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Enhancing water productivity through conjunctive use of surface and groundwater resources in upland plateau regions of Odisha

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ABSTRACT

Non-availability of water during post-monsoon and summer seasons is a major impediment to crop production in upland areas. Keeping this in view, a study was conducted to evaluate the impact of integrated water resource development and management strategies on agricultural production in a plateau area of Sundargarh district, Odisha. For development of water resources, flow regulating devices like inlet, outlet and surplus escape were designed and created in one of the canal linked service reservoir located in Ghurlijore Minor irrigation project (MIP) of the study area, based on the drainage coefficient of 136 mm d^{-1}. A dug well of 6.0 m outer diameter and 9.0 m depth was also created along the drainage line adjacent to the canal linked service reservoir. Based on the available water resource, an area of 1.1 ha was selected for growing different crops (*kharif* rice, mustard in *rabi* and groundnut and green gram in summer) under the study. The pipe conveyance system coupled with sprinkler irrigation was laid out for irrigating the crops in the area. The flow regulating pattern in the outlet device and surplus escape were observed in sub-critical flow range. The hydraulic evaluation of dug well indicated that drawdown of the well was 36 cm hr^{-1} when a 5 hp pump was used in pumping with recuperation rate of 3.0 cm hr^{-1}. With using 6300 m^3 water from the well as supplemental irrigation (4 numbers) during dry spells, the yield of rice could be increase by 32% compared with non-irrigated rice in monsoon season. Among different irrigation methods (check basin, furrow and sprinkler), sprinkler irrigation saved 30-33% irrigation water with producing 24-27% higher yield, resulting in 84% improvement in water productivity compared with check basin irrigation in groundnut and green gram. The net economic water productivity could be achieved as ₹ 1.14 m^{-3}, ₹ 5.93 m^{-3}, ₹ 8.03 m^{-3} and ₹ 5.38 m^{-3} for paddy, rapeseed, groundnut and green gram crops, respectively under irrigation. Further, pisciculture taken up in the service reservoir showed that after 210 days of rearing of fish fingerlings, the average mean body weight (MBW) obtained as 17.5 g, 11.5 g and 12 g for *catla, rohu* and *mrigal*, respectively with total harvested biomass of 2.57 t ha^{-1}. Overall, the development and management of surface and groundwater resources and its efficient management helped in bringing diversification in crop production integrating with pisciculture which resulted higher profit in farming in an upland plateau area of the study region.

1. INTRODUCTION

In order to keep pace with the increasing world population, crop production from both rainfed and irrigated areas needs to be enhanced by at least 40% by the year 2025. This necessitates the improvements and implementation of water resource development and management strategies in agriculture (Shakir *et al.,* 2010). In this regard, Indian irrigation system is in search for ways and means to expand water use efficiency (WUE), as the present WUE of canal irrigation is only 35% and it is estimated that with 10% increase in WUE, 14 million hectares (M ha) additional land could be brought under irrigation (Kalyan Kumar, 2010). Timely harvesting and judicious utilization of available surface runoff is an important proposition in order to ward off the ill effects of aberrant weather conditions, as total 24 million ha-m equivalent runoff is available for harvesting in India. Barring few states like north-eastern states, almost all states in the country are already phasing through adverse weather condition. The state of Odisha is no exception to it. Erratic and uneven distribution of rain during monsoon coupled with prevalence of flood, drought and cyclone destabilizes the crop production in the state. Especially, uplands consisting of plateau and undulating topography in around 64% of the geographical area in the state are facing water scarcity during post monsoon resulting in sustenance cropping (Panigrahi *et al.*, 2015a). As far as irrigation is concerned, about 49.94 lakh ha crop area is equipped with irrigation facility in the state (Government of Odisha, 2015). However, the ineffective management of irrigation infrastructure along with water supplied from the reservoir limits crop production to a large extent; resulting only about 40% WUE in the state. In this scenario, effective management of rainwater and groundwater is needed for profitable farming with higher WUE in agriculture in uplands.

Earlier, it was reported that the water loss in conveyance can be reduced up to 15% through lining over the loss of 181 l s^{-1} per 100 m length in an unlined canal in the state (Panda *et al.*, 2016a). However, canal lining alone can't help in equitable and efficient water management in the command and/rainfed areas. Rainwater harvesting and its efficient management in upland/ hilly terrain showed positive impact on crop productivity and socio-economic conditions in several parts of the country (Rana and Gupta, 2010; Samuel *et al.,* 2013 and Singh, 2015). Shrivastava *et al.* (2015) reported that with rainwater harvesting, the crop and animal productivity in uncultivated wasteland could be enhanced with benefit cost (B:C) ratio of more than two. Study conducted by Badiger *et al.* (2016) indicated that rainwater harvesting structures significantly enhanced cropped area, cropping intensity and irrigation intensity with improving net income by 17-87% over without rainwater harvesting structures in north Karnataka. Similarly, renovation of traditional water harvesting structures in Bhilwara district of Rajasthan resulted in increase in average irrigations number in crop from 1.8 to 3.86; crop diversification index increased from 0.432 to 0.782 and 0.432 to 0.659 during monsoon and post monsoon seasons, respectively; and ground water recharge increased by 15-41% (Jat *et al.,* 2016). Overall, earlier studies indicated that harvesting of rainwater and its use could increase the productivity of crops and groundwater resources of an area (Kumar *et al.,* 2011). However, the information on effects of conjunctive use of surface (rain/canal) and groundwater through efficient methods of irrigation such as pressurized irrigation on productivity and profitability from farming in rice-dominated upland plateau region is very limited. Keeping this in view, a study was conducted in a strategically selected location in north-western plateau region (Ghurlijore MIP area) in Sundargarh district of Odisha (India), which is dominated by rice mono-cropping and habitated typically with tribal communities. The main objective was to improve livelihood of the farmers by enhancing crop yields, profitability and water productivity in farming through creation/improvement of irrigation infrastructures and efficient water management in the region. Moreover, the hydraulic evaluation of the irrigation infrastructures executed in the command area was also done under the study.

2. MATERIALS AND METHODS

Study Area

The study area is located in Ghurlijore MIP in Sundargarh district of Odisha (22°01' 51.3''N latitudes; 84°07'13.0''E longitudes; and 233 m mean sea level) and located 18 km from district headquarter (Fig. 1). This reservoir type MIP was initially constructed by Revenue Department during the year 1955-56 and subsequently renovated by Department of Water Resources, Government of Odisha during 1984 and 2004. Finally, the canal was brought to functional stage during the year 2015-16. Total design command area of the MIP is 364 ha and 210 ha during monsoon and post monsoon seasons, respectively. Total five irregular shape canal linked service reservoirs within a stretch of 3.5 km distance help the tribal farmers in irrigation for crops and domestic use (Fig. 2). This

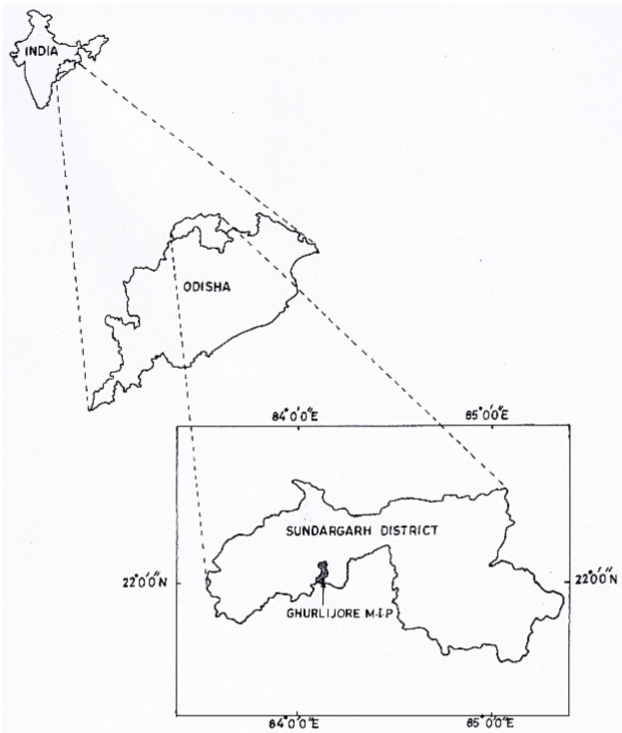


Fig. 1. Location map of the study area

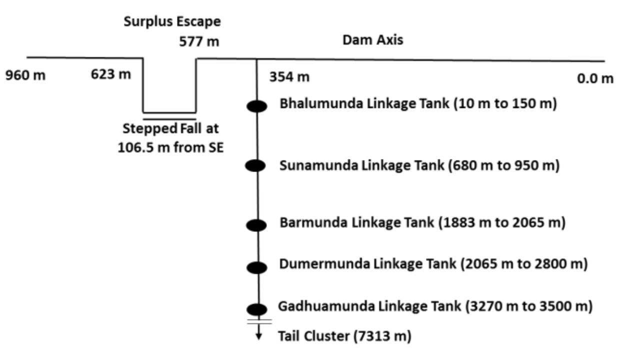


Fig. 2. Details of Linked tanks in Ghurlijore Minor Irrigation command area

research work was aimed through augmentation of the irrigation infrastructures by utilizing both surface and groundwater resources in the tail end Gadhuamunda linked service reservoir. Irrigation infrastructures like inlet, outlet and surplus escape were created and the hydraulic performances were studied. The annual average rainfall at the study area was 1200 mm, out of which 80% occurs during the monsoon period (June to October).

Canal hydraulics was studied and canal water was tapped in the service reservoir and an open dug well was created along the drainage line adjacent to the service reservoir. Pipe conveyance alongwith sprinkler irrigation system was designed and installed in farmers' field of an area of 1.1 ha at a patch belongs to nine farmers. Water availability in the service reservoir was calculated based on average capacity-depth basis. Depth of water level in the dug well was measured on monthly basis. Pumping cum recuperation test was done using a 5 hp diesel pump during November-March (2015-17) to determine the drawdown and recuperation rate of the well at the site. Based on the availability of water in both service reservoir and dug well, crop planning was done. While selecting the types of crops, farmers' preference was also considered. Further, to enhance the water productivity of the system, pisciculture was taken in the service reservoir.

Hydraulics of the Canal Linked Service Reservoir

The inlet and outlet flow hydraulics of the constructed irrigation infrastructures were studied to ensure the non-scouring velocity of flow in down-stream channel of reservoir. The specific energy at a particular point in the channel with respect to the channel bottom was computed as summation of potential energy and kinetic energy as follows:

$$\text{Specific Energy, } E = y + \frac{v^2}{2g} \quad ...(1)$$

Where, y is the depth of flow and v is the velocity. In terms of discharge term:

$$E = y + \frac{Q^2}{2gA^2} \quad ...(2)$$

Where, Q is the discharge and A is the cross-sectional flow area.

The Froude number, Fr, which describes flow regimes in the channel was computed as the ratio of inertial and gravitational forces.

$$Fr = \frac{V}{\sqrt{gD}} \quad ...(3)$$

Where, V is the velocity of water flow, D is hydraulic depth (cross sectional area of flow/top width) and g is acceleration due to gravity. For Fr = 1, flow is critical; for Fr > 1, flow is supercritical (fast rapid flow); and for Fr < 1, flow is subcritical (slow / tranquil flow).

Based on the drainage coefficient of 136 mm day^{-1} for 20-year recurrence interval, the inlet, outlet and surplus escape structures were designed and constructed. The drainage coefficient was determined based on 3-days tolerance limit of the paddy crop in monsoon season, following the procedure suggested by Panda *et al*. (2015). The three determining variables such as depth of flow, width of flow and slope of the canal section were measured in the inlet and outlet sections during the monsoon season of 2014-15 and 2015-16. Four empirical equations: Rand (1955); Gill (1979); Chanson (1994); Moghaddam (1999) were used for obtaining the design parameters in the single drop surplus escape structure.

Design of Pressurized Irrigation System

A sprinkler irrigation system was designed in the command area. Total 210 m length of main and sub-main PVC pipe conveyance system was laid out. The performance of the sprinkler irrigation system was studied in relation to water saving and crop response and compared with that under furrow irrigation and farmers' irrigation practices (flooding) in groundnut. The system performance was studied through uniformity coefficient and wetted area coverage.

Pisiculture in Service Reservoir

Low input based pisciculture was taken up in the service reservoir. During the year 2015-16 and 2016-17, fish fingerlings of Indian major carps (C*atla, Labeo rohita* and *C. mrigal*) were stocked @ 6000 ha^{-1} with a stocking composition of 30:30:40 and MBW of 17.5, 11.5 and 12 g for *catla, rohu* and *mrigal*, respectively. Feed (groundnut oil cake and rice bran, 40:60) was given twice a day at 2% MBW of fish during the culture period.

Economics

The gross expenditure in the system was worked out based on the expenditures involved in development and operation of irrigation infrastructures (well, inlet, outlet and surplus escape structure and sprinkler irrigation), crop cultivation (land preparation, seed, fertilizer, plant protection chemicals, labour) and pisciculture. The cost of well, surplus escape including inlet and out let, and sprinkler irrigation system were of ₹ 1.00 lakh, 0.6 lakh and ₹ 0.4 lakh, respectively. Considering the life of the well and surplus escape as 20 years and life of sprinkler system as 10 years, the gross annual expenditure in the system with 6% annual interest on investment was worked out as ₹ 24000 ha^{-1}. The gross annual expenditure in pisciculture (₹ 80000 ha^{-1}) was the sum of the cost of fish fingerlings (₹ 12000 ha^{-1}), fish feed (₹ 55000 ha^{-1}) and other operation expenditures (₹ 13000 ha^{-1}) in the study.

The gross return from crop production was worked out based on prevailing minimum support price (MSP) of the commodities and prevailing market prices for inputs. The MSP for rice grain (₹ 1450 q t^{-1} for year 2015-16 and ₹ 1510 q t^{-1} for year 2016-17), groundnut pod (₹ 40230 q t^{-1} for year 2015-16 and ₹ 4220 q t^{-1} for year 2016-17), rapeseed seed (₹ 3350 q t^{-1} for year 2015-16 and ₹ 3700 q t^{-1} for year 2016-17), and green gram seed (₹ 4850 q t^{-1} for year 2015-16 and ₹ 5225 q t^{-1} for year 2016-17) was used for calculating gross and net returns for the year 2015-16 and 2016-17, respectively. The fish was sold at the local market @ ₹ 120 kg^{-1} during both the years. Average of the gross and net returns for two years was calculated for economic analysis.

3. RESULTS AND DISCUSSION

Hydraulics of the System

The rating curves and the flow versus the specific energy relations for the constructed structures were developed. For both the cases, the Froude numbers were computed to be less than 1.0 (Fig. 3), which implied a continuous subcritical flow in the canal regime (characterized by non-scouring deep flow).

The important design parameters of the surplus escape device are described in Fig. 4. Where, h = the

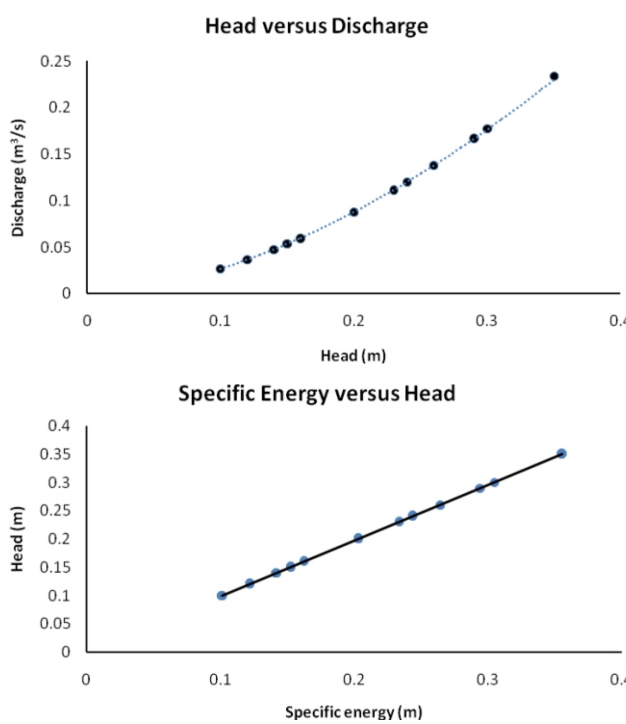


Fig. 3. Inlet rating curve and flow depth versus specific energy relation (Fr < 1.0)

drop height for single drop; y_c : critical depth; y_b : brink depth; y_p : pool water depth; and L_d : horizontal length from the brink of the drop to the length of the drop. The design details are presented in Fig. 5.

Normalized toe water depth (y_1/h) and normalized pool water depth (y_p/h) as a function of the critical depth to drop water height ratio (y_c/h) were found to be in close agreement among all four empirical equations with an absolute mean deviation of 0.1 and 0.7, respectively; when compared with the observed data. This result corroborates the earlier observation with drop structure by Farouk and Elgamal (2012). Moreover, the aeration condition did not find near the toe of the single drop surplus escape structure as ratio of pool water depth and drop height of the surplus escape (y_p/h) was found to be 1 (if y_p/h <1, it is aerated); creating a non-scouring flow condition (Panda *et al.*, 2016b).

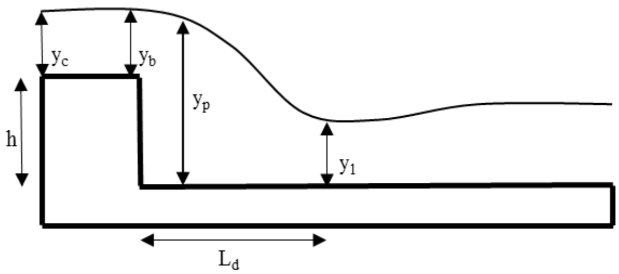
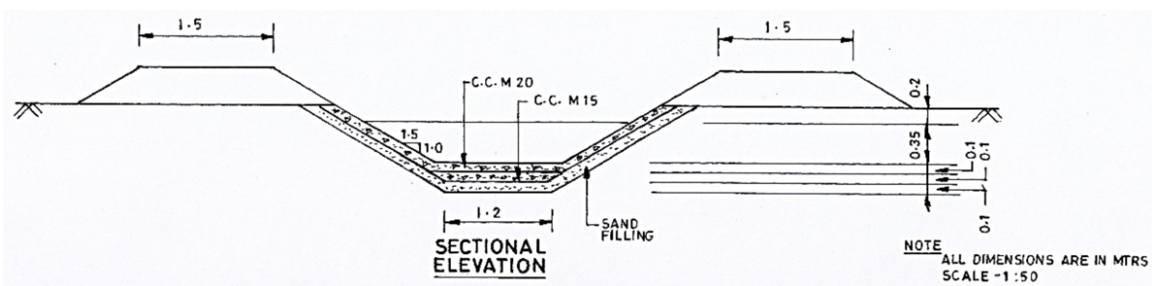
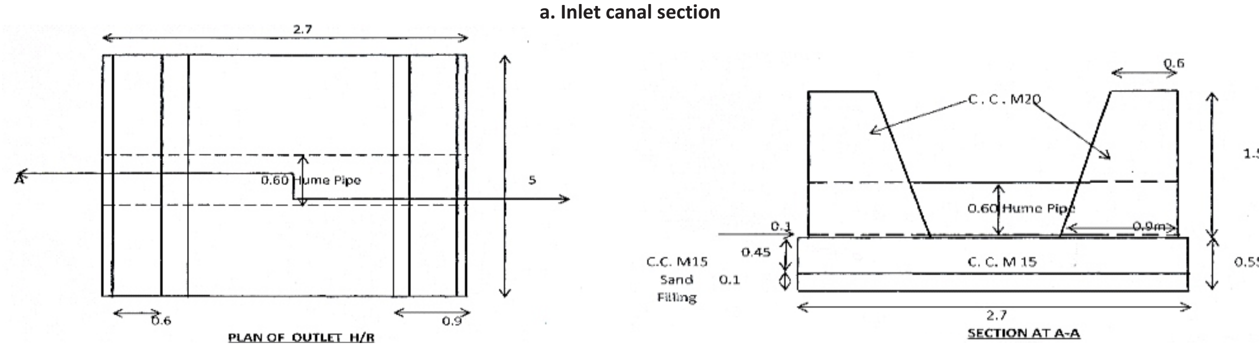


Fig. 4. Design parameters for surplus escape structure

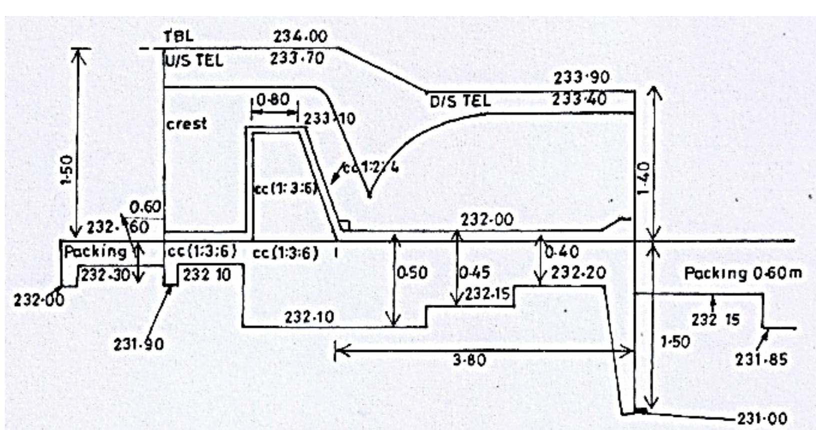
The depth-capacity relationship of the existing Gadhuamunda linked service reservoir was developed. The surface spreading area of the canal linked service



a. Inlet canal section



b. Outlet pipe flow section



c. Single drop surplus escape

Fig. 5. Design details of inlet and outlet structures

reservoir was observed as 2.3 ha (maximum) and 1.1 ha (minimum) with average depth of ponding of 1.7 m and 0.6 m during monsoon and pre monsoon season, which amounts to 3.8 ha-m and 0.6 ha-m capacity, respectively. During the same period, depth of water in the dug well was observed as 8.0 m and 4.0 m, respectively (Fig. 6). Study of dug well hydraulics during post monsoon season for consecutive two years 2015 and 2016 for a period of 2 hrs revealed an average drawdown of 36 cm h^{-1} with average recuperation rate of 3 cm h^{-1}. The recuperation rate showed that the dug well can command up to 0.5 ha area to meet the crop water requirement of 280 mm for groundnut crop in *rabi*/summer season.

The hydraulic of the pipe conveyance and sprinkler irrigation system studied from time to time in the cropping seasons during the experimental period indicated that the distribution efficiency of water application under pipe conveyance was 67%,

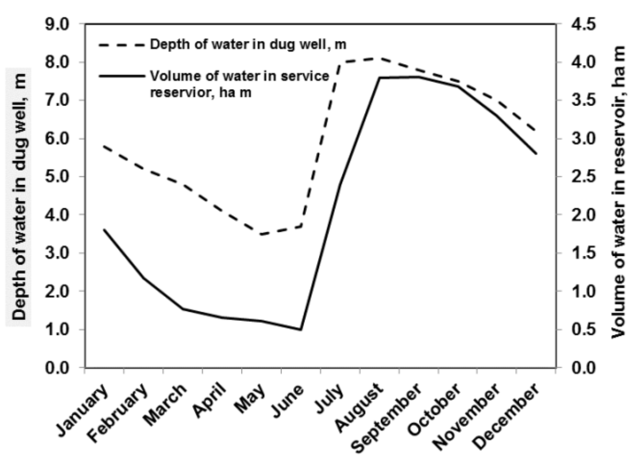


Fig. 6. Depth of water in dug well and volume of water in linked service reservoir

whereas the uniformity coefficient under sprinkler irrigation was 89% with wetted radius of 12 m for each sprinkler head.

Yield and Water Productivity

Impact of the service reservoir along with the dug well was studied for the monsoon (*kharif*) and post monsoon season (*rabi* and summer) during 2015-16 and 2016-17. The total command area was 1.1 ha under the system, out of which 0.5 ha was dug well commanded and 0.6 ha was commended by service reservoir. The details of the average data are presented in Table 1. From the results, it is evident that due to creation of irrigation infrastructures, crops like rapeseed in *rabi* season, and groundnut and green gram in summer season could be grown after *kharif* rice during 2015-16 and 2016-17 as against of paddy-fallow cropping system prior to the interventions. Moreover, supplemental irrigation could be provided to *kharif* rice due to developed water resources through PVC pipe conveyance line at the site. The yield of paddy crop (var. *Lalat*) under the study was 3.7 t ha^{-1} with water productivity of 0.35 kg m^{-3}, whereas the paddy yield of same variety in non-intervened areas near to the study site was 2.8 t ha^{-1} with water productivity of 0.26 kg m^{-3}. The increase in yield and water productivity of paddy by 32% and 35%, respectively over that in nearby non-intervened area was due to supplemental irrigation (300 mm) provided from the dug well and service reservoir at the site. Earlier, the yield enhancement up to 30% was observed in paddy with three supplemental irrigations by Panigrahi *et al.* (2015b).

Rapeseed crop (var. *Parvati*) yielded 1.25 t ha^{-1} with water productivity of 0.42 kg m^{-3} during *rabi* season.

Table: 1
Yield and water productivity of crops during study years

Crop season	Crop	System of irrigation	Crop area (ha)	Number of irrigation	Water used/ applied (mm)	Yield (t ha^{-1})	Water productivity (kg m^{-3})
Kharif	Paddy (Lalat)	Flooding	2.1	-	1044*	3.7	0.35
				4	300**		
	Paddy (Lalat)	Without supplemental irrigation	2.0	0	1044	2.8	0.26
Rabi	Rapeseed (Parvati)	Flooding	1.1	1	300	1.25	0.42
Summer	Groundnut (Smruti)	Paired row (Furrow)	0.3	4	330	1.39	0.42
		Check basin	0.3	4	406	1.26	0.31
		Sprinkler	0.5	7	280	1.60	0.57
	Green gram (K-851)	Check basin	0.625	2	180	0.73	0.41
	Green gram (K-851)	Sprinkler	0.625	4	120	0.91	0.75

**Rainfall and supplemental irrigation; **Dug well and Service reservoir*

Further, introduction of sprinkler irrigation could produce 27% higher yield with 31% less water use, resulting in 84% higher water productivity compared with check basin irrigation in groundnut (var. *Smruti*) during 2015-17. Similarly, paired row furrow irrigation system helped in saving 15% irrigation water with producing 15% higher yield resulting in 36% higher water productivity compared with check basin irrigation in groundnut. In green gram, yield enhancement of 25% with 33% less water use was observed under sprinkler irrigation compared to check basin irrigation. The higher yield with less water application in groundnut and green gram under sprinkler irrigation was attributed to better uniformity of distribution and application efficiency of water under sprinkler compared to paired row and check basin irrigation. Higher yield and water productivity with minimizing water application under sprinkler irrigation in comparison to surface irrigation were also observed earlier in groundnut (Shivashankar *et al.*, 2014) and green gram (Luxmini *et al.*, 2015).

Yield of Pisciculture

The MBW of *catla, rohu* and *mrigal* was increased to 830, 580 and 586.5 g from initial MBW values of 17.5, 11.5 and 12 g, respectively), after 210 days of rearing, with total harvested biomass of 1.72 t ha^{-1}. The performance index and apparent feed conversion ratio for different species was 232.2-288.8 and 1.38, respectively. Improved growth performance was due to lower stocking density with no requirement of water exchange that helped in improving the rearing environment of the reservoir (Mohanty *et al.*, 2018). Further, regular feeding (twice a day) and fortnightly manuring with raw cattle dung at the rate of 500 kg ha^{-1} helped in maintaining the natural food (plankton) availability that enhanced the growth performance of cultured species. The growth of *catla* was higher than that of *mrigal* followed by *rohu*. Usually *C. catla* grows faster, followed by *L. rohita* and *C. mrigala*. However, the bottom feeder (*C. mrigala*) registered better growth rates than the column feeder (*L. rohita*), mainly due to the superior feed utilizing capability and high degree of tolerance to fluctuations of dissolved oxygen of *C. mrigala* coupled with availability of rich detrital food web for the species in the reservoir at the study site.

Economics

The economics of crop production and economic water productivity have been computed and presented in Table 2. The gross annual return from rice-rapeseed-groundnut + pisciculture was ₹ 16525 higher than that in rice-rapeseed-green gram + pisciculture. The gross return of ₹ 206400 from pisciculture was generated from selling of 1720 kg fish captured from service reservoir @ ₹ 120 kg^{-1} in the local market of the study site. The net annual return (₹ 126400) from pisciculture was higher than that (₹ 52226 ha^{-1}) from rice-rapseed-groundnut cropping system. The higher net return from pisciculture was due to more gross return with lower investment in it compared with cropping systems. The higher economic benefit indicated the potentiality of pisciculture in plateau region of Odisha, which may be encouraged further with appropriate strategies. The similar strategy was earlier suggested by Mandal *et al.* (2017) for generating higher income from farming in Odisha. The interventions of water resource development and management in rice-rapeseed-groundnut cropping sequence with pisciculture enhanced the average annual net return from ₹ 17,000 ha^{-1} with B:C ratio of 1.49 in mono-cropped *kharif* rice to ₹ 178626 ha^{-1} net return with B:C ratio of 1.94 at the study site. Moreover, the gross water productivity

Table: 2
Economics of crop production and economic water productivity

Crops	Gross returns (₹ ha^{-1})	Gross Expenditure (₹ ha^{-1})	Net Returns (₹ ha^{-1})	B:C ratio	Gross water productivity (₹ m^{-3})	Net water productivity (₹ m^{-3})
Rice	54700	42750	11950	1.28	5.24	1.14
Rapeseed	41288	23500	17788	1.76	13.76	5.93
Groundnut	65713	43225	22488	1.52	23.47	8.03
Green gram	36381	26700	9681	1.36	20.21	5.38
Rice-rapeseed-groundnut + pisciculture	368101	189475	178626	1.94	14.95	6.43
Rice-rapeseed-green gram + pisciculture	338769	172950	165819	1.96	14.13	5.76
Rice (without supplemental irrigation) in non-intervened lands near to the study site	51500	34500	17000	1.49	5.77	1.39

and net water productivity under the intervention improved by 160 and 360%, respectively over that under mono-cropped rice cultivation.

4. CONCLUSIONS

Inlet and outlet flow regulating devices designed and constructed in canal linked service reservoir brought a positive impact in guiding the unregulated flow of canal water. The water stored in the service reservoir due to construction of flow regulating devices facilitated pisciculture in the reservoir which was found a profitable option in farming. Further, the provision of dug well and use of water from well in conjunction with water from service reservoir through pressurized irrigation not only helped in growing crops round the year, but improved the yield of *kharif* rice through supplemental irrigations. Overall, the study demonstrates that the conservation of rainwater and its conjunctive use with ground water through efficient means not only converted the mono-cropped rice areas to areas with productive cropping sequence throughout the year, but facilitated higher income from farming through pisciculture in upland plateau region of Odisha. This option may be replicated in large scale within the area or in the regions with similar agro-climate of the study area for profitable farming.

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