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Evaluation of Soil and Water Conservation Interventions Impact on Water, Crop and Economic Resources Development: A Case Study of Karma Micro-Watershed in Eastern Plateau of India

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Abstract: Strategic management of soil and water conservation measures for water resources generation through small farm pond reservoirs to harvest rainfall-runoff from agricultural land for crop irrigation are the focal points for enhancing agricultural productivity and economic profitability in semiarid Karma micro-watershed of Bankura, West Bengal, India under IWMP were evaluated for impact of technological interventions on improvement of water, crop and economic resources. The increased pond-water availability augmented irrigated areas by 40.23-46.94% in kharif, 30.53-38.46% in rabi and 23.08-33.33% in summer season after the programme, which encouraged the beneficiary farmers to grow diversified crops across the year. In lowland ecosystem with sporadic stressed water regime, imposition of conservation tillage, stubble mulching, draught-resistant varieties use and low-water consuming short duration crops were advocated. The marginal increase in productivity for Aman paddy (1.75%) and a greater increase for maize (14.16%) after programme were observed. Net income and BCR for Aman paddy increased from ₹ 6165/ha and 1.23 during pre-programme to ₹ 40124/ha and 2.41 during post-programme, respectively due to adoption of specific soil and water conservation technologies.

Keywords: Micro-watershed, Soil and water conservation, Rainwater harvesting, Crop productivity index, Benefit-cost ratio

A micro-watershed is a natural geo-hydrological unit encompassing less than 400 ha area that drains the rainfall-runoff flow to a common outlet. The area with undulating topography causes different degrees of land degradation in terms of severe soil erosion, fertility depletion and water scarcity due to indiscriminate anthropogenic and hostile natural activities along with increasing climate variability that have deleterious effects on agricultural productivity, food and nutritional security and environmental quality (Manivannan et al 2017, Dimtsu et al 2018, Demelash and Stahr 2020, Tilahun and Desta 2021). Rapid deterioration of soil health and water resources is a growing concern in arid and semiarid regions of the world. About 146.8 Mha out of 329 Mha geographical area are degraded in different extents in India by various factors, where water erosion is the most threatening one and accelerates topsoil loss, fertility depletion and land deformation (Bhattacharyya et al 2015, Manivannan et al 2017).The lack of technical knowledge and skills, non-availability of site-specific management interventions and poor resource base of farmers are the key inhibitors for adoption of appropriate remedial measures to restraint such adverse conditions. The suitable watershed management strategy can provide an improved technological support to conserve the precious soil and water resources and its maximum economic utilization for resilience of agriculture, besides strengthening the food and livelihood security to the farming community (Palanisami and Suresh Kumar 2009, Rathod and Rathod 2017, Khan 2018). The tapping and storage of excess rainfall-runoff flow through appropriate rainwater harvesting structures during wet season and its reuse for supplemental irrigation during lean dry season in a planned way is a cost-effective small-scale irrigation strategy to mitigate the worst surface and groundwater conditions and enhance the productivity in rainfed areas (Fazlul et al 2009, Nagaraj et al 2011, Khajuria et al 2014, Kashiwar et al 2016). The integrated watershed management is eco-friendly and climate adaptation strategy for sustaining ecosystem and environment, restoring natural resources, improving agricultural productivity and upscaling the income and livelihoods of the rural people (Pathak et al 2013, Gwozdziej-Mazur et al 2022).

Karma micro-watershed in Purulia district of West Bengal in eastern plateau of India is a draught prone semi-arid area, where agricultural activity is risky and at subsistence level due to acute irrigation water constraints and land degradation. An Integrated Watershed Management Programme (IWMP) with recommended soil and water conservation techniques was launched during 2010-11 and continued its operation up to

2015-16 for conservation and management of precious natural resources for sustainable agricultural development. The watershed technological approaches, specifically the construction or renovation of farm pond structures, were more focused for in-situ harvesting and storage of excess rainfall-runoff water to guarantee assured irrigation facility for crop production over the year. But till date, no comprehensive data based scientific literatures is available on the integrated effects of watershed technologies on changing agricultural production scenario in the area. In these perspectives, the present survey-based investigation was carried out to evaluate the impacts of soil and water conservation measures on the availability of irrigation water resources, crop productivity enhancement and economic elevation in the Karma micro-watershed areas.

MATERIAL AND METHODS

Study area: The field survey was conducted in Karma micro-watershed of Balarampur block in Purulia district of West Bengal in the eastern plateau of India during 2017-18. The site is located between 23^{0}5'51.009" to 23^{0}11'12.411" N latitudes and 86^{0}7'45.398"E to 86^{0}13'40.139" E longitudes and the altitude ranges between 165 to 280 m above mean sea level. The watershed covers a geographical area of 813 ha and is characterized by the problems of undulating topography, soil erosion hazards, severe water scarcity and marginal crop productivity. It represents a typical semiarid climate with a hot and dry summer and a cold winter. The variations in Climatological parameters of the study area before and after IWMP are depicted in Figure 1. The area has 1268 mm mean annual rainfall, the most of which is received during June-September. The mean monthly maximum temperature was noticed in May (40.3^{0}C) and mean monthly minimum temperature in December (14.2^{0}C). The mean relative humidity across the year was 46-84%. The soils are mostly red lateritic and sandy loam in texture with high soil porosity and low water holding capacity. Three major soil orders in the site are Alfisols, Entisols and Inceptisols. The farmers are largely small and marginal with poor socio-economic condition. Rainfed agriculture is the main livelihoods of rural people. The farming system is traditional, subsistence and unrewarding. The chances of crop damage or even failure is common in the area due to uncertain or erratic rainfall.

Soil and water conservation practices: The different adaptable soil and water conservation interventions under IWMP such as conservation tillage, stubble mulching, soil and stone bunds, terraces along the contour, grass stripped drainage lines, grassland and farm forestry management and construction or renovation of rainwater harvesting structures (farm ponds, dug wells) for tapping rainfall-runoff flow and recharging shallow aquifers, along with seasonal training programmes for the farmers and other stakeholders were implemented over the five years' period to solve the problems and develop the study area from low-productive to high-productive one with active participation and involvement of the beneficiary farmers.

Construction and renovation of water harvesting structures: The new farm ponds were built-up by excavation in the target area and storage capacity of the existing farm ponds were improved by desilting for harvesting the surplus runoff flown over the micro-watershed areas while IWMP in operational stage. This reservoir water was mainly used for

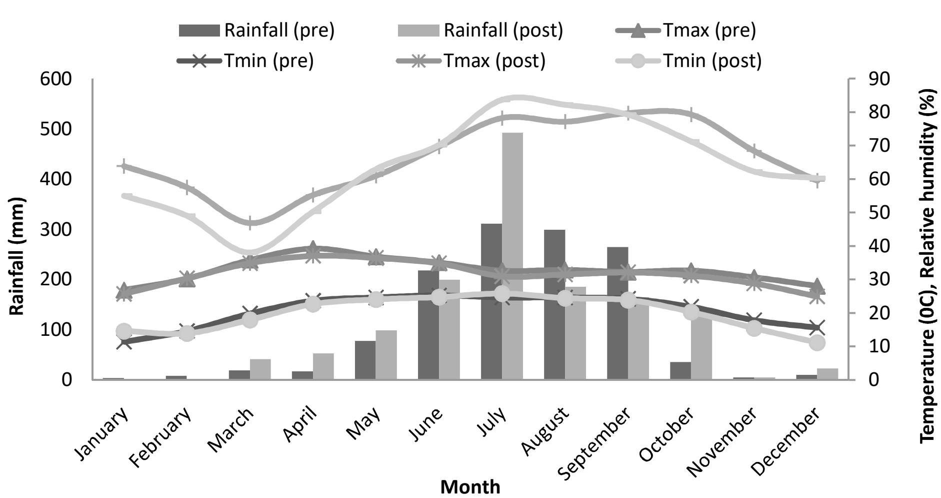
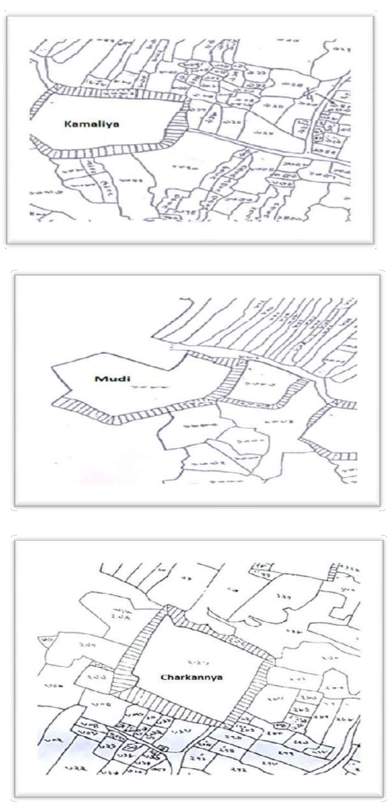


Fig. 1. Mean monthly rainfall, maximum and minimum air temperature (T) and relative humidity (RH) during pre-project (2009-11) and post-project (2017-18) period of IWMP in the study area (Source: Forest office, Balarampur, Bankura, West Bengal)

providing supplemental irrigation during the period of water scarcity (winter and summer crops). Three different sized farm ponds in diverse topographical situations such as pond-1 (Kamaliya village) from low land, pond-2 (Mudi village) from medium land and pond-3 (Charkannya village) from upland of the watershed areas were randomly selected for our investigation (Fig. 2). The configuration of each farm pond was irregular in shape and pond area was calculated by triangular method using Heron's formula (Dunham 1990). The depth of pond water was measured by placing seven bamboo sticks from center to periphery of each pond at equal distance and depth of water was recorded with a measuring tape. The volume of water stored in each pond was calculated by multiplying pond area with average depth of pond water. The data was recorded at monthly interval over a period of two years for each pond. The month-wise volumetric water storage in each farm pond was partitioned into kharif (June-September), rabi (October-January) and summer (February-May) growing seasons.

Collection and computation of climatic variables: The secondary sources of month-wise data on climatological parameters such as total rainfall, temperature and potential evapotranspiration (PET) during pre-project (2010-11) and post-project (2017-18) period of IWMP in the watershed area were collected from the forest office, Balarampur, Bankura and their monthly average values were calculated.



Pond-1 (Kamaliya village)
Location: 23.158690 N latitude, 86.205832 E longitude
Pond area: 1.05 ha
Land situation: low

Pond-2 (Mudi village)
Location: 23.159444 N latitude, 86.203056 E longitude
Pond area: 1.26 ha
Land situation: medium

Pond-3 (Charkannya village)
Location: 23.162778 N latitude, 86.198611 E longitude
Pond area: 1.61 ha
Land situation: upland

Source: mouza map of Karma village in Bankura district of West Bengal, India

Fig. 2. Location of small ponds in the Karma micro-watershed

Farmers' households sample survey: The IWMP was started functioning during 2010-11 and continued up to 2015-16 in the Karma micro-watershed. About 315 farmers' households of the area were involved in watershed management activities. One-fifth of the households (61) were randomly selected and the head of each household was contacted personally and direct interview with him was conducted. The primary data before and after IWMP implementation was documented through a set of questionnaires containing the specific information related to the surface water resources induced physical (irrigated area), biological (crop productivity) and economics (net income, BCR) improvement of agriculture due to the adoption of soil and water conservation (SWC) interventions in the area. Based on the highest irrigated area and crop production in *kharif* season under pond-2 ecosystem, the major crops of aman paddy and maize were selected for evaluation of crop productivity index in the micro-watershed area. Accordingly, 27 beneficiary farmers of pond-2 command area were interviewed. The base year for the study was 2010-11 and the assessment year was 2017-18.

Crop productivity index: Crop productivity index (CPI) was determined by the relationship given by Enyedi (1964) as,

$$\text{CPI} \quad \frac{Y/Yn}{T/Tn} * 100$$

where, Y= production of selected crop in unit area, Yn = total production of same crop in the region, T = area of selected crop in unit area, Tn = area under the same crop in the region.

Economics of aman paddy cultivation: Aman paddy is the main staple crop with highest cultivated area in the area, which was selected for calculation of various costs following the recommendations of Commission for Agricultural Costs and Prices, Ministry of Agriculture, Government of India (CACP, 1965). The different cost concepts used are given below:

Cost A_1= Value of hired human labour, hired bullock labour, owned bullock labour, hired machine labour, seeds (both farm produce and purchase), insecticides and pesticides, manures (owned and purchased), fertilizers, depreciation on implements and farm buildings, irrigation charges, land revenue and other taxes, interest of working capital and other expenses.

Cost A_2 = Cost A_1 + Rent paid for leased in land

Cost B_1= Cost A_1 + Interest on value of owned fixed capital assets (excluding land)

Cost B_2= Cost B_1 + Rental value of owned land and rent paid for leased in land

Cost C_1= Cost B_1 + Imputed value of family labour

Cost C_2= Cost B_2 + Imputed value of family labour

Cost C_3= Cost C_2 + Value of management input at 10% of cost C_2.

The various profitability was determined by using the following economic formula:

Gross income = Main product × Price per unit + By product × Price per unit

Net income = Gross income – Cost C_3

Farm business income = Gross income – Cost A_1

Family labour income = Gross income – Cost B_2

Farm investment income = Net Income + Rental of owned land + Interest on fixed capital

Benefit-cost ratio (BCR) = Gross income / Cost C_3

Cost of production = (Total cost – Value of by product) / Yield of main product

Statistical analysis: The secondary data for the dependent variable of mean monthly variations in depth of water in each pond with the specific values of the independent variables of mean monthly rainfall, temperature and potential evapotranspiration, before and after the IWMP programme, were subjected to the bivariate and multivariate linear regression analysis using software MS excel and SPSS 12.0 version.

RESULTS AND DISCUSSION

Impact of SWC measures on water resources in pond-1: The multiple regression of mean monthly total rainfall (MMTR), mean monthly temperature (MMT) and mean monthly potential evapotranspiration (MMPET) with mean monthly water depth of pond-1 (MMDP-1) for pre-programme had coefficient of determination (R^2) value of 0.37 which appeared to be very low and non-significant in influencing MMDP-1 (Table 1).This also indicates that only 37% of total variation in dependent variable (MMDP-1) is explained by the linear function of independent variables of MMTR, MMT and MMPET. The relationships of MMDP-1 with MMTR, MMT and MMPET were statistically non-significant. In contrast, the multiple regression of MMTR, MMT and MMPET with MMDP-1 for post-programme showed R^2 value as 0.54, indicating 54% of total variation in MMDP-1 could be determined by independent variables of MMTR, MMT and MMPET. MMDP-1 had highly significant relation with MMTR.

Impact of SWC measures on water resources in pond-2: The multiple regression of MMTR, MMT and MMPET with MMDP-2 for pre-programme showed R^2 as 0.63 (Table 1), suggesting 63% of total variation in dependent variable MMDP-2 could be described by the independent variables of MMTR, MMT and MMPET. The association of MMDP-2 with overall dependent parameters was significant, whilst with MMTR was highly significant. In post-programme, R^2 value

Table 1. Coefficients of regression (R^2) and P values before and after IWMP

Pond 1 (MMDP1)						
Variables	Before programme			After programme		
	R^2	Overall P	P	R^2	Overall P	P
MMTR	0.37	0.267	0.098	0.54	0.001**	0.0003**
MMT			0.577			0.702
MMPET			0.932			0.709
Pond 2 (MMDP2)						
Variables	Before programme			After programme		
	R^2	Overall P	P	R^2	Overall P	P
MMTR	0.63	0.036*	0.008**	0.58	0.0004**	0.0002**
MMT			0.957			0.555
MMPET			0.426			0.640
Pond 3 (MMDP3)						
Variables	Before programme			After programme		
	R^2	Overall P	P	R^2	Overall P	P
MMTR	0.56	0.070	0.018*	0.50	0.002**	0.0007**
MMT			0.652			0.399
MMPET			0.828			0.417

*Significant at 0.05 level of probability, **Significant at 0.01 level of probability was recorded as 0.58 which elucidated 58% of total variation in MMDP-2 by the independent variables of MMTR, MMT and MMPET. The relationship of MMDP-2 with overall independent components as well as MMTR was highly significant.

Impact of SWC measures on water resources in pond-3: Multiple regression exhibited R^2 value of 0.56 and 0.50 implying 56% and 50% of total variation in MMDP-3 could be described by independent variables of MMTR, MMT and MMPET for pre- and post-programme, respectively (Table 1). The mutual relation of MMDP-2 with MMTR for both programmes was significant, while it showed highly significant association only with overall independent variables for post-programme. The results indicated that among three climatic variables studied, monthly rainfall produced a significant impact on water resources augmentation in all the three ponds and the relative effect was less pronounced before than after IWMP implementation. Similarly, among the three ponds studied, the impact of monthly rainfall on enhancing water reserves was appreciably higher in pond-2 as compared with two other ponds. These variations were attributed to adoption level of soil and water conservation measures during IWMP, pond topographical situations, extents of rainwater harvesting by small ponds and magnitudes of groundwater replenishment.

Impact of SWC measures on irrigated area expansion: Highest seasonal mean volume of water was found in pond-2 lying in medium land and lowest in pond-1 in lowland over the years (Table 2). The plausible reasons were the accumulation of relatively higher amounts of rainfall-runoff in all the three growing seasons, especially during the monsoon season and the greater possibility of significant amounts of groundwater contribution during summer season due to the adoption of soil and water conservation measures effectively in the form of re-excavation of pond while IWMP was in operational stage. This development of assured surface water resources facility through rainwater-runoff harvesting in pond reservoirs could help the farmers of the area to grow diversified crops round the year under irrigated environment, as evidenced from the primary data from the households' survey report. The results also indicated that irrespective of ponds, highest positive change in irrigated area in *kharif* season (June-September) after programme were 46.94% for pond-2 (Mudi village), 44.29% for pond-1 (Kamaliya village) and 40.23% for pond-3 (Charkannya village). For rabi season (October-January), highest positive change in irrigated area after programme was in pond-1 (38.46%) followed by pond-3 and pond-2. Likewise, the change in irrigated area after programme for summer season (February-May) was highest in pond-2 (33.33%) followed by pond-3 and pond-1.

Table 2. Change of irrigated area during *kharif, rabi* and summer cropping with seasonal mean volume of water stored in different three ponds before and after IWMP

Pond 1				
Season	Volume of water (m^3) stored during 2017-18	Irrigated area (ha)		Change in irrigated area (%)
		Before programme	After programme	
Kharif	13796	7	10.1	44.29
Rabi	11812	5.2	7.2	38.46
Summer	11321	3.9	4.8	23.08
Pond 2				
Season	Volume of water (m^3) stored during 2017-18	Irrigated area (ha)		Change in irrigated area (%)
		Before programme	After programme	
Kharif	19431	9.8	14.4	46.94
Rabi	16733	9.5	12.4	30.53
Summer	17000	4.2	5.6	33.33
Pond 3				
Season	Volume of water (m^3) stored during 2017-18	Irrigated area (ha)		Change in irrigated area (%)
		Before programme	After programme	
Kharif	18146	8.7	12.2	40.23
Rabi	15327	6.1	8.2	34.43
Summer	13078	4.8	6.2	29.17

Source: Primary data from survey

These results amply indicated that on utilizing the additional water sources created, the beneficiary farmers could put their unirrigated lands under surface irrigation network for enhancing production and productivity of diverse crops and increasing cropping intensity with higher economic returns. The pond-1 lying in lower topographical situation recorded lowest water storage and hence, there was a possibility of water shortage for dry season crops. In this adverse situation, the beneficiary farmers could employ the soil and water conservation measures appropriate to their field conditions like mulching practice, growing of draught resistant crops and cultivars and low-water requiring short duration crop, particularly during summer season and paddy cultivation during *kharif* season. The pond-3 in upland situation was found to store voluminous amounts of water as compared with pond-1. In this favorable water available condition, the beneficiary farmers could easily take up different crops through the seasons of the year. They could opt for paddy or maize or groundnut in kharif; wheat, potato and vegetables in winter and mustard, green gram and black gram in summer season. The farmers in pond-2 ecosystem could safely grow all types of field crops with assured irrigation facility.

Crop productivity index: The major irrigated cereal crops of kharif paddy and maize grown in pond-2 command was selected for evaluation of crop productivity index (CPI). It is evident that CPI for paddy increased marginally from 96.79% before the programme to 98.54% after the programme (Table 3). In contrast, CPI for maize increased substantially from 80.61% before the programme to 94.77 after the programme. This was attributed to the adoption of soil and water conservation interventions, particularly the re-excavation and renovation work in pond-2 command, which eventually caused guaranteed availability of plentiful irrigation water after programme that helped the farmers for irrigating crops as per necessity or under conditions of low and uncertain rainfall occurrence.

Cost of cultivation of aman paddy: Aman paddy cultivation in pond-2 command under different watershed technological interventions was selected for economic appraisal (Table 4-6). Total cost of cultivation was ₹25976/ha during pre-project and ₹27490/ha during post-project, where per unit cost of production was increased by ₹1514 during post-project as compared to pre-project period. Variable cost and fixed cost of aman paddy during pre-project period were ₹13592/ha and₹10023/ha, whereas the corresponding figures during post-project period were ₹14837/ha and ₹10154/ha, respectively. Aman paddy cultivators invested less expenses on irrigation charges and more on other agricultural inputs during post-project as compared to pre-project, because of higher quantity of easily accessible water for irrigation during post-project period due to increased capacity of the reservoir to store surplus rainfall-runoff water as a result of re-excavated and renovated works under IWMP activities. The productivity of aman paddy during post-project period (3705 kg/ha) was much higher than that of pre-project period (2300

Table 3. Crop productivity index of aman paddy and maize before and after IWMP

Crop	Crop productivity index (%)	
	Before programme	After programme
Aman paddy	96.79	98.54
Maize	80.61	94.77

Table 4. Detailed cost of cultivation for aman paddy (₹/ha) in pond-2 command

Particulars	Before programme	After programme
A. Variable cost		
Hired human labour	2178	2506
Family labour	1341	1560
Machine labour	3120	3428
Seed	1680	1838
Fertilizers	2438	2720
Plant protection materials	710	828
Irrigation charges	1564	1338
Interest on working cost @ 7%	561	619
Sub-total	13592	14837
B. Fixed cost		
Land revenue	23	25
Rental value of owned land	8200	8305
Interest on fixed capital	825	842
Depreciation	975	982
Sub-total	10023	10154
C. Managerial cost @ 10% of (A+ B)	2361	2499
D. Total cost of cultivation (A + B + C)	25976	27490

Table 5. Cost of cultivation using cost concept of aman paddy (₹/ha)

Cost concept	Before programme	After programme
Cost A1	14240	15125
Cost A2	14240	15125
Cost B1	15064	15968
Cost B2	23264	24273
Cost C1	16405	17528
Cost C2	24605	25833
Cost C3	27065	28417

Table 6. Economics of aman paddy cultivation in Karma micro-watershed

Particulars	Before programme	After programme
Main product (kg/ha)	2300	3705
Price (₹/kg)	14.10	17.80
Value of main product (₹/ha)	32430	65949
Byproduct (kg/ha)	1000	1800
Price (₹/kg)	0.80	1.44
Value of byproduct (₹/ha)	800	2592
Gross income (₹/ha)	33230	68541
Net income (₹/ha)	6165	40124
Farm business income (₹ha^{-1})	18990	53416
Family labour income (₹/ha)	9966	44268
Farm investment income (₹/ha)	15189	49272
Benefit-cost ratio (BCR)	1.23:1	2.41:1
Cost of production (₹/kg)	10.95	6.72

kg/ha). Straw productivity followed the same trend (Table 10). Based on the various cost involvements in aman paddy cultivation (Table 9), gross income, net income, farm business income, family labour income and farm investment income were substantially higher in post-project than pre-project period. Besides, the cost per unit of grain production was considerably decreased in post-project as compared with pre-project period. Benefit-cost ratio (BCR) for aman paddy was 1.23 during pre-programme which increased almost twice to reach 2.41 during post-programme, which means that aman paddy cultivators could obtain ₹1.23 for one rupee investment before programme, but they could gain ₹2.41 per rupee investment after programme. This indicates that aman paddy cultivation was more profitable after project as compared with pre-project period.

CONCLUSIONS

The strategic adoption of soil and water conservation measures with greater emphasis on the water resources development through water harvesting pond structures have a significant impact on agricultural and socio-economic scenario in arid Karma micro-watershed in Bankura district of West Bengal in the eastern plateau of India. Increasing availability of pond water resources substantially augmented the irrigated areas which enabled the beneficiary farmers to grow more diversified throughout the year. In water-stressed low land especially during summer, the practices of conservation tillage, stubble mulching, use of draught resistant crops and cultivars and low-water demanding short duration crops are advocated. Crop productivity index increased marginally for aman paddy and markedly for maize during post-project period, preferably in pond-2 command. Net income and benefit-cost were increased manifolds for aman paddy during post-project period.

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