymous, 1993; Samra et al., 1996). Studies at the farm of Himachal Pradesh Agricultural University, Palampur, H.P., India show that water harvesting structures can be maintained with little labour and no major desilting operations are needed for about 30 years (Anonymous, 2003). However, 5% of the cost of construction of water harvesting structures has been considered necessary for annual repair and maintenance including desilting if needed. The volume of water to be stored for the entire Soan catchment is estimated to be 30060 Ml. We used that volume to determine the cost of construction.

The estimated cost of constructing a small sized reservoir is 30,060 Ml × 640 $ Ml^{-1}, or $ 19,238,400. Thus, total cost, including annual repair and maintenance cost of a small reservoir is $ 20,200,320. The estimated average cost for medium and large reservoirs for 25-year life are $ 17,675,280 and $ 15,150,240, respectively. The present annual maintenance cost using a discount rate of 0.10 for small structures for 25-year life has been estimated as $ 9,604,525 for 19,680 ha. Thus, the present value of total estimated costs (construction and maintenance) for small, medium and large reservoirs are $ 1466, $ 1282, $ 1099 ha^{-1} and $ 1503, $ 1315, $ 1128 ha^{-1} for 25 and 40 year life of the structure, respectively.

3. Results and discussion

The estimated evaporation losses at 4.0 mm day^{-1} for the period of storage of 119 days (27th–43rd week) are 4371 Ml for the entire catchment. Assuming seepage losses as 20% (6011 Ml) of the volume of water stored the sum of losses is 10,382 Ml for the study area. Thus about one third of the water stored is lost as seepage or evaporation and is not available for later use. Table 1 depicts that the variation in evaporation and seepage loss for various sub-catchments is 68–236 and 94–324 Ml, respectively. The volume of net available water varies from 306 to 1060 Ml for various sub-catchments.

From economic and convenience points of view, large water harvesting structures are preferred (Joshi and Seckler, 1981; Dhruvanarayana et al., 1997). However, even if a site for a large water harvesting structure is available, landowners may not be willing to allow construction. Hence, we examine three possible choices of water harvesting structures in Table 2. The number and sizes of structures are selected in accordance with the prevailing topography, land use and ownership conditions in each sub-catchment.

The lower annual return from supplemental irrigation of maize in comparison with wheat, with one pre-sowing irrigation may be due to the lower response and low procurement price of maize. The average cost of construction and maintenance is higher for smaller reservoirs (Table 3). However, the trend is opposite for the present value of additional net returns. Reservoirs with longer lives generate greater returns. The estimated benefit/cost ratio range from 0.41 to 1.33 for various alternatives. The highest benefit/cost ratio of 1.33 is observed for large size reservoirs with 40-year life for annual additional net revenue of maize with 0.5 t ha^{-1} and wheat with 1.5 t ha^{-1} (Table 3).

Table 1
Statistical detail of watershed area, water to be stored, losses, net available and culturable command area

Parameter	Area (km^2)	Weighted value (%)	WHCA (ha)	Water to be stored (Ml)	Evaporation loss (Ml)	Seepage loss (Ml)	NAW (Ml)	CCA (ha)
Average	37.7	14.4	527.1	957.0	138.0	189.7	621.2	621.2
Maximum	65.0	20.0	900.0	1620.0	236.0	324.0	1060.0	1060.0
Minimum	18.0	5.0	260.0	468.0	68.0	94.0	306.0	306.0
S.D.	12.7	3.1	183.0	331.7	47.9	65.9	215.4	215.4
Av. Dev.	10.1	2.0	145.4	261.2	38.0	52.4	171.3	171.3
Total	1204	–	16700	30060	4371	6011	19680	19680

WHCA: water harvesting catchment area; NAW: net available water; CCA: culturable command area.

Table 2
Cost of construction of different sized water harvesting structures

Parameter	Number of structures			Cost of construction (thousand US$)		
	Small	Medium	Large	Small	Medium	Large
Whole catchment	4006	1003	403	19238.4	16833.6	14428.8

Small: 5–10 ml; medium: 10–50 ml; large: 50–100 ml.

Any project plan is economically viable if its benefit/cost ratio is more than one (Linsley and Franzini, 1979; Tung, 1992; Tiwari and Goyal, 1998). Thus it is evident from Table 3 that any of the proposed plans might be recommended for the study area if its benefit/cost ratio is one i.e., only large structures can be recommended and that too if additional annual crop return of wheat is also at the maximum of 1.5 t ha^{-1}. Joshi and Seckler (1981) analyzed a rainwater-harvesting project at Sukhomajri near Chandigarh (India) and reported many other benefits of water harvesting such as fish production and higher production of fuel and fodder due to increased groundwater recharge. There are other benefits, which cannot be quantified and assessed in terms of dollars. The conserved soil, water and fertiliser will continue to increase agricultural production for a long time. Due to decreased rate of soil erosion, siltation in the reservoirs would reduce thereby increasing their expected life. Flood damage and loss of life and property would dwindle. The benefit/cost ratio for Sukhomajri was reported to be 1.63 for small earthen dams. Rambabu (1985) evaluated economics of soil and water conservation programmes. He justified the viability of farm ponds at benefit/cost ratios varying from 1.85 to 1.96 in the hill region of Dehradun (India) considering their projected life to be 30 years and using a 10% rate of interest.

In the context of a broader perspective of the plan, it can be inferred that if the current price of the maize is assumed as $ 96 t^{-1} and input fertiliser cost is $ 28 ha^{-1}, the additional annual income from a culturable command area of 19680 ha of the catchment works out to be $ 393,600 for an increase in yield 0.5 t ha^{-1} by providing one supplemental irrigation. Similarly the additional annual income in case of wheat with present price of $ 136 t^{-1} and same fertiliser cost, varies from $ 787,200 to 2,361,600 from the same culturable command area for annual increase in grain yield from 0.5 to 1.5 t ha^{-1} by providing one pre-sowing irrigation of 5 cm. Thus by implementing the proposed water management plan, the total additional annual income from the catchment works out to be $ 1,180,800 to 3,857,280. However, the cost of construction for storage of 30060 Ml of water in small, medium and large structures amounts to $ 19,238,400, $ 16,833,600 and $ 14,428,800, respectively by considering the cost of construction to be $ 680, 560 and 480 per ml capacity of storage of water.

From the above discussion, it is apparent that the total cost for implementing the proposed water management plan considering various alternatives varies from 15.15–20.20 million US$, whereas the total additional net annual income from the catchment considering the minimum increase in grain yield of wheat and maize each to the tune of 0.5 t ha^{-1} comes to be $ 1,180,800. Thus, even if the minimum life of the structure (25 years) and additional increase in grain yield of maize and wheat (each 0.5 t ha^{-1}) are considered, the project cost can be recovered in just 13–17 years. However, the project cost is likely to be recovered in 4 years if only large structures are constructed and additional

Table 3
Benefit/cost ratios for various crop returns and different life and size of water harvesting structures

Life of structure (years)	Crop return	Present value of additional net revenue ($ ha^{-1})	Size of reservoir	Present value of construction and maintenance cost ($ ha^{-1})	Benefit/cost ratio
	M5 + W5	600			0.41
	M5 + W10	1000	Small	1466	0.68
	M5 + W15	1400			0.96
	M5 + W5	600			0.47
25	M5 + W10	1000	Medium	1282	0.78
	M5 + W15	1400			1.09
	M5 + W5	600			0.54
	M5 + W10	1000	Large	1099	0.91
	M5 + W15	1400			1.27
	M5 + W5	645			0.43
	M5 + W10	1075	Small	1503	0.72
	M5 + W15	1505			1.00
	M5 + W5	645			0.49
40	M5 + W10	1075	Medium	1315	0.82
	M5 + W15	1505			1.14
	M5 + W5	645			0.57
	M5 + W10	1075	Large	1128	0.95
	M5 + W15	1505			1.33

M5 and W5, W10, W15 are additional increase in yield with 0.5 t ha^{-1} for maize and 0.5, 1.0, 1.5 t ha^{-1} for wheat, respectively.

increase in yield is 1.5 t ha^{-1} for wheat. Thus the plan proposed for the Soan catchment for large structures can be considered economically viable satisfying both the criteria of early recovery of cost of construction and high benefit/cost ratio. The concerned governmental agency will pay for constructing the reservoirs and additional infrastructure required for proper implementation of the project.

4. Conclusions

The following salient conclusions can be drawn from the present study:

1. The total volume of water to be stored and the culturable command area, were determined to be 30,060 Ml and 19,680 ha respectively for the entire Soan catchment.
2. Various alternative plans for different sizes (small, medium and large) and life (25 and 40 years) of water harvesting structures have been proposed for the Soan catchment with benefit/cost ratios varying from 0.41 to 1.33.
3. Total additional net annual income from the different plans for the entire catchment varied from 1.18–3.86 million US$, whereas the total expenditure for storage of water in harvesting structures was expected to vary from 15.15–20.20 million US$. Thus the project cost is likely to be recovered in just 13–17 years even if the minimum life of structure (25 years) and minimum additional return of wheat and maize (each 0.5 t ha^{-1}) are considered.
4. For all the proposed plans discussed in the study, considering different combinations of water harvesting structures' sizes and life and additional increase in grain yield, the benefit/cost ratio is greater than one for large structures only.

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