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ICAR-IIWM

ICAR-Indian Institute of Water Management
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Odisha, India

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Preface

Water is one of the important natural resources required for agricultural production systems. But its availability for irrigation is being seriously affected due to increase in population, rapid industrialization, urbanization, increase in cropping intensity and declining groundwater table. Because of heavy demand and less availability, safe and fresh water has now become the costliest input in agriculture. The rising cost of irrigation projects and low rate of returns make the situation even more difficult. It is therefore of the utmost importance that water resources are conserved and prudently used for integrated agricultural development and to achieve 'more food, more income with less water'. Though there has been a significant achievement in water resources development, a wide gap still exists between irrigation potential created and irrigation potential utilized. Most of the canal projects suffer from inadequate supply and poor reliability of water delivery, especially at the tail-end during lean season. Hence, it has become a great challenge to bridge the gap as well as enhancing irrigation efficiency from current level to at least 60% by proper maintenance and modernization of existing infrastructures, participatory irrigation management and efficient cropping.

This research bulletin has emanated from R & D works by a multidisciplinary team of scientists and research associates from Indian Institute of Water Management (formerly Directorate of Water Management), ICAR, Bhubaneswar on infrastructure development, on-farm water management and improving water productivity under Kuanria Medium Irrigation Project command at Daspalla block of Nayagarh district, Odisha, sponsored by the INCSW (formerly INCID), Ministry of Water Resources, Govt. of India. It has been demonstrated that integrated farming systems can be developed by proper utilization and conservation of runoff and rainwater, excess canal water in storage tanks during rainy season, fish culture and by recycling the same in conjunction with groundwater from open wells for irrigation, especially during post-rainy season. Following an introductory discussion on the importance of water management, this bulletin contains sections viz. methodology, research findings, discussion, summary and conclusion. There has been the detailed characterization of Kuanria canal command site, rainfall pattern, rainfall-runoff relationship, account on seepage losses, soil physical and chemical characteristics in head-, mid- and tail-ends, soil hydrological properties, conveyance systems, design and measured discharge rate of minors and sub-minors, water allocation, delivery and demand-supply gap, participatory development of integrated farming systems, fish production, conjunctive use of water and innovative cropping systems, groundwater fluctuation, pond and well water quality, economic assessment of systems, impact on water availability, soil fertility and farmers' participation, and functioning of water users' association (WUA) etc.

This bulletin is intended for use by researchers, stake holders/development agencies, water resources departments, water users' associations/ farmers, field assistants under agricultural extension and to all those who will be interested for management of water in the canal command. Authors are grateful to Deputy Director General and Assistant Director General of Natural Resources Management Division of the ICAR, New Delhi, Research Advisory Committee and Director of the Institute for their valuable support, suggestions and encouragement in carrying out this on-farm water management research. We sincerely thank research students, all colleagues and staffs of Indian Institute of Water Management for their help, cooperation and encouragement.

Authors

Content

		Page No.
	Preface	
1.	**Introduction**	01
2.	**Methodology**	04
2.1	The study site	04
2.2	Climatic condition of the study area	06
2.3	Topography and geohydrology	06
2.4	Rainfall pattern during the project period (2010-2015)	07
2.5	Rainfall-runoff relationship	08
2.6	Soil and land use pattern	09
2.7	Methods of analysis of soils	09
2.8	Salient features of the Kuanria irrigation project (KIP)	10
2.9	Assessing fish growth and performance	11
2.10	Estimation of water productivity	11
2.11	Study on socio-economic status of farmers	11
2.12	Water users' association (WUA)	12
2.13	Social issues: impact on farmers' participation	12
2.14	Intervention sites to carry out research and development	13
3.	**Research Findings**	14
3.1	Soil properties at head-, mid- and tail-ends of the canal command	14
3.1.1	Head-reaches of the command	14
3.1.2	Mid-reaches of the command	14
3.1.3	Tail-ends of the command	14
3.2	Soil hydrological properties	16
3.3	Study on the rainfall-runoff relationship	16
3.4	Study on seepage losses during 2011-2015	18
3.5	Monthly reservoir level, distribution, canal water availability, water supply, delivery schedule and discharge rate	19
3.5.1	Monthly mean reservoir water level in Kuanria dam	19
3.5.2	Conveyance system	20
3.5.3	Water allocation, availability, requirement and release	20
3.5.4	Opening schedule of the canal system	25
3.6	Studies on discharge rate of minors and sub-minors	25
3.7	Studies on authorized and unauthorized outlets	26
3.8	Development of rain/ runoff water storage tanks and open wells under the canal irrigation command	26
3.9	Studies on cropping pattern	33
3.10	Economic assessment of benefit due to pond-based integrated farming system	33
3.11	Studies on pond water quality, fish production, fish performance index and fish water productivity	39
3.12	Study on groundwater fluctuation and groundwater quality in the canal command	41

3.12.1 Groundwater fluctuation and dynamics 41
3.12.2 Studies on groundwater quality in the command area 41
3.13 Conjunctive use of water and evolving of improved cropping pattern 43
3.14 Impact assessment on availability of water, crop and fish production, groundwater dynamics and other issues 45
3.14.1 Availability of water 45
3.14.2 Impact on crop, fish production and water productivity 46
3.14.2.1 Integrated farming at head-reach under Odasar sub-minor command 46
3.14.2.2 Integrated farming at mid-reach under Mangalpur sub-minor command 47
3.14.2.3 Integrated farming at mid-reach under Khamarsahi sub-minor 48
3.14.2.4 Integrated farming at tail-end under Khairapankalsahi sub-minor 48
3.14.2.5 Integrated farming at tail-end under Madhyakhanda sub-minor 49
3.14.2.6 Integrated farming at tail-end under Madhyakhanda sub-minor (2) 50
3.14.2.7 Integrated farming at tail-end under Lunisara sub-minor command 51
3.14.2.8 Integrated farming at tail-end under Soroda sub-minor-II command 51
3.15 Soil fertility and water quality in the command area 52
3.15.1 Soil chemical properties and soil fertility 52
3.15.2 Impact on availability of soil micronutrients 53
3.15.3 Studies on pond water quality in the command area 54
3.16 Farmers' participation Discussion Summary and conclusions 54
4. **Discussion** 55
5. **Summary and conclusions** 57
Acknowledgement 61
References 62

1. Introduction

Water resources development and its management play a major role to meet the increasing food demand and sustain agricultural systems. India accounts for only about 2.4% of the world's geographical area and 4% of world's renewable water resources, but the country has to support about 18% of the world's human population and 15% of livestock (DES, 2013). The net sown area has remained about 140 M ha since 40 years (DES, 2015). Per capita availability of water per year is steadily declining from 5177 m^3 in 1951 to 1820 m^3 in 2001, 1588 m^3 per year in 2010 (CWC, 2010, 2013) due to increase in population, rapid industrialization, urbanization, cropping intensity and declining groundwater table; and it is expected to decline further to 1341 and 1140 m^3 by the years 2025 and 2050, respectively (MoWR, 2011); the problems are likely to aggravate in future if suitable measures are not adopted.

Average rainfall in the country is 1183 mm, 75% of it occurs in about 100-120 days; 68% of the sown area is subjected to drought with varying degrees (DAC, 2014). Increased climate variability has made rainfall patterns more inconsistent and unpredictable (Kumar et al., 2005). There is an increase in the recurrence of drought or draught like situations. Though there has been a significant achievement in water resources development, a wide gap still exists between irrigation potential created (123.3 M ha) and irrigation potential utilized (91.5 M ha) (CWC, 2013); hence, it has become the great challenge to bridge the gap by evolving innovative as well as adopting existing technologies. There is need for focused research directed towards enhancing irrigation efficiency from current level of about 30-40% to at least 60% (Planning Commission, 2009, 2013) by proper maintenance and modernization of existing infrastructures, participatory irrigation management, and efficient irrigation & crop management practices. Similarly, the efficiency of groundwater facilities can be increased from the present level of about 65% to 75%. In fact, the country has the challenges of meeting its water needs along with sustaining pace of development.

India ranks first among the countries that practice rainfed agriculture both in terms of extent (86 M ha) and value of production (Sharma et al., 2010). More than 70% of net sown area of eastern Indian ecosystem is rainfed where the yield of rice which is the predominant rainy season crop, is very low as compared to irrigated ecosystem. The most important factor for low rice yield in the whole country is due to the lack of assured water supply (Panigrahi and Panda, 2002). Current irrigation withdrawals already cause stress in many of the world's major river basins (Molle et al., 2007). Agricultural systems in canal command area needs infrastructure development, rejuvenation of existing structures, management of rainwater as well as canal water. Kothari et al. (2007) opined that on the basis of water harvesting, water can be utilized for saving crops during severe moisture stress and also to raise the post-monsoon crops thereby enhancing cropping intensity and net returns from the cultivated lands. Increasing water use efficiency by 20% over the existing is a very important goal for the National Water Mission in India.

The gross irrigated area in the country increased from 23 M ha in 1950-51 to 88 M ha in 2008-09 and the gross water demand by irrigation sector alone contributes 71% of the gross water demand by all users by 2025 (DES, 2015). It was also reported that net irrigated area in India is 63 M ha which accounts for 44.5% of total net sown area. Major irrigation source in India is through tube wells and other wells (60%) followed by canal irrigation (26%). Tank irrigation is confined to few pockets accounting for less than 5% (DES, 2015). Further, depletion of groundwater and limitation of surface water imply that not all of the net sown area is amenable to irrigation. Depletion of groundwater aquifer and reduced stream flows (Khan et al., 2008) affect drinking water supplies, health and rural livelihoods (Meijer et al. 2006). Implications on social equity for the poor and groundwater dependent communities for drinking and irrigation are quite large (EPW, 2007). Regional variability exits in groundwater development. Punjab, Haryana, Rajasthan, parts of Gujarat, Tamil Nadu and Karnataka are over-exploited; Maharastra, Uttar Pradesh, Madhya Pradesh have groundwater development (GWD) more than 50%; eastern Indian states viz. Assam, Bihar, Chhattisgarh, Odisha and West Bengal have GWD less (22-43%) than that of country average (61%) (CGWB, 2011). Hence, a critical analysis would be required what are the challenges ahead in agricultural water management and there is a strong need to focus on improved/ advanced water resource development and its management supported with the appropriate policies.

Most of the canal projects suffer from inadequate supply and poor reliability of water, especially at the tail end during lean season. Baseline survey conducted in selected projects in Mahanadi canal command area revealed that 30 to 60% of the total canal command farmers do not get adequate and timely water supplies. Similar type of situation exists in many irrigation schemes in eastern India. This situation can be changed by proper utilization and conservation of runoff and rainwater in storage tank during rainy season and by recycling the same for life saving irrigation during post rainy season (Srivastava, 2001). To ensure water availability and dependability to all the farmers, it is necessary that some storage tanks (to harvest runoff and subsurface water) and shallow wells (to utilize ground water) are introduced in command area as per needs (Mandal et al., 2015). By switching over to supplementing canalwater through rainwater storage and conservation tanks and shallow wells systems would go a long way in improving the overall project efficiency, equity, adequacy, dependability and thereby reducing the risk factor in agriculture and increase in the agricultural production.

The eastern region of India has one of the most favourable ecosystems for agriculture, yet the agricultural production from this area is much lower than its potential. In fact, agricultural growth in eastern states is low. Odisha, an eastern Indian state, is mainly an agrarian state where about 70% of the population is engaged in agricultural activities and 50% of the state's economy comes from agricultural sector (Panigrahi et al., 2010). Even though several factors are responsible for poor growth of agricultural productivity, lack of irrigation water availability and its reliability are the major constraints in realizing the production potential. Water availability during post-monsoon season from the major state irrigation projects is either low (from runoff type or diversion canal system), or the cost of water is quite high (for pump canal system). In Odisha, rice-fallow is the most common practice in major command areas. Farmers keep their fields fallow after kharif season because water availability is very unreliable and undependable. It is, therefore, essential to develop and create a dependable and reliable water supply system in the canal command through conjunctive use of rain water, canal water and ground water.

Tank irrigation is an age-old practice. Most of them have independent source of water supply. Many of these tanks located in the commands could be made adjunct to the existing canal system, and deciding water harvesting structures for providing round the year full irrigation (Srivastava et al., 2009). The economic analysis shows that the increased crop yields, resulting from improved temporal distribution of water supply to match the crop water requirement at critical growth stages, more than compensate the cost of providing the auxiliary reservoir storage. It is essential that every farm entity to have a service reservoir so that the farmer can use his allocation at his convenience, both in time and size of stream/canal. Attempts have been made to study and examine the technical, economic and other feasibility of a canal irrigation system supplemented by water availability through rainwater harvesting in water storage tanks and dug wells for irrigation to crops during dry spells and post-monsoon seasons; and development of integrated farming systems including components viz. crop, fish culture, on-dyke horticulture etc. in the canal command, i.e., Kuanria medium irrigation project in Odisha, India.

2. Methodology

2.1 The study site

The study has been carried out under the Kuanria Medium Irrigation Project (KIP) at Daspalla, Nayagarh district of Odisha (Fig. 2.1). The ayacut map of the command is presented in Fig. 2.2. The project area is located at $20^{0}21'$ N latitude and $84^{0}51'$ E longitude at an elevation of 122 m above mean sea level. The district is in the higher altitude than the sea level and above the flood level. The site is about 135 km from Bhubaneswar, the state capital via Khurda_and Nayagarh. National highway 224 passes through Daspalla. During pre-independence era it was a small garhjat (princely state) named as Daspalla state with headquarters at Kunjabanagarh.

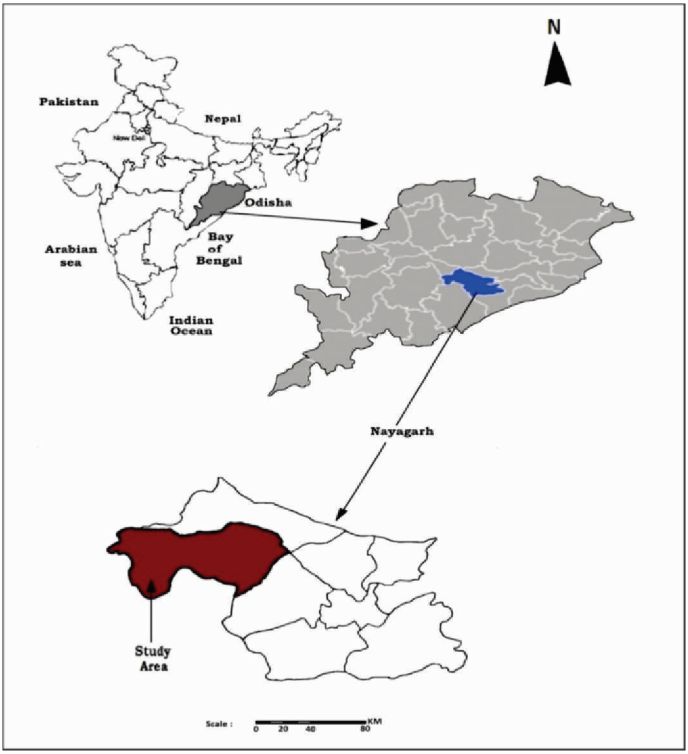


Fig. 2.1 The study area i.e., Daspalla region of Nayagarh district in Odisha

The district of Nayagarh lies between $19^{0}54$ to $20^{0}32$ N latitude and $84^{0}29$ to $85^{0}27$ E longitudes. The irrigation command serves two blocks viz. Daspalla and Nuagaon. The geographical area of Daspalla and Nuagaon blocks is 571.57 and 385.24 km^2, respectively. This study site comes under Agro-Eco Sub-Region 12.2 (AESR 12.2) and Agro-Climatic Zone 7 (ACZ 7) according to the classification by NBSS&LUP (ICAR) and Planning Commission, Govt. of India, respectively (Gajbhiye and Mandal, 2008).

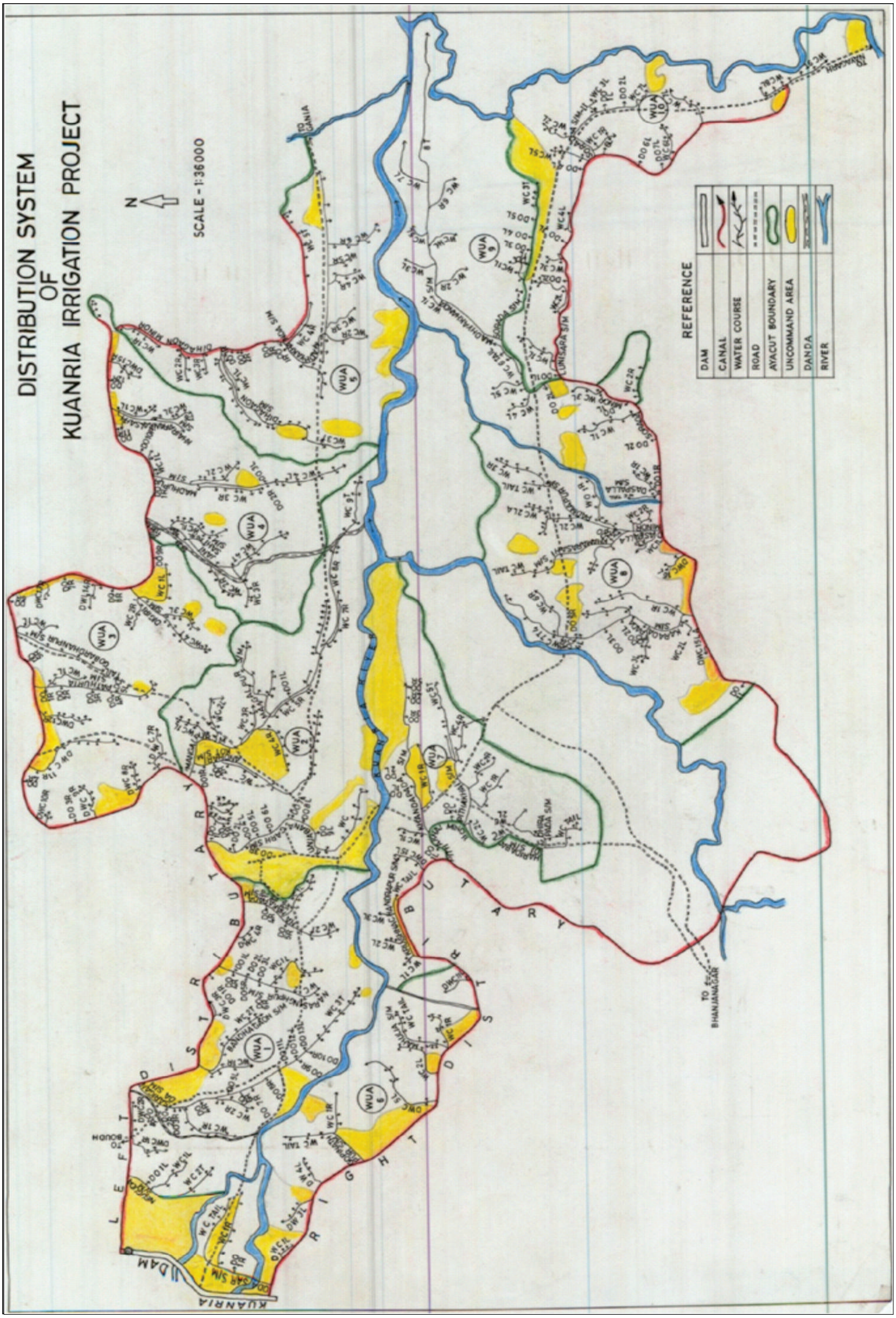


Fig. 2.2 Ayacut map of Kuanria Irrigation Project (KIP) at Daspalla, Nayagarh district of Odisha

2.2 Climatic condition of the study area

Climate is characterized by high temperature during summer months and low during winter. The climate of the command area is sub-tropical in nature with hot summer, mild winter and having medium to high humidity. The command area experiences mainly three seasons i.e., rainy, winter and summer. Rainfall patterns have been discussed in details and reported earlier (Mandal et al., 2013, 2015), rainfall pattern during 2010-2015 has been described in a separate subhead hereunder. South-west monsoon starts from mid-June and continues till September with heavy to very heavy rainfall during July and August. The mean maximum temperature in the project area was 34.5 ^{0}C and mean minimum temperature was 19.5 ^{0}C. The highest temperature occurs in the month of May. Winter is experienced from November to January. The mean wind speed is generally moderate with increase in rainy season due to south-west monsoon (Table 2.1). In summer season, wind flow occurs in different directions and the maximum speed occurs in the month of April and May with whirlwind. Average sunshine hour fairly increases from November to May and gradually reduces thereafter being the lowest in July and August. Average relative humidity varies from 64.8 to 85%.

Table 2.1 Month-wise average weather condition of the study area, Daspalla, Nayagarh district of Odisha

Months	Average temperature (^{0}C)	Average relative humidity(%)	Average sunshine hours(h)	Wind velocity (km h^{-1})
January	20.5	65.4	8.4	3.8
February	23.4	66.0	8.6	5.1
March	25.4	67.4	8.6	8.2
April	24.7	67.6	8.6	13.4
May	34.6	72.0	7.9	14.1
June	32.6	77.8	5.3	9.8
July	30.9	83.0	4.0	7.6
August	29.7	85.0	4.1	7.1
September	27.5	84.0	5.2	5.6
October	24.0	79.0	6.8	3.5
November	22.6	68.6	7.3	4.5
December	19.5	64.8	8.0	3.8

2.3 Topography and geohydrology

The topography of the ayacut is undulating with steep slope towards the main drainage side. Numerous streams originating from the hill slopes flow towards the main river. The cultivated land lies parallel to foot hills and drainage valley in the ayacut area except some granite rocks here and there. Daspalla is a place of hills and mountains, forests, streams, rivers, falls, gorge, wild growth and wild animals predominantly. Odisha has four well defined broad physiographic zones, viz. north-eastern plateau, central table land, eastern ghat region, and coastal plain zone. Kuanria irrigation project covers two blocks namely Daspalla and Nuagaon block which come under south-eastern coastal plain. Geohydrology indicates that the southern portion of the state is covered with rocks of eastern ghat mobile belt. It comprises mainly granitic gneiss, charnokite, khondalite etc (Table 2.2). These rocks cover the vast stretch of the area i.e., on the Daspalla and Nuagaon area under the Nayagarh district. The lithologic assemblage is characterized by the cyclic sedimentation of sand and gravel with subordinate clay. The river Mahanadi flows in the eastern boundary of this area. The river Kuanria is a tributary of Mahanadi. There is proper drainage system consisting of many *nalas* which fall in main drain and river.

Table 2.2 Characteristic geology of the area in Daspalla block

Observation well no. & well type	Village name in Daspalla block	Latitude	Longitude	Geology
73D-3C1, dug well	Banigocha	20^{0}2343N	84^{0}3522E	Granite gneiss
73D-3C2A, dug well	Takara	20^{0}2350N	84^{0}3654E	Granite gneiss
73D-3D1, dug well	Daspalla-I	20^{0}2014N	84^{0}5125E	Alluvium
73D-3D3, dug well	Daspalla-II	20^{0}1948N	84^{0}5117E	Alluvium
73D-3D4, dug well	Subalaya	20^{0}1902 N	84^{0}5425 E	Granite gneiss

2.4 Rainfall pattern during the project period (2010-2015)

The rainfall pattern in the project site i.e., under Kuanria canal command area was studied for every year of the project duration (2010-2015). The total annual rainfall ranged from 1304 to 1895 (Table 2.3). The variation in rainfall was less during pre-monsoon period (Mar-May) for every year (Fig. 2.3). Rainfall is quite low during the period, November to May. Maximum rainfall occurred during monsoon months i.e., June-September i.e., 75, 81.4, 74.5 and 53.5, 75% in the year 2010, 2011, 2012, 2013 and 2014, respectively; the least or no rainfall occurred during the months of December to March every year. In the year 2013, rainfall during post-monsoon (Oct-Dec) was greater due to very high rainfall (a total of 679 mm) during October (1^{st}, 13^{th}, 22-27 Oct). In the year 2015, the monsoon rainfall (1071 mm in June to September) was slightly less than normal. Winter season (Jan-Feb) contributed negligible to only 5.4% of the total annual rainfall received in the command area. In the year 2014-15, total annual rainfall was 1453 mm in 2014 and 1341 mm upto September 2015; most of the rainfall occurred during the SMW 27 through 41 i.e., within three and half months; afterwards, there was no or very less rainfall during 42 through 52 SMW in the year 2014 (Fig. 2.4).

Table 2.3 Distribution of rainfall in different seasons during the year 2010-2015

Year/ Seasons	2010	2011	2012	2013	2014	2015
Pre-monsoon (Mar-May)	185.3	173	154	180	191	248.8
Monsoon (Jun-Sep)	1115	1062	1412	994	1089	1070.9
Post-monsoon (Oct-Dec)	163	42	226	679	173	*
Winter (Jan-Feb)	26	27	103	4	0	21
Total	1489	1304	1895	1857	1453	1341

*rainfall upto September for 2015

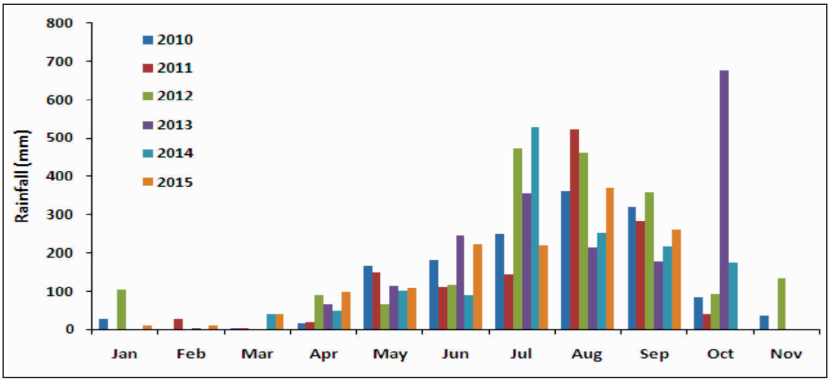


Fig. 2.3 Monthly rainfall during years (2010- Sep 2015) in the project site

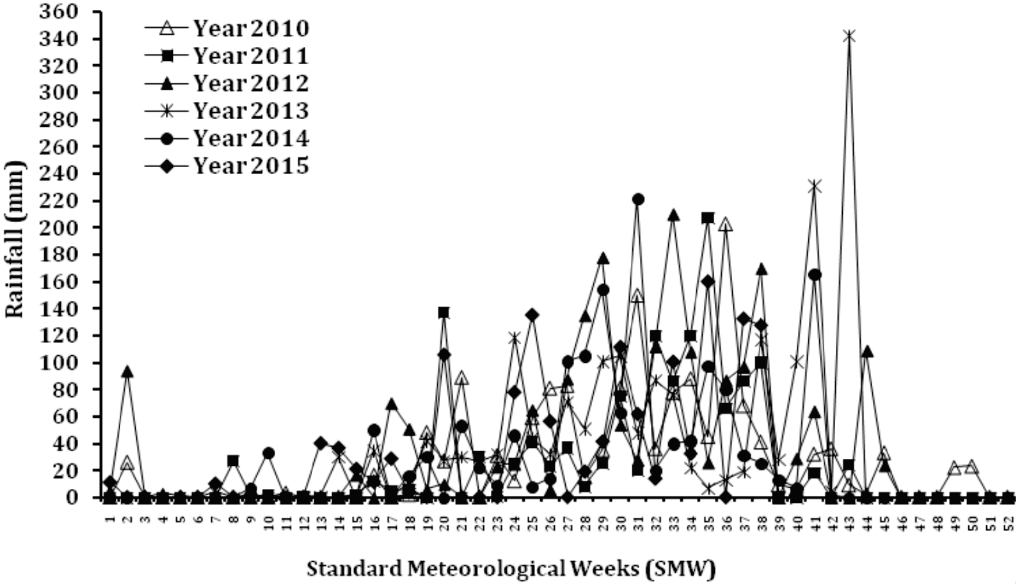


Fig. 2.4 Rainfall distribution and trends in 52 standard meteorological weeks (SMW) in the project site the years (2010-2015)

2.5 Rainfall- runoff relationship

Runoff is a major component in hydrologic cycle. It has been estimated for the study site. Runoff estimation was made by using 20 years (1995-2014) meteorological rainfall data. The area receives an average annual rainfall of 1532 mm. The soil property of the study area was found to be in hydrological soil group C; having low infiltration rate when thoroughly wetted and a low rate of water transmission and the soils are with a layer that impedes the downward movement of water and of moderately fine to fine texture. Effective rainfall was estimated by using FAO CROPWAT model for the period of 1995 to 2014. Runoff was estimated by using SCS curve number method. It is the ratio of actual retention to potential maximum retention equal to the ration of actual runoff to potential maximum runoff, as the following.

$$\frac{F}{S} = \frac{Q}{P - I_a}$$

where, F = actual retention, mm
S = potential maximum retention, mm
Q = accumulated runoff depth, mm
P = accumulated rainfall depth, mm
I_a = initial abstraction, mm

By simplifying

$$Q = \frac{(P-0.2S)^2}{P+0.8S} \text{ for } P > 0.2S$$

Potential maximum retention S has been converted to Curve Number as follows:

$$\text{CN} = \frac{25400}{254+S}$$

The curve number (CN) values were decided based on this field condition (Table 2.4).

Table 2.4 CN values for command area soil condition relating to different crop growing seasons

Crop growing season	Land use	Hydrological condition	Hydrologicals oil group	CN value
Kharif (June- September)	Paddy	Poor	C	84
Rabi (October-February)	Legumes	Poor	C	85
Summer (March-May)	Fallow	Poor	C	91

2.6 Soil and land use pattern

Soil characteristics have been reported in details in a separate section. The important soil groups of the district are laterite, alluvial, red and mixed red and black soils. The soils are mostly acidic in reaction ranging from 74 to 88% across the blocks while neutral soils range from 11 to 24 %. Alkaline soils are limited to 1 to 2%. The available nitrogen in the soils is low while availability of phosphorus and potassium is in medium range. It has black grey, clayey soils also. On the whole the soil of the command is fertile and suitable for agriculture. Different types of crops are grown in the command. It has about 39, 49 and 9% of area by acidic, neutral and alkaline soils, respectively. The land use pattern of Daspalla block of Nayagarh district in Odisha shows that net area sown was about 17000 ha, almost similar area was occupied by forests (Table 2.5). The area under current fallow is quite high, and the maximum in Daspalla block among all eight blocks of Nayagarh district.

Table 2.5 Land use pattern of Daspalla block of Nayagarh district in Odisha

Sl. No.	Land use pattern	Area (ha)
1.	Forests	17076
2.	Misc. tree crops & groves not included in net area sown	444
3.	Barren & uncultivable land	4274
4.	Land put to non-agricultural use	5254
5.	Culturable waste lands	970
6.	Permanent pastures and other grazing land	1656
7.	Current fallows	4575
8.	Other fallows	5081
9.	Net sown area	16888

Source: District Statistical Handbook, Nayagarh, Department of Economics and Statistics, Odisha, 2006-07.

2.7 Methods of analysis of soils

Soil samples were collected up to 120 cm depth from different head-, mid- and tail-reaches of the command through right and left distributaries. Important physical, chemical and soil hydrological characteristics were determined. Soil particle size distribution was determined by the hydrometer method (Bouyoucous, 1951) and soil texture class was determined by following the procedure of USDA classification. Soil pH was measured with the help of a digital pH meter (pHTestr30, Malaysia) (Jackson, 1973). Available N, expressed in kg ha^{-1} was determined by alkaline permanganate method (Subbiah and Asija, 1956), available P, expressed in kg ha^{-1} by Olsen's extractant (Olsen et al., 1954), available K i.e. exchangeable K expressed in kg ha^{-1} by flame photometer method (Jackson, 1973), available S, expressed in kg ha^{-1} by extraction with 0.15% $CaCl_2$ extractant (Massoumi and Cornfield, 1963), and available B, Zn, Fe, Mn, Cu expressedvolume of water per unit volume of soil, was estimated as the difference between field capacity (FC) and permanent wilting point (PWP). Saturated hydraulic conductivity (Ks) was measured by constant head method. Five replicates of bulk density (BD, expressed as Mg m^{-3}) samples down to the profile was also collected using soil cores (Black, 1965) and core samplers (Eijkelkemp Agrisearch Equipment). The hydraulic properties of soils and the functional θ-Ψ relationships of different soil properties were also developed. Organic carbon was determined by wet digestion method (Walkley and Black, 1934 in Jackson, 1973) (Page et al., 1982). SOC storage was calculated by using soil organic carbon content (SOC), bulk density (BD), thickness of soil layer and the area.

Soil enzymes dehydrogenase, phosphatase and urease were assayed using the procedure of Tabatabai (1982). Twenty g of air-dried soil (<2 mm) was mixed thoroughly and 2 g of $CaCO_3$ and placed 6 g of this mixture in each test tubes. The procedures was adopted as per the above-mentioned method as applicable to triphenyl formazan (TPF) method. The amount of triphenyl formazan (TPF) produced was calculated by a reference calibration graph prepared from TPF standards. Soil phosphatase activity was measured by disodium phenyl phosphate method (Tabatabai and Bremner, 1972). The absorbance of color in the solution was measured at 660 nm. Urease activity was assayed using tris (hydoxymethyl) aminomethane (THAM) buffer and NH_4^+-N was determined through distillation method as outlined by Tabatabai (1982).

2.8 Salient features of the Kuanria irrigation project (KIP)

Kuanria Irrigation Project (KIP) is located near village Odasar in the western side of Daspalla Tahasil in Nayagarh district of Odisha. The earth dam is 1576 m long with maximum height of 21 m at deepest section (Table 2.6). The top bank level of the dam (TBL) with 5.0 m top width is 138.0 m, maximum water level (MWL) or flood reservoir level (FRL) of the reservoir is 135.7 m and the dead storage level is 130.3 m. The project has two number of head regulators such as right and left distributaries. Right and left distributaries (abbreviated as RD and LD) runs for a length of about 18.2 and 16.5 km having design discharges of 2.00 and 1.98 $m^3 s^{-1}$, respectively. The length of all minors and sub minors are 49.86 km. The gross storage capacity of the reservoir is 2200 ha m with a live storage of 1750 ha m. The gross command area (GCA) is 4800 ha and cultivable command area (CCA) is 3780 ha. The CCA of RD is 1868.13 ha and that of LD is 1911.87 ha. There are total of 32 sub-minors and 5 minors distributed over the entire command area. Among these, 16 sub-minors each are distributed in left and right distributaries, 3 minors in RD and 2 in LD. Discharge rate for all minors and sub-minors of RD and LD were measured. The water released data through RD and LD of Kuanria dam was also collected. in ppm by DTPA extraction method (Lindsay and Norvell, 1978).

Field capacity and permanent wilting point were determined by a pressure plate apparatus (Eijkelkamp, Model 505). The available water capacity (AWC, $cm^3 cm^{-3}$) of soils, expressed as

Table 2.6 Salient features of the Kuanria irrigation project (KIP)

SL No.	Salient features/ parameters	Values
1	Name of the river/ basin	Kuanria/ Mahanadi
2	Longitude & latitude	84 28′ E & 20 20′ N
3	Catchment area at the dam site	124 km^2
4	Length of dam	1576 m
5	Maximum height of dam from deepest level	21 m
6	Flood reservoir level (FRL)	135.7 m
7	Maximum water level (MWL)	135.7 m
8	Dead storage level (DSL)	130.3 m
9	Length of right and left distributary (RD & LD)	18.2 & 16.5 km
10	Total length of minors & sub minors	49.864 km
11	Gross command area (GCA)	4800 ha
12	Cultivable command area (CCA)	3780 ha; kh 3780 ha, rabi 1908 ha
13	Command area under RD	1920.71 ha
14	Command area under LD	1859.29 ha

2.9 Assessing fish growth and performance

Weekly growth study was carried out by sampling prior to feeding, so that complete evacuation of gut was ensured. Weekly mean body weight (MBW in g), mean total length (cm) was estimated. Other growth parameters such as performance index (PI), and production-size index (PSI) were estimated as follows:

PI = Per day increment (g) x survival rate (%)
PSI = Production (kg ha^{-1}) x MBW (g) / 1000

Apparent feed conversion ratio (AFCR) and feeding efficiency (FE) was estimated as follows:

AFCR = Total feed used (kg) / net biomass gain (kg)
FE(%) = Biomass gain (kg) / feed used (kg) × 100

2.10 Estimation of water productivity

Water productivity was estimated for fish and crop production to assess the efficiency of water management. The gross water productivity (GWP) and net water productivity (NWP) was calculated (Rs. m^{-3}) keeping the total volume of water used into account as: GWP = total economic value of produce (Rs.) / total volume of water used (m^3); NWP = {total economic value of produce (Rs.) - production cost (Rs.)} / total volume of water used (m^3). Total volume of water use (precipitation + management additions or regulated inflows) and consumptive water use (evaporation + seepage + intentional discharge or regulated discharge + water in harvest biomass) was estimated for fish culture in water storage tanks. Average water in harvest biomass was about 0.75 m^3 per tonne of fish biomass, was taken into account. Further, to separate the evaporation from the total loss, evaporation was estimated using the following equation:

Pond evaporation (mm) = Pond-pan coefficient x Class-A pan evaporation (mm)

Pond pan coefficient of 0.8, most appropriate for ponds, was used in the above equation. The pond seepage was quantified by subtracting the evaporation loss from the total loss.

Economic water productivity of crops was estimated as: total economic value of produce (Rs.) / total volume of water used (m^3) to irrigate different crops under the pond-command.

2.11 Study on socio-economic status of farmers

The Kuanria irrigation project irrigates 3780 ha of land benefitting about 37000 people living in 67 villages under the command area. The total number of villages under two blocks comes to 560, out of which 90 numbers are un-inhabited villages. There are 216 numbers of villages under Nuagaon block and 344 villages under Daspalla block. The area is occupied by tribals of '*Kandha*' and '*Khaira*' tribe. Daspalla block has 19 grampanchayats. According to information, it is revealed that 90% of the farmers belong to marginal and small farmers while remaining 10% belongs to medium and large farmers. On the other hand, marginal and small farmers are in possession of 62% land as operational holdings while the medium and large farmers have 38% land. The working group of the people may be divided into cultivators, agricultural labourers and other type of workers. Area held by marginal farmers (upto 1 ha) is 1836 ha; area held by small farmers (1-2 ha) is 1409 ha; percentage of marginal holdings to total number of holdings is 51%, percentage of small holdings to total number of holdings is 39.24%; percentage of ST to the total population in the command area is 16.76%, percentage of SC to the total population in the command area is 19.28%.

2.12 Water users' association (WUA)

A total of 10 numbers Pani Panchayats (water users' associations) have been operational under the command area. The jurisdiction area of the Pani Panchayats varies from 274.95 ha to 501.70 ha (Table 2.7). The elected bodies under the Pani Panchayat are involved in operation and management. Distribuatries having less than 150 cusec capacity, all minors and sub-minors will be maintained through participatory irrigation management (PIM) by the apex body of the Pani Panchayats. There are 10 water users' association (WUA) distributed over the entire area of the Kuanria Medium Irrigation Project (KIP). WUA 1 and 6 are situated towards head end, WUA 2, 3, 7 and 8 are in the mid end and similarly WUA 4, 5, 9 and 10 are situated at tail end under KIP. The composition of WUAs is well represented by both male and female farmers with dominance of former which is due to the association of membership right with the land ownership and in the patriarchal society male members of the family are mostly owners of the land.

Table 2.7 Pani Panchayats under Kuanria Irrigation Project, Daspalla, Nayagarh

Sl. No.	Name of the Pani Panchayat (PP)	Area (ha)	Location	Date of election / handed over
WUA1	Nilakantheswar PP	351.96	LD, Head	28.05.07 / 07.11.07
WUA2	Jaya Mahabir PP	436.74	LD, Head	29.05.07 / 07.11.07
WUA3	Baradayeeni PP	274.95	LD, Middle	30.05.07 / 07.11.07
WUA4	Jaleswar PP	366.82	LD, Middle	31.05.07 / 07.11.07
WUA5	Maa Bankamunda PP	428.82	LD, Tail	01.06.07 / 07.11.07
WUA6	Maa Odasriani PP	287.01	RD, Head	07.09.07 / 07.11.07
WUA7	Bira Bajaranga PP	313.25	RD, Head	07.09.07 / 07.11.07
WUA8	Bhuinani PP	501.70	RD, Middle	15.10.07 / 07.11.07
WUA9	Baladevjew PP	491.67	RD, Tail	10.06.08 / 20.06.08
WUA10	Kapileswar Dev PP	327.08	RD, Tail	30.03.10 / 04.04.10

*LD and RD stand for left and right distributary, respectively

2.13 Social issues: impact on farmers' participation

Farmers' participation was assessed through analyses of WUA's composition including its executive committee members, matrix of members by location of their land at head/ middle/ tail reach and productivity, review of WUA formation process (awareness of WUA, individual farmer's role: active/ passive, who elect members of WUA, what is the process of election), functionality and powers of WUA and farmers-members' involvement in activities of WUA. Farmers-members' participation in different activities undertaken by WUA was studied with the help of farmers' participation index (FPI):

FPI = (mean participation score / maximum participation score) x 100

where, mean participation score = P_i / N and P_i = PP_j

PP_j = Total score of farmers' participation

i = 1,2, ………, N and j = 1,2, ………, K

N and K = total number of respondents and total number of activities, respectively.

2.14 Intervention sites to carry out research and development

Intervention sites in different head, mid- and tail ends are presented in Table 2.8.

Table 2.8 Intervention sites in different head, mid- and tail ends under different water users' association (WUA) jurisdictions

Sl No.	Name of the village	WUA No.	Distributary	Canal reach
1	Odasar	6	RD	Head reach
2	Kunjabanagarh	2	LD	Middle reach
3	Paikabaghuarani	8	RD	Middle reach
4	Malisahi	4	LD	Tail- end
5	Dwargaon	5	LD	Tail- end
6	Dendabhuin	9	RD	Tail- end
7	Soroda	10	RD	Tail- end
8	Subalaya	10	RD	Tail- end

3. Research Findings

3.1 Soil properties at head-, mid- and tail-ends of the canal command

3.1.1 Head-reaches of the command

Soil properties in the head-reaches in the command, under Odasar s/m of right distributary under jurisdiction of WUA 6, revealed that texture in the 0-30 cm soil layer was sandy clay loam while in other layers it was sandy clay (Table 3.1). There was little variation of bulk density among different soil layers; EC values were quite less for all soil layers. Soil was slightly acidic to alkaline. Soil organic carbon (SOC) content gradually decreased from top to bottom soil layers. Saturated hydraulic conductivity (Ks) was highest for 0-15 cm soil layer and lowest for 90-120 cm depth of soil.

Table 3.1 Soil properties of head- reach in the right distributaries under Odasar s/m

Soil depth cm	Sand%	Silt%	Clay%	Textural class	Bulk density Mg m^{-3}	EC dS/m	pH	K_s	SOC
0-15	66.6	5.7	27.7	scl	1.50	0.02	6.93	0.140	0.43
15-30	61.6	8.2	30.2	scl	1.48	0.01	7.64	0.128	0.24
30-45	56.6	8.2	35.2	sc	1.50	0.03	7.88	0.121	0.23
45-60	56.6	8.2	35.2	sc	1.48	0.02	7.91	0.103	0.21
60-90	61.6	3.2	35.2	sc	1.48	0.01	7.44	0.104	0.19
90-120	61.6	3.2	35.2	sc	1.50	0.06	7.71	0.100	0.14

3.1.2 Mid-reaches of the command

It was observed that, texture in the 0-15 cm soil layer was sandy clay loam; 15-45 cm soil layer clay loam while in other layers it was clay. Bulk density of the soil varied between 1.48 to 1.53 Mg m^{-3} whereas EC varied from 0.23 to 0.62 dS m^{-1} in all the soil layers. In general, soil was slightly alkaline in nature and soil organic carbon content varied between 0.27 and 0.67%. Saturated hydraulic conductivity varied from 0.011 to 0.026 cm h^{-1} for all the soil layers (Table 3.2).

Table 3.2 Soil properties of mid-reach soils in the left distributaries under the Mangalpur s/m

Soil depth cm	Sand%	Silt%	Clay%	Textural class	Bulk density Mg m^{-3}	EC dS/m	pH	K_s	SOC
0-15	48.4	16.8	34.8	scl	1.48	0.28	7.63	0.026	0.67
15-30	43.4	16.8	39.8	cl	1.48	0.23	7.96	0.018	0.49
30-45	43.4	16.8	39.8	cl	1.50	0.28	8.22	0.019	0.27
45-60	38.4	16.8	44.8	c	1.52	0.23	8.30	0.012	0.39
60-90	38.4	16.8	44.8	c	1.52	0.55	8.45	0.013	0.29
90-120	38.4	16.8	44.8	c	1.53	0.62	8.60	0.011	0.36

3.1.3 Tail-ends of the command

The soils of tail-end command, was clay loam for the site under Madhyakhanda s/m with the jurisdiction of WUA 5 (Table 3.3).

Table 3.3 Soil properties of tail-end in left distributaries under Madhyakhanda s/m

Soil depth cm	Sand%	Silt%	Clay%	Textural class	Bulk density Mg m^{-3}	EC dS/m	pH	K_s	SOC
0-15	44.2	22.3	33.5	cl	1.41	0.11	8.15	0.023	0.58
15-30	44.9	22.8	32.3	cl	1.42	0.05	8.55	0.021	0.46
30-45	44.8	18.7	36.5	cl	1.44	0.05	8.50	0.022	0.39
45-60	43.5	9.7	46.8	c	1.45	0.01	8.54	0.017	0.39
60-90	41.8	8.9	49.3	c	1.46	0.01	8.53	0.015	0.33
90-120	44.3	8.7	47.0	c	1.47	0.02	8.45	0.014	0.29

Table 3.4 Soil properties of mid-reach command area in right distributaries under Khamarsahi s/m

Soil depth cm	Sand%	Silt%	Clay%	Textural class	Bulk density Mg m^{-3}	EC dS/m	pH	K_s	SOC
0-15	66.6	5.7	27.7	scl	1.46	0.03	7.65	0.176	0.29
15-30	59.1	3.2	37.7	sc	1.48	0.02	8.49	0.157	0.10
30-45	61.6	3.2	35.2	sc	1.48	0.01	8.49	0.147	0.10
45-60	61.6	3.2	35.2	sc	1.50	0.02	8.51	0.110	0.02
60-90	61.6	3.2	35.2	sc	1.50	0.03	8.48	0.085	0.07
90-120	59.1	0.7	40.2	sc	1.52	0.02	8.50	0.080	0.10

There was a definite trend that sand content was greater in every soil layer than silt and clay contents (Table 3.4), but there was slight difference in different layers of the soil profile. It reveals that, soil was moderately alkaline in nature. The soil organic carbon content decreased as soil depth increased. Bulk density of soil varied between 1.41 to 1.47 Mg m^{-3} and EC varied between 0.01-0.11 dS m^{-1}. Saturated hydraulic conductivity was highest in 0-15 cm soil layer and decreases towards lower depth of soil.

The soils in the tail reach of right distributaries under Sorada s/m-II were predominantly clay up to 45 cm soil depth and sandy clay in the 45-120 cm soil depths due to higher proportion of sand and clay contents (Table 3.5). Soil pH was moderately alkaline. Bulk density of the soil increased gradually towards the lower depth of soil profile as amount of clay content was less in 45-120 soil depth in comparison to 0-45 cm soil depth. EC varied from 0.02-0.07 dS m^{-1} where as organic carbon content varied between 0.23-0.39%. Saturated hydraulic conductivity was highest within 0-15 cm soil depth and lowest in 90-120 cm soil depth.

Table 3.5 Soil properties of tail-end command area in left distributaries under Sorada s/m-II

Soil depth cm	Sand%	Silt%	Clay%	Textural class	Bulk density Mg m^{-3}	EC dS/m	pH	K_s	SOC
0-15	35.9	15.7	48.4	cl	1.51	0.07	0.07	0.072	0.39
15-30	38.4	13.2	48.4	cl	1.52	0.03	0.03	0.060	0.33
30-45	43.4	13.2	43.4	cl	1.55	0.03	0.03	0.058	0.42
45-60	48.4	10.7	40.9	sc	1.56	0.02	0.02	0.055	0.23
60-90	48.4	10.7	40.9	sc	1.58	0.02	0.02	0.045	0.30
90-120	53.4	10.7	35.9	sc	1.58	0.02	0.02	0.042	0.27

3.2 Soil hydrological properties

The hydraulic properties of soils and the functional θ-Ψ relationship of different soil properties were also developed for soils of tail and mid reaches, respectively (Table 3.6 and 3.7). Based on these relationships, water retention potential of soils are easily determined; the relationships showed that tail end soils are more retentive than mid-reach as has been reflected from the slope of log (θ-Ψ) relationships. This gives an insight into ways for efficient management of water.

Table 3.6 Hydraulic characteristics of sandy clay loam soils of mid-reach command area in right distributaries under Khandapada s/m

Soil depth cm	Ks (m/s)	θs (m^3/m^3)	θ (m^3/m^3) at 0.033 MPa	θ (m^3/m^3) at 1.5 MPa	AWC (m^3/m^3)	Functional relation between θ and Ψ (Ψ in m, θ in m^3/m^3)
0-15	39.7×10^{8}	0.371	0.197	0.060	0.137	Log Ψ = -3.223 Log θ – 1.688, R^2 = 0.979
15-30	35.3×10^{8}	0.447	0.265	0.106	0.159	Log Ψ = -3.917 Log θ – 1.683, R^2 = 0.992
30-45	32.5×10^{8}	0.487	0.310	0.126	0.184	Log Ψ = -4.305 Log θ – 1.620, R^2 = 0.991
45-60	28.1×10^{8}	0.503	0.332	0.143	0.189	Log Ψ = -4.655 Log θ – 1.638, R^2 = 0.984
60-90	27.8×10^{8}	0.504	0.334	0.144	0.190	Log Ψ = -4.841 Log θ – 1.727, R^2 = 0.977
90-120	27.8×10^{-8}	0.493	0.325	0.145	0.180	Log Ψ = -4.924 Log θ – 1.754, R^2 = 0.957

Table 3.7 Hydraulic characteristics of sandy clay to clayey soils of tail-end command area in left distributaries under Madhyakhanda s/m

Soil depth cm	Ks (m/s)	θs (m^3/m^3)	θ (m^3/m^3) at 0.033 MPa	θ (m^3/m^3) at 1.5 MPa	AWC (m^3/m^3)	Functional relation between θ and Ψ (Ψ in m, θ in m^3/m^3)
0-15	6.39×10^{8}	0.578	0.429	0.218	0.211	Log Ψ = -5.694 Log θ – 1.573, R^2 = 0.997
15-30	5.83×10^{8}	0.553	0.416	0.206	0.210	Log Ψ = -5.579 Log θ – 1.617, R^2 = 0.995
30-45	6.11×10^{8}	0.563	0.422	0.211	0.211	Log Ψ = -5.569 Log θ – 1.581, R^2 = 0.996
45-60	4.72×10^{8}	0.566	0.428	0.223	0.205	Log Ψ = -5.884 Log θ – 1.673, R^2 = 0.997
60-90	4.17×10^{8}	0.507	0.386	0.197	0.189	Log Ψ = -5.577 Log θ – 1.802, R^2 = 0.995
90-120	3.89×10^{-8}	0.532	0.396	0.203	0.193	Log Ψ = -5.835 Log θ – 1.864, R^2 = 0.995

3.3 Study on the rainfall-runoff relationship

Rainfall data (1995 to 2014) showed that on an average 75.8% of the annual rainfall is received during monsoon season. Pre- and post-monsoon rainfall contributed only 10.6 and 10.4% of the total annual rainfall in the study area; rest 3.2% rainfall occurred during winter season (Table 3.8). It also observed that pre-monsoon rainfall contributed maximum rainfall (89%) as effective rainfall followed by monsoon and winter rainfall. Monthly average rainfall and runoff in the command area is presented in Table 3.9

Table 3.8 Rainfall, effective rainfall distribution in Daspalla, Nayagarh district of Odisha

Soil depth	Average rainfall (mm)	Percentage of total rainfall	Average effective rainfall (mm)	Effective rainfall (% of rainfall)
Pre-monsoon (March-May)	163.3	10.6	42.9	89.2
Monsoon (June-September)	1134.5	75.8	124.2	82.6
Post-monsoon (October-December)	162.6	10.4	572.1	51.5
Winter (January-February)	48.6	3.2	114.0	82.0

Table 3.9 Monthly average rainfall and runoff in the command area (1995-2014)

Soil depth	Rainfall (mm)	Runoff (mm)	Runoff as % of rainfall
January	19.8	2.9	14.5
February	24.2	2.7	11.1
March	23.4	6.5	28.0
April	38.3	10.3	26.8
May	101.0	42.0	41.5
June	203.3	44.9	22.1
July	334.3	94.9	28.4
August	335.6	72.8	21.7
September	255.3	59.3	23.2
October	151.8	42.7	28.1
November	37.7	6.6	17.5
December	7.5	0.8	10.9
Total	1532.2	386.3	25.2

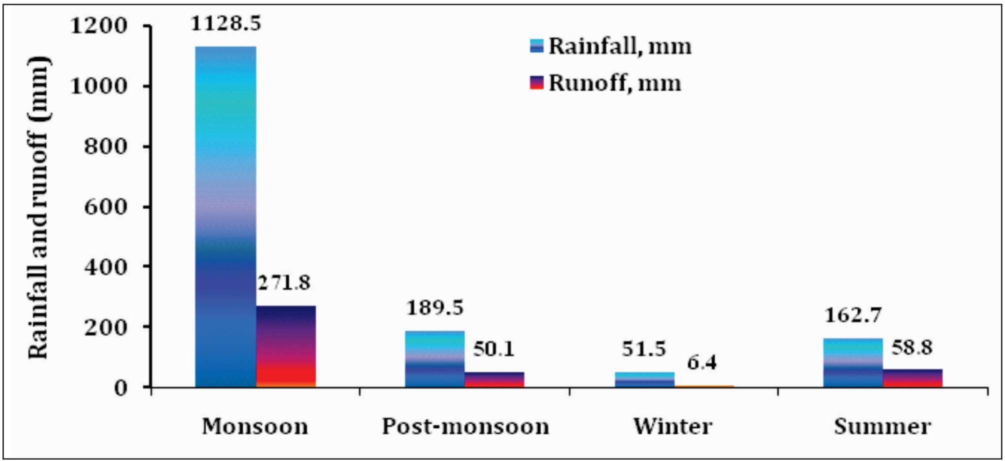


Fig. 3.1 Average rainfall and runoff during monsoon (Jun-Sep), post-monsoon (Oct-Dec), winter (Jan-Feb) and pre-monsoon or summer (Mar-May) seasons in years 1995-2014 in Kuanria canal command area in Daspalla, Nayagarh district, Odisha

On an average, the area receives 1532 mm of rainfall annually; out of this 386 mm (25%) is lost due to runoff (Table 3.10). Runoff during post-monsoon and summer season was nearly 12% and 14% of rainfall received during that season respectively (Fig. 3.1).

Table 3.10 Annual rainfall and runoff analysis for the year 1995-2014

Soil depth	Rainfall (mm)	Runoff (mm)
1995	1901.8	586.8
1996	993.5	132.4
1997	1583.3	384.5
1998	1583.0	249.1
1999	1481.8	397.9
2000	1238.0	220.4
2001	1740.7	457.5
2002	1540.0	488.0
2003	1750.8	409.7
2004	1370.1	330.3
2005	1510.5	344.6
2006	1269.2	296.3
2007	1475.1	286.4
2008	1741.5	480.0
2009	1444.3	470.0
2010	1512.3	311.4
2011	1304.0	347.4
2012	1895.0	595.3
2013	1857.0	537.3
2014	1453.0	399.8
Average	1532.2	386.3

The annual rainfall varies between 994 and 1902 mm with an average of 1532 mm. The highest annual rainfall of 1902 mm occurred in the year 1995 with its highest runoff of 408 mm. The lowest rainfall of 994 mm occurred during the year 1996 with lowest runoff of 56 mm. It showed the positive correlation between the rainfall and runoff. Similarly highest monthly average rainfall was recorded during the month of August, July and September with 335.6, 334.3 and 255.3 mm, respectively. The highest runoff was also recorded for the respective months with 72.8, 94.9 and 59.3 mm, respectively. In the month of July, there were heavy intensity rainfall, thus the runoff was higher than other months.

3.4 Study on seepage losses during 2011-2015

Monthly seepage losses from the reservoir and canal show that it was the maximum during the months of January to May during the year 2011-13 (Fig. 3.2). In 2011, seepage was also higher during Oct-Nov, which was amounted to 86 ha m. Total seepage losses were 352, 246.25 and 262 ha m in 2011, 2012 and 2013, respectively.

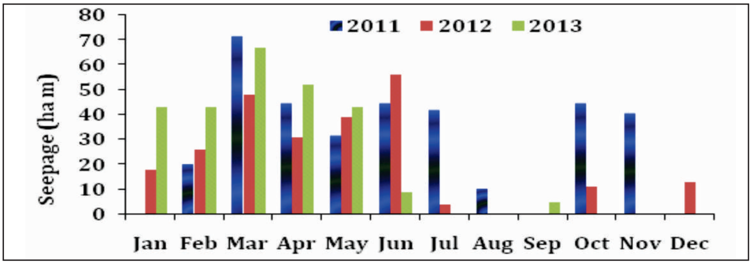


Fig. 3.2 Month-wise seepage losses from the dam and canal distributaries in the year 2011-2013

Similarly, during the year 2014-15, it was the maximum during the months of January to May (Fig. 3.3); total seepage losses were 362 ha m in 2014 and 73 ha m in Jan-Feb in 2015; seepage during January to May was 319 ha m in 2015; and it was 89 ha m during Dec 2014 to Feb 2015.

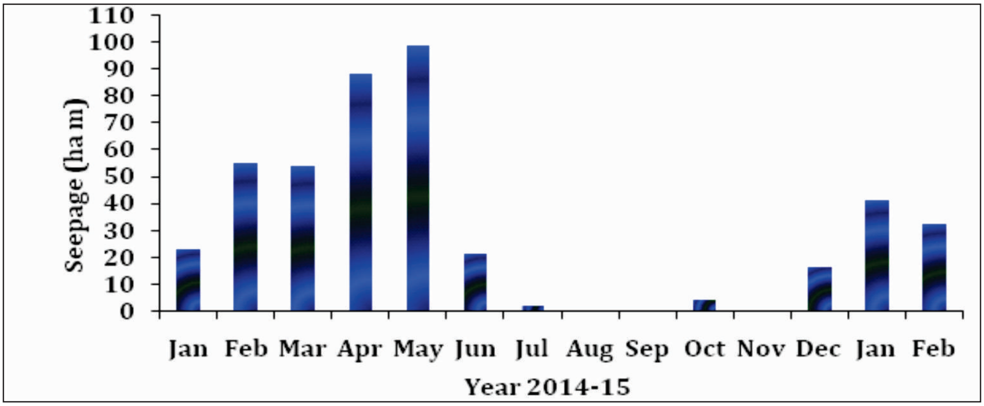


Fig. 3.3 Month-wise seepage losses from the dam and canal distributaries in the year 2014-15

3.5 Monthly reservoir level, distribution, canal water availability, water supply, delivery schedule and discharge rate

3.5.1 Monthly mean reservoir water level in Kuanria dam

A picture of Kuanria dam and the left distributary

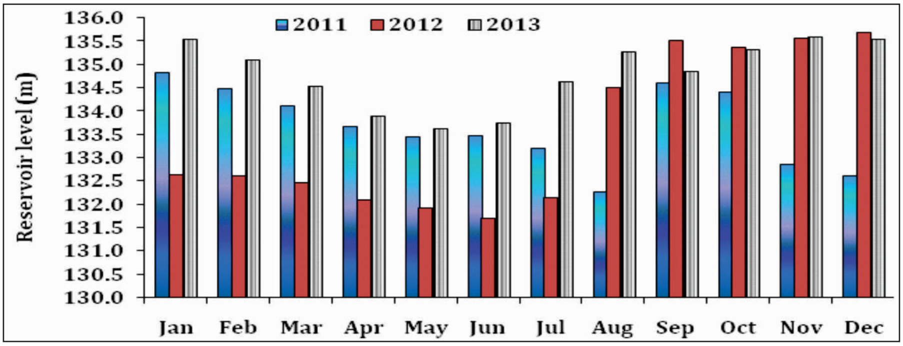


Fig. 3.4 Monthly mean reservoir water level during the year 2011, 2012 and 2013

There was variation in reservoir water level over years (Fig. 3.4 & 3.5). In the year 2012, the level was lower than the other years. During the year 2013, monthly reservoir level was 135.56 m in January; it dropped to 133.63 m in the month of May and then with the rainfall received it was raised gradually to 135.60 m in November 2013. During the year 2014-15, monthly reservoir level was 135.54 m in January 2014; it drops to 133.98 m in the month of June 2014 and then with the rainfall received it raised gradually to 135.47 m in September 2014 (Fig. 3.5). Reservoir level in January and February 2015 was much lower than those of January-February 2014 because of more canal water supply during 2015.

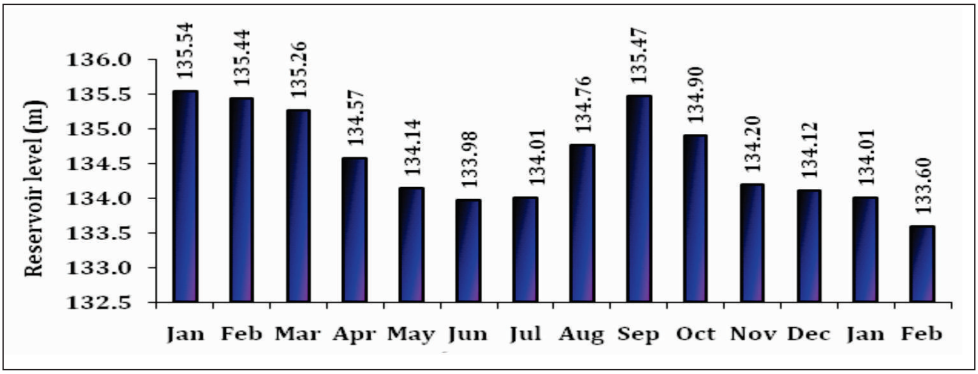


Fig. 3.5 Monthly average reservoir water level during the year 2014-15

3.5.2 Conveyance system

The project has two number of head regulators, one is located on the left of spillway and another at the right side of the earth dam. The main canal off-taking from head regulators run for a length of 16.5 km and 18.20 km. The full supply discharge of left and right distributary was 1.98 cumec and 2.00 cumec, respectively. The total length of minors and sub-minors were 51.105 km. The flow diagram is shown (Fig. 3.6). Supply of irrigation water to tail-end of the left distributary was not possible; farmers generally are deprived of getting irrigation water.

3.5.3 Water allocation, availability, requirement and release

Canal-wise distribution/ allocation of water at the head (Table 3.11 & 3.12) and the month-wise water supply (Table 3.13) show that the maximum availability was in the months of July, August, September and October, and the minimum in April and May. The water released data through left and right distributary of Kuanria Dam was collected for last 15 years. The water availability, water released and water required (ha m) during different months in the command area are presented in Table 3.14. It is observed that the gross average and net volume of water available in a year is 11823 and 7093 ha m respectively. The largest volume of canal water was available in September, which is 11.87% of the total volume of water available in the year. The second largest volume is available in October. The lowest and the second lowest volume are observed in May and June respectively. Water available in five months from July to November is 49.6% of the total available water. The released amount of water was much less during lean period in comparison to the same during monsoon, and there is gap between released and the required, hence a large gap exists between demand and supply as indicated in Table 3.14. Month-wise discharge (cumec) and canal water supply for the year 2013 indicate that there was no supply in the month of June (Fig. 3.7 and 3.8). Supply was started and increased from July with total discharge and supply 19.99 cumec and 167.00 ha m in the month of July; it increased to total of 69.28 cumec and 598 ha m in the month of September.

Thereafter it decreased from October and there was no supply in the month of December. There was also a considerable supply during the period of January through May in 2013, however the amount was less than July to November of the same year. During the period of July to October major amount of water was released which was sufficient to irrigate total culturable command area. Amount of released water was 424 ha m in the month of July. The released amount of water was much less during lean period in comparison to the same during monsoon. In the year 2014-15 there was very less supply in June (Fig. 3.9); supply was started and increased from July with total supply of 135.21 ha m in the month of July; it increased to a total of 416 ha m in the month of August, it decreased to 200 ha m in September, and it increased to 680 ha m in October and there was no supply in the month of December. There was a demand-supply gap.

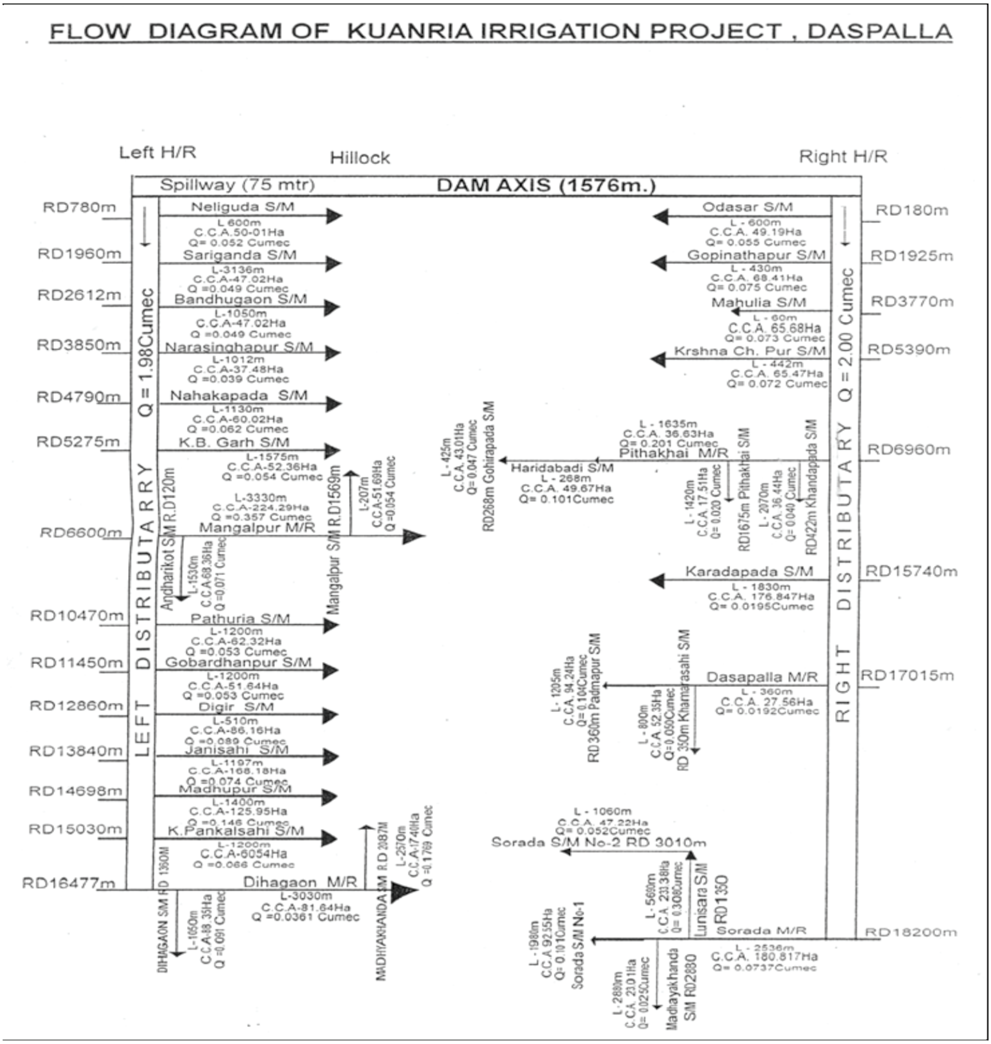


Fig. 3.6 Flow diagram of Kuanria irrigation project; discharge capacity of various minors and sub-minors is also presented in the flow diagram

Table 3.11 Canal-wise details of allocation of water in the left distributaries (LD) under Kuanria irrigation command

Sl. No.	Name of the minor/ subminor and outlet in the left distributaries (LD)	Discharge in cumec
1	Neliguda subminor	0.052
2	Direct water course 1R	0.015
3	Direct water course 2R	0.007
4	Sariganda s/m	0.140
5	Bandhugaon s/m	0.049
6	Direct water course 3R	0.010
7	Direct outlet 1R	0.019
8	Narasinghpur s/m	0.039
9	Direct water course 4R	0.008
10	Nahakpada s/m	0.062
11	Kunjabangarh s/m	0.054
12	Direct outlet 2R	0.007
13	Direct water course 5	0.015
14	RDirect water course 6R	0.011
15	Mangalpur minor	0.357
16	Andharikot s/m	0.071
17	Mangalpur s/m	0.054
18	Direct water course 7R	0.023
19	Direct water course 8R	0.020
20	Direct water course 9R	0.020
21	Direct outlet 3R and direct water course 10R	0.031
22	Direct outlet and Direct water course 12R	0.019
23	Pathuria s/m	0.015
24	Direct outlet 5R	0.050
25	Gobardhanpur s/m	0.017
26	Direct outlet 6R	0.053
27	Direct water course 14	0.020
28	RDirect s/mJanisahi s/m	0.015
29	Madhupur s/m	0.030
30	Direct outlet HR	0.174
31	Khairapankalsahi s/m	0.146
32	Direct outlet 12R	0.015
33	Direct water course 15R	0.066
34	Dihagaon minor	0.007
35	Dihagaon s/m	0.010
36	Direct outlet 1R, 2R and 3R of Dihagaon minor	0.361
37	Madhyakhanda s/m	0.091
38	Direct water course 16 tail	0.015
39		0.177
40		0.015

Table 3.12 Canal-wise details of allocation of water in the right distributaries (RD) under Kuanria irrigation command

Sl. No.	Name of the minor/ sub-minor and outlet in the right distributary (RD)	Discharge in cumec
1	Odosar s/m	0.055
2	Direct water course 1L	0.002
3	Direct water course 3L	0.006
4	Direct water course 4L	0.012
5	Gopinathpur s/m	0.075
6	Direct water course 5L	0.020
7	Mahulia s/m	0.073
8	Direct water course 11L	0.154
9	Krushnachandrapur s/m	0.072
10	Direct water course 15L	0.003
11	Pithakhai minor	0.201
12	Karadabari s/m	0.040
13	Pithakhai s/m	0.020
14	Haridabadi s/m	0.101
15	Gohirapada s/m	0.047
16	Direct outlet 1L	0.005
17	Water course 12 of Karadapada s/m	0.222
18	Karadapada s/m	0.195
19	Direct outlet 16L	0.012
20	Daspalla minor	0.192
21	Khamarasahi s/m	0.050
22	Padmapur s/m	0.104
23	Daspalla s/m	0.050
24	Direct outlet 2L	0.003
25	Sorada minor	0.737
26	Lunisara s/m	0.308
27	Sorada s/m-II	0.052
28	Sorada minor, Direct outlet 1L	0.017
29	Sorada minor, Direct outlet 2L	0.016
30	Sorada s/m-I	0.101
31	Madhyakhanda s/m	0.025

Table 3.13 Month-wise average water supply from left and right distributaries of Kuanria dam for 15 years

Month	Water supply through left distributaries (ha.m)	Water supply through right distributaries (ha.m)	Total supply (ha.m)
January	56.3	49.6	105.9
February	53.3	48.9	102.2
March	79.5	69.5	148.9
April	84.9	71.3	156.2
May	27.1	33.1	60.2
June	0.01	0.5	0.5
July	50.1	131.6	281.7
August	277.6	218.1	495.7
September	62.0	259.6	521.6
October	354.3	314.2	668.5
Novembe	62.0	55.0	117.1
December	6.8	5.8	12.6

Table 3.14 Total water availability, water release and water requirement (ha-m) during different months in the command area of Kuanria Irrigation Project

Month	Gross volume of water available	Net volume of water available	Present volume of water released	Present volume of water required	Gap between water released and water required
January	1137	682	96	73.04	+22.96
February	1025	615	96	56.27	+39.73
March	856	513	150	42.32	+107.68
April	650	390	163	37.15	+125.85
May	533	320	53	20.69	+32.31
June	568	341	1	2.75	-1.75
July	788	473	266	705.91	-439.91
August	1100	660	442	382.59	+59.41
September	1404	842	499	382.60	+116.4
October	1371	823	638	570.66	+67.34
November	1202	721	105	424.39	-319.39
December	1189	713	16	47.82	-31.82
Total	11823	7093	2525	2746.19	-221.19

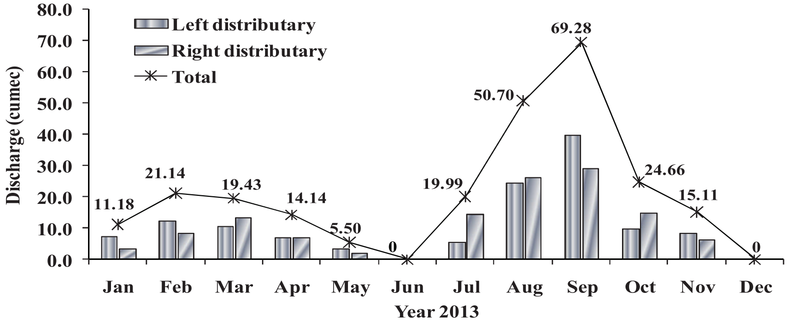


Fig. 3.7 Monthly discharge (cumec) pattern of water from the reservoir through left and right distributary (LD & RD) and the total discharge (cumec) during the year 2013

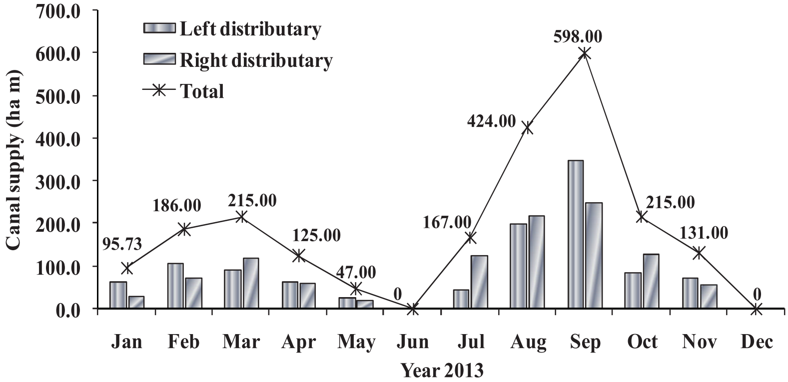


Fig. 3.8 Variation in monthly canal water supply (ha m) through left and right distributary (LD & RD) and the total supply (ha m) during the year 2013

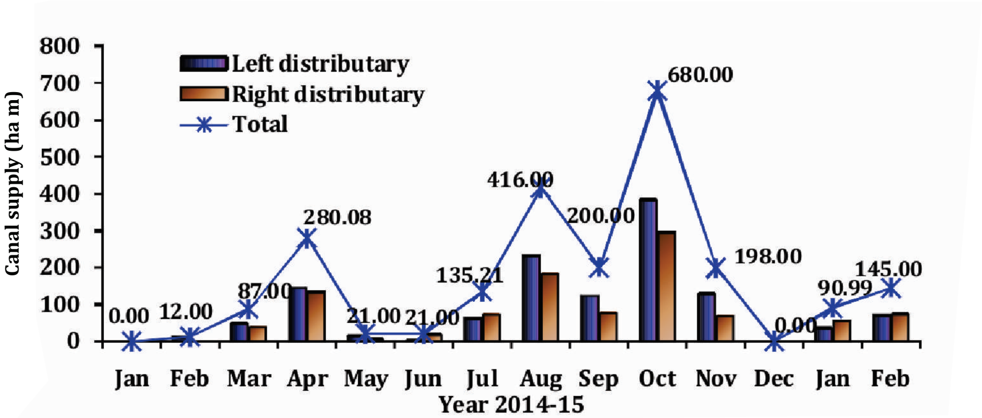


Fig. 3.9 Monthly canal water supply (ha m) through left and right distributaries and the total supply (ha m) during the year 2014-15

3.5.4 Opening schedule of the canal system

The canal has been opened and closed at the head regulator end of two distributaries, i.e. left and right distributaries as indicated in Table 3.15. For kharif crops, the canal system normally opens for 105 days. The canals are allowed to flow with full capacity for a period of about 45 days. During occurrence of flood in the river, the canal system is closed. Besides, opening and closing of the canal system depend upon frequency and intensity of monsoon rainfall in the command. No rotational supply of water was made in the canal network.

Table 3.15 Opening schedule of the canal system under Kuanria Irrigation Command

Sl. No.	Month/ period of opening canal	Number of days
1	1st to 31st July	31
2	11th to 20th August	10
3	1st to 9th and 16th to 23rd September	17
4	1st to 16th October	16
5	1st to 7th November	7
6	15th to 24th December	10
7	1st to 5th and 16th to 20th January	10
8	1st to 5th and 16th to 20th February	10
9	1st to 3rd and 15th to 17th March	6
10	1st to 3rd and 15th to 17th April	6
11	1st to 3rd May	3
12	1st to 3rd June	3
Total		129

3.6 Studies on discharge rate of minors and sub-minors

Comparison of design and measured discharge of minors and sub minors for right and left distributaries was made and are presented in Fig. 3.10 and 3.11. It is observed that, in all the minors and sub minors of right and left distributaries, the carrying capacities (i.e. measured discharge) have been reduced in comparison to the original design discharge. It is found that the cross section of the minors and sub-minors are changed due to soil erosion and high amount of soil is also deposited on the bed. For this reason, velocity of flow and ultimately the carrying capacity is reduced.

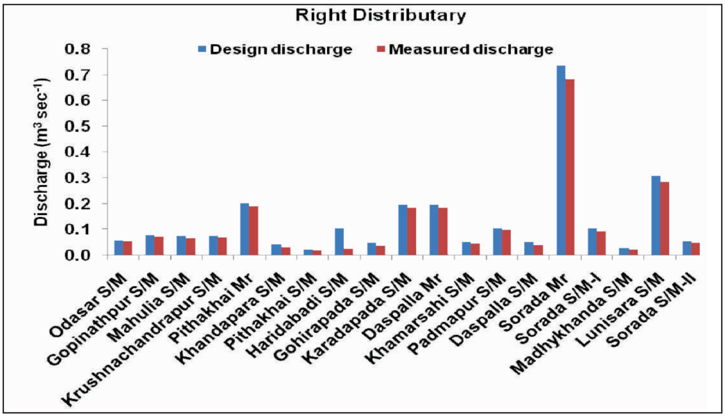


Fig. 3.10 Comparison of design and measured discharge rates of minors and sub-minors in right distributaries

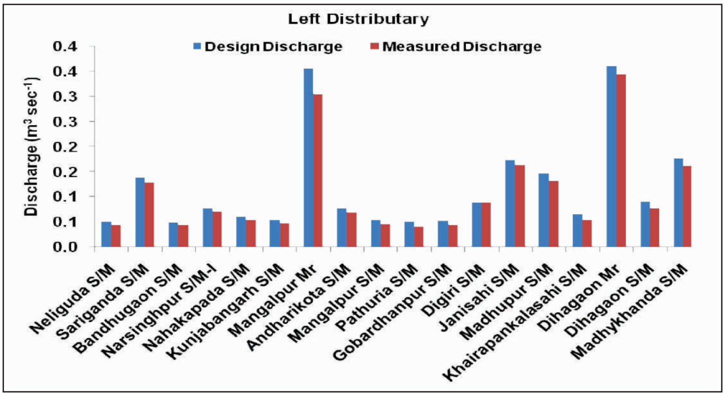


Fig. 3.11 Comparison of design and measured discharge rates of minors and sub-minors in left distributaries

3.7 Studies on authorized and unauthorized outlets

There were about 192 and 112 numbers of authorized and unauthorized outlets in left and right distributaries, minors and sub-minors of Kuanria irrigation project. More number of unauthorized outlets was found in left distributaries in comparison to right distributaries. Due to presence of large number of unauthorized outlets, tail-end farmers do not get adequate and timely supply of water.

3.8 Development of rain/ runoff water storage tanks and open wells under the canal irrigation command

In the region, most of the farmers keep their fields fallow after harvesting of rainy season rice because of lack of irrigation to entire land during post-monsoon season. Rainfall is quite low during winter and pre-monsoon season. Therefore, it is essential that every farm entity to have a service reservoir for effective and efficient use of water, so that the farmer can use his allocation at his convenience. Thus, in order to conserve the rainfall, seepage and excess canal water ponds were constructed within the command area under beneficiary farmers (photo plates). Detailed list of beneficiary farmers have been presented in Table 3.16.

Rain/ runoff water storage tank developed in the tail end (Soroda sub-minor -II)

Rain/ runoff water storage structures developed in the tail-end
(Madhyakhand sub-minor)

Rain/ runoff water storage structures developed in the tail-end
(Lunisara sub-minor)

Rain/ runoff water storage structures developed in the mid-end
(Khamarasahi sub-minor)

Rain/ runoff water storage structures developed in the tail-end
(Madhyamkhanda sub-minor)

Rain/ runoff water storage structures developed in the tail-end
(Khairapankalsahi sub-minor)

Rain/ runoff water storage structures developed in the mid-end of KIP
(under Mangalpur sub-minor)

A view of the open well constructed
at the mid-reach of left distributary under
Mangalpur sub-minor

A view of the open well constructed
at the tail-end of right distributary under
Soroda sub-minor (II)

A view of the open well constructed
at the tail-end right distributary under
Lunisara sub-minor

A view of the open well construction
at the tail-end of right distributary under
Madhyakhand sub-minor (2)

Table 3.16 List of beneficiary farmers, name of villages, and the capacity of rain/ runoff water storage tanks developed in different minor/ sub-minors under the Kuanria command area

Sl. No.	Name of the beneficiary farmer	Name of the village	Name of sub-minor canal	Distributary	WUA No.	Latitude at tank site	Longitude at tank site	Tank capacity (m^3)	Pond command (ha)
1	Mrs. Itishree Mishra	Odasar	Odasar S/M	RD	6	20°20′04″N	84°49′10″E	1630	2.43
2	Mrs. Jyotsnamai Nanda	Kunjabanagarh	Mangalpur S/M	LD	2	20°20′18″N	84°52′18″E	1630	2.83
3	Mr. Sudarsan Das	Paikabaghuarani	Khamarasahi S/M	RD	8	20°18′36″N	84°53′08″E	1630	2.43
4	Sh. Banamali Mishra	Malisahi	Khairapankalsahi S/M	LD	4	20°20′18″N	84°52′18″E	1630	2.02
3	Mr. Balakrusna Pradhan	Dwargaon	Madhyakhand S/M	LD	5	20°20′18″N	84°52′18″E	1630	1.82
6	Mr. Banbihari Muduli	Dendabhuin	Madhyakhand S/M	RD	9	20°19′39″N	84°55′11″E	1630	2.43
7	(Late) Mr. Hadia Nayak	Soroda	Lunisara S/M	RD	10	20°19′01″N	84°55′25″E	1630	1.01
8	Mr. Bhagirathi Nayak	Subalaya	Soroda S/M-II	RD	10	20°18′52″N	84°55′59″ E	1630	2.02

Construction of tank facilitates fish culture, storage of water for irrigation and on-dyke horticulture

In an event of fish catching for IMC- rohu, catla and mrigal

On-dyke horticultural crops like papaya, banana and other vegetable crops with a beneficiary farmer

On-dyke horticultural crops like papaya with a beneficiary farmer

On-dyke horticultural crops like banana is very successful due to intervention through construction of pond and crop-fish culture

Rice is the principal crop during kharif season in the Kuanria canal command

Photo plates shows the development of pond-based integrated farming systems in the command

On-dyke vegetable and papaya cultivation by a beneficiary farmer due to construction of water storage tank

Sunflower crop was grown in the command area where irrigation facilities have been developed through water storage tank

Brinjal-maize intercropping with conjunctive use of water from storage tank and open wells done by a beneficiary farmer

Sole maize crop including sweet corn with conjunctive use of water from storage tank and open wells done by a beneficiary farmer

On-dyke vegetable cultivation by a beneficiary farmer

On-dyke brinjal and other vegetable cultivation by a beneficiary farmer

Photo plates shows the development of pond-based integrated farming systems in the command

3.9 Studies on cropping pattern

Cropping pattern was mainly rice based. Rice is grown during kharif season followed by pulses which are grown normally with available soil moisture. Rice is grown over 2000 ha. Out of total CCA of 3780 ha, pulses are grown in 180 ha area, remaining area i.e., 1780 ha remain fallow. Various types of crops grown under Kuanria command are presented in Table 3.17 and Fig. 3.12 & 3.13. It is observed that, kharif rice, brinjal and green gram are the most important crops occupying 90.4, 8.8 and 10.6% of the total command area, respectively. Kharif rice and green gram are the important crops of monsoon and post-monsoon season, respectively. Both these crops occupy maximum area in the respective seasons. Arhar is also grown in the upland areas. Sugarcane is a major cash crop in the region.

Table 3.17 Cropping pattern in the command area of Kuanria Irrigation Project

Sl. No.	Crops	Area (ha)	Command area (%)
1	Kharif rice	3416	90.4
2	Rabi rice	88	2.4
3	Sugarcane	114	3.0
4	Banana	10	0.3
5	Brinjal	332	8.8
6	Bhindi	24	0.6
7	Cowpea	24	0.6
8	Groundnut	32	0.9
9	Maize	10	0.3
10	Sesame	5	0.1
11	Sunflower	30	0.8
12	Green gram	401	10.6
13	Black gram	154	4.1
14	Peas	41	1.1
15	Mustard	13	0.3
16	Potato	20	0.5
17	Onion	105	2.8
18	Tomato	185	4.9
19	Cabbage	59	1.6
20	Cauliflower	52	1.4
21	Cucumber	74	2.0
22	Pumpkin	37	1.0

3.10 Economic assessment of benefit due to pond-based integrated farming system

Due to the intervention by construction of rain/ runoff water storage tanks and open wells, better cropping systems have been followed in the intervention area by the trained and beneficiary farmers. Due to our intervention crop management was better even for rice also. Due to pond-based integrated system, the pooled data are presented in Table 3.18. The benefit i.e., the net income from the whole systems including fish culture varied from Rs 157224 to Rs 199776 per ha. The integrated farming systems gave satisfactory and significantly higher farm income as compared to the systems with only crop components having no water storage tanks. Due to water storage tank, fish culture has become a major option for increasing total farm income. The better and appropriate cropping system was rice + (fish in pond) -greengram, rice + (fish in pond) –blackgram, rice + (fish in pond) –maize, rice + (fish in pond) –sunflower, rice + (fish in pond) –vegetables compared to only rice-fallow, rice-greengram and rice-blackgram; rice + (fish in pond) +vegetables (on dyke) -greengram and rice + (fish in pond) + banana/ papaya (on-dyke)- pigeonpea (on dyke); rice+(fish in pond) –vegetables (on-dyke)-vegetables.

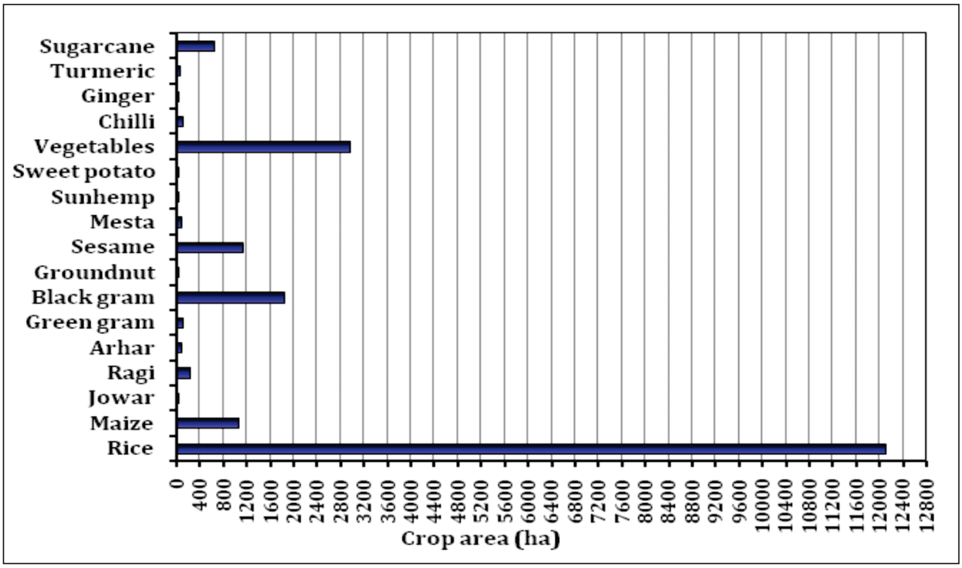


Fig. 3.12 Cropping pattern in the Kuanria canal command in the year 2013-14

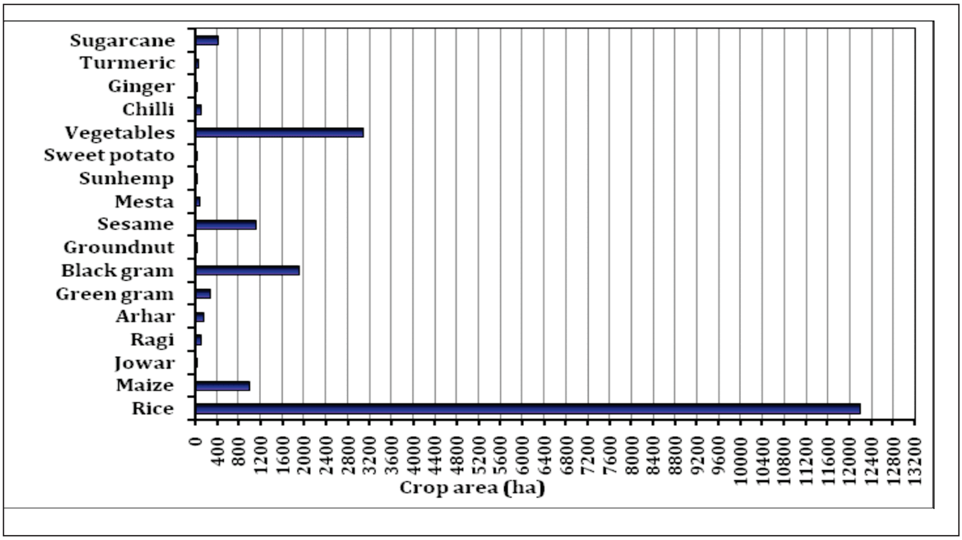


Fig. 3.13 Cropping pattern in the Kuanria canal command in the year 2014-15

The economic assessment of non-command system with no water storage tank involved only crop component, no fish culture was applicable; whereas pond-based system involved integrated crop, fish and on-dyke horticultural components. However, the economic assessment of kharif crop cultivation (kharif rice and kharif vegetables) in kharif season 2013 revealed that the cost of cultivation ranged from Rs 36060 to Rs 53800 per ha and the benefit was from Rs 22080 to Rs 43230 per ha in the pond-based intervention sites under eight sub-minors viz. Mangalpur, Khairapankalsahi, Madhyakhanda, Odasar, Khamarsahi, Madhyakhanda s/m-2, Lunisara and Soroda sub-minor.

Table 3.18 Economic analyses of pond-based systems in different canal commands

Name of canals/ sub minors	Pond command/ study area (ha)	Cost of cultivation (Rs/ha)					Gross return (Rs/ha)					Benefit (Rs/ha)
		Kharif crop	Kharif veg	Rabi crop	Fish	Total	Kharif crop	Kharif veg	Rabi crop	Fish	Total	
With water storage tank												
Mangalpur S/M	2.83	22323	4940	21360	92300	140923	38450	13832	35640	238500	326422	185499
Khairapankalsahi S/M	2.02	24117	**	12300	88400	124817	43856	-	15630	232290	291776	166959
Madhyakhand S/M	1.42	23801	5928	21460	98600	149789	40343	15808	32450	244800	333401	183612
Odasar S/M	2.43	19241	4446	14600	95500	133787	39251	12350	18640	220770	291011	157224
Khamarasahi S/M	2.43	21824	7410	19630	105200	154064	44240	17290	25550	266760	353840	199776
Madhyakhand S/M	2.43	19405	**	22460	97800	139665	44235	-	31260	247500	322995	183330
Lunisara S/M	1.01	21553	**	9850	99600	131003	37206	-	12600	255690	305496	174493
Soroda S/M-II	2.02	19899	4199	13680	95300	133078	41249	10374	22380	236070	310073	176995
Without water storage tank												
Mangalpur S/M	2.83	22194	-	9650	na	31844	37438	-	12978	na	50416	18572
Khairapankalsahi S/M	2.02	21864	-	-	na	21864	41002	-	-	na	41002	19138
Madhyakhand S/M	1.42	20994	-	-	na	20994	38144	-	-	na	38144	17150
Odasar S/M	2.43	21827	-	-	na	21827	38123	-	-	na	38123	16296
Khamarasahi S/M	2.43	18926	-	-	na	18926	38532	-	-	na	38532	19606
Madhyakhand S/M	2.43	20361	-	10500	na	30861	41227	-	16086	na	57313	26452
Lunisara S/M	1.01	18221	-	-	na	18221	33592	-	-	na	33592	15371
Soroda S/M-II	2.02	19062	-	8600	na	27662	39569	-	10374	na	49943	22281

**Kharif vegetable was very less, na- fish culture was not applicable; kharif vegetable was not grown in non-command area with no pond.

In the area where intervention was not made i.e., non-pond command was mainly grown with kharif rice. No vegetable cultivation was made during the kharif season 2013; the cost of cultivation of rice ranged from Rs 19560 to Rs 23140 per ha and the benefit was from Rs 11912 to Rs 16948 per ha. There was an improvement in the benefit for pond-command sites due to better management of rice crop and additional benefit of on-dyke vegetable cultivation in the sites of constructed ponds under our intervention. During the year 2014-15, improved crop management and better cropping systems have been followed in the intervention area by the trained and beneficiary farmers due to our intervention through construction of rain/ runoff water storage tanks and open wells, and technological support. Due to water storage tank, fish culture has become a major option for increasing total farm income by the farmers. Across different sites, better and appropriate cropping systems are listed below:

- ❖Rice + (fish in pond)-maize,
- ❖Rice + (fish in pond)-vegetables (bhindi/ tomato/ cauliflower/ onion/ pointed gourd/ brinjal/ pumpkin etc.)
- ❖Rice + (fish in pond) + on-dyke vegetables/ papaya/ banana/ arhar vegetable (on dyke)-green gram/ black gram/ ragi etc.
- ❖Rice + (fish in pond)-green gram
- ❖Rice + (fish in pond)-black gram
- ❖Rice + (fish in pond)-arhar
- ❖Rice + (fish in pond)-sesame
- ❖Rice + (fish in pond)-ragi

The integrated farming systems were developed under different sites (head-, mid- and tail end) of the canal command in Mangalpur S/M, Khairapankalsahi S/M, Madhyakhand S/M, Odasar S/M, Khamarasahi S/M, Madhyakhand S/M (second site) Lunisara S/M and Soroda S/M-II. The crops were grown under the command with the recommended package of practices. The performance of crops with water storage tanks were compared with the performance of crops without water storage tanks. For every site, rice was the primary crop during kharif season in the pond command as well as in the non-command area. The rice varieties were 'Swarna', 'Priya', 'CR-1018', 'Pooja' and 'CR-1009' etc. Fish culture was made in the constructed pond. Rabi crops were grown with conjunctive use of water. On-dyke horticultural crops were grown.

Table 3.19 Kharif, rabi crop yields and fish yield and differences in performance of crops with water storage tank under integrated farming system and without water storage tanks in different canal commands (2011-12)

Sl. No.	Canal command	Tank command area (ha)	Yield (kg/ha)		
			Yield (kg/ha)	Rabi crop	Fish$
1	Mangalpur S/M	-	-	-	-
2	Khairapankalsahi S/M	-	-	-	-
3	Madhyakhand S/M	-	-	-	-
4	Odasar S/M	-	-	-	-
5	Khamarasahi S/M	2.43	3890	563***	2880
6	Madhyakhand S/M	2.43	3527	386@@	2712
7	Lunisara S/M	1.01	3211	296#	2831
8	Soroda S/M-II	2.02	3335	346#	2460

*kharif crop was rice for every study site, #rabi crop was greengram, **average rabi crop yield of greengram and blackgram ***average of greengarm, blackgram and chickpea, @@average of pigeonpea and greengram, $fish yield relates to total yield of *catla, rohu and mrigala*

Table 3.20 Kharif, rabi crop yields differences in performance of crops without water storage tank under only crop cultivation system in different canal commands (2011-12)

Sl. No.	Canal command	Study area (ha)	Yield (kg/ha)		
			Kharif crop*	Rabi crop	Fish
1	Mangalpur S/M	2.83	3067	479**	-
2	Khairapankalsahi S/M	2.02	3582	-	-
3	Madhyakhand S/M	1.42	3424	-	-
4	Odasar S/M	2.43	3129	412#	-
5	Khamarasahi S/M	2.43	3277	383**	-
6	Madhyakhand S/M	2.43	3170	371#	-
7	Lunisara S/M	1.01	3335	-	-
8	Soroda S/M-II	2.02	3108	-	-

*kharif crop was rice for every study site, #rabi crop was greengram, **average rabi crop yield of greengram and blackgram, ***average of greengarm, blackgram and chickpea, blank data on rabi crop represents is due to no rabi crop cultivation, and fish yield was not applicable.

*In Khamarsahi sub-minor, crop was grown with all required management practices. One irrigation could be given to kharif season rice of 2011 due to the prolonged dry spell; whereas during 2012, irrigation was not required due to somewhat optimum distribution of rainfall. Pond command area was compared with the non-command area of the same farmer (Table 3.19 and 3.20). Paddy yield ranged from 3829 to 3952 kg ha^{-1} with an average of 3890 kg ha^{-1} under the pond command, and 3162 to 3396 kg ha^{-1} with an average of 3277 kg ha^{-1} in the non-command in the year 2011-12. In the year 2012-13, average paddy yield was 3664 kg ha^{-1} under the pond command, 3335 kg ha^{-1} in the non-command area (Table 3.21 & 3.22). During rabi season (2011-12), greengram, blackgram and chickpea were grown with residual soil moisture. One supplementary irrigation was applied from the pond. In the non-command area, greengram and blackgram was grown with residual soil moisture only. The crop yield of greengram, blackgram and chickpea was 453, 494 and 741 kg ha^{-1}, respectively with an average of 563 kg ha^{-1} under the pond command, whereas crop yields were 371 and 395 kg ha^{-1} for greengram and blackgram, respectively in the non-command area.

In Madhyakhanda sub-minor paddy yield ranged from 3293 to 3890 kg ha^{-1} with an average of 3527 kg ha^{-1} under the pond command, and 2779 to 3520 kg ha^{-1} with an average of 3170 kg ha^{-1} in the non-command in the year 2011-12. In the year 2012-13, average paddy yield was 3636 kg ha^{-1} under the pond command, 3088 kg ha^{-1} in the non-command area. During rabi season (2011-12), greengram after harvesting of kharif rice, with residual soil moisture, and pigeonpea was grown on-dyke. One supplementary irrigation was applied to greengram from the pond. In the non-command area, greengram was grown. The crop yield of greengram and pigeonpea was 401 and 371 kg ha^{-1}, respectively with an average of 386 kg ha^{-1} under the pond command, whereas crop yield was 371 kg ha^{-1} for greengram in the non-command area.

In Lunisara sub-minor, paddy yield was 3211 kg ha^{-1} under the pond command, and 3211 to 3458 kg ha^{-1} with an average of 3335 kg ha^{-1} in the non-command in the year 2011-12. In the year 2012-13, average paddy yield was 3026 kg ha^{-1} under the pond command, 2902 kg ha^{-1} in the non-command area. During rabi season (2011-12), greengram after harvesting of kharif rice, with residual soil moisture, and pigeonpea was grown on-dyke. One supplementary irrigation was applied to greengram. In Soroda sub-minor-II, one irrigation could be given to kharif season rice of 2011 due to the prolonged dry spell; whereas during 2012, irrigation was not required due to optimum distribution of rainfall. Paddy yield ranged from 3088 to 3458 kg ha^{-1} with an average of 3335 kg ha^{-1} under the pond command, and 3088 to 3149 kg ha^{-1} with an average of 3108 kg ha^{-1} in the non-command in the year 2011-12. In the year 2012-13, average paddy yield was 3232 kg ha^{-1} under the pond command, 2964 kg ha^{-1} in the non-command area. During rabi season (2011-12) greengram was grown after harvesting of kharif rice. One supplementary irrigation was applied to greengram from the pond. In the non-command area, there was no crop due to scarcity of water. The crop yield of greengram was 346 kg ha^{-1} under the pond command.

Table 3.21 Kharif, rabi crop yields and fish yield and differences in performance of crops with water storage tank under integrated farming system and without water storage tanks in different canal commands (2012-13)

Sl. No.	Canal command	Study area (ha)	Yield (kg/ha)		
			Kharif crop*	Rabi crop#	Fish$
1	Mangalpur S/M	2.83	3211	2882	2650
2	Khairapankalsahi S/M	2.02	3643	474	2581
3	Madhyakhand S/M	1.42	3227	2964	2720
4	Odasar S/M	2.43	3225	542	2453
5	Khamarasahi S/M	2.43	3664	1635	2964
6	Madhyakhand S/M-2	2.43	3636	3164	2750
7	Lunisara S/M	1.01	3026	364	2841
8	Soroda S/M-II	2.02	3232	1007	2623

*Kharif crop was rice for every study site, #rabi crop was maize, sunflower, vegetables for sl. No.1; moong bean and arhar for sl. No. 2; maize, vegetables and moong bean for sl. No. 3; maize and vegetables for sl. No. 4; maize, vegetables, sunflower for sl. No. 5; maize, arhar, moong, vegetables for sl. No. 6; moong, arhar for sl. No. 7 and moong, onion, arhar, vegetables for sl. No. 8, $fish yield relates to total yield of *catla, rohu and mrigala*.

Table 3.22 Kharif, rabi crop yields differences in performance of crops without water storage tank under only crop cultivation system in different canal commands (2012-13)

Sl. No.	Canal command	Study area (ha)	Yield (kg/ha)		
			Kharif crop*	Rabi crop#	Fish$
1	Mangalpur S/M	2.83	3115	309	-
2	Khairapankalsahi S/M	2.02	3409	-	-
3	Madhyakhand S/M	1.42	3094	-	-
4	Odasar S/M	2.43	3149	-	-
5	Khamarasahi S/M	2.43	3335	-	-
6	Madhyakhand S/M-2	2.43	3088	383	-
7	Lunisara S/M	1.01	2902	-	-
8	Soroda S/M-II	2.02	2964	247	-

*kharif crop was rice for every study site, #rabi crop was greengram, blank data on rabi crop represent no rabi crop cultivation, and fish yield was not applicable.

In the year 2011-12, the yield of paddy ranged from 3067 kg ha^{-1} in Mangalpur sub-minor to 3582 kg ha^{-1} in Khairapankalsahi sub-minor. Kharif crop was rice for every study site; rabi crop was maize, sunflower, vegetables for Mangalpur S/M; and arhar for Khairapankalsahi S/M; maize, vegetables and green gram for Madhyakhand S/M; maize and vegetables for Odasar; maize, vegetables, sunflower for Khamarasahi S/M; maize, arhar, green gram, vegetables for Madhyakhand S/M-2; green gram, arhar for Lunisara S/M and green gram, onion, arhar, vegetables for Soroda S/M-II. Paddy yield ranged from 3026 to 3664 kg ha^{-1} under the pond command, and 2902 to 3409 kg ha^{-1} in the non-command area. During the rabi season (2012-13) crop yields ranged from 364 to 2964 kg ha^{-1} depending upon the site and the type of crop grown by the farmers. In the non-command area, the rabi crops could not grown due to lack of irrigation water, hence green gram and black gram was grown in three sites using the residual soil moisture, and the yield of green gram/ black gram varied from 247 to 383 kg ha^{-1}.

Table 3.23 Kharif crop yields and fish yield, differences in performance of crops with water storage tank under integrated farming system and without water storage tanks in different canal commands (2013-14)

Sl. No.	Canal command	Tank command area (ha)	Yield (kg/ha)		
			Kharif crop*	Rabi crop	Fish
1	Mangalpur S/M	2.83	2984	2653	2760
2	Khairapankalsahi S/M	2.02	2836	945	2640
3	Madhyakhand S/M	1.42	3124	2764	2780
4	Odasar S/M	2.43	2740	645	2560
5	Khamarasahi S/M	2.43	3360	1957	3060
6	Madhyakhand S/M-2	2.23	3225	3024	2880
7	Lunisara S/M	1.01	2985	462	2900
8	Soroda S/M-II	2.02	2830	1257	2830

Table 3.24 Kharif crop yields and differences in performance of crops in the non-command area in different canal commands and sub-minors (2013-14)

Sl. No.	Canal command	Study area (ha)	Yield (kg/ha)		
			Kharif crop	Rabi crop	Fish*,$
1	Mangalpur S/M	2.83	2921	347	-
2	Khairapankalsahi S/M	2.02	2945	-	-
3	Madhyakhand S/M	1.42	3064	-	-
4	Odasar S/M	2.43	2856	523	-
5	Khamarasahi S/M	2.43	3124	426	-
6	Madhyakhand S/M-2	2.43	3115	-	-
7	Lunisara S/M	1.01	2950	-	-
8	Soroda S/M-II	2.02	2785	-	-

*For the year (2013-14), rabi/ summer crop yields is not available till the reporting period i.e., upto Mar 2014; $fish yield is not applicable because of without ponds

For the year 2013-14, paddy yield ranged from 2740 to 3360 kg ha^{-1} under the pond command (Table 2.23 and 3.24), and 2785 to 3124 kg ha^{-1} in the non-command. There was no much difference in rice yield in the pond command and in non-command area, as no irrigation was required to be given to kharif rice was required to be provided during kharif season 2013. However, the overall rice yield was less compared to previous year because of post-monsoon heavy rainfall during the month of October 2013, the period was coincided with the maturity phase of rice crop. For the year 2014-15, the multiple uses of water, conjunctive use of water and impacts of integrated farming systems have been presented under impact assessment section.

3.11 Studies on pond water quality, fish production, fish performance index and fish water productivity

As one of the components of integrated faming system in the command area, low input-based medium-duration fish culture was undertaken in eight water storage tanks to enhance the economic output and water productivity. Every year, fish fingerlings of IMCs (*Catla catla, Labeo rohita* and *C. mrigala*) were stocked in the last week of August @ 5000 per ha with a stocking composition of 30:30:40 (MBW- 22, 15.5 & 12 g for *catla, rohu & mrigala*, respectively) in each pond. The recorded mean minimum and maximum values of various water quality parameters prevailed in the ponds during the rearing period were: water temperature 27.6-35.1 ^{0}C; water pH 6.9-

8.8; dissolved oxygen 4.2-6.5 ppm; total alkalinity 88-131 ppm; dissolved organic matter 2.8-4.8 ppm; nitrite –N 0.006-0.08 ppm; nitrate-N 0.06-0.5 ppm; ammonia 0.01-0.3 ppm; transparency 34$\pm$6; and total suspended solid 186 - 377 ppm. TSS and DO concentration showed a decreasing trend with the advancement of rearing period while, gradual increase in nitrite, nitrate, ammonia were observed. After 210 days of rearing, harvesting was carried out. The recorded fish production ranged between 2.45-2.96 t ha^{-1} $210d^{-1}$. Species-wise production-size index and performance index is presented in Table 3.25, indicating the normal growth performance of the cultured species. Pond-wise gross water productivity ranged between 6.47-7.85 Rs m^{-3} while the net water productivity ranged between 4.6-5.86 Rs m^{-3}.

Similarly, during 2013-14, fish fingerlings of IMCs were stocked in the first week of September in each pond. The recorded mean minimum and maximum values of various water quality parameters prevailed in the ponds during the rearing period were: water temperature 27.2 - 35.8 ^{0}C; water pH 6.7 – 8.7; dissolved oxygen 4.4 - 6.8 ppm; total alkalinity 83 - 127 ppm; dissolved organic matter 2.8 - 5.2 ppm; nitrite –N 0.006 - 0.08 ppm; nitrate-N 0.063 - 0.55 ppm; ammonia 0.01 - 0.3 ppm; transparency 31$\pm$7; and total suspended solid 178 - 389 ppm. TSS and After 210 days of rearing, fish production ranged between 2.56-3.06 t ha^{-1} $210d^{-1}$ (Table 3.26).

Table 3.25 Fish production, performance indices of IMCs and fish water productivity for eight constructed water storage tanks during the year 2012-13

Pond in the sub-minor	Fish species	Initial MBW (g)	Final MBW (g)	PSI / PI	Productivity (t ha^{-1})	AFCR/ FE%	GWP (Rs.m^{-3})	NWP (Rs.m^{-3})
Mangalpur	Catla Rohu Mrigala	22.0 15.5 12.0	555.2 466.5 480.5	541.6/ 273.2 241.7/ 195.9 324.4/ 200.6	2.65	1.41/ 50.7	7.09	5.25
Khairapankalsahi	Catla Rohu Mrigala	22.0 15.5 12.0	545.0 462.5 485.5	540.7/ 274.2 241.1/ 196.7 338.6/ 200.1	2.58	1.33/ 62.3	6.94	5.10
Madhyakhanda (Dwargaon)	Catla Rohu Mrigala	22.0 15.5 12.0	510.0 436.5 455.5	536.7/ 270.5 239.1/ 193.7 328.6/ 197.1	2.72	1.49/ 61.6	7.37	5.35
Odasar	Catla Rohu Mrigala	22.0 15.5 12.0	553.2 476.2 498.5	522.7/ 264.2 238.1/ 194.7 333.4/ 200.0	2.45	1.45/ 55.5	6.47	4.60
Khamarsahi	Catla Rohu Mrigala	22.0 15.5 12.0	565.0 482.5 500.0	542.6/ 274.8 242.6/ 197.7 344.6/ 205.5	2.96	1.62/ 58.3	7.85	5.86
Madhyakhand (Dendabhuin)	Catla Rohu Mrigala	22.0 15.5 12.0	585.0 492.5 470.0	606.8/ 305.5 282.2/ 211.9 385.4/ 207.8	2.75	1.44/ 70.7	7.54	5.44
Lunisara	Catla Rohu Mrigala	22.0 15.5 12.0	572.5 470.0 485.0	611.2/ 302.0 265.5/ 208.4 359.2/ 204.4	2.84	1.37/ 67.3	7.66	5.61
Soroda	Catla Rohu Mrigala	22.0 15.5 12.0	590.0 510.5 520.0	612.5/ 288.2 247.1/ 202.9 376.7/ 211.5	2.62	1.45/ 57.8	6.98	5.13

Fish productivity (t ha^{-1} per 210 days), PSI- production-size index, PI- performance index, AFCR- apparent feed conversion ratio, FE- feeding efficiency, Fish sold @ Rs.90 kg^{-1}, GWP- gross water productivity, NWP- net water productivity.

Table 3.26 Production performance of IMCs in water harvesting structures (2013-14)

Pond in the sub-minor	Fish species	Initial MBW (g)	Final MBW (g)	PSI / PI	Productivity (t ha^{-1})	AFCR/ FE%	GWP (Rs.m^{-3})	NWP (Rs.m^{-3})
Mangalpur	Catla Rohu Mrigala	20.0 14.0 12.0	566.5 466.0 485.5	546.9 / 275.2 245.6 / 198.2 326.4 / 202.2	2.76	1.47/ 53.5	7.28	5.36
Khairapankalsahi	Catla Rohu Mrigala	20.0 14.0 12.0	560.0 470.5 485.0	543.6 / 274.8 241.8 / 197.7 339.6 / 201.5	2.64	1.43/ 62.0	7.11	5.22
Madhyakhanda (Dwargaon)	Catla Rohu Mrigala	20.0 14.0 12.0	530.0 455.5 475.5	538.3 / 272.5 239.5 / 193.7 330.5 / 197.5	2.78	1.49/ 60.4	7.35	5.44
Odasar	Catla Rohu Mrigala	20.0 14.0 12.0	580.2 485.2 507.5	525.7 / 264.8 240.1 / 195.5 333.4 / 200.0	2.56	1.55/ 58.5	6.64	4.70
Khamarsahi	Catla Rohu Mrigala	20.0 14.0 12.0	572.0 482.5 505.0	543.5 / 276.2 244.0 / 199.0 348.6 / 209.5	3.06	1.65/ 61.3	8.05	5.98
Madhyakhand (Dendabhuin)	Catla Rohu Mrigala	20.0 14.0 12.0	600.0 505.5 495.0	608.5 / 306.5 284.2 / 212.5 385.4 / 207.8	2.88	1.54/ 66.7	7.62	5.54
Lunisara	Catla Rohu Mrigala	20.0 14.0 12.0	588.5 490.5 485.0	604.2 / 300.0 265.8 / 208.8 361.0 / 207.4	2.9	1.46/ 65.5	7.85	5.71
Soroda	Catla Rohu Mrigala	20.0 14.0 12.0	615.0 510.0 540.0	610.5 / 290.2 247.5 / 204.0 382.0/212.5	2.83	1.58/ 59.2	7.58	5.47

PSI- production-size index, PI- performance index, AFCR- apparent feed conversion ratio, FE- feeding efficiency, Fish sold @ Rs.90 kg^{-1}, GWP- gross water productivity, NWP- net water productivity

3.12 Study on groundwater fluctuation and groundwater quality in the canal command

3.12.1 Groundwater fluctuation and dynamics

Studies were carried out to assess the groundwater fluctuation and dynamics over the year in the command area in five representative sites viz. one in head reach in the RD under Odasar s/m, one in mid-reach in the RD at Khamarsahi s/m, one in mid-reach in the LD at Mangalpur s/m, one in tail-end in the RD at Soroda s/m-II and one in tail-end in the LD at Madhyakhanda s/m (Fig 3.14). Overall, depth of groundwater decreases during rainy season due to monsoon rainfall; and increases during the post-monsoon and summer season. There is high potential to explore groundwater for irrigation as there is sufficient water; it gets fully recharged during rainy season.

3.12.2 Studies on groundwater quality in the command area

The chemical quality parameters of groundwater in Kuanria command area were determined in the laboratory, as listed in Table 3.27, based on the water samples collected randomly from well water after monsoon season from different sites. It indicates that mean values of each parameter was within the permissible limits for irrigation purpose as per the FAO guidelines, hence were found suitable for irrigation.

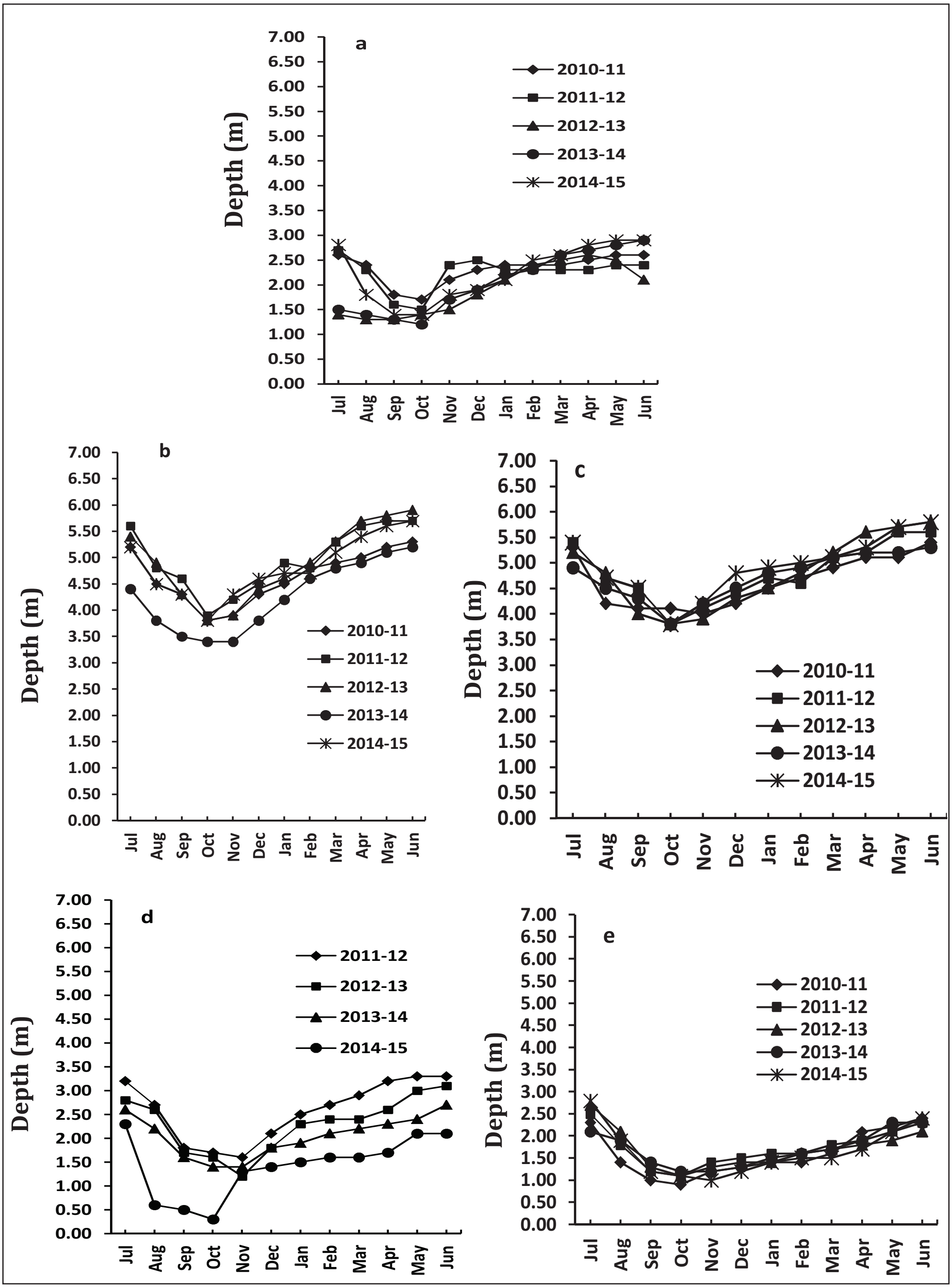


Fig. 3.14 Groundwater fluctuation over the year in the command area, a) head reach in the RD at Odasar s/m, b) mid-reach in the RD at Khamarsahi s/m, c) mid-reach in the LD at Mangalpur s/m, d) tail-end in the RD at Soroda s/m-II and e) tail-end in the LD at Madhyakhanda s/m

Table 3.27 Water quality of groundwater in the Kuanria canal commands in Daspalla, Nayagarh

Groundwater quality parameters	Groundwater quality	
	Mean (±s.d.)	Range
pH	6.47 (±0.38)	6.08-6.84
EC ($\mu S\ cm^{-1}$)	497 (±183)	388-771
TDS ($mg\ l^{-1}$)	243 (±90)	190-378
Na ($me\ l^{-1}$)	1.56 (±0.60)	1.17-2.46
K ($me\ l^{-1}$)	0.38 (±0.06)	0.02-1.37
P (ppm)	1.43 (±0.15)	0.50-3.10
Ca ($me\ l^{-1}$)	1.60 (±0.60)	1.20-2.50
Mg ($me\ l^{-1}$)	1.33 (±0.82)	0.30-2.30
NH_4-N ($mg\ l^{-1}$)	23.6 (±1.0)	10.5-35.0
NO_3-N ($mg\ l^{-1}$)	43.0 (±3.5)	38.5-46.0
Cl ($me\ l^{-1}$)	1.57 (±0.66)	0.60-2.12
HCO_3 ($me\ l^{-1}$)	9.5 (±0.5)	5.0-15.0

3.13 Conjunctive use of water and evolving of improved cropping pattern

Sweet corn was introduced in the pond-command under Mangalpur sub-minor

Paired-row cultivation of sunflower in the pond-command in Mangalpur sub-minor

Okra was grown in rabi and summer season using irrigation from open wells and water storage tank in Madhyakhanda sub-minor

Conjunctive use of groundwater and pond water was made possible for irrigation to okra in Madhyakhanda sub-minor

Banana was grown in the tank-command using irrigation from water storage tank under the Odasar sub-minor

Cultivation of fruits in the pond-command was successful and profitable in the Odasar sub-minor

On-dyke cultivation of greengram and pigeonpea in the Lunisara sub-minor

On-dyke pigeonpea cultivation in Madhyakhand sub-minor

Very good crop of brinjal intercropped with maize in the tank and open well command in the Madhyakhanda sub-minor

Bitter gourd cultivation was made in the tank and open well command areas in the Madhyakhanda sub-minor

Onion cultivation using irrigation water from constructed tank and open well under the Sorada sub-minor II

Fish harvested (*rohu, catla and mrigala*) from constructed water storage tank under Sorada sub-minor II

3.14 Impact assessment on availability of water, crop and fish production, groundwater dynamics and other issues

3.14.1 Availability of water

The availability of water has been increased due to intervention through construction of rain/ runoff water storage tanks and open wells in different head, mid and tails end sites (Fig. 3.15 and 3.16).

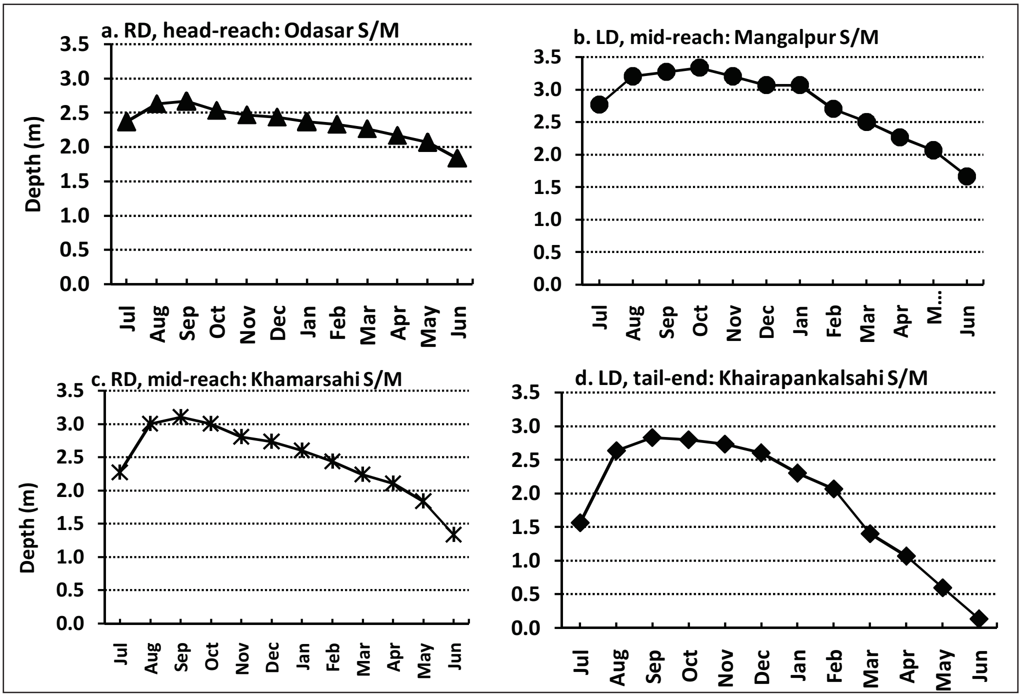


Fig. 3.15 Fluctuation of pond water depth (mean of 3 years, 2011-12 to 2014-15) in different sites a) Odasar s/m, b) Mangalpur s/m, c) Khamarsahi s/m, d) Khairapankalsahi s/m

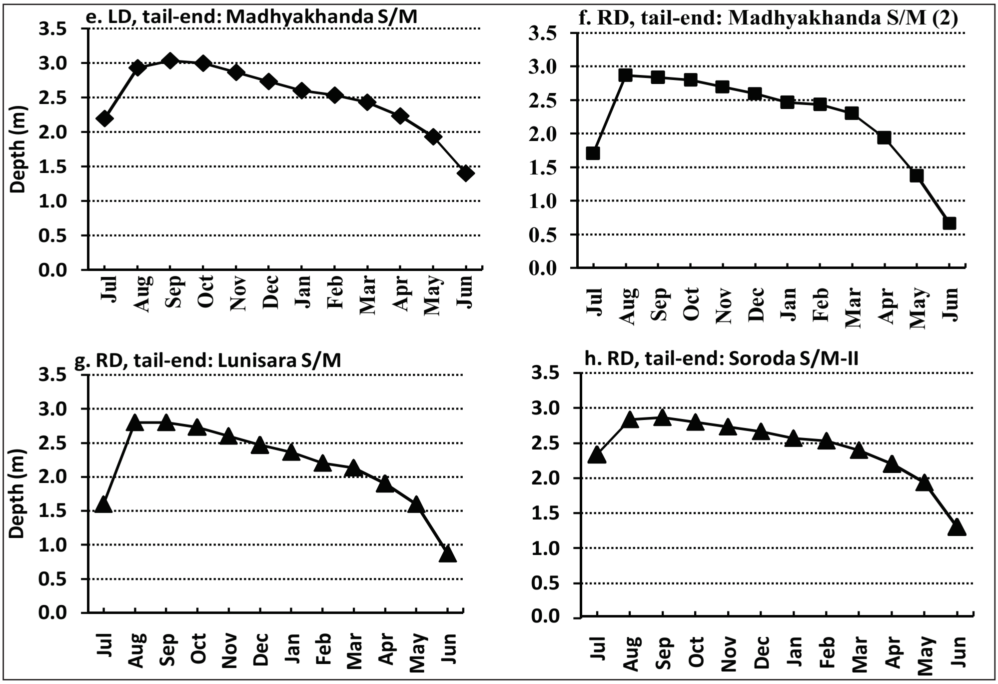


Fig. 3.16 Fluctuation of pond water depth (mean of 3 years, 2011-12 to 2014-15) in different sites in the KIP command, e) LD, tail-end under Madhyakhanda s/m, f) RD, tail-end under Madhyakhanda s/m (2) g) RD, tail-end under Lunisara s/m, h) RD, tail-end under Soroda s/m-II

3.14.2 Impact on crop, fish production and water productivity

There has been a significant impact on the crop and fish production due to intervention through the project activities. The integrated farming systems were developed under different sites (head-, mid- and tail end) of the canal command. The sites belong to the Odasar S/M, Mangalpur S/M, Khamarasahi S/M, Khairapankalsahi S/M, Madhyakhand S/M, Madhyakhand S/M (second site), Lunisara S/M and Soroda S/M-II. The site villages and location etc. are mentioned in previous sections. The crops were grown under the command with the recommended package of practices. For every site, rice was the primary crop during kharif season in the pond command as well as in the non-command area. Fish culture was made in the constructed pond. Rabi crops were grown with conjunctive use of water. On-dyke horticultural crops were grown for improving farm income.

3.14.2.1 Integrated farming at head-reach under Odasar sub-minor command

Fish, crop production, crop diversification, water used from storage tank and water productivity for various components of the integrated farming system are depicted in Table 3.28. Fish production was 5.20 t ha^{-1} with fish water productivity of 17.40 Rs m^{-3}. Rice, moong, brinjal, tomato and cauliflower were the major crop grown by the beneficiary farmer with water use of 450 to 800 m^3 and crop water productivity ranged from 38.57 to 53.33 Rs m^{-3}; total return of Rs 2,23,270. The farmer gets the advantage of head-reach in the canal command; has good liaison with Govt. Departments, and have considerable investment potential; hence the impact was highly beneficial to the farmer.

A view of vegetable crops like brinjal and tomato grown with conjunctive use of water

Table 3.28 Crop & fish production and water productivity in the site under Odasar sub-minor in the head-reach of right distributary

Fish/ Crops	Area (ha)	Production (kg)	Yield (kg/ha)	Gross return (Rs)	Water used (m^3)	Water productivity (Rs/m^3)
Fish(IMC)	0.098	510	5204	51000	2930	17.40
Rice	1.5	4200	2800	57120	-	-
Moong	1.0	525	525	24150	600	40.25
Brinjal	0.2	1800	9000	27000	700	38.57
Tomato	0.2	2000	10000	40000	800	50.00
Cauliflower	0.1	1200	12000	24000	450	53.33
Total				223270		

3.14.2.2 Integrated farming at mid-reach under Mangalpur sub-minor command

Fish, crop production, conjunctive use of water used from storage tank and open well, water productivity are presented in Table 3.29. Fish production was 5.45 t ha^{-1} with its fish water productivity of 8.74 Rs m^{-3}. Rice, arhar, moong and vegetables were the major crop grown by the beneficiary farmer in the pond command with water use of 70 to 1320 m^3 and crop water productivity ranged from 38.33 to 60.23 Rs m^{-3} with the total return of Rs 1,74,330. The farmer is progressive has good liaison with Govt. Departments, and have considerable investment potential; hence the farmers accrued the full benefit of the constructed storage tank and open well.

Table 3.29 Crop & fish production and water productivity the site under Mangalpur sub-minor in the mid-reach

Fish/ Crops	Area (ha)	Production (kg)	Yield (kg/ha)	Gross return (Rs)	Water used (m^3)	Water productivity (Rs/m^3)
Fish (IMC)	0.098	240	2449	24000	2744	8.74
Coconut (on-dyke)	-	27plants	-	-	-	-
Rice	2.2	6500	2955	88400	-	-
Arhar	0.2	180	900	7830	130	60.23
Moong	2.0	1100	550	50600	1320	38.33
Vegetables	0.02	-	-	3500	70	50.00
Total				174330		

3.14.2.3 Integrated farming at mid-reach under Khamarsahi sub-minor command

Fish, crop production, crop diversification, water used from storage tank and water productivity for various components of the integrated farming system are presented in Table 3.30. The farmer used the water storage tank for fish seed rearing, and accrued the return of Rs 52,000 with fish water productivity of 21.48 Rs m^{-3}. Rice, arhar (on-dyke), papaya (on-dyke), moong and bhindi were the major crops grown in the pond command with water use of 256 to 520 m^3 and water productivity of 39.81 to 42.97 Rs m^{-3} and a total return of Rs 1,63,675. The impact was highly beneficial to the farmer.

Direct seeded rice crop in the pond command under bushening operation in July 2014

The beneficiary farmer in the field during early seedling stage of bhindi

Table 3.30 Crop & fish production and water productivity in the site under Khamarasahi sub-minor in the mid-reach

Fish/ Crops	Area (ha)	Production (kg)	Yield (kg/ha)	Gross return (Rs)	Water used (m^3)	Water productivity (Rs/m^3)
Fish (IMC)	0.098	Seed rearing	-	52000	2420	21.48
Rice	2.0	5500	2750	74800	-	-
Arhar (on-dyke)	0.04	50	1250	2175	-	-
Papaya (on-dyke)	0.02	300	15000	3000	-	-
Moong	0.80	450	563	20700	520	39.81
Bhindi	0.08	550	6875	11000	256	42.97
Total				163675		

3.14.2.4 Integrated farming at tail-end under Khairapankalsahi sub-minor command

Fish, crop production, water used from storage tank and open well and water productivity are presented in Table 3.31. The fish production in the constructed tank was not very satisfactory because of high iron content in the water. There is problem of retention of water in the pond. Farmer's participation for the development of the system is low; WUA was also not very active. Farmer gives more time for his business. However, he could accrue the total return of Rs 77,940. Rice, moong and sesame were the major crops grown in the pond command with water productivity of 52.57 to 54.36 Rs m^{-3}. The impact was not very satisfactory to the farmer.

Conjunctive use of water through open well and pond water for irrigation to post-monsoon crops

A view of standing sesame crop grown in the pond command, irrigated from both storage tank and open well

Table 3.31 Crop & fish production and water productivity in the site under Khairapankalsahi sub-minor in the tail-end

Fish/ Crops	Area (ha)	Production (kg)	Yield (kg/ha)	Gross return (Rs)	Water used (m^3)	Water productivity (Rs/m^3)
Fish(IMC)	0.098	130	1327	13000	2455	5.29
Rice	1.5	4200	2800	57120	-	-
Moong	0.2	130	650	5980	110	54.36
Sesame	0.05	40	800	1840	35	52.57
Total				77940		

3.14.2.5 Integrated farming at tail-end under Madhyakhanda sub-minor command

Fish and crop production, crop diversification, water used from storage tank and open well, water productivity for various components of the integrated farming system under Madhyakhand sub-minor in the tail-end are depicted in Table 3.32. Fish production was 2.65 t ha^{-1} with fish water productivity of 9.7 Rs m^{-3}. Rice, banana (on-dyke), papaya (on-dyke), vegetables (on-dyke), maize, bhindi and pumpkin were the major crops grown with conjunctive water use of 560 to 2250 m^3 and water productivity of 23.39 to 31.11 Rs m^{-3}; total return of Rs 2,00,600. Crop diversification is very beneficial to the farmer. Though it is in tail end, water retention in the tank facilitates fish culture and irrigation to crops satisfactorily.

Table 3.32 Crop & fish production and water productivity in the site under Madhyakhand sub-minor in the tail-end

Fish/ Crops	Area (ha)	Production (kg)	Yield (kg/ha)	Gross return (Rs)	Water used (m^3)	Water productivity (Rs/m^3)
Fish (IMC)	0.098	260	2653	26000	2680	9.7
Rice	1.4	4500	3214	61200	-	-
Banana (on-dyke)	0.02	40 bunch	-	3000	-	-
Papaya (ondyke)	0.01	180	18000	1800	-	-
Vegetables (on-dyke)	0.01	-	-	3500	-	-
Maize	0.2	1000	5000	13100	560	23.39
Bhindi	0.2	1100	5500	22000	800	27.50
Pumpkin	0.6	7000	11667	70000	2250	31.11
Total				200600		

Conjunctive use of water through lifting of water from open well and water storage tank for irrigation to bhindi

A view of the standing maize crop grown in the pond command, irrigated from both water storage tank and open well

3.14.2.6 Integrated farming at tail-end under Madhyakhanda sub-minor (2) command

Fish and crop production, crop diversification, water used from storage tank and open well, water productivity for various components of the integrated farming system under Madhyakhand sub-minor (2) in the tail-end are presented in Table 3.33. Fish production was 2.60 t ha^{-1} with fish water productivity of 9.36 Rs m^{-3}. Rice, arhar (on-dyke), moong and pointed gourd were the major crops grown with conjunctive water use of 240 to 1600 m^3 and water productivity of 37.50 to 47.92 Rs m^{-3} with the total return of Rs 1,84,800. Crop diversification to pointed gourd is very beneficial to the farmer. Though it is in tail end, water retention in the tank and full participation of the farmer helps in fish culture and development of integrated farming system.

A view of moong crop i.e., green gram grown by the farmers in the command, irrigated once from pond water

Pointed gourd cultivation using water from storage tank and the open well constructed in the sub-minor

Table 3.33 Crop & fish production and water productivity in the site under Madhyakhand sub-minor (2) in the tail-end

Fish/ Crops	Area (ha)	Production (kg)	Yield (kg/ha)	Gross return (Rs)	Water used (m^3)	Water productivity (Rs/m^3)
Fish (IMC)	0.098	255	2602	25500	2722	9.36
Rice	2.1	6200	2952	84320	-	-
Arhar (on dyke)	0.05	80	1600	3480	-	-
Moong	0.4	250	625	11500	240	47.92
Pointed gourd	0.4	3000	7500	60000	1600	37.50
Total				184800		

3.14.2.7 Integrated farming at tail-end under Lunisara sub-minor command

Fish, crop production, water used from storage tank and open well and water productivity in the Lunisara sub-minor are presented in Table 3.34. The fish production in the constructed tank was 1.73 t ha^{-1} with the fish water productivity of 6.84 Rs m^{-3}. There is the lack of management by the farmer. As the farmer is expired, his unit is managed by other person and the concerned. However, it was Rs 34,663 which was accrued from the developed system. Rice, arhar (on-dyke) and moong were the major crops grown in the pond command. The water storage tank is very useful for community purposes and for providing drinking and bathing water for animals.

Table 3.34 Crop & fish production and water productivity in the site under Lunisara sub-minor in the tail-end

Fish/ Crops	Area (ha)	Production (kg)	Yield (kg/ha)	Gross return (Rs)	Water used (m^3)	Water producti-vity (Rs/m^3)
Fish (IMC)	0.098	170	1735	17000	2485	6.84
Rice	0.41	1150	2805	15640	-	-
Arhar (on-dyke)	0.03	35	1167	1523	-	-
Moong	0.04	25	625	500	20	25.00
Total				34663		

3.14.2.8 Integrated farming at tail-end under Soroda sub-minor-II command

Fish and crop production, crop diversification, water used from storage tank and open well, water productivity for various components of the integrated farming system under Soroda sub-minor (II) sub-minor in the tail-end are presented in Table 3.35. Fish production was about 2.35 t ha^{-1} with fish water productivity of 8.05 Rs m^{-3}. Rice, banana (on-dyke), arhar (on-dyke), ragi, onion and bhindi were the major crops grown with conjunctive water use of 92 to 220 m^3 and water productivity of 31.70 to 60.28 Rs m^{-3} with total return of Rs 1,12,515. Crop diversification was very beneficial to the farmer. The farmer could save his rice nursery from drought by irrigation from the water storage tank and open well during pre-monsoon drought in 2014. Though the developed system is in tail end, water retention in the tank facilitates fish culture favourably and providing irrigation to crops satisfactorily.

Table 3.35 Crop & fish production and water productivity in the site under Soroda sub-minor-II in the tail-end

Fish/ Crops	Area (ha)	Production (kg)	Yield (kg/ha)	Gross return (Rs)	Water used (m^3)	Water producti-vity (Rs/m^3)
Fish (IMC)	0.098	230	2347	23000	2854	8.05
Rice	1.52	4250	2796	57800	-	-
Arhar (on-dyke)	0.02	40	2000	1740	-	-
Banana (on-dyke)	0.02	70 bunch	-	5250	-	-
Ragi	0.20	450	2250	6975	220	31.70
Onion	0.09	850	9444	12750	212	60.28
Bhindi	0.04	250	6250	5000	92	54.35
Total				112515		

Rice nursery was saved from drought by irrigation from water storage tank and open well during pre-monsoon drought in 2014

A view of the constructed tank and canal at the tail-end and on-dyke banana cultivation under Soroda sub-minor (II)

3.15 Soil fertility and water quality in the command area

3.15.1 Soil chemical properties and soil fertility

Soil chemical properties like pH, electrical conductivity (EC) and soil organic carbon (SOC) were measured for different head, mid- and tail end commands under the intervention sites in the Kuanria command (Table 3.36). Soil pH ranged from 6.91 to 8.32 in 0-15 cm soil depth, and 7.15 to 8.39 in 15-30 cm soil depth i.e., soil reaction is almost neutral to slightly alkaline; soil salinity was not found significant as the EC values were very less; SOC varied from 0.47 to 0.65% in 0-15 cm soil depth and 0.19 to 0.37% in 15-30 cm soil depth.

Table 3.36 Soil chemical properties in different head, mid- and tail end commands with water users' association (WUA) jurisdictions

Sl. No.	Name of sub-minor canal command	WUA No.	pH	EC (dS/m)	SOC (%)
	0-15 cm soil depth				
1	Odasar S/M	6	6.91	0.022	0.52
2	Mangalpur S/M	2	7.75	0.021	0.53
3	Khamarasahi S/M	8	7.84	0.032	0.47
4	Khairapankalsahi S/M	4	6.88	0.017	0.45
5	Madhyakhand S/M	5	8.11	0.037	0.65
6	Madhyakhand S/M (II)	9	8.32	0.036	0.51
7	Lunisara S/M	10	7.11	0.026	0.63
8	Soroda S/M-II	10	6.95	0.019	0.46
	15-30 cm soil depth				
1	Odasar S/M	6	7.38	0.025	0.27
2	Mangalpur S/M	2	7.92	0.026	0.28
3	Khamarasahi S/M	8	8.21	0.029	0.24
4	Khairapankalsahi S/M	4	7.15	0.023	0.25
5	Madhyakhand S/M	5	8.32	0.039	0.37
6	Madhyakhand S/M (II)	9	8.39	0.022	0.24
7	Lunisara S/M	10	7.37	0.021	0.36
8	Soroda S/M-II	10	7.27	0.012	0.19

Soil fertility was low to medium; available N, P, K and S varied from 166 to 302, 13.76 to 25.58, 114 to 159 and 20.27 to 37.53 kg ha^{-1}, respectively in 0-15 cm soil depth; from 110 to 211, 8.52 to 13.29, 73 to 104 and 12.39 to 23.22 kg ha^{-1}, respectively in 15-30 cm soil depth (Table 3.37).

Table 3.37 Soil fertility (N, P, K & S) in different head, mid- and tail end commands with water users' association (WUA) jurisdictions

Sl. No.	Name of sub-minor canal command	WUA No.	Avail. N (kg/ha)	Avail. P (kg/ha)	Avail. K (kg/ha)	Avail. S (kg/ha)
	0-15 cm soil depth					
1	Odasar S/M	6	216	21.62	155	29.82
2	Mangalpur S/M	2	226	23.26	143	32.12
3	Khamarasahi S/M	8	166	13.76	119	20.27
4	Khairapankalsahi S/M	4	179	20.14	119	23.74
5	Madhyakhand S/M	5	302	18.06	163	37.53
6	Madhyakhand S/M (2)	9	222	16.52	121	30.38
7	Lunisara S/M	10	275	25.58	159	35.72
8	Soroda S/M-II	10	189	16.18	114	23.22
	15-30 cm soil depth					
1	Odasar S/M	6	166	8.99	93	16.37
2	Mangalpur S/M	2	153	12.37	84	19.71
3	Khamarasahi S/M	8	113	11.63	84	12.79
4	Khairapankalsahi S/M	4	112	10.33	73	12.39
5	Madhyakhand S/M	5	211	11.93	104	23.22
6	Madhyakhand S/M (2)	9	154	8.52	79	18.93
7	Lunisara S/M	10	110	13.29	90	22.53
8	Soroda S/M-II	10	143	12.66	69	14.73

3.15.2 Impact on availability of soil micronutrients

Availability of soil micronutrient was assessed and presented in the Table 3.38. It indicates that available Zn and B were deficient by about 25-30% of the samples; Fe, Mn and Cu were not deficient.

Table 3.38 Impact on soil micronutrient environment in different head, mid- and tail end commands

Sl. No.	Name of sub-minor canal command	Avail. Fe (ppm)	Avail. Mn (ppm)	Avail. Cu (ppm)	Avail. Zn (ppm)	Avail. B (ppm)
	0-15 cm soil depth					
1	Odasar S/M	32.85	22.17	0.79	0.67	0.49
2	Mangalpur S/M	33.15	41.74	0.82	0.58	0.69
3	Khamarasahi S/M	33.84	28.24	0.55	0.75	0.57
4	Khairapankalsahi S/M	35.94	27.38	0.38	0.83	0.55
5	Madhyakhand S/M	26.73	32.57	0.66	0.46	0.63
6	Madhyakhand S/M (2)	25.39	30.13	0.95	0.53	0.47
7	Lunisara S/M	32.93	32.11	0.79	0.79	0.64
8	Soroda S/M-II	34.22	26.29	0.88	0.61	0.43
	15-30 cm soil depth					
1	Odasar S/M	26.83	17.29	0.52	0.33	0.28
2	Mangalpur S/M	29.48	29.39	0.53	0.21	0.35
3	Khamarasahi S/M	27.98	22.49	0.32	0.21	0.28
4	Khairapankalsahi S/M	33.7	15.58	0.25	0.27	0.25
5	Madhyakhand S/M	20.81	24.83	0.47	0.25	0.32
6	Madhyakhand S/M (2)	20.71	26.11	0.58	0.29	0.18
7	Lunisara S/M	30.22	19.36	0.39	0.29	0.22
8	Soroda S/M-II	30.19	20.38	0.52	0.18	0.27

3.15.3 Studies on pond water quality in the command area

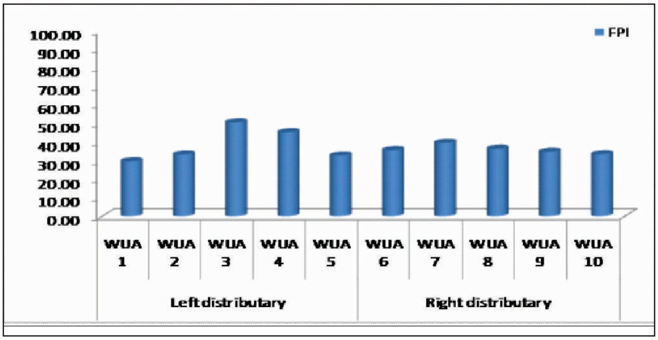
A study was carried out on chemical quality parameters of pond in Kuanria command area. Chemical parameters was determined in the laboratory, as listed in Table 3.39. It indicated that mean values of each parameter was within the permissible limits for irrigation purpose as per the FAO guidelines. The recorded mean minimum and maximum values of various water quality parameters were: water temperature 28.8-34.6 ^{0}C; water pH 6.4-8.9; dissolved oxygen (DO) 4.4-7.3 ppm; total alkalinity 92-133 ppm; dissolved organic matter 2.9-5.6 ppm; nitrite-N 0.006-0.08 ppm; nitrate-N 0.06-0.62 ppm; ammonia-N 0.01-0.3 ppm; water transparency 34$\pm$8; and total suspended solid (TSS) 228-437 ppm. The TSS and DO concentration showed a decreasing trend with the advancement of fish rearing in the ponds; while, gradual increase in nitrite, nitrate, ammonia were attributed by increased level of metabolites and organic matter.

Table 3.39 Quality of pond water in the canal commands in Daspalla, Nayagarh

Water quality parameters	Pond water quality	
	Mean (±s.d.)	Range
pH	7.68 (±0.35)	7.26-8.18
EC (µS cm^{-1})	506 (±185)	267-640
TDS (mg l^{-1})	248 (±91)	131-314
Na (me l^{-1})	2.66 (±1.18)	1.21-3.78
K (me l^{-1})	0.34 (±0.16)	0.21-0.55
P (ppm)	2.40 (±1.18)	0.70-4.20
Ca (me l^{-1})	0.98 (±0.21)	0.70-1.30
Mg (me l^{-1})	0.73 (±0.24)	0.50-1.10
NH_4-N (mg l^{-1})	14.0(±4.43)	10.5-21.0
NO_3-N (mg l^{-1})	20.42 (±6.79)	14.00-31.5
Cl (me l^{-1})	2.03 (±1.12)	0.70-3.25
HCO_3 (me l^{-1})	9.33 (±2.73)	6.00-13.00

s.d. is standard deviation

3.16 Farmers' participation



The farmers' participation in different WUA activities is indicated through farmers participation index (FPI) (Fig. 3.17). It is evident that overall participation of the members was below average in case of all WUAs which might be due to the fact that major responsibilities in WUA's activities were often taken up by the executive committee members and involvement of general members was low. WUA3 was having highest FPI value followed by WUA4 and WUA7. The farmers' participation was the lowest in WUA1. It was interesting to note that jurisdiction areas of WUA1 and WUA2 fall under head reach of left distributary and farmers comparatively face less difficulty with respect to irrigation service leading to relatively lower participation in WUA activities. There was not much difference in extent of participation in the WUAs under right distributary.

4. Discussion

The overall agricultural strength of the command area indicates that the area is rich in natural resources. Soil fertility is favourable for agricultural production systems (Mandal et al., 2013a & b). Most of the farm families (~85%) depend on agriculture. Total literacy percent is about 52% (male above 65%, female 40%) which facilitates adoption of new technologies. Geo-climatic condition and its soil are suitable for pisciculture also. The area is endowed with good amount of annual rainfall, of course its distribution over different agricultural seasons was not uniform. On an average 75.8% of the annual rainfall is received during monsoon season. Pre- and post-monsoon rainfall contributed only 10.6 and 10.4% of the total annual rainfall in the study area; rest 3.2% rainfall occurred during winter season (Mandal et al., 2013b, 2015b).

The study reveals that a considerable amount of rainfall is lost through surface runoff. In case of rainfall of high intensity, only a part of it enters and stored in the root zone and the quantity of effective rainfall is low. In this region, in general, farmers keep their lands fallow after harvesting of rainy season rice because, only 162.6 mm of rainfall takes place during post-monsoon season (Oct-Dec) and 48.6 mm in winter (Jan-Feb). Therefore, it is essential that every farm entity should have a service reservoir (Srivastava et al., 2009; Mohanty et al., 2014) so that the farmer can use the harvested water at his/ her convenience for irrigation to post-monsoon and winter season crops. Our study revealed that there is considerable amount of seepage loss from the main reservoir i.e., Kuanria dam, which amounts to 246-362 ha m annually. This calls for management intervention to prevent the losses in one hand, and utilization of the seepage water for crops or recharging ponds and groundwater on the other. As the canal water supply during lean months is less compared to the demand, the water storage tanks facilitated irrigation to crops within its pond-command areas as well as ponds have been favourable for fish culture, on-dyke horticulture and also for community use. The excess canal water supplied during monsoon season was stored in the pond. This is immensely important for enhancing the cropping intensity and increasing crop and fish production.

The comparison on head-, mid-reach and tail-end soils shows that texture for all the soil layers sandy clay or sandy clay loam except the site under WUA 5 i.e. at the tail end of the canal system where soils are clayey (Mandal et al., 2013d); water availability through canal supply is relatively less than the mid or head reaches; water storage for longer duration facilitates fish culture and irrigation to crops for extended period. It has the scope for improving SOC in soils (Mandal et al., 2012). Saturated hydraulic conductivity values of tail reach soils of left distributaries were lower in comparison to tail reach soils of right distributaries. As the soil properties were different for head, mid and tail reach soils of left and right distributaries under Kuanria command area, management of irrigation is required appropriately for optimal use of canal water, rainwater and groundwater. The study of hydraulic conductivity of soils give an insight into proper management in terms of storage in the ponds and recharging potential in the open wells, improvement of water productivity can be achieved.

Based on these hydrological relationships, it is observed that tail end soils are more retentive than mid-reach as has been reflected from the slope of log (θ-Ψ) relationships. This gives an insight into the ways for efficient management of water. The study on the canal water supply, delivery mechanism, availability of water, supply-demand gap etc. along with groundwater development would form the basis of further policy making on enhancing irrigation efficiency. The improvement of system efficiency would be possible in conjunction with infrastructure development, efficient management of rainwater and appropriate crop planning.

There is an ample scope of fish farming in the command especially in the water storage tanks. Our study reveals that farmers are interested for this important component of integrated farming from where farm income increases many fold compared to command area where pond facility is not there. There is assured demand of fish by the surrounding people. There is good market in Nayagarh, Khurda and also in Bhubaneswar; hence a tremendous scope for development of pond-based integrated farming systems for overall improvement of crop production, farm income and livelihood improvement of farmers.

The construction of open wells facilitated conjunctive use of water for growing of different crops, through providing irrigation during critical growth stages and at the time of dry spells. Harvesting the excess rainfall, even a small fraction, and utilizing the same for supplemental irrigation would mitigate the impacts of dry spells in rainfed regions (Rockström, 2001; Jain and Kumar, 2012). Adoption of pressurized irrigation, as advocated by previous researchers (Srivastava et al., 2010), during post-monsoon season would be useful for enhancing the water use efficiency of crops. Another approach would be growing of short duration and low water-requiring crops like groundnut, maize, sorghum, green gram, sunflower, field bean, cowpea, aerobic rice and others which have high monetary return (Mandal et al., 2013c, 2014, 2015a). Pigeon pea is a very good crop for growing in this area under upland situation and on the bunds separated by rice fields. Another advantage of growing short duration cereals, pulses and oilseeds in the first fortnight of June is that these crops can be harvested by the end of September and short duration post-monsoon crops can be sown during October. Hence, careful management of water should be the basis for improving water and crop productivity.

Agricultural production systems are under pressure due to changes in rainfall pattern and hydrological regimes and greater dependency on land and water resources. Along with the canal water, rainwater management and its optimum utilization is a prime issue of present day for sustainability of agriculture. Innovations in soil, water and crop management are required for enhancing production in the region. There is the need for efficient management practices, proper maintenance and further modernization of existing infrastructures, command area development, participatory irrigation management and improved agricultural practices.

5. Summary and Conclusions

The eastern part of India has one of the most favourable ecosystem for agriculture, yet the agricultural production is much lower than its potential. Rice-fallow is the most common practice in the command. Farmers keep their fields fallow after kharif season because water availability is very unreliable and undependable. Attempts were made to study the technical, operational, environmental and economic feasibility of a canal system, Kuanria Medium Irrigation project (KIP) in Daspalla block of Nayagarh district in Odisha, augmented with rainwater harvesting and well systems for supplementing canal waters and integrated farming system including fish, vegetables and pulses production. Project site has been characterized with respect to physiography, topography, geohydrology, soil characteristics, rainfall pattern and land use etc.

Interventions were made through construction of rain/ runoff water storage tanks and open wells under in the canal command area. The study was also made on the feasibility of integrated farming system including fish culture, crop cultivation and on-dyke horticulture with augmented water that was harvested in storage tanks and open wells. Improving water productivity under canal irrigation command through conservation of rainwater and groundwater using tanks and wells has been implemented and demonstrated through participatory development of eight water storage tanks and dug wells at different villages in the command area.

The soil of the command area is light to medium textured i.e., sandy clay to sandy clay loam having 29.6- 53.8% clay in the head and mid-reaches, and heavy i.e., clay in the tail end of the canal systems; pH slightly acidic to neutral; bulk density ranged from 1.40 to 1.47 Mg m^{-3}; EC varied from 0.01 to 0.02 dS m^{-1} and soil organic C was low, mostly less than 0.5%. Saturated hydraulic conductivity (Ks) in mid-reach soils was higher than the tail-end soils, but available water content (AWC) in mid reach soils were lower than tail-end soils. The hydraulic properties of soils and the functional θ-Ψ relationships of different soil properties were also developed for soils of tail and mid reaches.

Total annual rainfall in Daspalla region ranged between 993.5 and 1901.8 mm with an average of 1509.2 mm (14.8% CV). The variation in rainfall was less during the pre-monsoon period and during the period of November to May. Maximum amount of rainfall occurred during the monsoon months i.e., June-September i.e., 75, 81.4, 74.5 and 53.5, 75% in the year 2010, 2011, 2012, 2013 and 2014, respectively; and the least or no rainfall occurred during the months of December to March every year.

Runoff was estimated for Kuanria irrigation project of Daspalla using 20 years (1995-2014) of rainfall. On an average, the area receives 1532 mm of rainfall annually. It was estimated that on an average 386 mm i.e., 25.2% of actual rainfall is going as runoff in each year from the study area, again out of which 24% of annual runoff occurs during monsoon months. Monthly seepage losses from the reservoir and canal during the year 2011-13 show that it was the maximum during the months of January to May.

Total seepage losses were 352, 246.25 and 262 ha m in 2011, 2012 and 2013, respectively. Seepage losses from the reservoir during 2014-15 were the maximum in the months of January to May. Total seepage losses were 362 ha m in 2014 and 73 ha m in Jan-Feb in 2015; 319 ha m in Jan-May 2015; 89 ha m in Dec 2014 to Feb 2015.

The cropping system is predominantly rice-based. Rice is being grown during rainy season and green gram is mostly grown during post-monsoon season. Arhar is also grown in upland areas. Among vegetables, brinjal is leading. Rice, brinjal and green gram occupy about 90.4, 8.8 and 10.6% of the total command area, respectively. Sugarcane crop occupied about 2-3% and vegetables 2-11% of the total cultivable command area during the kharif season. During rabi seasons, pulses and sesame occupied about 61 and 83% of the CCA in left and right distributary, respectively. Average farm size in the study area was 3.6 acre; 76.6% of total farmers belong to medium household and remaining small (14.1%), large (6.3%) and very large (3.1%).

The catchment area of the reservoir is 124 km^2; project irrigates 3780 ha out of GCA of 4800 ha benefiting about 37,000 people living in 67 villages under the command area. Maximum height of dam from deepest level was 21 m, flood reservoir level (FRL) 135.7 m, dead storage level (DSL) 130.3 m. Mean monthly reservoir water level for the year 2011-2015 has been monitored. There was variation in water level over years. In the year 2012, the level was lower than the other years. During the year 2013, monthly reservoir level was 135.56 m in January; it drops to 133.63 m in the month of May and then with the rainfall received it was raised gradually to 135.60 m in November 2013. During the year 2014-15, monthly reservoir level was 135.54 m in January 2014; it drops to 133.98 m in the month of June 2014 and then with the rainfall received it raised gradually to 135.47 m in September 2014. Reservoir level in January and February 2015 was much lower than those of January-February 2014 because of more canal water supply during 2015. Canal water delivery and supply for each year of the study has been reported in details.

Groundwater fluctuation data were collected and it was observed that groundwater fluctuation varied in different observation wells. Studies were carried out to assess the groundwater fluctuation and dynamics over the year in the command area in five representative sites viz. one in head reach in the RD under Odasar s/m, one in mid-reach in the RD at Khamarsahi s/m, one in mid-reach in the LD at Mangalpur s/m, one in tail-end in the RD at Soroda s/m-II and one in tail-end in the LD at Madhyakhanda s/m. Overall trend is that the depth of groundwater decreases during rainy season due to monsoon rainfall. There is high potential to explore groundwater for irrigation. A study was carried out on chemical quality parameters of groundwater. It indicated that mean values of each parameter was within the permissible limits for irrigation purpose as per the FAO guidelines.

Fish production was successful in the newly constructed ponds. The production and performance index, and fish water productivity were studied for four water storage tanks. Indian major carps i.e., IMCs (Catla catla, Labeo rohita and C. mrigala) were stocked @ 5,000/ha with a stocking composition of 30:30:40 in each pond. After 210 days of rearing, harvesting was carried out. The recorded fish production ranged between 2.45-2.96 t ha^{-1} $210d^{-1}$. Species-wise production-size index ranged between 540.7-609.6, 241.1-279.2, and 338.6-382.4 for Catla catla, Labeo rohita and C. mrigala respectively. Similarly, the species-wise performance index ranged between 274.2-303.5, 196.7-210.9, and 200.1-209.4 for *Catla catla, Labeo rohita* and *C. Mrigala,* respectively, indicating the normal growth performance of the cultured species. Pond-wise gross water productivity ranged between 6.47-7.85 Rs m^{-3} while the net water productivity ranged between 4.6-5.86 Rs m^{-3}. Water quality like water temperature, pH, dissolved oxygen, total alkalinity, dissolved organic matter; nitrite and nitrate N, ammonia, suspended solid etc. were assessed.

Soil fertility was low to medium; available N, P, K and S varied from 166 to 302, 13.76 to 25.58, 114 to 159 and 20.27 to 37.53 kg ha-1, respectively in 0-15 cm soil depth; from 110 to 211, 8.52 to 13.29, 73 to 104 and 12.39 to 23.22 kg ha^{-1}, respectively in 15-30 cm soil depth. A study was carried out on chemical quality parameters of pond water in Kuanria command area. The recorded mean minimum and maximum values of various water quality parameters were: water temperature 28.8-34.6 0C; water pH 6.4-8.9; dissolved oxygen (DO) 4.4-7.3 ppm; total alkalinity 92-133 ppm; dissolved organic matter 2.9-5.6 ppm; nitrite-N 0.006-0.08 ppm; nitrate-N 0.06-0.62 ppm; ammonia-N 0.01-0.3 ppm; water transparency 34+8; and total suspended solid (TSS) 228-437 ppm. The TSS and DO concentration showed a decreasing trend with the advancement of fish rearing in the ponds; while, gradual increase in nitrite, nitrate, ammonia were attributed by increased level of metabolites and organic matter. All the parameters in pond and the open well water were in permissible limits for irrigation to crops.

Studies were conducted on multiple use of stored water through integrated farming system of crop cultivation, crop and fish culture due to pond-based intervention under different sub-minors viz. Khamarasahi sub-minor, Madhyakhanda sub-minor (2), Lunisara sub-minor, Soroda sub-minor-II. Pond-commands were compared with non-command areas of the same farmer. Even during kharif season, when rainfall was not distributed uniformly, irrigation to kharif rice was beneficial in most of the pond-based systems. During rabi season, supplementary irrigation to pigeonpea, greengram, blackgram, sunflower, vegetables and chickpea could be given and yield of crops was enhanced compared to non-command area.

The integrated farming systems were developed under different sites (head-, mid- and tail end) of the canal command viz. Odasar S/M, Mangalpur S/M, Khamarasahi S/M, Khairapankalsahi S/M, Madhyakhanda S/M, Madhyakhanda S/M (second site), Lunisara S/M and Soroda S/M-II. Fish production was 1.32-5.20 t ha^{-1} with gross water productivity of 5.29-21.48 Rs m^{-3} and net water productivity of 3.52-15.66 Rs m^{-3}. Water productivity of crops and overall water productivity was improved due to intervention through construction of rain/ runoff water storage tanks and open wells with total return of Rs 34,663 to Rs 2,23,270. Multiple use of harvested water was meant for on-dyke horticultural crops, fish culture (rohu, catla and mrigal) and life saving irrigation to field crops in the command area especially during dry/ lean period. The life saving irrigation was found beneficial to rice nursery in the command area during the drought period prior to late onset of monsoon in 2014.

Development of appropriate cropping systems was made and assessment of economic benefit of pond-based integrated farming in the canal command was made. Rice-fallow is a predominant cropping system. Due to intervention by construction of rain/ runoff water storage tanks and open wells, better cropping systems have been followed in the intervention area. Our experiments showed that better and appropriate cropping system was rice + (fish in pond) -greengram, rice + (fish in pond) -blackgram and rice + (fish in pond) -chickpea compared to rice-fallow, rice-greengram and rice-blackgram in the Khamarsahi sub-minor; rice + (fish in pond) +pigeonpea (on dyke) -greengram and rice + (fish in pond) + pigeonpea (on-dyke)-pigeonpea (on dyke) compared to rice-fallow and rice-greegram only in Madhyakhanda sub-minor; rice+(fish in pond) -greengram compared to rice-fallow cropping system in Lunisara sub-minor; and rice+(fish in pond) -greengram compared to rice-fallow cropping system in Soroda sub-minor under the KIP command in the study area.

The economic assessment of pond-based integrated farming was made in comparison to the same canal, which has no such system i.e., without pond-based system. Non-pond system involved only crop component whereas pond-based system integrated crop, fish and on-dyke horticultural crop components. The cost of cultivation for the system, including the cost for kharif crop, fish culture and rabi crops, ranged from Rs 1,19,772 to Rs 1,24,230 and the benefit was Rs 1,37,210 to Rs 1,74,012 in the pond-based interventions. Water productivity of crops and overall water productivity was improved due to intervention through construction of rain/ runoff water storage tanks and open wells.

Studies were conducted for monitoring of water quality in pond and open well. Water temperature was 28.8-34.6 ^{0}C; water pH 6.4-8.9; dissolved oxygen (DO) 4.4-7.3 ppm; total alkalinity 92 - 133 ppm; dissolved organic matter 2.9- 5.6 ppm; nitrite –N 0.006-0.08 ppm; nitrate-N 0.06-0.62 ppm; ammonia-N 0.01-0.3 ppm; water transparency 34$\pm$8; and total suspended solid (TSS) 228 - 437 ppm. The TSS and DO concentration showed a decreasing trend with the advancement of fish rearing in the ponds; while, gradual increase in nitrite, nitrate, ammonia were attributed by increased level of metabolites and organic matter.

Conjunctive use of water facilitated alternate cropping systems viz. rice + (fish in pond)-maize, rice + (fish in pond)-vegetables (bhindi/ tomato/ cauliflower/ onion/ pointed gourd/ brinjal/ pumpkin etc.), rice + (fish in pond) + on-dyke vegetables/ papaya/ banana/ arhar vegetable (on dyke)-green gram/ black gram/ ragi etc., rice + (fish in pond)-green gram, rice + (fish in pond)-black gram, rice + (fish in pond)-arhar, rice + (fish in pond)-sesame and rice + (fish in pond)-ragi. The excess canal water and rain water stored in tanks and dug wells provided irrigation to post-monsoon crops, and thereby enhanced productivity of dry season crops and improved livelihood of farmers.

It can be concluded that infrastructure development under the canal command in a participatory mode and adopting appropriate integrated farming system will improve both land and water productivity through augmented water resources. There will be definite social and economic impact of the beneficiary farmers through the integration of multi-enterprise components viz. fish culture, high value horticulture crops and remunerative diversified field crops. This will improve livelihood of farmers without affecting the environment. Participatory development of integrated crop & fish culture systems accrue greater economic return to the farmers and improvement in water productivity; greater success depends on financial support to the farmers, economic condition of the farmer, extent of farmers' participation, functioning of WUA, liaison with Government departments, and capacity development of the farmers. Hence, there is need for participatory integrated water management (PIWM) in canal commands in future along with capacity building of farmers through training and demonstration for enhancing agricultural productivity.

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भाकृअनुप-भारतीय जल प्रबंधन संस्थान
ICAR - Indian Institute of Water Management
(An ISO 9001:2008 Certified Organization)
Bhubaneswar-751 023, Odisha, India
Web: http://www.iiwm.res.in
E-mail: director.iiwm@icar.gov.in