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Performance evaluation of a rehabilitated minor irrigation project and augmentation of its water resource through secondary storage reservoir

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ABSTRACT

Performance of a rehabilitated and turned over flow based minor irrigation project with respect to irrigation, agriculture and institutional aspects was assessed. The irrigation system was found performing better. However, inadequacy of irrigation water availability in dry season and spatial inequity of water distribution, even after rehabilitation and irrigation management transfer were the couple of shortcomings which have been observed. In order to augment the water resource of the system, the feasibility of introducing secondary storage reservoir in each outlet command was conceptualized and field tested. Keeping in view the area required for providing secondary reservoirs, the existing water bodies in the command of the study system were surveyed. The utility and functioning of the secondary reservoir was field demonstrated. Utilization of the harvested water in the secondary reservoir for irrigating dry season crop in addition to the irrigation water from the main reservoir have resulted in increasing the yield of sunflower, tomato, brinjal and groundnut by 14.29, 14.95, 16.95 and 20%, respectively. Among the cropping patterns considered, rice–tomato cropping pattern resulted in highest net return (Rs. 29,457 per ha) followed by rice–brinjal cropping pattern (Rs. 22,430 per ha). Highest benefit–cost ratio of 2.09 was obtained for rice–sunflower cropping system. The low input-based scientific fish culture in the secondary storage reservoir has enhanced the fish yield by three fold over traditional practice.

1. Introduction

Over last few decades, rapid expansion of irrigation facilities has taken place globally as well as also in India. Due to small capital requirement, less execution time and better control over flow, minor irrigation projects (MIP) have received equal importance to that of major and medium irrigation projects. Large number of MIPs have been found in derelict condition as the cost and resource required to operate and maintain them is simply too high for the government departments. Water taxes have also been historically set too low to maintain the irrigation systems. Therefore, it is considered late that these derelict projects should be rehabilitated and handed over to the farmers for their future operation and maintenance. Transfer of irrigation management responsibilities from government agencies to farmers has been made as an important policy in many countries, including India. As a result, farmers' participation in irrigation management has taken the center stage and the irrigators who were considered as beneficiaries are now considered partners in planning, development, operation and maintenance of irrigation systems (Parthasarathy, 2000).

In India, the irrigation projects are classified into three categories i.e., major (cultivable command area (CCA) >10,000 ha), medium (2000–10,000 ha CCA), and minor (<2000 ha CCA) irrigation. The ultimate irrigation potential of India is estimated at 140 M ha, out of which the share of minor irrigation (MI) is 58.58% i.e., 81.54 M ha. Similarly, in the state of Odisha (located in the eastern part of the country), it has been estimated that out of the total cultivable area of 6.56 Mha, 5.9 Mha (3.95 from major and medium, 0.97 from minor flow, 0.89 from minor lift and 0.09 Mha from other sources) can be brought under irrigation through different sources. The irrigation potential created till tenth five year plan period ending on March 2007, is estimated as 2.76 Mha (1.25 from major and medium, 0.52 from minor flow, 0.42 from minor lift and 0.57 Mha from other sources). Thus, about 1/3rd of the irrigated area in the state of Odisha gets irrigation water from MIPs.

In Odisha, out of 3696 number of minor irrigation projects, the defunct and partially defunct projects command area occupy 0.16 Mha, which is about 28% of the net CCA of all flow based MIPs. Government of Odisha with support from European Commission (EC) through Union Ministry of Water Resources has rehabilitated 49 MIPs in the state during 1995–2005, where the philosophy of

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irrigation management transfer (IMT) has been put into practice. Rehabilitation process included repair of head regulator, resectioning of the canal system to its design dimensions, formation of water user association (WUA), capacity building of WUA members and finally handing over the project to WUA. Since the inception of the rehabilitation, farmers' groups were involved in planning, implementation, decision-making and hydraulic testing, etc.

Most of the flow based MIPs in the state of Odisha are protective irrigation system, designed to provide supplemental irrigations to monsoon season crops dominated by Paddy. Due to inadequate availability of irrigation water in the main reservoir, these MIPs suffer from poor irrigation intensity and cropping intensity. These systems often endure with improper crop planning especially during dry season by taking into account the availability of irrigation water in the reservoir. Higher crop coverage leads to severe scarcity of irrigation water in the advanced crop growth stages thereby restricting the productivity of the crop significantly. Further, the WUA which is formed to look after the operation and maintenance of the project and collect water tax from the farmers have several problems and its sustainability is questionable. Therefore, the challenges in minor irrigation sector call for immediate assessment of their performance to identify the gaps and develop suitable ways and means to bring improvement in the existing projects performance level.

The success of rehabilitation and IMT can be realized though performance assessment studies. Researchers in the past have explored various parameters to evaluate the irrigation system's performance from farmers' perspectives (Svendsen and Small, 1990; Sam-Amoah and Gowing, 2001; Ghosh et al., 2005) as flow measurements are not given a high priority in most irrigation systems in developing countries (Horst, 1999). Even in many cases where data are available, quality and integrity are questionable (Murray Rust and Snellen, 1993). In the present study, efforts have been made in assessing the performance of a recently rehabilitated MIP with respect to irrigation, agriculture and effectiveness of WUA mostly from the farmers' perspective. After assessing the performance, measure for further improvement in system's performance has been conceptualized and field demonstrated by augmenting water resource through provision of secondary reservoirs in each outlet command.

In the past, several researchers have studied different aspects of secondary storage reservoir concept in the command of major irrigation projects. Zimmerman (1966) stated "for effective and efficient use of water, it is essential for every farm entity to have a service reservoir so that the farmer can use his allocation at his convenience, both in regard to time of irrigation and size of the stream". Khanjani and Busch (1983) developed a method to specify the optimal sizes and locations of farm service reservoirs within an irrigation project. Mishra and Tyagi (1988) analyzed the performance of irrigation water delivery with introduction of auxiliary storage reservoir at the farm outlet level. Gowing et al. (2004) incorporated a large number of secondary reservoirs to reduce the management problems and enhance non-irrigation usage of water in a large scale irrigation project. Mishra et al. (2009) formulated a multi objective optimization model to determine the optimal size of auxiliary storage reservoir and optimal cropping pattern for a minor irrigation project. The research outcome reported in this paper presents the performance of a minor irrigation project after rehabilitation. Further, the scope and feasibility of introducing secondary storage reservoir in the outlets command of the MIP to harvest rainwater during monsoon in addition to capturing the excess irrigation water supplied from the main reservoir through canal network is discussed. The intervention brought improvement in the water resource scenario of the project and thereby increased the cropping intensity, irrigation intensity and crop productivity of the command.

2. Description of the study system

Devijhar Minor Irrigation Project, located in the Ganjam district of Odisha state (19°43′00″N latitude and 85°07′00″E longitudes) was chosen for this study. The CCA of the minor irrigation project is about 500 ha. The catchment and command area of Devijhar Minor Irrigation Project is shown in Fig. 1. The reservoir has a live and dead storage of 85.41 ha m and 2.59 ha m, respectively. The irrigation project has a main canal whose design discharge at its head regulator is 0.545 m^3/s. It is 5.30 km long having 24 outlets. There is a minor canal, which off takes from the main canal at 932 m. The design discharge of the minor canal is 0.204 m^3/s. The minor canal is 3.507 km long having 17 outlets. About half of the canal length is lined with cement concrete and the remaining half is unlined earthen channel. The minor irrigation project was rehabilitated by the Government of Odisha with the assistance from European Commission and handed over to WUA during July 2004 for its operation, maintenance and management. The project has a WUA comprising of 934 members from 10 villages. The irrigation dates, irrigation intervals and water taxes for different crops are decided by the executive body of the WUA. WUA receives the requisition for irrigation water from outlet committees and then decides about the irrigation dates and intervals based on the requirement of farmers/outlet committee, experience of the executive body of WUA and water availability in the main reservoir. The marginal (<1 ha land holding) and small (1–2 ha land holding) farmers account for more than 85% of the total farming community. During the rainy season, paddy is the predominant crop and during winter and summer season groundnut, black gram and green gram are grown in almost 2/3rd of the total command area leaving 1/3rd CCA as fallow due to scarcity of irrigation water. The average annual rainfall of Devijhar MIP is about 1290 mm. The predominant soil of the study area is sandy loam.

3. Methodology

The study involves the following steps:

(i) Assessing the performance of the irrigation system due to rehabilitation and IMT on irrigation, agriculture and WUA's functioning.
(ii) Studying the scope of secondary reservoir and collecting information on existing water bodies in the command which can be used as secondary reservoirs with suitable modifications.
(iii) Multiple use management of the stored water in the secondary reservoir in the outlet command and assessing its effect on improved crop production, productivity and net return through field demonstration.
(iv) Understanding the WUA's role in the operation and maintenance of secondary reservoir and suggesting measures for creation, operation, maintenance of such intervention.

3.1. Performance assessment

After rehabilitation, the MIP was handed over to WUA during July 2004. The performance was assessed during 2005–2006 using the following indicators.

3.1.1. Irrigation and water delivery performance indicators

A methodology based on farmer's assessment of the irrigation water supply was followed where farmers' opinions were recorded on 11 indicators (Mishra et al., 2011). The indicators considered were:

P_1: Adequacy/sufficiency of irrigation water to meet crop water requirement; P_2: Point of delivery of water; P_3: Stream size of

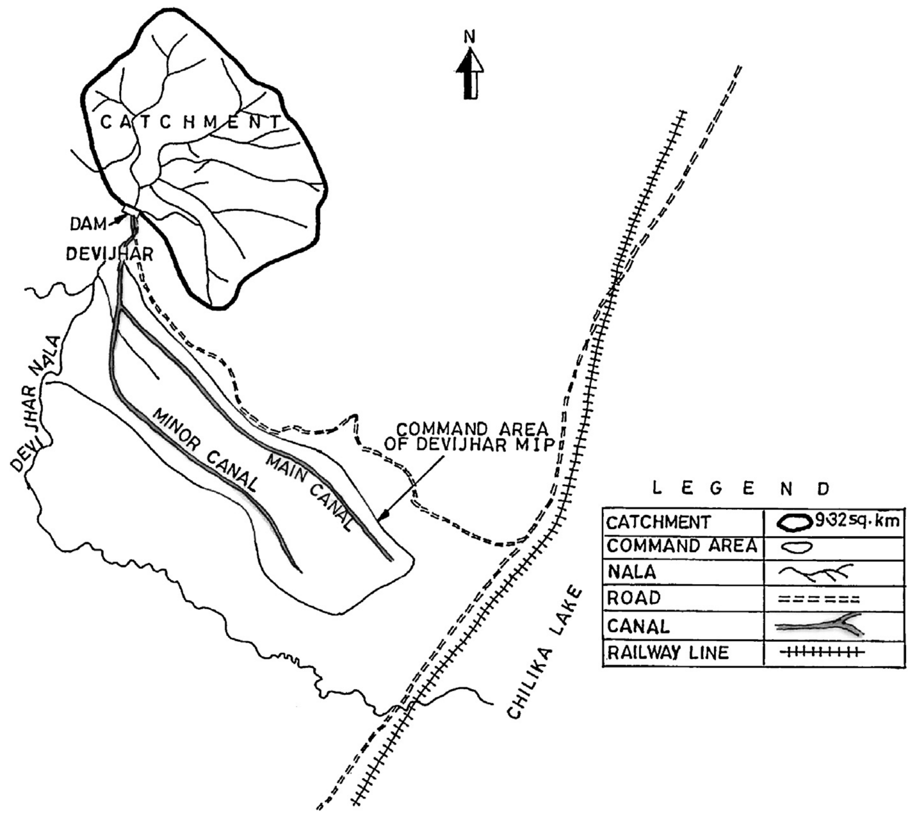

Fig. 1. Catchment and command area of the Devijhar Minor irrigation project.

water/outlet stream size; P_4: Timing of irrigation water supply; P_5: Equity of water distribution among the farmers per ha of cultivated land; P_6: Sufficiency in duration of irrigation water supply; P_7: Frequency of irrigation water supply; P_8: Prior knowledge/awareness about water delivery schedules; P_9: Management decisions on cultivation practices based on irrigation supply; P_{10}: Certainty of irrigation water availability; P_{11}: Performance of the canal system to cater the irrigation requirement.

Ninety one farmer-respondents were asked to give their judgments with respect to each above-mentioned indicators for both wet and dry season on a 5-point continuum scale (0–1, very bad; 1–2, bad; 2–3, average; 3–4, good; and 4–5, very good). Mean and standard deviation were calculated to aggregate the responses of farmers across different reaches (head, middle and tail) of the MIP. Subsequently, the overall irrigation service to farmers was also assessed taking the mean score of all the above mentioned eleven indicators.

Further, the performance of the irrigation water delivery system was assessed using two performance indicators (Molden et al., 1998), such as Adequacy and Relative Water Supply (RWS).

3.1.1.1. Adequacy. Adequacy of water delivery is dependent on water supply, specified delivery schedules, the capacity of the hydraulic structures to deliver water according to the schedules and the operation and maintenance of hydraulic structures. A measure of performance relative to this objective for a region or sub region R served by the system over the period T is given by (Molden and Gates, 1990).

$$P_A = \frac{1}{T}\sum_{T}\left(\frac{Q_{Dt}}{Q_{Rt}}\right) \quad (1)$$

where, Q_{Dt}: the actual amount of water delivered by the system in the period of time t^{th} and Q_{Rt} is the amount of water required for consumptive use, leaching requirement, land preparation, farm application and conveyance losses downstream of the delivery point in the period of time t^{th}. Sum total all these time periods is *T*. The delivery is considered adequate when Q_{Dt} is equal to Q_{Rt}.

3.1.1.2. Relative water supply (RWS). Relative water supply is defined as the ratio of water supplied to an irrigation unit to the demand for water in that unit over a period of time. Relative water supply relates the water available for crops (including surface irrigation, ground water pumped and rainfall) to the amount that crops need (Bos et al., 2005).

$$\text{RWS} = \frac{\text{Total water supply}}{\text{Crop demand}} = \frac{\text{Irrigation supply} + \text{rainfall}}{\text{Crop ET} + \text{seepage} + \text{percolation}} \quad (2)$$

3.1.2. Agriculture performance indicators

Agricultural performance of the system was assessed by making a comparison between pre-project and post-project scenario of the command with respect to cropping pattern, crop productivity, area under irrigation, irrigation intensity and cropping intensity. The terms irrigation intensity and cropping intensity are defined as follows.

3.1.2.1. Irrigation intensity. Irrigation intensity is defined the ratio of total irrigated area in year to total command area. This is generally expressed in percentage. Thus,

$$\text{Irrigation intensity} = \frac{\text{Total irrigated area in a year}}{\text{Total command area}} \times 100 \quad (3)$$

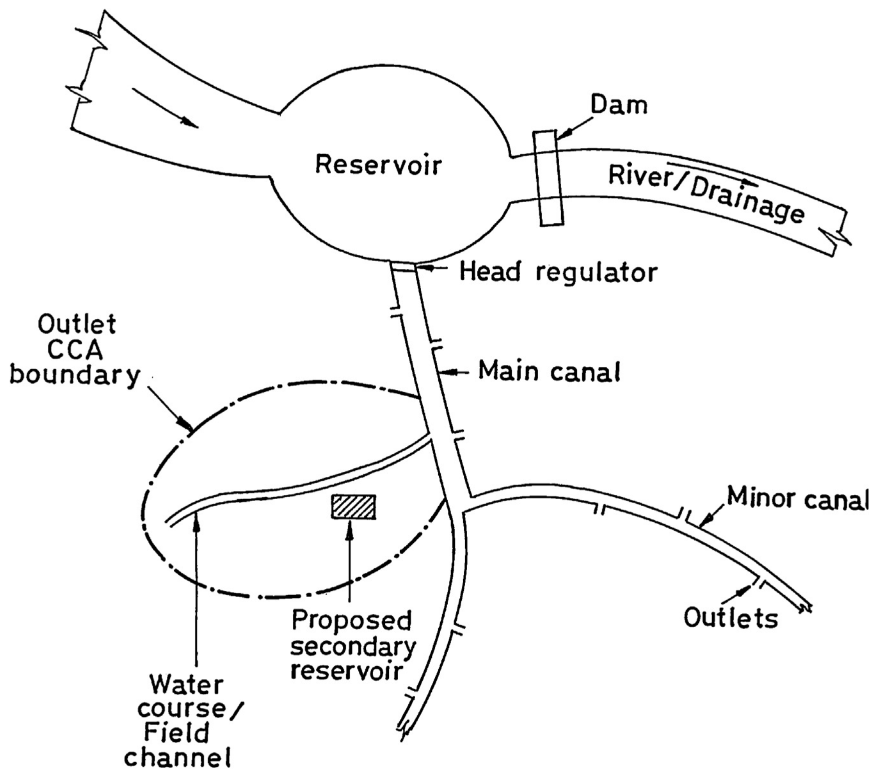

Fig. 2. Definition sketch of the proposed secondary reservoir in the Minor irrigation project.

3.1.2.2. Cropping intensity. Cropping intensity is defined the ratio of total cropped area in year to total command area. This is also expressed in percentage.

$$\text{Cropping intensity} = \frac{\text{Total cropped area in a year}}{\text{Total command area}} \times 100 \quad (4)$$

Responses were taken from the selected 91 farmers with respect to above-mentioned variables both for wet and dry season with the help of an interview schedule developed for this purpose. The means of the percent change between pre- and post-rehabilitation with respect to aforesaid variables were computed.

3.1.3. Institutional performance indicators

Institutional intervention was taken place through formation of WUA and handing over the irrigation system to WUA for its operation and management. The extent of farmers' participation in irrigation management and group effectiveness of WUA were studied through interview schedule survey of 91 farmers. The extent of WUA member-farmers' participation in irrigation management was measured with the help of a Farmers' Participation Index (FPI).

$$\text{FPI} = \frac{\text{Mean participation score } (P)}{\text{Maximum participation score}} \times 100 \quad (5)$$

where, $P = \sum P_i/N$ and $P_i = \sum \text{PP}_j$ and where, PP_j is total score of farmers' participation. $i = 1, 2, \ldots, N$ and $j = 1, 2, \ldots, K$. N is the total number of respondents, K is the total number of statements (statements related to farmers' participation and score was assigned as 1 for 'yes' and 0 for 'no' response to each statement).

To understand the effectiveness of WUA, a Group Dynamic Effective Index (GDEI) was used (Ghosh et al., 2010) that included 10 different parameters with different weightage. GDEI was studied on the basis of ten different parameters, which are participation (P), decision making procedures (D), operation, maintenance and management functions (O), interpersonal trust (T), fund generation (F), social support (S), group atmosphere (A), membership feelings (M), group norms (N) and empathy (E). Each parameter was assessed on the basis of 5 statements on which farmers' responses were taken on 3-point continuum ranging from 0 to 2. Mean and standard deviation values of each parameter were calculated at first step and thereafter, overall GDEI was calculated as follows:

$$\begin{aligned}\text{GDEI} = {} & 0.20 \times P + 0.15 \times D + 0.12 \times O + 0.10 \times T + 0.10 \times F \\ & + 0.08 \times S + 0.08 \times A + 0.07 \times M + 0.05 \times N + 0.05 \times E\end{aligned} \quad (6)$$

3.2. Conceptualization and field validation of secondary storage reservoir

The performance assessment study diagnose that inadequacy in irrigation water availability during dry season was one of the major impediments in the irrigation system. Therefore, the second part of our study focuses on the augmenting the water resource scenario in the chosen MIP. The possibility of increasing the capacity of the main reservoir is very remote. Therefore, the concept of secondary storage reservoir in the command of each outlet was hypothesized to overcome the irrigation water scarcity. These reservoirs harvest the rainwater during monsoon as well as capture excess irrigation water if any at the time of irrigations. The harvested water in the secondary reservoirs are utilized for raising crops in the dry season along with the water available in the main reservoir after meeting the requirement of rainy season crops. The augmented water resource is utilized in more effective and productive manner through multiple use management. The definition sketch of the proposed secondary storage reservoir is shown in Fig. 2.

The optimal size of secondary storage reservoir and optimal cropping pattern was developed through a multi objective optimization model (Mishra et al., 2009). The area under the existing

Table 1
Impact of rehabilitation and IMT on irrigation performance (mean score).

Performance indicator	Wet season			Dry season		
	Head reach	Middle reach	Tail reach	Head reach	Middle reach	Tail reach
P_1	4.84	4.12	3.52	4.38	3.39	3.10
P_2	4.31	3.82	3.38	3.92	3.48	3.09
P_3	4.08	3.81	3.43	3.46	3.14	3.19
P_4	4.54	3.64	3.33	3.77	3.15	3.09
P_5	4.31	3.64	3.33	3.85	3.18	3.19
P_6	4.75	3.58	3.43	4.25	3.08	3.29
P_7	4.63	3.94	3.86	4.36	3.51	3.67
P_8	4.61	4.14	3.52	4.38	3.78	3.57
P_9	3.85	3.44	3.38	3.62	3.26	3.33
P_{10}	4.46	3.96	4.14	3.85	3.41	3.57
P_{11}	4.46	3.88	3.81	3.92	3.24	3.19

water bodies in the command of Devijhar MIP was subsequently assessed through field survey in the command. This was carried out to answer the question of how to meet the area required for construction of the proposed secondary reservoirs. An existing community owned water body located in the command area of outlet 8R of the main canal system was converted to a secondary reservoir. The possibility of growing winter/summer crops using the stored water of the secondary reservoir was explored and field demonstrated. The farmers having their lands in the vicinity of the secondary reservoir were encouraged to grow vegetables and oilseed crops in the dry season utilizing the water from it through a pump set in addition to the water from main reservoir.

Fish culture in the reservoir was also undertaken to enhance the productivity of stored water. Fish seed of Indian Major Carps (IMCs) (*Catla catla*, *Labeo rohita* and *C. mrigala*) and exotic carp *C. carpio* were stocked after proper acclimatization @ 15,000 early fingerlings/ha {Mean body weight (MBW)3.2 ± 0.7 g}. Stocking composition was 20:40:35:5. Supplemental feeding was provided with a ratio of 55:35:10 (rice bran: mustard oil cake: fish meal) @ 5%, 4%, 3% and 2.5% of MBW, twice a day, during 1st, 2nd, 3rd and 4th month to harvesting, respectively. Growth performance indicators of stocked fish such as mean body weight (MBW), per day increment (PDI), performance index (PI), production size index (PSI) and survival rate (SR) were estimated. Performance index was calculated by combining the two responses such as growth and survival. PI is Growth rate in g/day at the time of harvesting i.e., [(final mean body weight at harvesting in g − initial mean body weight in g)/(rearing duration)] × final survival rate in %. Production-size index (PSI) was also estimated to evaluate production performance of each species with respect to their size. PSI = (Production in kg/ha × mean body weight in g)/1000. Both PI and PSI were estimated after the final harvest. Various water quality parameters such as temperature, pH, dissolved oxygen, total alkalinity, dissolved organic matter, nitrite-N, nitrate-N, ammonia, transparency and total suspended solid were measured using standard procedure (APHA, 1995; Biswas, 1993). Mechanism for participatory creation, utilization and maintenance of secondary reservoir with a micro-level institutional arrangement was suggested based on the experience gained during the study.

4. Results and discussion

4.1. Irrigation and water delivery performance evaluation

The overall impact on irrigation system's performance due to rehabilitation was assessed taking the mean score of all the eleven indicators (P_1 to P_{11}). The mean values of indicators for head, middle and tail reach of the study MIP during wet and dry seasons are presented in Table 1. As evident, the overall hydrological situation in wet season looks slightly better in comparison to dry season. In both the seasons, all the indicators are in the range of good to very good. During the wet season, among the indicators considered, stream size of water (P_3) and management decisions on cultivation practices based on availability of irrigation water (P_9) in the head reach; duration of water supply (P_6) and management decisions on cultivation practices based on availability of irrigation water (P_9) in the middle reach; and timing of irrigation water availability (P_4) and equitable distribution of irrigation water among the farmers per ha of cultivated land (P_5) have scored the least. Thus, during monsoon season, management decisions on cultivation practices based on availability of irrigation water (P_9) has been the concern of most of the farmers of Devijhar MIP. Further, the farmers have also shown their concern about the equitable distribution of water. During the dry season, among the indicators considered, stream size of water (P_3) and management decisions on cultivation practices based on availability of irrigation water (P_9) in the head reach; stream size of water (P_3) and duration of irrigation water supply (P_6) in the middle reach; point of delivery of water (P_2) and timing of irrigation water availability (P_4) in the tail reach have scored lowest indicating the concern of the farmers on these indicators. Considering all the above points, it is the stream size of water/outlet stream size (P_3) which needs more attention during dry season.

The overall performance has been observed better in monsoon than the dry season. During monsoon, the differences in performance are clearly seen among the reaches. Head reach has

Table 2
Adequacy of water delivery during 2nd irrigation for Devijhar MIP.

Total volume of irrigation water supplied during 2nd irrigation (m^3)	Crops grown	Area Under different crops (ha)	Crop water requirement between 1st and 2nd irrigation (m)	Flow volume required at the head regulator of the main canal (m^3)	Adequacy
180014.4	Groundnut	242.705	0.107	259694.35	0.396
	Sunflower	0.070	0.107	74.90	
	Green gram	86.299	0.218	188131.82	
	Brinjal	1.000	0.269	2690.00	
	Cabbage	1.000	0.245	2450.00	
	Cauliflower	0.500	0.245	1225.00	
Total				454266.07	

Table 3
Relative water supply during the dry season, 2005–2006 in Devijhar MIP.

Total volume of irrigation water supplied during dry season, 2005–2006 (m^3)	Total rainfall volume during the dry season (m^3)	Crops grown	Area Under different crops (ha)	Total crop water requirement, (PET + seepage + percolation losses) (m)	Total volume of water required by the crops (m^3)	Relative water supply
A	B		C	D	C × D	$(A+B)/\sum(C \times D)$
500040	436400	Groundnut	242.71	0.47	1143140.55	0.687
		Sunflower	0.07	0.36	254.80	
		Green gram	86.30	0.24	204528.63	
		Brinjal	1.00	0.57	5740.00	
		Cabbage	1.00	0.53	5320.00	
		Cauliflower	0.50	0.45	2230.00	
Total					1361213.98	

performed better over middle and tail reaches. The overall performance in the wet season ranges from 3.56 (good) to 4.44 (very good). However, in dry season it ranges from 3.29 to 3.98 and is considered good. The focused group discussion (FGD) reveals that due to paucity of water in the main reservoir during dry season, the crops cultivation (primarily groundnut cultivation) remains confined to head reach. This may be the reason for better overall scoring of indicators value in the head reach. Therefore, to improve the irrigation performance in the middle and tail reaches, ways and means for increasing water availability need to be worked out.

In order to assess the performance of water delivery, the adequacy value was determined at the head regulator of the main canal during 2nd irrigation in dry season of 2005–2006. The water requirement of the total cropped area in the command between 1st and 2nd irrigation period was estimated and compared with the total volume of irrigation water supplied during the 2nd irrigation (Table 2). In this season, about 331.67 ha were put under cultivation. The adequacy value for the project during the 2nd irrigation was determined as 0.396. Ideally it should have been one.

The value of relative water supply was computed for the entire dry season. RWS relates the irrigation water available for crops from surface water and rainwater to the amount of water the crop needs (Table 3). The value of RWS was determined as 0.687 indicating that about two third of the crop water demand is met from irrigation and rainfall.

Thus, from the values of adequacy of 0.396 and RWS of 0.687, it is clearly concluded that the project badly suffers from inadequate irrigation water supply due to non-availability of water in the main reservoir emphasizing ample scope for creation of additional water resources. It is also observed during the field survey and FGD that the farmers don't take into account the availability of water in the main reservoir while making their crop planning. Due to this, they do not get adequate amount of water to irrigate their crops and end up with low crop productivity.

4.2. Agricultural performance evaluation

Impact on agriculture addresses the effectiveness of on-farm water management. To realize the visible impact of irrigation system's functioning due to rehabilitation and IMT, impact on agriculture was assessed by making a comparison between pre- and post-project rehabilitation scenario of the command with respect to land utilization, cropping intensity, area under irrigation, irrigation intensity and cropping pattern.

Table 4 presents the cultivated area before and after the rehabilitation of Devijhar MIP. Water being one of the prime inputs for agriculture, it is expected that with the rehabilitation, the area under cultivation will increase. Overall increase in cultivated area of 17.72% was recorded during post rehabilitation period. The head reach has recorded maximum increase (25.45%) followed by middle reach (18.18%) and tail reach (10.51%). There is an overall increase of about 26% in cropping intensity. The head reach has been benefited maximum with an increase of 36.87% followed by middle reach with 26.82% and tail reach with 15.32%.

Table 4 also presents the irrigated area during pre- and post-rehabilitation period. There is an overall increase of 41.54% in the irrigated area in the post rehabilitation period. Maximum increase in irrigated area has been recorded in the head reach (61.6%). The least increase in irrigated area has been recorded in the middle reach (34.69%). Thus, the problem of spatial discrepancy in availability of irrigation water still prevails. The canal network is partially lined and that is why the irrigation water finds it difficult to reach the tail end. Perusal of the data on cultivated area and irrigated area (Table 4) reveals that due to rehabilitation, most of the cultivated areas have now turned out to be irrigated areas.

The improvement in irrigation intensity due to rehabilitation is presented in Table 5. There is an overall increase in irrigation intensity by about 40%. The head reach has registered maximum increase in irrigation intensity (58.16%). During the wet season negligible increase in irrigation intensity is recorded. However, a marked increase (2.22–39.78%) is recorded during dry season. Thus, rehabilitation has significantly increased the irrigated area during dry season. In spite of these increases, more than half of the

Table 4
Change in cultivated area and irrigated area.

Reach	Average land holding (ha)	Mean value					
		Gross cultivated area (ha)			Gross irrigated area (ha)		
		Before rehabilitation	After rehabilitation	Change (%)	Before rehabilitation	After rehabilitation	Change (%)
Head ($n=13$)	1.54	2.23	2.8	25.45	1.45	2.34	61.60
Middle ($n=57$)	1.37	2.02	2.39	18.18	1.37	1.85	34.69
Tail ($n=21$)	1.33	1.94	2.14	10.51	1.21	1.81	49.20
Overall ($N=91$)	1.39	2.03	2.39	17.72	1.35	1.91	41.54

Table 5
Improvement in irrigation intensity due to rehabilitation.

Particular	Before rehabilitation			After rehabilitation			Percent change in irrigation intensity
	Irrigated area in wet season (%)	Irrigated area in dry Season (%)	Irrigation intensity (%)	Irrigated area in wet season (%)	Irrigated area in dry Season (%)	Irrigation intensity (%)	
Head reach (n = 13)	94.00	0.00	94.00	95.16	57.00	152.16	58.16
Middle reach (n = 57)	97.81	2.56	100.37	99.42	35.29	134.71	34.34
Tail reach (n = 21)	87.86	2.86	90.72	95.71	40.00	135.71	44.99
Overall (N = 91)	94.96	2.22	97.18	97.92	39.78	137.7	40.52

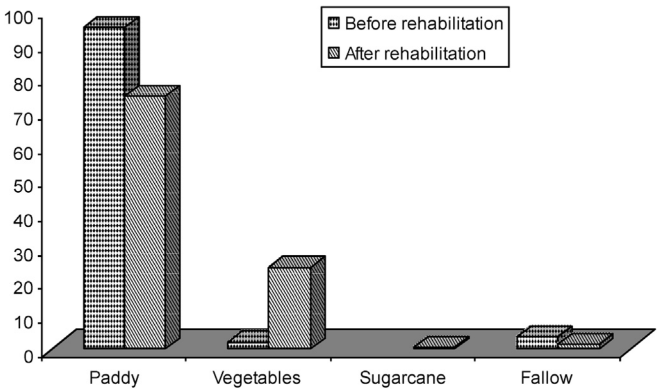

Fig. 3. Cropping pattern of Devijhar MIP during wet season before and after rehabilitation.

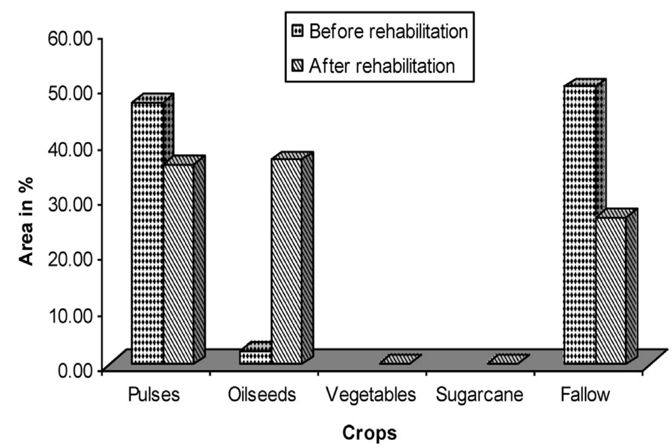

Fig. 4. Cropping pattern of Devijhar MIP during dry season before and after rehabilitation.

command remains un-irrigated during the dry season due to inadequate water availability in the reservoir.

Fig. 3 presents the cropping pattern during rainy season before and after rehabilitation. After rehabilitation, a major shift in the cropping pattern has been recorded with a decrease in paddy area (94.77–74.57%), increase in vegetable area (1.84–23.93%). Thus, in the rainy season there is a shift from paddy to non-paddy crops which might be due to the capacity building of the farmers through different agencies on crop diversification. Fig. 4 depicts the cropping pattern before and after rehabilitation during the dry season. The fallow area has been reduced from 50.14% to 26.52%. Before rehabilitation, pulses used to be the major crop of the command during dry season. After rehabilitation, the area under pulse crops has gone down from 47.33% to 36.03%. With the availability of irrigation water farmers have shown interest to go for cash crop like groundnut because of which the area under oilseeds has increased from 2.52% to 36.91%. Thus, there is a need to create more water resource to bring the remaining fallow area under cultivation.

4.3. Institutional performance evaluation

The institutional performance indicators such as the extent of WUA members' participation and group effectiveness of WUA were studied through interview schedule survey of selected 91 farmers.

A detail account of the farmers' responses on different issues related to farmers' participation is given in the Table 6. It is to note that member-farmers of WUA do not participate in fund generation activity other than water tax collection. They are also not involved in deciding the cropping pattern. Most of the farmers have not received training relating to participatory irrigation management. Lack of participation of member farmers on these aspects have influenced overall level of participation which is found as 65.92%.

Group dynamics effectiveness was studied on the basis of ten different parameters of GDEI, values of which are presented in the Table 7. It is evident that parameters like participation, group

Table 6
Farmers' opinions with respect to their participation in irrigation management activities of WUA.

Statements under issues related to participation	No. of farmers with positive response	Mean score (N = 91)	Standard deviation
Farmers involve in internal water distributions	91	1.00	0.00
Farmers fix water rates for different crops	91	1.00	0.00
Farmers participate in the collection of water taxes	91	1.00	0.00
Farmers follow water sharing for irrigating crops	87	0.96	0.20
Farmers select specific cropping pattern to be adopted by all member farmers	1	0.01	0.12
Farmers take care of maintenance of outlets, channels and distribution systems	87	0.96	0.20
Farmers aware about law/rule/act, which support farmers' participation in irrigation management	87	0.96	0.20
Farmers raise their own fund other than water taxes	0	0.00	0.00
Farmers have got mobilized for participatory irrigation management through training	4	0.04	0.20
Farmers understand problems related to irrigation service controlled by outsiders, therefore, adopt participatory methods to solve such problems	91	1.00	0.00
All member-farmers participate in periodical meetings of WUA	87	0.96	0.20
WUA arrange financial support for participatory agricultural activities time to time	3	0.03	0.17
FPI value = 65.92			

Table 7
Group dynamics effectiveness index of WUA in Devijhar MIP.

Parameters of GDEI	WUA at Devijhar (N = 91)	
	Mean	Standard deviation
Participation	7.99	0.10
Decision making	5.37	1.55
O & M functions	6.84	0.58
Fund generation	6.93	0.74
Group atmosphere	9.20	1.29
Membership feeling	7.88	0.47
Norms	6.45	0.85
Empathy	3.32	0.73
Interpersonal trust	6.02	0.30
Social support	6.01	0.10
Overall GDE	6.82	0.26

Maximum and minimum possible mean score is 10 and 0, respectively

Table 8
Area and number of existing water bodies in the command of Devijhar MIP.

Sl No.	Village name	Area under existing water bodies (ha)		
		Community owned	Individual owned	Total
1	Aitipur	3.28 (2)	0.11 (2)	3.39 (4)
2	Tentulia Palli	1.13 (4)	1.04 (6)	2.17 (10)
3	Biripur	1.81 (2)	0.07 (1)	1.88 (3)
4	Parinuagaon	18.12 (6)	0.93 (3)	19.05 (9)
5	B K Saranpur	0.64 (2)	0.04 (1)	0.68 (3)
6	Ustapada	14.86 (3)	0.00 (0)	14.86 (3)
7	Laxmanpur	7.91 (5)	1.47 (4)	9.38 (9)
8	Bagalpur	2.56 (9)	0.00 (0)	2.56 (9)
9	Kamarsingh	0.14 (1)	0.00 (0)	0.14 (1)
10	Kaithapada	0.83 (1)	0.12 (2)	0.95 (3)
	Total	51.28 (35)	3.78 (19)	55.06 (54)

Figures within the parenthesis indicate number of water bodies.

atmosphere and membership feeling were perceived relatively high by the member-farmers. Inspite of largeness of the WUA, member-farmers perceived most of the parameters favourably. Prevalence of village water user groups at each village and their representation in the management committee of WUA might have catered better to the awareness of farmers thereby influencing their perceptions. Relatively lower values of the parameters viz. empathy and decision making indicate the disatisfaction of the members on WUAs understanding of indivdual member's need and process of making decision regarding crop planning, water control and delivery, revenue generation etc.

The entire exercise of performance evaluation clearly brings out the fact that the system has started performing in a better manner after rehabilitation in terms of water delivery, agriculture and WUAs functioning. However, farmers perceived that the irrigation water is not sufficient and as a result of which tail end farmers are the worst sufferer and quite a sizeable area remains fallow during dry season. Inadequacy of irrigation water availability is clearly seen from the adequacy and relative water supply values (Tables 2 and 3). Thus, there is a need to augment the water resource of the irrigation system. The possibility of providing secondary storage reservoirs in the command was explored and field demonstrated to enhance the irrigation water availability and crop productivity.

4.4. Scope and feasibility of secondary reservoir

Keeping in view the afore-said performance analysis and the issues of irrigation water unavailability over space and time, the scope and feasibility of secondary storage reservoir in the outlet command of selected MIP was studied. A multi objective optimization model was developed to determine the optimal size of secondary storage reservoir and optimal cropping pattern (Mishra et al., 2009). The optimization routine had three objective functions i.e., (i) Maximization of net seasonal benefit, (ii) Maximization of cropped area, and (iii) Minimization of secondary storage reservoir construction and pumping costs. The priority level of the objective function was also changed while carrying out the optimization. Four levels of water availability in the main reservoir i.e. 25, 50, 75 and 100% of its capacity was considered at the beginning of the dry season while making the simulation run of the optimization model through Goal Programming technique. The results reveal that water availability at 50% of main reservoir capacity for irrigating dry season crops and fixing the 1st priority level of the objective function as maximization of net seasonal benefit, the optimal surface area for secondary storage reservoir as the percentage of the command area was obtained as 17.40%. Similarly, for water availability at 50% of the main reservoir capacity for irrigating dry season crops and fixing the 1st priority level of the objective function as maximization of cropped area, the optimal surface area for secondary storage reservoir as the percentage of the command area was obtained as 10.92%. The performance of the MIP significantly increased due to provision of secondary storage reservoir. The economic analysis resulting in B/C ratio of more than 1, positive value of net present value (NPV) and higher value of internal rate of return (IRR) than the bank interest rate establish the economic viability of the intervention (Mishra et al., 2009).

4.5. Assessment of area under existing water bodies

After determining the optimal area required for secondary storage reservoir, the immediate question that comes to the mind is from where and how the area required for the secondary reservoir will be met? To answer this query, the area under the existing water bodies in the command of Devijhar MIP was assessed. In total there are 10 villages which come under the command of this MIP. Table 8 indicates the village-wise area and number of water bodies (both individually owned and community owned) present in the command area. In total, there are 54 water bodies present, occupying about 55 ha which works out to be 11% of the command area. This figure will vary from system to system. However, it is certain that major portion of the area required for secondary reservoir can be met through use of existing water bodies with suitable modifications such as providing inlet, outlet, pumping unit etc. The remaining area can be obtained either from community owned land or from individual owned land with development of suitable institutional mechanism.

4.6. Utilization of harvested water in the secondary reservoir

4.6.1. Crop performance

An existing community owned water body located in Kamarsingh village in the command of outlet 8R of the main canal system (having water spread area of 700 m^2 and depth of 3.6 m) was converted into secondary storage reservoir. The outlet has a design discharge of 19.6 l/s and command area of 17.98 ha with 34 beneficiary farmers. Effective utilization of stored water from this secondary reservoir was field demonstrated in two successive years (2006–2008) by irrigating the dry season crops and growing aquaculture.

Farmers having their lands in the vicinity of the secondary reservoir were encouraged to grow vegetables and oilseed crops in the dry season utilizing the water from it through a 3.5 HP pump set. The secondary reservoir stores the excess irrigation water supplied through the canal system from the main reservoir besides harvesting rainwater during rainy season. The depth of water in the secondary reservoir fluctuated between 1.5 m (in the month of

Table 9
Economics of different rice based cropping systems.

Cropping system	Gross return (Rs./ha)		Cost of cultivation (Rs./ha)		Net return (Rs./ha)		Benefit cost ratio	
	MR + SR	Only MR	MR + SR	Only MR	MR + SR	Only MR	MR + SR	Only MR
Rice–sunflower	39582	36982	18875	18175	20707	18807	2.09	2.03
Rice–brinjal	50741	46456	28310	27260	22430	19196	1.79	1.70
Rice–tomato	56982	52222	27525	26475	29457	25747	2.07	1.97
Rice–groundnut	44951	40986	22920	22220	22031	19766	1.96	1.84

Farm-gate price of crop produce during 2007–2008: Rice grain @ Rs. 6.50/kg, rice straw @ Rs. 0.3/kg, groundnut pods @ Rs. 23/kg and brinjal fruits @ Rs. 5/kg, and tomato fruits @ Rs. 4/kg, sunflower @ Rs.20/kg.

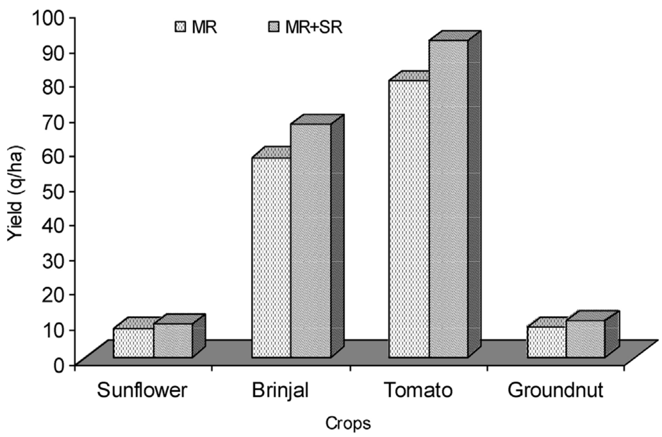

Fig. 5. Productivity of different crops utilizing water from main and secondary reservoir.

May) in summer to 3.3 m (in the month of September) in the rainy season.

Sunflower, brinjal, tomato and groundnut were grown in winter season of both the years and the average yield of these crops utilizing water from Main reservoir (MR) and main reservoir + secondary reservoir (MR + SR) is shown in Fig. 5. The establishment of sunflower and brinjal was observed to be quite good in terms of plant population, stem circumference, seed or fruit number and fruit/grain yield due to timely irrigations at critical crop growth stages. During the crop growing period, the average water level in the secondary reservoir fluctuated between 2.85 and 1.9 m. In total, two irrigations were given from the main reservoir during winter season. The 1st irrigation was for a period of 8 days and the second irrigation was for a period of 10 days. In addition to irrigation water from main reservoir, additional 2–3 irrigations were supplied from secondary reservoir for irrigating the crops. These additional irrigations have resulted in increasing the yield by 14.29, 14.95, 16.75 and 20% in sunflower, tomato, brinjal and groundnut, respectively.

The economics of rice based cropping system in the command using water from the main reservoir and water from main + secondary reservoir have been computed (Table 9). In all the cropping patterns, crops receiving water from both the reservoirs have yielded more and resulted in higher net return. Among the cropping pattern considered, rice–tomato cropping pattern has resulted in highest net return of Rs. 29,457 per ha followed by rice–brinjal cropping pattern (Rs.22,430 per ha). The benefit cost ratio of 2.07 was computed for rice–tomato cropping pattern followed by 1.79 for rice–brinjal. Highest benefit–cost ratio of 2.09 was obtained for rice–sunflower cropping system due to relatively lower cost of cultivation of sunflower. Therefore, the farmers are recommended to grow sunflower and tomato during winter season after harvest of monsoon paddy.

4.6.2. Aquaculture in the secondary reservoir

Low input-based scientific fish culture was carried out for two consecutive years (2006–2008) in the secondary reservoir by the User group. After 226 days of rearing, the 1st crop harvesting was carried out in the month of April, 2007. The average MBW was 1246.5 g, 219 g, 243.4 g and 379.3 g for *Catla*, *Rohu*, *Mrigal* and *C. carpio* respectively (Table 10). Total yield was 186 kg and productivity was 2.65 t/ha/226 days as against the previous year yield of 60 kg (0.85 t/ha/year) i.e., farmer's practice. The apparent feed conversion ratio was 1.34. Biomass contribution was maximum by *C. catla* (88.5 kg) followed by *C. mrigala* (46 kg). Higher and lower Performance Index (PI) was recorded incase of *C. catla* (185.9) and *L. rohita* (41.8), respectively, while higher and lower Production Size Index (PSI) was recorded incase of *C. catla* (1575.9) and *C. carpio* (59.6), respectively. Similarly, after 273 days of rearing, the 2nd crop harvesting was carried out in the month of May, 2008. In the 2nd crop, the average MBW was 1050 g, 269 g, 252 g and 302 g for *Catla*, *Rohu*, *Mrigal* and *C. carpio*, respectively (Table 10). Total yield was 191.8 kg and productivity was 2.74 t/ha/273 days. The apparent feed conversion ratio was 1.48. Biomass contribution was maximum by *C. catla* (84.5 kg) followed by *L. rohita* (49.2 kg). Higher and lower PI was recorded incase of *C. catla* (116.3) and *L. rohita* (26.7) respectively, while higher and lower PSI was recorded incase of *C. catla* (1267.5) and *C. carpio* (104.5) respectively.

Higher PI, PSI and per day increment (PDI) in case of surface feeder was probably due to the stocking composition and minimal inter specific competition with column feeders (Mohanty et al., 2010), while moderate growth performance of both column and bottom feeders were due to stronger competition for food and space among each other (Mohanty et al., 2009). The low input-based scientific intervention has enhanced the overall yield by three fold (up by 210% during the 1st year and 220% during the 2nd year) in comparison to yield before intervention i.e., farmer's practice.

Users group was formed for maintenance and management of the secondary reservoir. Two persons were chosen as their group leaders by the User group. The decision related to crop diversification activities, irrigation application schedule, fish culture in the secondary reservoir, selling of fish, operation of bank account, etc. were carried out by the group leaders. Group meetings were often

Table 10
Species-wise production characteristics of IMCs in secondary reservoir.

Species	*C. catla*	*L. rohita*	*C. mrigala*	*C. carpio*
2006–2007				
SR%	33.8	44.0	51.0	58.0
Biomass (kg)	88.5	40.5	46.0	11.0
PDI (g)	5.5	0.95	1.1	1.7
Performance index (PI)	185.9	41.8	54.1	96.3
Production-Size Index (PSI)	1575.9	126.7	159.9	59.6
2007–2008				
SR%	30.3	27.2	73.0	33.0
Biomass (kg)	84.5	49.2	34.5	23.6
PDI (g)	3.8	1.0	0.9	1.1
Performance index (PI)	116.3	26.7	67.2	36.3
Production-Size Index (PSI)	1267.5	189.8	125.6	104.5

held during evening hours to take decision on above mentioned activities. The group opened its saving account in the nearby bank by depositing Rs. 5000 which was obtained from sale produce of harvested fish in the year 2007. Subsequently, the revolving fund was utilized for procurement of inputs like fish seeds, feed, fuel for the pump set, etc.

4.7. Institutional mechanism for improved performance of WUA in creation and utilization of water resource

Secondary reservoirs in the command of each outlet have been found to have significant potential in augmenting the irrigation water resource and overall production. The productivity of stored water can be enhanced through multiple use management by way of fish culture in the reservoir, horticulture in the reservoir's embankment, providing irrigation water to dry season crops, etc. In this context, participatory creation, utilization and maintenance of secondary reservoir with a micro-level institutional arrangement is important which is described below based on the experience gained during this study.

4.7.1. Creation of secondary reservoir

- Place of creation: Initially the feasibility of existing water bodies (both community owned and individually owned), which are already in existence in the command of the outlet need to be explored to convert them into secondary reservoir. Further, if some more area is required for the secondary reservoir, then it is ideal to have it on community land. If common land is not available, individual farmer is to be motivated to construct the reservoir on his land and accordingly benefit sharing mechanism need to be worked out among the farmers who have given their land for the secondary reservoir.
- Users' group formation: The farmers having land in command area of a given outlet as well as getting water through secondary reservoir would be members of users group. The formation of users group would be on the basis of utilization of water by the farmers from specific secondary reservoir. The number of user groups depends on number of secondary reservoirs created under a given outlet of the canal system. Thus, each secondary reservoir will have a user group.
- Process of creation: The construction of secondary reservoir may be under taken following participatory approach in which users will bear the expenditure. This may be realized through self or hired labour or proportionate contribution of the fund required for construction.

4.7.2. Utilization of secondary reservoir

- Mode of utilization: The utilization of secondary reservoir includes irrigation to the crops raised in its command, on-dyke horticultural crops cultivation, fish farming, duckery in the reservoir, etc. The user group needs to decide on cropping pattern, irrigation schedule and intricacies of fish and duck farming.
- Fund generation: User group need to decide the water rates and collect from each users depending upon the types of crop grown, area under different crops and number of irrigations received from the reservoir. Similarly, a percentage of accrued income from fish farming and/or duckery as decided by the group would be saved in group's account.
- Method of benefit sharing: Benefit sharing becomes simple and easy, if the secondary reservoir is located on the common land. When the reservoir is constructed in individual's land, benefit sharing needs to be worked out through agreement between the individual farmer on whose land the reservoir is created and the other user members. A percentage of accrued income from fish farming and/or crop cultivation may be given to the farmer who has provided the land for reservoir. It may also so happen that individual farmer given out the land may enjoy entire right of fish farming in the reservoir while others get water for irrigation to the crops by paying water tax.

4.7.3. Maintenance of secondary reservoir

Major shortcomings of any operation research project are speedy withdrawal of technology and poor maintenance of resources created after completion of the project. This makes the project unsustainable after withdrawal of the project functionaries. Therefore, maintenance of secondary reservoirs by the user group is of paramount importance. The important aspects in this regard are as follows:

- Responsibility of maintenance of resource should be shouldered by the users group.
- Financial support to manage and maintain the resources by farmers' groups would be through group's own generated fund.
- Contribution of own labour and resource for repair and maintenance of reservoir.
- Irrigation and line department officials should act as facilitator and supportive to farmers' participation in water management.
- Follow up action through farmers training on scientific water management, providing technical guidance, advice and support to properly maintain the created water resource for effective utilization would ensure sustainability of technological intervention.

It is essential to develop a sustainable water management strategy compatible to the socio-economic conditions and aspiration of the people. Concerted efforts by the user group for achieving common goals and sharing benefits are essential.

5. Conclusions

Performance assessment of a recently rehabilitated and turned over minor irrigation project indicated considerable improvement in the systems performance level after rehabilitation. The performance analysis also indicated ample scope for further improving the performance of the system through creation of additional water resources within the irrigated command. Secondary storage reservoir in the command of the outlets to create additional water resources was found to be a promising technological option for augmenting the water resource. Survey revealed existence of large number of poorly maintained water bodies within the command which can be utilized as secondary storage reservoirs with suitable modifications and maintenance. Harvesting of rainwater in the secondary reservoir and multiple use management of harvested water has been found beneficial through successful participation of user's group. This has resulted substantial increase in crop and fish yield. The intervention found to be highly promising in augmenting water resource and agricultural productivity of the command.

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