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Growth Performance and Economic Analysis of Indian Major Carps and Tilapia in Rainwater Ponds

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Abstract

Enhancing water resources is crucially important for improving food production in rainfed regions. The income of rural people in these regions is mainly tied with water availability. One option is disseminating rainwater harvesting for conserving rainwater and utilizing it for food production. Here we propose a rainwater harvesting method, which helps to conserve rainwater in the rainy season, provide water storage for rearing fish and facilitate supplemental irrigation to crops in the dry season. To verify the suitability of rainwater harvesting approach for improving food production and rural income, here we conducted a field study, which involved designing rainwater harvesting ponds (lined and unlined), storing rainwater and water recycling for irrigating crops. The growth of *Catla catla*, *Labeo rohita*, *Cirrhinus mrigala*, and tilapia in lined and unlined rainwater harvesting ponds was assessed and the resulting benefits were calculated under various scenarios. Water quality measurements showed the suitability of water stored in both rainwater harvesting ponds for fish culture. The Specific Growth Rates (SGR) of all the species in the lined ponds were greater than the unlined ponds except *SGR* of *C. mrigala*. Results show that the fish culture in the ponds improved the annual net benefit of rainwater harvesting systems. For estimating Internal Rate of Return (IRR) and Net Present Value (NPV), the cost and benefits of the rice-fish integration was inflated using Consumer Price Index (*CPI*) data of 2001-2002 and 2011-2012. Unlined and lined ponds with fish culture produced annual net benefits of 118 and 188% of that without fish culture. The IRR in unlined and lined pond rainwater harvesting systems without fish rearing were 9.5 and 9.0%, while with fish culture these values increased to 13 and 26%, respectively. We anticipate that the research presented here demonstrates the potential benefits of the rainwater harvesting system and will enhance water resources in rainfed regions.

Keywords: Rainwater harvesting ponds, fish growth, net benefits, water quality

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Introduction

Predictions have shown that by 2050, more than 59% of people will live in areas with limited water resources (Rockström et al., 2009). As agriculture consumes the largest amount of water, approximately 75% of the total water consumption in the world, the scarcity of water will impact agriculture production the most, particularly in rainfed regions. Increasing crop production in rainfed areas is challenging primarily due to the lack of water during dry seasons. Rice is a major crop in rainfed regions, and it is the main ingredient in the daily diets of more than 3 billion people worldwide (Frei & Becket, 2005). One option for improving water availability in the rainfed regions for agriculture production is rainwater harvesting.

Previous researchers (Pandey et al., 2006; 2011; van der Zaag & Gupta, 2008; Panigrahi et al., 2001) have shown the applicability of rainwater harvesting ponds to improve crop yields in rainfed regions; however, only a few have studied the use of rainwater harvesting ponds for fish culture.

Here we propose rearing fish in rainwater harvesting ponds designed in rice fields and providing stored water in the ponds to the rice crop for supplemental irrigation during the dry season. In the traditional rice-fish integration approach, usually fish are reared in rice fields (*viz.,* capture and culture systems) in concurrent schemes (Mishra & Mohanty, 2004; Ahmad et al., 2011). In concurrent schemes, fish can move around in the rice field freely (Vromant et al., 2001). In Indian rice-fish culture systems, *C. catla*, *C. mrigala*, and *L. rohita* are the most common fish stocked in rice fields. In other Asian countries, the practice of raising catfish (*Clarias macrocephalus*) and snakehead (*Channa striata*) are also reported (Mohanty et al., 2004).

The benefits such as an increase in rice crop yields, additional food production (*viz.,* fish) and utilization of excess labour available in rural areas are reported in the traditional rice-fish integration (Das, 2002; Xiuzehn, 2003). In order to improve the understanding of rainwater harvesting ponds for fish culture and potential impacts on annual net benefits, the objectives of this study are to: 1) assess the fish growth (*viz., C. catla, L. rohita, C. mrigala,* and tilapia) in rainwater harvesting ponds; 2) understand water quality changes in the lined and unlined ponds during fish culture; 3) estimate Net Present Value (*NPV*) and Internal Rate of Return (*IRR*) of rainwater harvesting ponds with fish culture and without fish culture and 4) calculate the sensitivity of the initial investment and net annual return to the *NPV*.

Materials and Methods

A field study was conducted in an experimental farm of the Department of Agriculture and Food Engineering, Indian Institute of Technology, Kharagpur, India, which is located at $22^0 19'$N Latitude and $87^0 19'$E Longitude with an altitude of 48 m above mean sea level. The ponds were designed before the beginning of monsoon season in 2002. A total of 16 dugout ponds (side slope of 1:1 and depth of 2.5 m) were constructed in rice fields (area of 800 m^2) (Table 1). Out of 16 ponds, 8 were plastic lined with 600 gauge of LDPE (Low Density Polyethylene) sheet and 8 were unlined (no-lining material). Four lined and unlined ponds were with feeding conditions *viz.,* fish food was provided to ponds, four lined and unlined ponds were without feeding conditions. To understand the fish growth in lined and unlined ponds, a 115-day fish culture experiment was carried out between July and October 2002. Prior to the stocking of fish in the newly constructed ponds, the lined and unlined ponds were treated with lime (250 kg ha^{-1} of pond area). On day five (after lime application), fresh cow manure, urea, and Triple Super Phosphate (TSP) at 4500, 150, and 150 kg ha^{-1}, respectively, were applied in the ponds. On day 12, four different species: *L. rohita* (average 24 g and 8-10 cm), *C. catla* (average 38 g and 8-12 cm), *C.mrigala* (average 23 g and 7-11 cm), and tilapia (average 20 g and 6-8 cm) were stocked in the ponds. Stocking density and stocking ratio are shown in Table 1. To assess the species wise fish weight, the ponds were seined using fish nets and at least 10% of the total fish population of each species was harvested. At the end of the experiment (October 31, 2002), all the fish available in the ponds were harvested and the pond's water was used for supplemental irrigation to crop. While performing rainwater harvesting experiments, two crops were grown *viz.,* rice and mustard, and crop yields are shown in Table 1. Additional information about crop land and cropping system used in the study are described elsewhere (Pandey et al., 2006).Water quality parameters shown in Table 2 were measured using Horiba Water Quality W-23 Instrument.

Fish were fed daily with fish feed at a rate of 6% of the total body mass of the fish in the lined and unlined ponds. In the fish feed, the moisture content, fat, protein and carbohydrate were 15.7, 2.17, 23.18 and 30.07% respectively. Crude fibre and ash content in the feed were 15.56 and 13.02% respectively. The specific growth rate (SGR) of fish was estimated using the formula proposed by Azim et al. (2001). To estimate the benefits of the lined and unlined rainwater harvesting ponds, we calculated *NPV* and *IRR*. The *NPV* value was estimated as:

$$NPV = E^0 + \sum_{i=1}^{n} \frac{(v)^i}{(1+r)^i} \qquad (1)$$

where E^0 is initial expenditure (investment) at 0 year in pond designing, v is net annual benefit from the pond system, i is year number, n is the life span of the ponds and r is the discount rate (Lorie et al., 1955). In this study, we considered $n$as 10 years; the E^0 in lined and unlined ponds are shown in Table 1. The v was the sum of the benefits from fish and rice production (Table 1). The *NPV* value was estimated for the r of 1 – 30%. The *NPV* value was related to the *IRR*, which is the discount rate (r) at which the *NPV* was equal to zero (Lorie et al., 1955). The cost and benefits of the rice-fish integration (shown in Table1) was inflated using Consumer Price Index (*CPI*) data of 2001-2002 and 2011-2012 for 2012. The *CPI* data were obtained from the Reserve Bank of India (RBI, 2012). Parameter sensitivity to NPV was estimated as absolute relative sensitivity index (S_r).

$$Sr = \left| \left(\frac{E^0}{NPV} \right) \left(\frac{\Delta NPV}{\Delta E^0} \right) \right| \qquad (2)$$

Where E^0 is the base value of investment for lined and unlined ponds (at r of 9%). The ΔNPV is the change in *NPV* value corresponding to the changes in ΔE^0 (± 20%) and v (± 20%). Similar approach for calculating S_r is described elsewhere (White & Chaubey, 2005).

Results and Discussion

The growth of *C. catla, L. rohita*, *C. mrigala* and tilapia in the lined ponds is shown in Fig. 1. The growth with feeding conditions was higher than the growth without feeding. In lined ponds with feed, average weight of *C. catla* during harvesting was 636% higher than the stocking weight of 39 g. The increase in weight for *L. rohita*, *C. mrigala* and tilapia were 606, 387 and 235% respectively. In ponds without feeding, weight of *C. catla* and *L. rohita* during harvesting (after 115 days) were 167 and

Table 1. Farm, pond designing, fish culture, cropping, and investment parameters of the rainwater harvesting study. Cost of pond systems (*viz.*, lined and unlined was inflated using Consumer Price Index (CPI) of 300 in 2000-2001 and 625 in 2011 - 2012. The CPI values were obtained from the Reserve Bank of India (source: RBI (2012))

Parameters	Lined pond	Unlined pond
Farm area (m^2)	800	800
Pond area (m^2)	74 (9.25 % of farm area)	87 (10.8% of farm area)
Fish stocking density (fingerlings/pond)	125	125
Stocking date	8th July 2002	8th July 2002
Stocking ratio	35% *L. rohita*, 25% *C. catla*, 24% *C. mrigala*, and 16% Tilapia	35% *L. rohita*, 25% *C. catla*, 24% *C. mrigala*, and 16% Tilapia
Stocking weight	24 g *L. rohita*, 38 g *C. catla*, 23 g *C. mrigala*, and 20 g Tilapia	24 g *L. rohita*, 38 g *C. catla*, 23 g *C. mrigala*, and 20 g Tilapia
Harvesting date	31th October 2002	31th October 2002
Total feed applied (kg $pond^{-1}$)	39	39
Fish yield (kg ha^{-1})	2340	755
Yield of rice crop (kg ha^{-1})	4050	3740
Yield of mustard crop (kg ha^{-1})	820	660
Initial investment (Rs)	7598	4752
Total annual cost of pond systems with fish (Rs)	1310	992
Total annual cost of pond systems without fish (Rs)	267	188
Annual return from pond systems with fish (Rs)	3535	1883
Annual return from pond systems without fish (Rs)	1452	946
Annual net benefit in pond systems with fish (Rs)	2225	892
Annual net benefit in pond systems without fish (Rs)	1185	758

Note: US $ 1 = Indian Rs 60 (approximately)

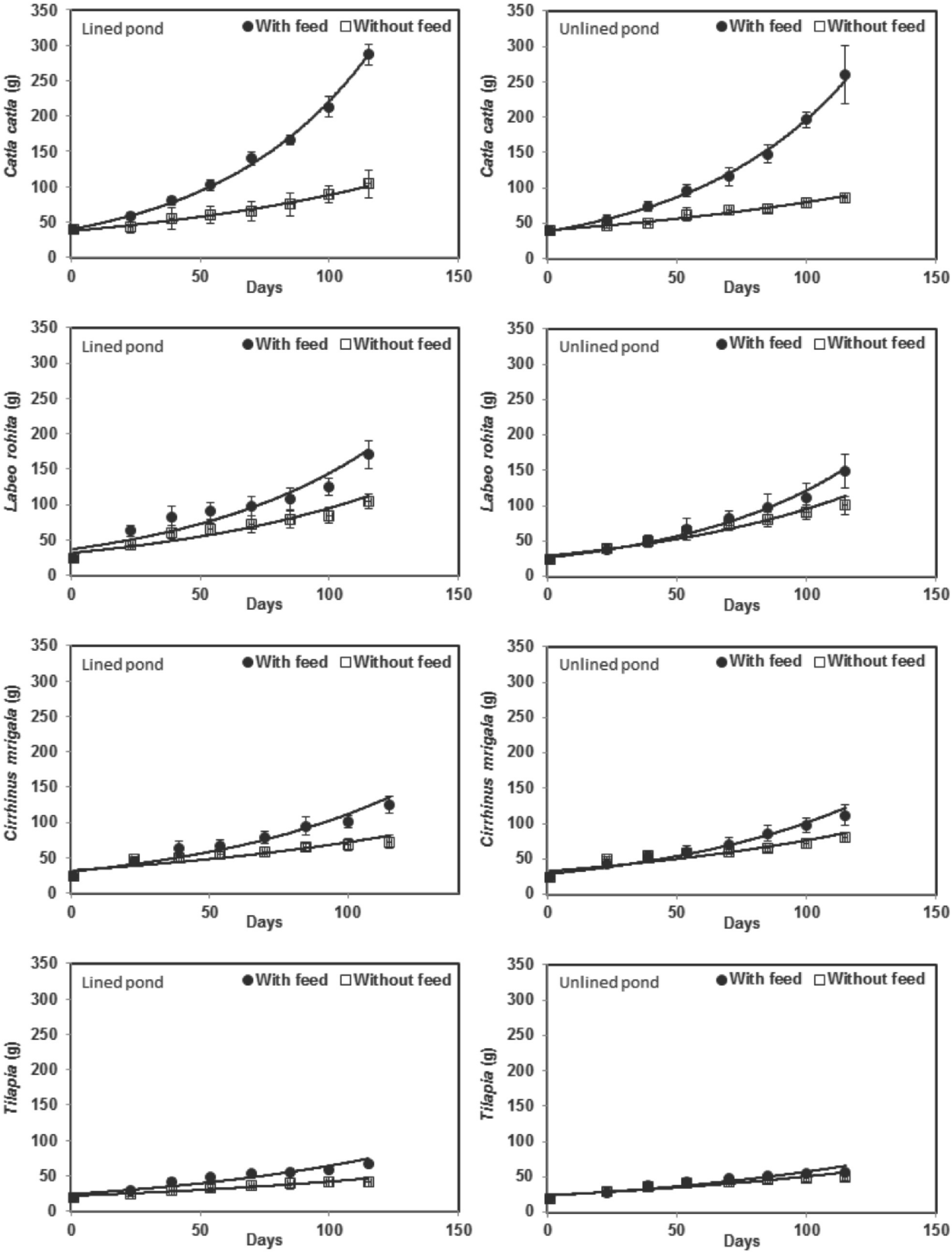

Fig. 1. Change in fish weight (average) over time: growth of *Catla catla, Labeo rohita, Cirrhinus mrigala* and tilapia are shown in lined and unlined ponds.

338% respectively of the stocking weight, while *C.mrigala* and tilapia weighed 252 and 142% of the stocking weight respectively. In the unlined ponds, which did not receive feeding, increase in weight for *C. catla, L. rohita*, C. *mrigala* and tilapia were 121, 213, 317 and 150% respectively. Overall, the increase in fish weight in lined ponds was greater than that of the unlined ponds except for *C. mrigala* and tilapia. The SGR values for lined ponds (with feeding) were 1.7, 1.6, 1.3 and 1.0 for *C. catla, L. rohita, C. mrigala* and tilapia respectively. However, the corresponding values for lined ponds without feeding were 0.8, 1.3, 1.0 and 0.7 respectively. In unlined ponds, the *SGR* values (with feed) for *C. catla, L. rohita, C. mrigala* and tilapia were 1.6, 1.4, 1.5, and 0.9, while the values for unlined ponds without feed were 0.7, 0.9, 1.2, and 0.7 respectively.

In lined ponds, the average water level was 2.12 m (± 0.14 m), while in unlined ponds the average water level was 1.74 m (± 0.37 m). The water levels in lined and unlined vary from 1.89 to 2.44 m and from 0.97 to 2.44 m respectively. The average water level in the lined pond was 22% greater than that of the unlined ponds. The changes in water quality of the lined and unlined ponds during the fish culture period are shown in Fig. 2. The average and range of the water quality parameters are listed in Table 2. In lined ponds, average pH was 6.9 (± 0.7), while in unlined ponds it was 7.1 (± 0.7). The average turbidity in the lined and unlined ponds were 105 NTU (± 50 NTU) and 263 NTU (± 169 NTU) respectively. Values of other water quality parameters are shown in Table 2.

The initial investments for lined and unlined ponds were Rs. 7598 and Rs. 4752 respectively. The total annual cost of lined and unlined pond systems with fish culture were Rs. 1310 and Rs. 992 respectively, while the total annual cost of lined and unlined ponds without fish culture were Rs. 267 and Rs. 188 respectively. Ponds with fish rearing under feeding condition resulted greater benefits, and incomes under various scenario is shown in Table 1. The annual returns from lined and unlined ponds with fish cultures were Rs. 3535 and Rs. 1883 respectively. In lined and unlined ponds without fish cultures, the annual return were Rs. 1452 and Rs. 946. The annual net benefits in lined and unlined ponds with fish cultures were Rs. 2225 and Rs.892, while the annual net benefits in lined and unlined ponds without fish cultures were Rs. 1185 and Rs. 758, respectively.

In the *NPV* curve, the relationship between the *NPV* and the discount rate are shown for lined and unlined ponds (Fig. 3). The *NPV* values of lined and unlined ponds without fish culture varied from Rs. 3723 to Rs. 3630 and Rs. 2273 to Rs. 2430 respectively. The *NPV* values of lined and unlined ponds with fish culture varied from Rs. 325 to Rs. 13476 and from Rs. -1837 to Rs. 3693 respectively.

Table 2. Water quality parameters between June 2, 2002 and October 31, 2002 (average, minimum, range, and standard deviation) in lined and unlined ponds

	Lined pond				Unlined pond				Sample
Parameters	Mean	Minimum	Maximum	Std. Dev.	Mean	Minimum	Maximum	Std. Dev.	n
Secchi disk transparency (cm)	42	22	79	18	11	7	16	3	130
Turbidity (NTU)	105	23	204	50	263	119	661	169	18
Electrical conductivity ($mScm^{-1}$)	0.24	0.13	0.33	0.06	0.11	0.06	0.16	0.12	19
Dissolved oxygen 0900h ($mg\ l^{-1}$)	6.5	3.8	10.16	1.5	6.2	4.9	7.8	0.63	129
Dissolved oxygen 1500h ($mg\ l^{-1}$)	3.3	2.1	4.45	0.6	4.1	2.9	4.9	0.45	129
Water temperature 0900 h (p C)	28	25	32	1.7	27	24	31	1.5	132
Water temperature 1500 h (p C)	32	28	38	2	30	27	35	1.7	132
Nitrate nitrogen ($mg\ l^{-1}$)	1.86	0.79	6.37	1.38	2.51	1.14	7.14	1.29	20
pH	6.9	4.75	8.89	0.7	7.1	4.85	8.97	0.7	133
Total phosphorous ($mg\ l^{-1}$)	0.1	0.04	0.21	0.04	0.29	0.18	0.55	0.09	19
Chloride concentration ($mg\ l^{-1}$)	9.84	7.59	12.8	1.42	5.48	4.23	7.15	0.81	19
Potassium ($mg\ l^{-1}$)	1.95	1.25	2.94	0.47	1.08	0.77	1.60	0.27	18
Chrolophylla ($\mu g\ ml^{-1}$)	17.70	3.18	34.51	9.26	40.33	13.36	59.46	13.86	19

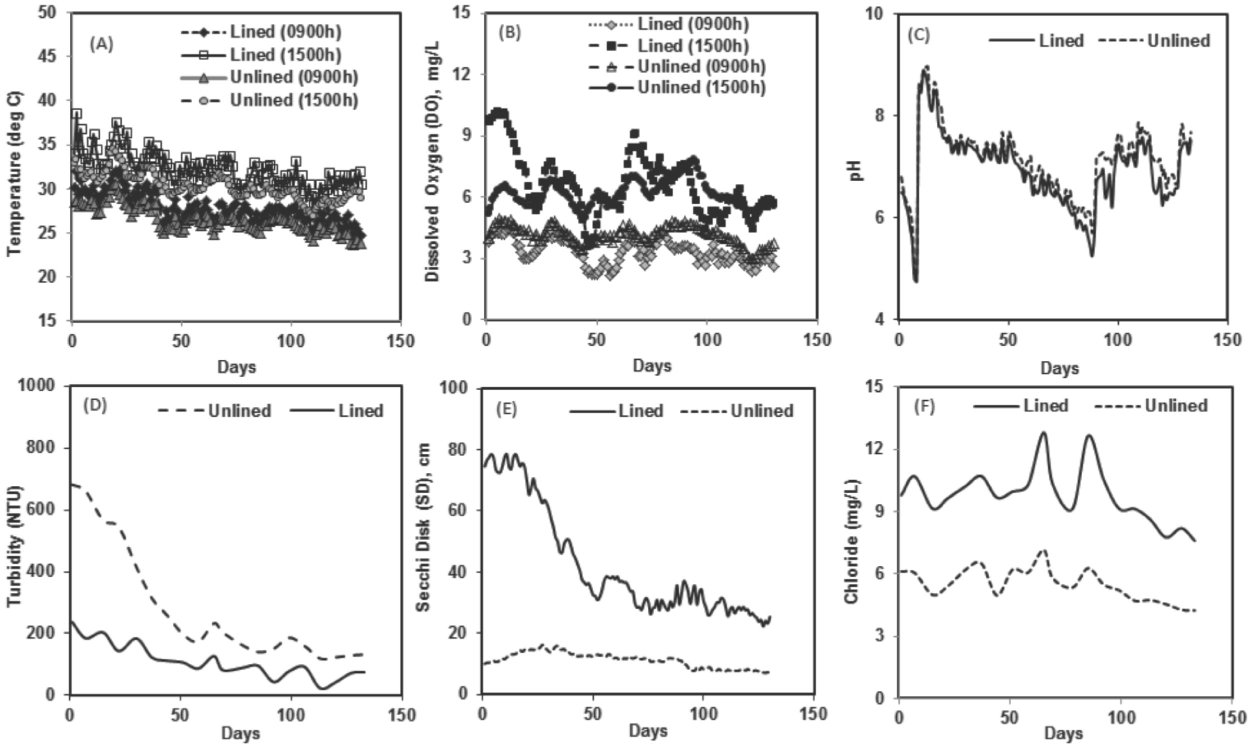

Fig. 2. Water quality in the lined and unlined ponds: (A) Water temperature (B) Dissolved oxygen (C) pH (D) turbidity (E) Secchi disk transparency depth variations and (F) Chloride concentrations variation in the lined and unlined ponds.

The *IRR* value for lined pond without fish culture was 9%, while that for unlined pond without fish culture was 9.5%. The *IRR* value for lined pond with fish culture was 26%, while IRR value for unlined pond with fish culture was 13%. The larger *IRR* values indicate better benefits over the systems which have lower *IRR* values. The relatively large S_r value was found for the lined ponds without fish culture and the lowest S_r was for the lined pond with fish cultures. The low S_r indicates potentially high benefits with less uncertainty. The ranking of the S_r values (in increasing orders) was: lined pond with fish culture < unlined pond with fish culture < unlined pond without fish culture < lined pond without fish culture.

In summary, the approach proposed here has been found to be useful for harvesting rainwater for rearing fish in the ponds while also providing supplemental irrigation to crops. The water quality measurements have shown that the water stored in the rainwater harvesting ponds was suitable for fish culture. Rearing fish in the ponds resulted in improved net annual benefit of the rainwater harvesting systems. Results show that a pond lining can elevate the water levels, which can extend the fish culture period and can also improve the water availability in the ponds for supplemental irrigation; however, it requiresa relatively large initial investment. Further studies using the approach proposed here over multiple seasons in different rainfed regions will be helpful for improving the rice-fish pond system.

In this research, a field study to evaluate the growth of Indian major carpsin rainwater harvesting ponds (lined and unlined) was carried out. We also calculated the potential benefits of the rainwater harvesting ponds with and without fish culture. Water quality measurements have shown the suitability of water storage in the lined and unlined ponds for fish culture. Results show that fish culture in the rainwater harvesting ponds improves the annual net benefits considerably. The rainwater harvesting method proposed here for rice-fish integration will have significant importance for disseminating rainwater harvesting in rainfed regions and improving rural income.

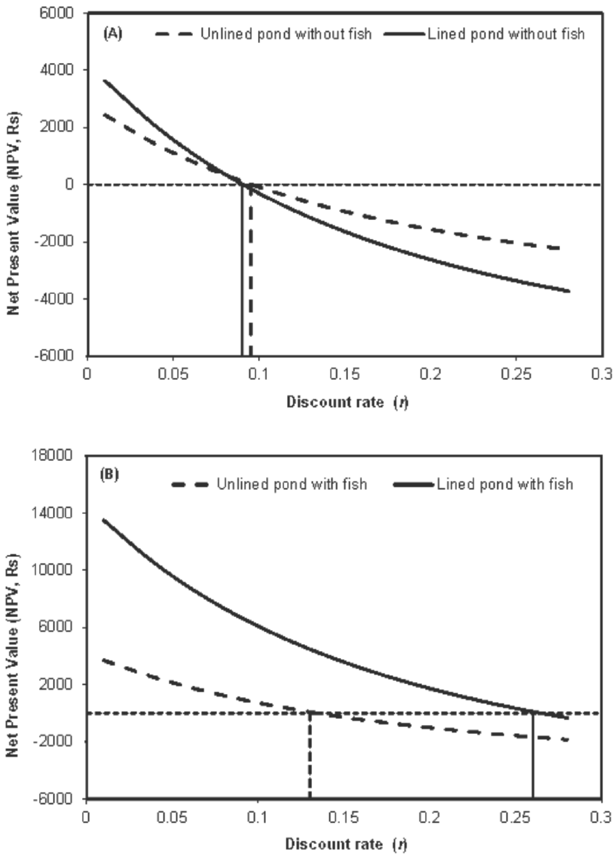

Fig. 3. Change in net present value (*NPV*) with discount rates (*r*): (A) change in the *NPV* in lined and unlined ponds without fish culture; B) change in the *NPV* in lined and unlined ponds with fish culture. Bold and long dashed lines in Fig. A and B indicate changes in the *NPV* in lined and unlined ponds respectively. Horizontal short dotted lines in the figures indicate the *NPV* value of 0, vertical solid and long dashed lines indicate internal rate of return (IRR) at the *NPV* of 0

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