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Name of R&D Scheme	**Improving Water Productivity under Canal Irrigation Command through Conservation and Recycling of Runoff, Seepage, Rainwater and Groundwater using Tanks and Wells**
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Completion Report

R & D Scheme

Improving Water Productivity under Canal Irrigation Command through Conservation and Recycling of Runoff, Seepage, Rainwater and Groundwater using Tanks and Wells

ICAR-Indian Institute of Water Management
(Formerly Directorate of Water Management)
Chandrasekharpur, Bhubaneswar-751 023
Odisha

Sponsored by
INCSW (formerly INCID), Central Water Commission
Ministry of Water Resources, Govt. of India

1. Title of the Scheme

"**Improving water productivity under canal irrigation command through conservation and recycling of runoff, seepage, rainwater and ground water using tanks and wells**"

MoWR, Govt. of India Sanction: No. 21/108/2009- R&D/ 432-440 dated Feb 18, 2010

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4. Financial details (Sanction cost; amount released; expenditure; unspent balance (if any) and return of unspent balance)

Please see the attached sheets (scanned copies) at the end of this report

5. Utilisation certificates (Utilisation certificates (UCs) for the Financial Years 2015-18; Final utilisation certificate; Expenditure statements)

Please see the attached sheets (scanned copies) at the end of this report

6. Statement of equipment purchased under the scheme and their condition/ scope for further use etc.

Please see the attached sheet (scanned copy) at the end of this report

[Signed sheets in original: sent by speed post on 18.02.2021]

7. Original Objectives and Methodology as in the Sanctioned Proposal

Original Objectives

1. To study the feasibility of harvesting, storage and conservation of canal, seepage water, runoff and rainwater in storage tanks in a command area for irrigation and fish production
2. To evaluate the performance of the new system in terms of water availability, change in cropping intensity and agricultural productivity; compare the same with another distributaries in the command of the same canal, which has no such system
3. To study the conjunctive use of canal and groundwater in the command area for enhancing agricultural productivity during lean/ dry seasons
4. To study social, economic and environmental consequences of newly developed irrigation system

Rational: Most of the canal projects suffer from inadequate supply and poor reliability of water 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 rain water in storage tank during rainy season and by recycling the same for life saving irrigation during post rainy season. 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) introduced in command area as per needs. By switching over to supplementing canal water through rain water 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 the production and crop diversification.

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. For instance, agricultural growth in Odisha averaged just over 1% per annum over the last two decades. Even though several factors are responsible for poor growth of agricultural productivity or production, 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.

In India, tank irrigation is an age-old practice. Most of them are independent source of water supply. Many of these tanks located in the commands could be made adjunct to the existing canal system. 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. This study examined technical, economic and other feasibility of a canal irrigation system supplemented by water availability through rainwater harvesting and shallow wells, and crop diversification including fish, vegetables and flower production in canal command.

Methodology

The study was proposed to be carried out in *Kuanria Medium Irrigation project in Nayagarh district of Orissa. Nayagarh district* is located towards the west of Puri district surrounded by Cuttack district in the north, Phulbani district in the west, Ganjam district in the south and Khurda district in the east. The district of Nayagarh lies between 19o54’ to 20o32’ North latitude and 84o29’ to 85o27’ East longitude. This district is situated in the hilly ranges in the west and its north eastern parts have formed a small well cultivated fertile valley intersected by small streams. This district is in the higher altitude than the sea level and above flood level. The river Mahanadi flows in the eastern boundary. The climate of the district is characterized by high temperatures during summer months and low temperature during winter. The geographical area of the district is 4242 sq km. The district has one subdivision and four Tahasils. The project area serves two blocks, viz. Daspalla and Nuagaon. The geographical area of Daspalla and Nuagaon blocks is 571.57 and 385.24 sq km, respectively. The total number of villages under these two blocks comes to 560 out of which 90 are uninhabited villages. There are 216 villages under Nuagaon block and 344 villages under Daspalla block. The project irrigates 3780 ha of land benefiting about 37,000 people living in 67 villages under the command area.

Distributaries/minors/subminors:

Canal	Total length in km	Portion lined in km (%)	Portion unlined in km (%)	Whether volumetric devices/ discharge measuring structures exist
Left distributary	16.500	0.06 (0.36%)	16.44 (99.64%)	Yes
Right distributary	18.200	--	18.20 (100%)	Yes
Minors and subminors	49.864	4.4 (8.82%)	45.46 (91.18%)	Yes

Storage

Year of first impounding	Gross (ha m)	Dead (ha m)	Live (ha m)	FRL (m)
1988	2200	450	1750	135.7

Major project activities

i. Site identification, soil characterization under canal irrigation commands
ii. Collection of data on availability of water in canal command area through dry and wet season
iii. To measure the portion of water subject to runoff and seepage
iv. Measurement of groundwater fluctuation and quality in canal irrigation commands
v. Construction of seepage/rain/runoff water storage tanks under canal irrigation commands

vi. Study the cropping systems, productivity levels and the existing socio-economic status of the farmers in canal irrigation commands
vii. Construction of open/dug wells under canal irrigation commands for using ground water in dry season
viii. Measurement of soil fertility and water quality in the canal command
ix. Development of appropriate cropping systems according to the availability of water in the storage tanks, wells and canal
x. Multiple use of water stored in canal commands through integrated farming system involving fishery etc.
xi. Impact assessment on availability of water, crop and fish production, groundwater dynamics, environmental and other issues.

8. Any Changes in the Objectives during the Operation of the Scheme: -No-

9. All data collected and used in the analysis with sources of data

To achieve the objectives, data collection and analysis with source of data have been presented hereunder.

Detailed methodology actually followed has been presented under the **sub-head no. 10.**

No.	Objectives	Data Collection and Sources
1.	To study the feasibility of harvesting, storage and conservation of canal, seepage water, runoff and rainwater in storage tanks in a command area for irrigation and fish production	Study site has been characterized using the secondary data from Kuanria Medium Irrigation Project (KIP) at Daspalla, Nayagarh district of Orissa. Agro-ecological conditions using 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. Secondary data used for ayacut map of the command, irrigation from dam, number of people benefited, number of villages, and basic information from KIP, at Daspalla, Nayagarh district of Orissa, and records from block/ panchayat office of Daspalla. Secondary data on geology (from 5 points, once) obtained from records of the Govt of Odisha (please refer page no. 13 in this report); land use pattern from District Statistical Handbook, Nayagarh, Department of Economics and Statistics, Odisha Soil characterisation by primary data of soils of the command, collected (upto 120 cm) and analysed (methods and points of observations, page no 14-16). Secondary data weather data were collected from records of KIP at Daspalla and Nayagarh district office (Please see detailed methods, years etc. in page no. 19-22, 26, 29) Effective rainfall, Runoff, rainfall-runoff relationship were developed using standard methods (Please refer page no. 31-32). Secondary and primary data, and information on canal water availability, dam data, water supply, time schedule and discharge rate from dam data and records

		maintained at Kuanria Irrigation Sub-division, Daspalla, Nayagarh (please refer detail methods, frequency etc. in page no 36, 37-46).
2.	To evaluate the performance of the new system in terms of water availability, change in cropping intensity and agricultural productivity; compare the same with another distributaries in the command of the same canal, which has no such system	Secondary data on groundwater fluctuation (6 observation wells, 4 times in year; please refer page no. 51); primary data on groundwater fluctuation (5 dug wells, monthly for 5 years, please refer page no. 51) and groundwater quality twice in a year before monsoon and post-monsoon). Secondary data on cropping pattern, agricultural practices and socio-economic status of the farmers (detailed in page no. 59, 63); Primary data on soil fertility from 8 sub-minors; Primary data on water availability in storage tanks (in 8 sites, monthly observation, 3 years, please refer page no. 91) Primary data on appropriate cropping systems were developed and economic assessments were made due to pond-based intervention using standard methods. Primary data on the new system has been compared with water storage tank and without water storage tanks in another distributaries in the command of the same canal, which has no such system.
3.	To study the conjunctive use of canal and groundwater in the command area for enhancing agricultural productivity during lean/ dry seasons	Primary data on physical and economic water productivity (for detailed method, calculation please refer page no. 93, Primary data for conjunctive use and study on multiple uses of stored water, and development of pond-based integrated farming system has been made; Primary data used to assess appropriate cropping systems were developed in the pond-based sites for enhancing agricultural productivity during lean/ dry seasons
4.	To study social, economic and environmental consequences of newly developed irrigation system	Secondary data for social and economic assessments has been made using data collected from WUAs of the KIP canal command, and also using primary data collected through questionnaire survey for participation index (please refer page no 110-111); Primary data on groundwater quality twice in a year before monsoon and post-monsoon). Primary data used to study soil fertility and water quality using primary data obtained from various sub-minors, as to assess the impact (detailed methods, observations points etc., please refer page no 66-67) Primary data used to study on impact assessment on availability of water, crop and fish production, groundwater dynamics, environmental and other issues.

10. Methodology Actually Followed
[Observations, Analysis, Results and Inferences]

10.1 The study location: site characterization, physiography, topography, geohydrology and land use

Site characterization

The study has been carried out in the Kuanria Medium Irrigation Project (KIP) at Daspalla, Nayagarh district of Orissa (Fig. 1.1). It 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. 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 district is in the higher altitude than the sea level and above the flood level. The climate of the district is characterized by high temperatures during summer months and low temperature during winter. The geographical area of the district is 4242 km^2. Its boundary touches the district border of Cuttack, Angul, Boudh, Kandhamal and Ganjam. Daspalla is situated in the middle of Odisha. The ayacut map of the command is presented in Fig. 1.2.

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. It 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. The project irrigates 3780 ha of land benefitting about 37000 people living in 67 villages under the command area. The total number of villages under these 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.

Climatic conditions of the study area

Rainfall patterns have been discussed in details in a separate section in this report. 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. 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 ^0C and mean minimum temperature was 19.5 ^0C. The highest temperature occurs in the month of May. Winter is experienced from November to January. The mean wind speed in terms of km h^{-1} for all the months of the year has been presented in Table 1.1. It is observed that the wind speed is generally moderate with increase in rainy season due to south-west monsoon. 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%.

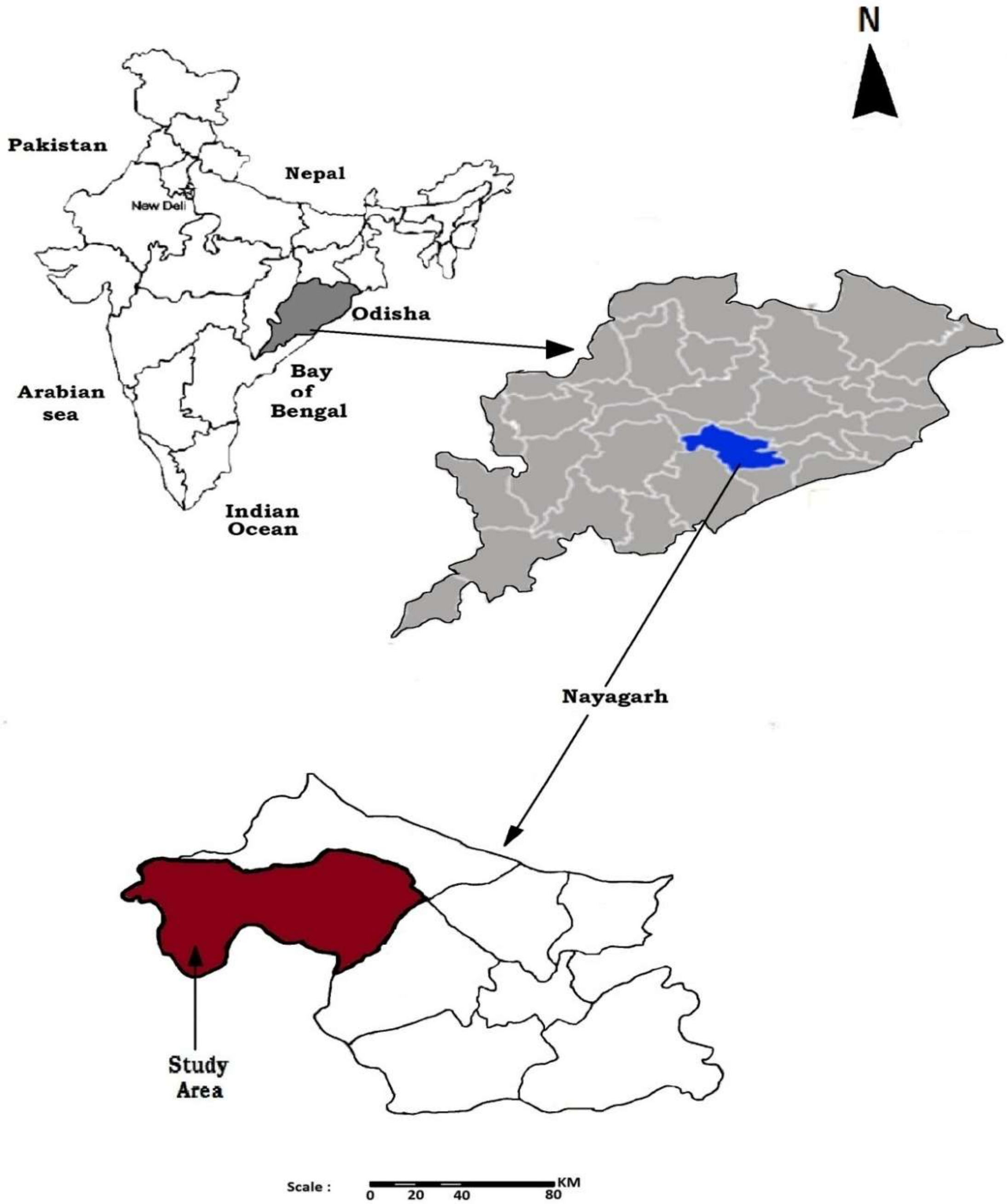


Fig. 1.1 The study area i.e., Daspalla region of Nayagarh district in Odisha

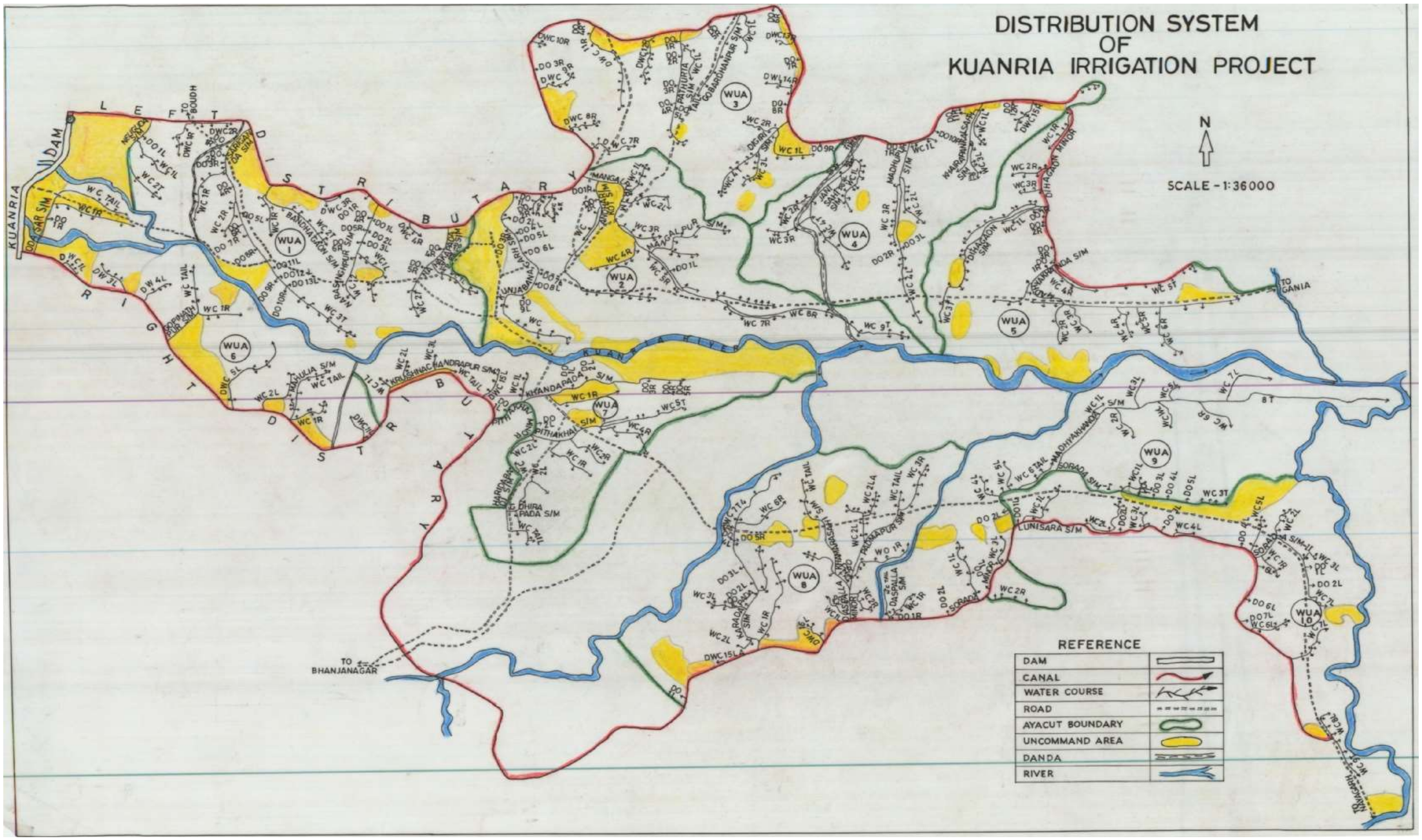


Fig. 1.2 Ayacut Map of Kuanria Irrigation Project (KIP) at Daspalla, Nayagarh district of Odisha

Table 1.1 Month-wise average weather condition of the study area, Daspalla, Nayagarh district of Odisha

Months	Average temperature (^0C)	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

Soil characteristics

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 taken in the command. It has about 39, 49 and 9% of area by acidic, neutral and alkaline soils, respectively.

Topography, physiographic zone & 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 the rocks of eastern ghat mobile belt. It comprises mainly granitic gneiss, charnokite, khondalite etc. 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 geological characteristics of the area have been presented in Table 1.2. 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. The detailed hydrological characteristics have been presented under a separate section on water availability.

Table 1.2 Characteristic geology of the area at different villages in the Daspalla block

Observation well no. & well type	Village name in Daspalla block	Latitude	Longitude	Geology
73D-3C1, dug well	Banigocha	$20^0 23'43''$ N	$84^0 35'22''$ E	Granite gneiss
73D-3C2A, dug well	Takara	$20^0 23'50''$ N	$84^0 36'54''$ E	Granite gneiss
73D-3D1, dug well	Daspalla-I	$20^0 20'14''$ N	$84^0 51'25''$ E	Alluvium
73D-3D3, dug well	Daspalla-II	$20^0 19'48''$ N	$84^0 51'17''$ E	Alluvium
73D-3D4, dug well	Subalaya	$20^0 19'02''$ N	$84^0 54'25''$ E	Granite gneiss

Land use pattern

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. The detailed land use pattern is presented in the form of a Table 1.3. The area under current fallow is quite high, and the maximum in Daspalla block among all eight blocks of Nayagarh district.

Table 1.3 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.

The overall agricultural strength of the area indicates that the area is rich in natural resources like rivers and streams. Soil fertility is favourable due to forest litters and more humus content. Most of the farm families (~85%) depend on agriculture. Total literacy percent is about 52% (male above 65%, female 40%) which facilitates the adoption of new technologies. Geo-climatic condition and its soil are suitable for pisciculture. There is assured demand of fish in Bhubaneswar, the capital city. There are weaknesses also. Irrigation potentiality is low, undulating topography; women farmers are less involved in agriculture sector. The ground water utilization is low. There are weak marketing facilities, inadequate cold storage facility; inadequate credit support to fish farmers. The threats are also there. Major pulses are grown under residual soil moisture condition with local varieties. Natural calamities with drought situation occur due to erratic and uneven distribution of rainfall during *kharif* season.

Interference of middle men in marketing network of agriculture produces. However, there are opportunities for development of marketing facilities as good communication facilities to state capital have been developed. Sugarcane cultivation can be developed as the industry is located in the district. Organic farming can be developed due to low consumption of chemical fertilizer in certain pockets.

There were eight intervention sites for implementation of the project activities as shown Table 1.4.

Table 1.4 Intervention sites in different head, mid- and tail ends under different water users' association (WUA) jurisdictions

Sl. No.	Name of the village	Name of sub-minor canal	WUA No.	Distributary	Canal reach
1	Odasar	Odasar S/M	6	RD	Head reach
2	Kunjabanagarh	Mangalpur S/M	2	LD	Middle reach
3	Paikabaghuarani	Khamarasahi S/M	8	RD	Middle reach
4	Malisahi	Khairapankalsahi S/M	4	LD	Tail- end
5	Dwargaon	Madhyakhand S/M	5	LD	Tail- end
6	Dendabhuin	Madhyakhand S/M (2)	9	RD	Tail- end
7	Soroda	Lunisara S/M	10	RD	Tail- end
8	Subalaya	Soroda S/M-II	10	RD	Tail- end

10.2 Soil characterization: physico-chemical and hydrological characteristics under the command area

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 and are presented in the following section.

Head-reaches of the command

Soil properties in the head-reaches in the command area were determined and presented (Table 2.1). It falls in the Odasar s/m of right distributary under the jurisdiction WUA 6. It was observed that, texture in the 0-30 cm soil layer was sandy clay loam while in other layers it was sandy clay in the head-reach of the Kuanria command area. There was little variation of bulk density among different soil layers. EC values were quite less for all the soil layers (i.e. 0.01 to 0.06 dS m^{-1}). Soil was slightly acidic to alkaline in nature. 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 2.1 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 cm/h	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

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 (SOC) content varied between 0.27 and 0.67%. Saturated hydraulic conductivity (Ks) varied from 0.011 to 0.026 cm h^{-1} for all the soil layers (Table 2.2).

Table 2.2 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 cm/h	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

Similarly, in the right distributaries, soil properties were determined for the mid-reach areas under Khamarsahi s/m (Table 2.3), Khandapada s/m (Table 2.4) and Kunjabanagarh s/m (Table 2.5)

Table 2.3 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 cm/h	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

Table 2.4 Soil properties of mid-reach command area in right distributaries under Khandapada s/m

Soil depth (cm)	Sand (%)	Silt (%)	Clay (%)	Textural class	Bulk density (Mg m^{-3})	EC_2 (dS/m)	pH_2	OC (%)
0-15	68.1	4.2	27.7	scl	1.45	0.02	7.23	0.35
15-30	61.6	5.7	32.7	scl	1.44	0.01	7.49	0.27
30-45	61.1	5.4	33.5	scl	1.46	0.02	7.41	0.24
45-60	59.2	5.6	35.2	sc	1.46	0.01	7.48	0.24
60-90	58.9	5.5	35.6	sc	1.48	0.01	7.34	0.18
90-120	60.6	5.9	33.5	sc	1.50	0.01	7.35	0.15

Table 2.5 Soil properties of mid-reach command area in left distributaries under Kunjabanagarh s/m

Soil depth (cm)	Sand (%)	Silt (%)	Clay (%)	Textural class	Bulk density (Mg m^{-3})	EC_2 (dS/m)	pH_2	OC (%)
0-15	55.0	7.3	37.7	sc	1.46	0.02	6.00	0.50
15-30	57.5	9.8	32.7	scl	1.46	0.02	6.64	0.34
30-45	57.5	7.3	35.2	sc	1.48	0.02	7.40	0.34
45-60	52.5	12.3	35.2	sc	1.48	0.02	7.51	0.21
60-90	55.0	9.8	35.2	sc	1.50	0.02	7.71	0.28
90-120	52.5	12.3	35.2	sc	1.50	0.02	7.79	0.19

Tail-ends of the command

The soils of tail end command areas were analysed for determination of their physical and chemical properties, and are presented in Table 2.6 and 2.7. Texture for all the soil layers was clay loam for the site under Madhyakhanda s/m with the jurisdiction of WUA 5 i.e., at the tail end of the left distributaries under KIP, where water availability through canal supply is relatively less than the mid or head reaches. There was a definite trend that sand content was greater in every soil layer than silt and clay contents, but there was slight difference in different layers of the soil profile. It is revealed that, soil was moderately alkaline in nature. The soil organic carbon (SOC) content decreased as soil depth increased for the site under WUA 5. 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 2.7). Soil pH in this site 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} whereas organic carbon (SOC) content varied between 0.23-0.39 percent. Saturated hydraulic conductivity (Ks) was highest within 0-15 cm soil depth and lowest in 90-120 cm soil depth.

Table 2.6 Soil properties of tail-end command area 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 cm/h	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 7.7 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 cm/h	SOC %
0-15	35.9	15.7	48.4	c	1.51	0.07	8.52	0.072	0.39
15-30	38.4	13.2	48.4	c	1.52	0.03	8.17	0.060	0.33
30-45	43.4	13.2	43.4	c	1.55	0.03	8.25	0.058	0.42
45-60	48.4	10.7	40.9	sc	1.56	0.02	8.33	0.055	0.23
60-90	48.4	10.7	40.9	sc	1.58	0.02	8.45	0.045	0.30
90-120	53.4	10.7	35.9	sc	1.58	0.02	8.57	0.042	0.27

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, different management of irrigation is required for optimal use of canal, rainfall and ground water. Through proper management, improvement of water productivity can be achieved.

Texture of the soil layers in left distributaries under Khairapankalsahi s/m with the jurisdiction of WUA 4 varied from sandy clay to sandy clay loam (Table 2.8). It can be predicted from that, clay content decreased as soil depth increased and there was no definite trend of sand and silt distribution was observed in the soil profile. Soil was slightly acidic to neutral in upper soil layers and alkaline 60-120 cm soil depths. Bulk density of the soil was highest towards the lower depth of soil. EC varied from 0.01 to 0.02 dS m^{-1} and soil organic C varied between 0.05 to 0.37%.

Soil hydrological properties

The hydraulic properties of soils and the functional θ-Ψ relationships of different soil properties were also developed for soils under WUA 5 and 7 i.e., the soils of tail and mid reaches, respectively (Table 2.9 and 2.10). Based on these relationships, water retention potential 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 2.8 Physico-chemical properties of tail-end soils in left distributaries under Khairapankalsahi s/m

Soil depth (cm)	Sand (%)	Silt (%)	Clay (%)	Textural class	Bulk density (Mg m^{-3})	EC_2 (dS/m)	pH_2	OC (%)
0-15	53.4	7.3	39.3	sc	1.45	0.02	5.98	0.35
15-30	53.4	7.3	39.3	sc	1.47	0.02	5.93	0.37
30-45	58.4	2.3	39.3	sc	1.45	0.01	6.89	0.35
45-60	60.9	2..3	36.8	sc	1.46	0.01	7.87	0.05
60-90	58.4	7.3	34.3	scl	1.48	0.02	8.36	0.06
90-120	60.9	4.8	34.3	scl	1.48	0.02	8.53	0.07

Table 2.9 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

Overall comparison in head-, mid-reach and tail-end soils show that texture for all the soil layers was clay for the site under WUA 5 i.e., at the tail end of the canal system where water availability through canal supply is relatively less than the mid or head reaches. There was a definite trend that sand content was greater in every soil layer than silt and clay contents, but there was slight difference in different layers of the soil profile. The soil organic carbon content decreased as soil depth increased for the site under WUA 5. Bulk density of soil varied between 1.41 to 1.47 Mg m^{-3} and EC varied between 0.01 to 0.11 dS m^{-1}. Reverse was the trend for mid-reach soils i.e., under the WUA 7 soils. The soils in the mid reach are predominantly sandy clay loam 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. Soil pH in mid reach soils are mostly neutral. Saturated hydraulic conductivity (Ks) in mid-reach soils is higher than the tail-end soils, but available water content (AWC) in mid reach soils are lower than tail end soils, as has been evident from the soil data of WUA 5 and 7. Due to higher Ks and lower AWC values in mid reach soils, there will a requirement of frequent irrigation and effective soil water conservation measures for successful cultivation of crops. In case of tail end soils, the interval of irrigation will be more due to higher AWC values. The careful management of water should be the basis for improving water and crop productivity.

Table 2.10 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

10.3 Rainfall data analyses: probability distribution, onset and withdrawal of monsoon rainfall, Markov chain model for dry/wet spell analyses

Collection and methods of analyses of rainfall

Rainfall data for 16 years (1995-2010) were collected from meteorological observatory of Kuanria dam, Daspalla, Nayagarh. Rainfall data are categorized into four seasons viz. pre-monsoon (March-May), monsoon (June-September), post-monsoon (October-December) and winter (January-February) season. Monthly effective rainfall was calculated using following equations of USDA Soil Conservation Service method. This method is being widely used in India for calculation of monthly effective rainfall. The same method has been used for calculation of effective rainfall for rainfed districts of India and also used by All India Coordinated Research Project for estimation of effective rainfall at different locations.

$$P_e = P_t\,(125-0.2\,P_t)/\,125 \text{ (when } P_t < 250 \text{ mm)}$$

$$P_e = 125 + 0.1\,P_t \text{ (when } P_t \geq 250 \text{ mm)}$$

where, P_e = monthly effective rainfall (mm) and P_t = total monthly rainfall (mm).

Calculation and probability distribution functions: In this study, rainfall was predicted by six probability distribution functions (PDF) i.e. Normal, 2-Parameter Log Normal, 3-Parameter Log Normal, Pearson Type III, Log Pearson Type III and Gumbel distribution by using

DISTRIB 2.13 component of SMADA 6.43 (Storm Water Management and Design Aid). Different probability distribution functions are given as follows.

Normal distribution

$$p_x(x) = \frac{1}{\sigma\sqrt{2\pi}} e\left[-\frac{(x-\mu)^2}{2\sigma^2}\right]$$

(Eq.3)

where, μ = mean of the population of x and σ = variance of the population of x.

2-Parameter Log Normal distribution

$$p_x(y) = \frac{1}{\sigma_y\sqrt{2\pi}} e\left[-\frac{(y-\mu_y)^2}{2\sigma_y{}^2}\right]$$

where, $y = \ln(x)$, μ_y = mean of the population of y and σ_y = variance of the population of y.

3-Parameter Log Normal distribution

$$p_x(y) = \frac{1}{\sigma_y\sqrt{2\pi}} e\left[-\frac{(y-\mu_y)^2}{2\sigma_y{}^2}\right]$$

where, $y = \ln(x-a)$, μ_y = mean of the population of y and σ_y = variance of the population of y.

Pearson Type III distribution

$$p_x(x) = p_o\,(1+x/\alpha)^{\alpha/\delta}\, e^{-x/\delta}$$

where, δ = difference between mean and mode ($\delta = \mu - X_m$), X_m = mode of population x, α = scale parameter of distribution, and p_o = value of $p_x(x)$ at mode.

Log Pearson Type III distribution

$$p_x(y) = p_{yo}\,(1+y/\alpha)^{\alpha/\delta y}\, e^{-y/\delta y}$$

where, δy = difference between mean and mode ($\delta_y = \mu_y - Y_m$), Y_m = mode of population y, α = scale parameter of distribution and p_{yo} = value of $p_x(y)$ at mode.

Gumbel distribution (also referred to as Fisher-Tippett Type I, Double Exponential, Gumbel Type I and Gumbel extremal distribution) is characterized by the probability density function,

$$p_x(x) = \frac{\alpha}{\beta-\gamma}\left(\frac{x-\gamma}{\beta-\gamma}\right)^{\alpha-1} e\left[\frac{x-\gamma}{\beta-\gamma}\right]^{\alpha}$$

where, α = scale parameter of distribution, and β = location parameter of the distribution. All six PDFs were compared by Chi-square test for goodness of fit as given in the following equation.

$$\chi^2 = \sum \frac{(O-E)^2}{E}$$

where, O is the observed value obtained by Weibul's method and E is the estimated value by probability distribution functions. Chi-square test was performed to obtain the best PDF and

Kolmogorov-Smirnov (K-S) test statistic was also used to decide the appropriate PDF, and the model having least value was selected as the best fit PDF.

Computation method for onset and withdrawal of rainy season: The onset and withdrawal of monsoon largely determine the success of rainfed agriculture. A prior knowledge on this helps in deciding cropping pattern and choice of suitable crop varieties and also to plan comprehensive strategies for proper and efficient rainwater management for improving crop production per unit of available water. Therefore, onset and withdrawal of rainy season was computed from weekly rainfall data by forward and backward accumulation methods. Each year was divided into 52 standard meteorological weeks (SMW). The first SMW of any year starts from 1-7th January and 52nd SMW is from 24-31st December. Weekly rainfall was summed up by forward accumulation (20+21+ --- +52 weeks) until 75 mm of rainfall was accumulated. An accumulation of 75 mm of rainfall has been considered as the onset time for summer monsoon which helps in land preparation and sowing of crops. The withdrawal of rainy season was determined by backward accumulation of rainfall (48+47+46+…+30 weeks) data. Twenty millimetres of rainfall accumulation was chosen for the withdrawal of the rainy season, which is sufficient for ploughing of fields after harvesting the first crop. The percent probability (P) of each rank was calculated by arranging them in ascending order and by selecting highest rank allotted for particular week. The following Weibull's formula was used for calculating percent probability.

$$P = (m/N+1) \times 100$$

where, m is the rank number and N is the number of years of data used.

Computation of dry and wet spells using Markov chain probability models: Weekly rainfall were computed from daily values and used for initial, conditional and consecutive dry and wet spell analysis based on Markov chain probability model; 20 mm or more rainfall in a week was considered as wet week otherwise dry. Initial, conditional and consecutive dry and wet spell analysis for 52 SMWs were made.

Initial probability

$$P(D) = F(D)/N$$
$$P(W) = F(W)/N$$

where, P(D) = probability of the week being dry, F(D) = frequency of dry weeks, P(W) = probability of the week being wet, F(W) = frequency of wet weeks, and N = total number of years of data being used.

Conditional probabilities

$$P(DD) = F(DD)/F(D)$$
$$P(WW) = F(WW)/F(W)$$
$$P(WD) = 1-P(DD)$$
$$P(DW) = 1-P(WW)$$

where, P(DD) = probability of a week being dry preceded by another dry week, F(DD) = frequency of dry week preceded by another dry week, P(WW) = probability of a week being wet preceded by another wet week, F(WW) = frequency of wet week preceded by another wet week, P(WD) = probability of a wet week preceded by a dry week, and P(DW) = probability of a dry week preceded by a wet week.

Consecutive dry and wet week probabilities

$$P(2D) = P(DW1)\times P(DDW2)$$
$$P(3D) = P(DW1)\times P(DDW2)\times P(DDW3)$$
$$P(2W) = P(WW1)\times P(WWW2)$$
$$P(3W) = P(WW1)\times P(WWW2)\times P(WWW3)$$

where, P(2D) = probability of 2 consecutive dry weeks starting with the week, P(DW1) = probability of the first week being dry, P(DDW2) = probability of the second week being dry, given the preceding week being dry, P(3D) = probability of 3 consecutive dry weeks starting with the week, P(DDW3) = probability of the third week being dry, given the preceding week dry, P(2W) = probability of 2 consecutive dry weeks starting with the week, P(WW1) = probability of the first week being wet, P(WWW2) = probability of the second week being wet, given the preceding week being wet, P(3W) = probability of 3 consecutive wet weeks starting with the week and P(WWW3) = probability of the third week being wet, given the preceding week wet.

Average rainfall, effective rainfall and distribution over seasons

Total annual rainfall in Daspalla region ranged between 993.5 and 1901.8 mm with an average of 1509.2 mm (14.8% coefficient of variation). If rainfall received in a year was equal to or more than the average rainfall plus one standard deviation for 16 years of rainfall (i.e. 1509.2+223.8=1733 mm), it was considered as excess rainfall year. On four occasions (1995, 2001, 2003 and 2008), this region had received rainfall of more than 1733 mm; these years were considered as excess rainfall years. Only 25% of total years of analyses under this study received rainfall of more than 1733 mm. It was also observed that 44% of the total years of rainfall were below average (1509.2 mm) which were considered as the deficit rainfall years. Monthly average and effective rainfall of Daspalla region for 16 years are presented in Fig. 3.1. It is revealed that, mean rainfall of July was 351.4 mm, which was the highest and its contribution was 23.3% (i.e. 1509.2 mm). August rainfall was slightly lower than July (i.e. 20.6% of annual average rainfall). December was the lowest rainfall month. Total annual effective rainfall (ER) was 858.2 mm which was 56.9% of the total annual rainfall. Therefore, 651 mm of rainfall water was lost in the form of surface runoff, deep percolation and evaporation.

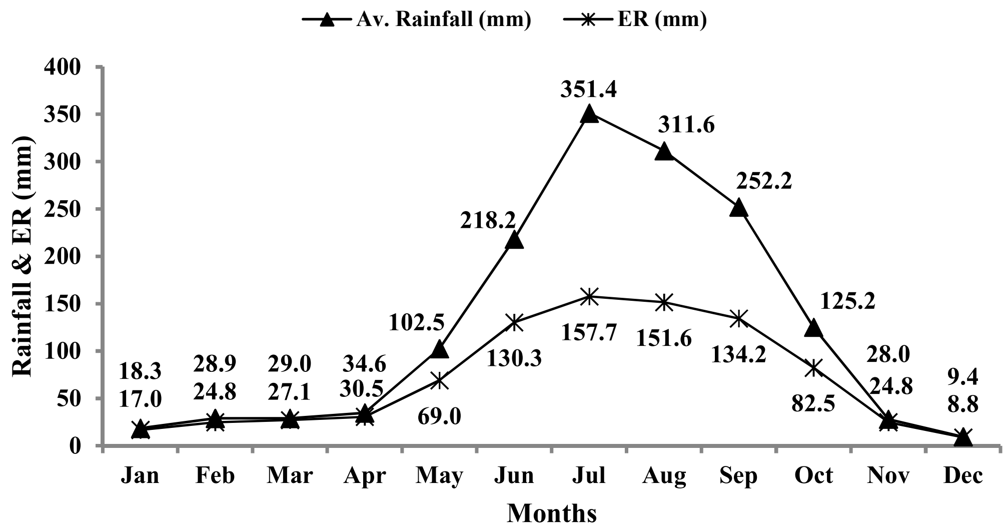


Fig. 3.1 Average monthly rainfall and effective rainfall for study area, Daspalla; ER is the effective rainfall

The distribution of rainfall for different seasons showed that the normal southwest monsoon, which delivers about 75.7% of annual rainfall, extends from June to September (Table 3.1). This is also the main season (rainy season) for cultivation of rainfed crops. The monsoon rainfall (1133.3 mm) was spread over few days with rain events of high intensity. It causes surface runoff and temporary water stagnation in agricultural fields. Winter season contributes only 3.1% of the total annual rainfall; 10.8 and 10.4% of the total annual rainfall occurred during pre- and post-monsoon season, respectively.

Prediction of rainfall using probability distribution functions

Annual rainfall for the region was predicted by using DISTRIB 2.13 component of SMADA 6.43 for 6 different probability distribution functions. Six predicted annual rainfall values were obtained for 6 PDFs by running the software (Fig. 3.2 & 3.3). After that Chi-square value for each PDF was estimated. Observed rainfall at different probability levels for monsoon and post-monsoon months were determined by using Weibul's formula and presented in Table 3.2.

Table 3.1 Rainfall distribution in Daspalla region over different seasons (data of 16 years for the period from 1995 to 2010)

Seasons	Average rainfall (mm)	Percentage of total rainfall
Pre-monsoon (March-May)	166.1	10.8
Monsoon (June-September)	1133.3	75.7
Post-monsoon (October-December)	162.6	10.4
Winter (January-February)	47.2	3.1

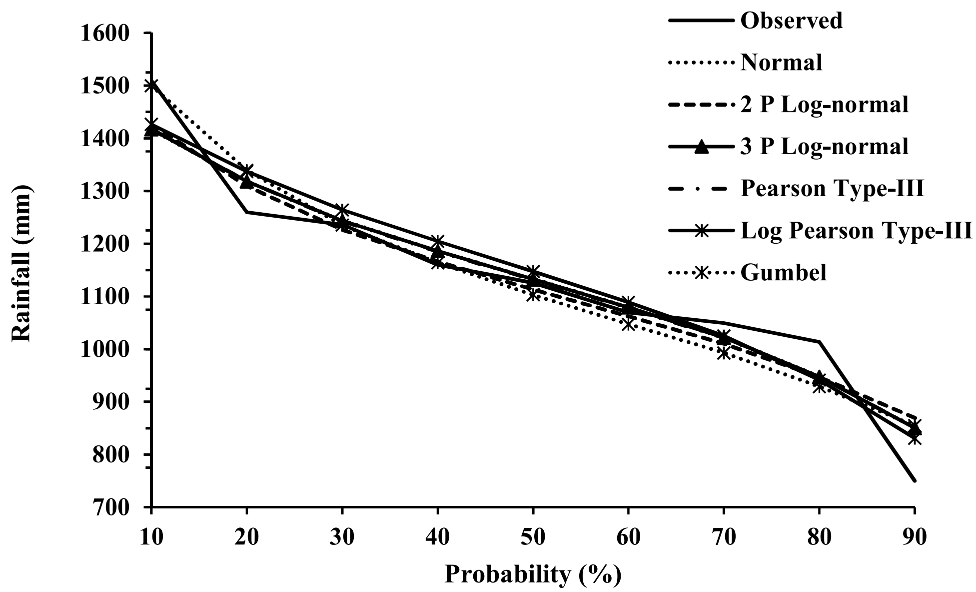


Fig. 3.2 Observed and predicted rainfall (mm) at different probability levels for the monsoon season

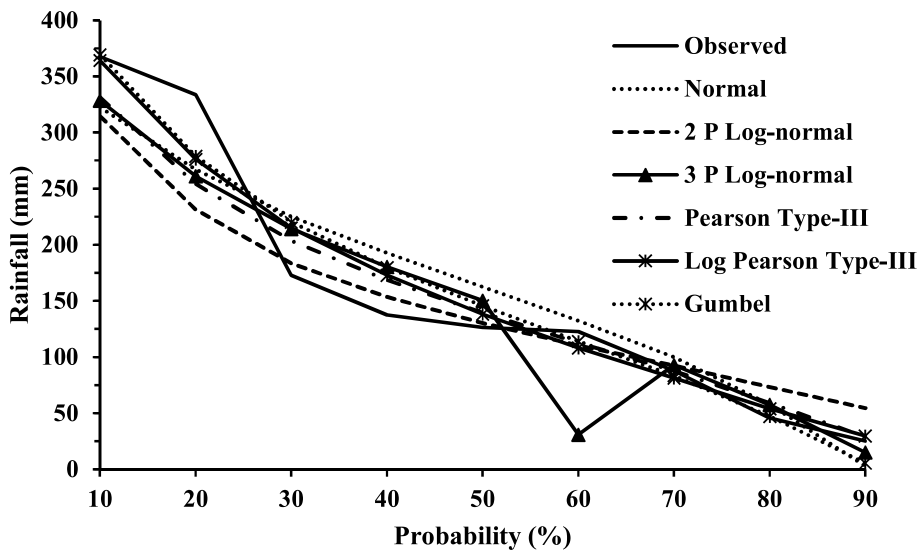


Fig. 3.3 Observed and predicted rainfall (mm) at different probability levels for post- monsoon season in the study area

Table 3.2 Observed rainfall at different probability levels for monsoon and post- monsoon months

Probability (%)	June	July	August	September	October	November	December
10	415.2	724.0	523.3	450.0	322.0	105.5	47.6
20	333.3	469.8	413.1	381.5	274.1	47.7	29.7
30	217.0	365.8	356.5	354.0	123.1	29.7	2.8
40	196.6	337.5	321.1	301.3	116.2	20.9	0.3
50	194.8	282.8	299.7	227.4	87.5	14.8	-
60	182.8	270.0	275.2	177.8	77.4	11.8	-
70	158.0	244.4	274.2	164.9	57.9	6.2	-
80	132.4	217.3	180.6	141.6	28.0	1.0	-
90	105.9	181.9	164.5	75.4	16.9	-	-

It is revealed that, during monsoon season, the observed monsoon rainfall was 1049.6 mm at 70% probability level and all the probability distribution functions predicted almost comparable rainfall. Least Chi-square values as well as lowest K-S test statistic were estimated for Log Pearson Type III distribution. Hence, Log Pearson Type III distribution is considered as the best fit PDF for prediction of monsoon rainfall in Daspalla. In this region, about 86% of the total annual rainfall occurs during monsoon and post-monsoon season and agricultural activities are almost totally dependent on the performance of south-west monsoon. Therefore, prediction of monsoon and post-monsoon rainfall is more important than annual rainfall for raising crops successfully with high and stable yields. With regard to the post-monsoon rainfall, the Chi-square values were 48.8 to 189.8, and the K-S test statistics were 0.137 to 0.251 for six PDFs. The lowest value, with Chi-square and K-S test, was obtained with Gumbel distribution; however, Log Pearson Type III distribution was also comparable with Gumbel distribution for prediction of post-monsoon rainfall.

Analyses of rainfall for onset and withdrawal of monsoon season

The data on onset, withdrawal and duration of the rainy season (difference between onset and withdrawal time) and its variability for the Daspalla region are presented in Table 3.3. Weekly rainfall data (1995-2010) indicated that the monsoon started effectively from 23rd SMW (4-10th June) and remained active up to 43rd SMW (22-28th October). Therefore, mean length of rainy season was found to be 21 weeks (147 days). The earliest and delayed week of onset of rainy season was 20th SMW (14-20th May) and 25th SMW (18-24th June), respectively. Similarly, the earliest and delayed week of cessation of rainy season was 39th SMW (24-30th September) and 47th SMW (19-25th November), respectively. The longest and shortest length of rainy season was coincided with 26th and 17th weeks, respectively. The probabilities of onset and withdrawal of rainy season was calculated by using Weibull's formula and results are presented in Table 3.4. The results reveal that there was 94% chance that the onset and withdrawal of rainy season would occur during 25th and 47th SMW, respectively.

Table 3.3 Characterization of rainy season at the study site, Daspalla (1995-2010)

Particulars	Week No.	Date
Mean week of onset of rainy season	23	4-10 June
Earliest week of onset of rainy season	20	14-20 May
Delayed week of onset of rainy season	25	18-24 June
Mean week of withdrawal of rainy season	43	22-28 October
Earliest week of withdrawal of rainy season	39	24-30 September
Delayed week of withdrawal of rainy season	47	19-25 November

Table 3.4 Probability of onset and withdrawal of rainy season at the study site, Daspalla

Probability of onset and withdrawal									
Onset									
SMW	20	21	22	23	24	25			
P (%)	17.6	29.4	35.3	64.7	82.4	94.1			
Withdrawal									
SMW	39	40	41	42	43	44	45	46	47
P (%)	5.9	11.8	23.5	41.2	47.1	64.7	76.5	88.2	94.1

SMW – Standard Meteorological Week, P – Probability in percentage

Markov chain model for predicting dry or wet spells

Results of initial and conditional probabilities of dry and wet weeks are presented in Table 3.5 for the 52 standard meteorological weeks. The results reveal that, the probability of occurrence of dry week was high until the end of 22nd SMW. The range of probability of occurrence of dry week from 1st to 22nd SMW was between 56 and 100%. The probability of occurrence of dry week preceded by another dry week (P_{DD}) and that of dry week preceded by another wet week (P_{DW}) varied from 54 to 100% and 28 to 100%, respectively during the periods of 1st-22nd SMW. However, from 23rd to 40th SMW the probability of both P_D and P_{DD} were low. The probability that these weeks (23rd-40th SMW) remaining wet (P_W) varied between 62 and 100%. The conditional probability of wet week preceded by another wet week (P_{WW}) varied between 30 and 100%. The chances of occurrence of dry spells were again high during the period from 42nd SMW to the end of the year. The analyses of consecutive dry and wet spells (Table 3.6) revealed that there were 31 to 100% chances that 2 consecutive dry weeks (P_{2D}) would occur within the first 22 weeks of the year. Similarly, the probabilities of occurrence of 3 consecutive dry weeks (P_{3D}) were also very high (15-86%) in the first 22 weeks of the year. The corresponding values of 2 and 3 consecutive wet weeks (i.e. P_{2W} and P_{3W}) from 1st to 22nd SMW were very low with values ranging from 0 to 31% and 0 to 13%, respectively. From 23rd to 40th SMW, the chances of occurrence of 2 and 3 consecutive dry weeks were only within 0 to 19% and 0 to 15%, respectively. Conversely, there are chances of 36 to 100% and 28 to 87% that the weeks from 23rd to 40th SMW would be getting sufficient rain with 2 and 3 consecutive wet weeks, respectively. This study reveals that the last 12 weeks of the year i.e., from 41 to 52th SMW may remain under stress on an average, as there were 75% chances of occurrence of 2 consecutive dry weeks. The corresponding value for 3 consecutive dry weeks during the period was 67%.

Table 3.5 Initial and conditional probabilities of dry and wet spells of rainfall at the study site, Daspalla region

SMW	Initial probabilities (%)		Conditional probabilities (%)			
	P_D	P_W	P_{DD}	P_{WD}	P_{WW}	P_{DW}
1	100.0	0.0	-	-	-	-
2	87.5	12.5	100.0	0.0	0.0	100.0
3	87.5	12.5	85.7	14.3	0.0	100.0
4	93.8	6.2	86.7	13.3	0.0	100.0
5	93.8	6.2	93.3	6.7	0.0	100.0
6	93.8	6.2	100.0	0.0	100.0	0.0
7	87.5	12.5	92.9	7.1	0.0	100.0
8	87.5	12.5	92.9	7.1	50.0	50.0
9	81.3	18.7	92.3	7.7	33.3	66.7
10	81.3	18.7	84.6	15.4	33.3	66.7
11	87.5	12.5	78.6	21.4	0.0	100.0
12	93.8	6.2	86.7	13.3	0.0	100.0
13	87.5	12.5	92.9	7.1	0.0	100.0
14	87.5	12.5	85.7	14.3	0.0	100.0
15	93.8	6.2	86.7	13.3	0.0	100.0
16	93.8	6.2	93.3	6.7	0.0	100.0
17	81.3	18.7	100.0	0.0	33.3	66.7
18	93.8	6.2	80.0	20.0	0.0	100.0
19	68.8	31.2	100.0	0.0	20.0	80.0
20	56.3	43.7	66.7	33.3	28.6	71.4
21	56.3	43.7	77.8	22.2	71.4	28.6
22	68.8	31.2	54.5	45.5	40.0	60.0
23	18.7	81.3	66.7	33.3	30.8	69.2
24	37.5	62.5	33.3	66.7	90.0	10.0
25	25.0	75.0	50.0	50.0	66.7	33.3
26	18.7	81.3	66.7	33.3	84.6	15.4
27	18.7	81.3	33.3	66.7	84.6	15.4
28	31.2	68.8	20.0	80.0	81.8	18.2
29	0.0	100.0	0.0	100.0	68.8	31.2
30	12.5	87.5	0.0	100.0	100.0	0.0
31	6.2	93.8	0.0	100.0	86.7	13.3
32	12.5	87.5	0.0	100.0	92.9	7.1
33	18.7	81.3	0.0	100.0	84.6	15.4
34	0.0	100.0	0.0	100.0	81.3	18.7
35	12.5	87.5	0.0	100.0	100.0	0.0
36	12.5	87.5	0.0	100.0	85.7	14.3
37	37.5	62.5	0.0	100.0	80.0	20.0
38	18.7	81.3	66.7	33.3	69.2	30.8
39	31.2	68.8	40.0	60.0	90.9	9.1
40	37.5	62.5	33.3	66.7	70.0	30.0
41	56.3	43.7	44.4	55.6	57.1	42.9
42	56.3	43.7	88.9	11.1	85.7	14.3
43	81.3	18.7	69.2	30.8	100.0	0.0
44	75.0	25.0	91.7	8.3	50.0	50.0
45	81.3	18.7	76.9	23.1	33.3	66.7
46	93.8	6.2	86.7	13.3	100.0	0.0
47	93.8	6.2	93.3	6.7	0.0	100.0
48	100.0	0.0	93.8	6.2	0.0	100.0
49	93.8	6.2	100.0	0.0	0.0	100.0
50	87.5	12.5	100.0	0.0	50.0	50.0
51	93.8	6.2	86.7	13.3	0.0	100.0
52	100	0.0	93.8	6.2	0.0	100.0

Table 3.6 Analyses of consecutive dry and wet week probabilities of rainfall at the study site

SMW	Consecutive dry week probabilities (%)		Consecutive wet week probabilities (%)	
	P_{2D}	P_{3D}	P_{2W}	P_{3W}
1	100.0	85.7	0.0	0.0
2	75.0	65.0	0.0	0.0
3	75.8	70.8	0.0	0.0
4	87.5	87.5	0.0	0.0
5	93.8	87.1	6.3	0.0
6	87.1	80.8	0.0	0.0
7	81.3	75.0	6.3	2.1
8	80.8	68.3	4.2	1.4
9	68.8	54.0	6.3	0.0
10	63.8	55.3	0.0	0.0
11	75.8	70.4	0.0	0.0
12	87.1	74.6	0.0	0.0
13	75.0	65.0	0.0	0.0
14	75.8	70.8	0.0	0.0
15	87.5	87.5	0.0	0.0
16	93.8	75.0	2.1	0.0
17	65.0	65.0	0.0	0.0
18	93.8	62.5	1.3	0.4
19	45.8	35.6	8.9	6.4
20	43.8	23.9	31.3	12.5
21	30.7	20.5	17.5	5.4
22	45.8	15.3	9.6	8.7
23	6.3	3.1	73.1	48.8
24	18.8	12.5	41.7	35.3
25	16.7	5.6	63.5	53.7
26	6.3	1.3	68.8	56.3
27	3.8	0.0	66.5	45.7
28	0.0	0.0	47.3	47.3
29	0.0	0.0	100.0	86.7
30	0.0	0.0	75.8	70.4
31	0.0	0.0	87.1	73.7
32	0.0	0.0	74.0	60.2
33	0.0	0.0	66.0	66.0
34	0.0	0.0	100.0	85.7
35	0.0	0.0	75.0	60.0
36	0.0	0.0	70.0	48.5
37	25.0	10.0	43.3	39.3
38	7.5	2.5	73.9	51.7
39	10.4	4.6	48.1	27.5
40	16.7	14.8	35.7	30.6
41	50.0	34.6	37.5	37.5
42	38.9	35.7	43.8	21.9
43	74.5	57.3	9.4	3.1
44	57.7	50.0	8.3	8.3
45	70.4	65.7	18.8	0.0
46	87.5	82.0	0.0	0.0
47	87.9	87.9	0.0	0.0
48	100.0	100.0	0.0	0.0
49	93.8	81.3	3.1	0.0
50	75.8	71.1	0.0	0.0
51	87.9	-	0.0	-
52	-	-	-	-

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 our intervention in the form of construction of rain/ runoff water storage structures and integrated crop and fish farming during the years 2010 through September 2015 (Fig. 3.4 & 3.5, and Table 3.7). The total annual rainfall was ranged from 1304 to 1895. The variation in rainfall was less during the pre-monsoon period (Mar-May) for all the years.

It is revealed from the data that rainfall is quite low during the period 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. Post-monsoon (Oct-Dec) was greater due to very high rainfall (a total of 679 mm) during October (1st, 13th, 22-27 Oct) in the year 2013. In the year 2015, the monsoon rainfall (1071 mm in June to September) is slightly less than average rainfall in the region.

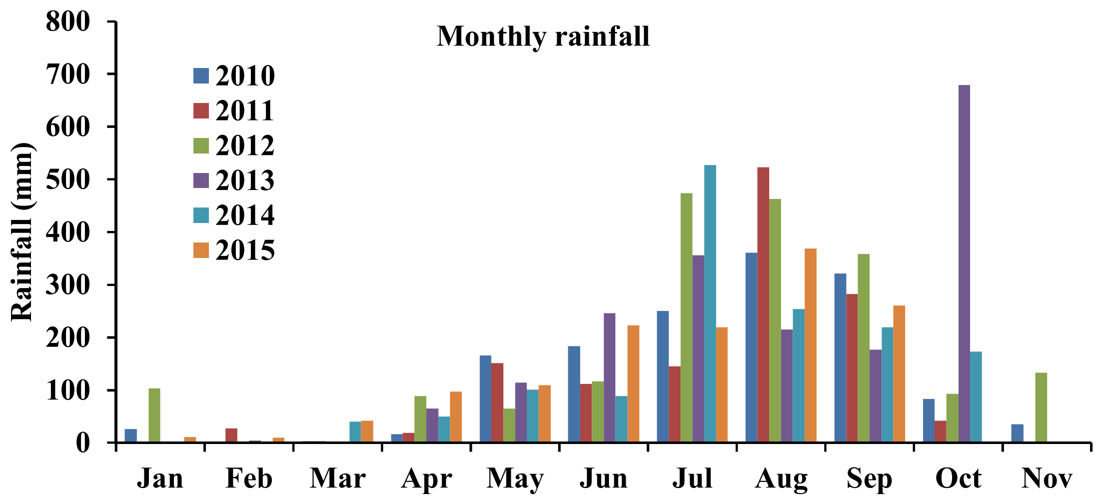


Fig. 3.4 Monthly rainfall (mm) in the project site during years (2010- Sep 2015)

Table 3.7 Distribution of rainfall in different seasons during the year 2011-2013

Seasons	**Year 2010**	**Year 2011**	**Year 2012**	**Year 2013**	**Year 2014**	**Year 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	165
Winter (Jan-Feb)	26	27	103	4	0	21
Total	1489	1304	1895	1857	1453	1341

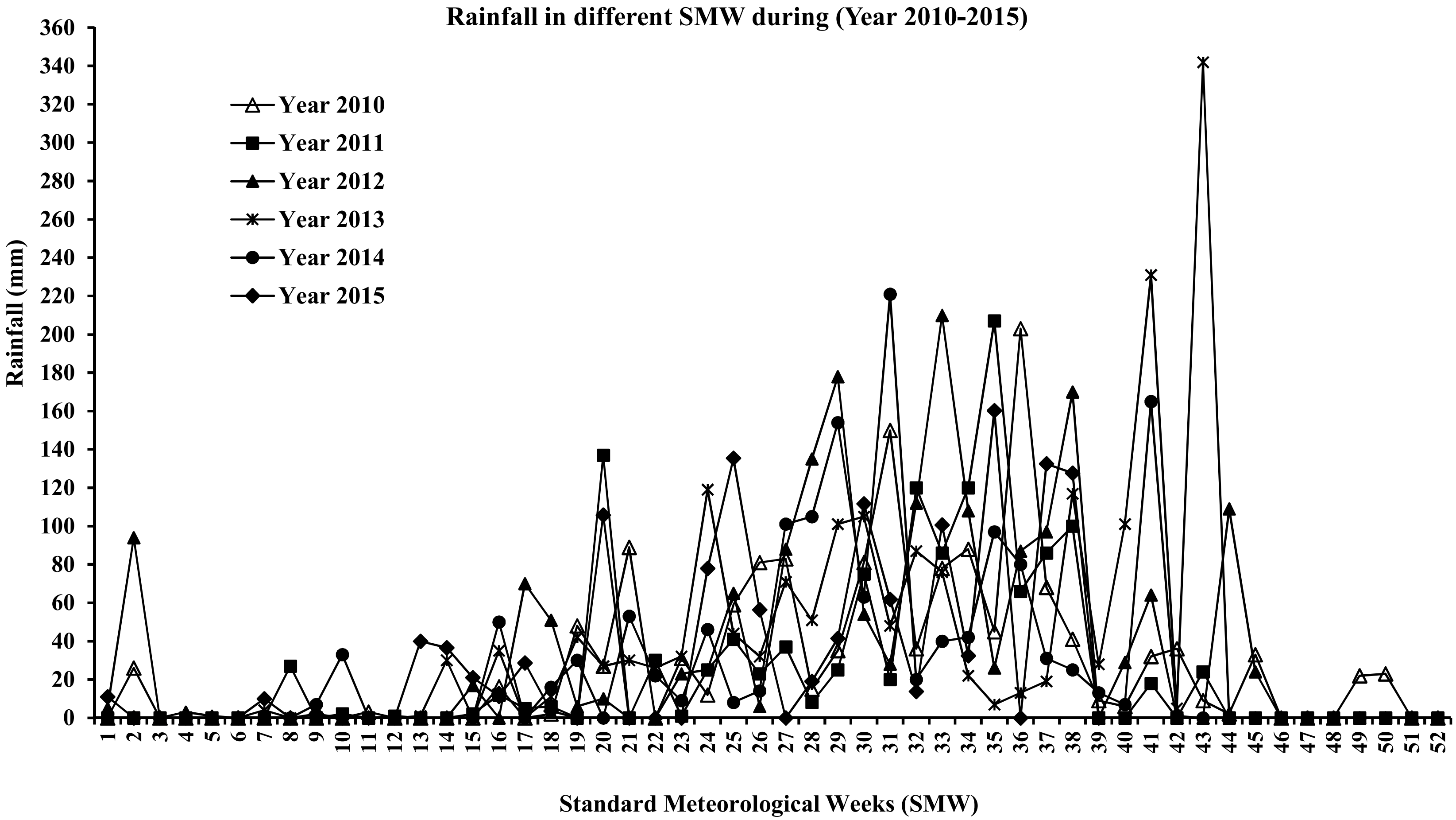


Fig. 3.5 Rainfall distribution and trends in 52 standard meteorological weeks (SMW) in the project site the years (2010-2015); *rainfall upto September for 2015

Winter season (Jan-Feb) contributed negligible to only 5.4% of the total annual rainfall received in the command area. It shows the variation of total monthly rainfall during the year 2010-2015. Month wise, maximum amount of rainfall occurred during the month of July and August, and the least or no rainfall occurred during the months of December to March every year. The rainfall pattern in year 2014-15 of our intervention in the form of construction of rain/ runoff water storage structures and integrated crop and fish farming are presented. The total annual rainfall was 1453 mm in 2014 and 1341 mm upto September 2015. It is revealed from the data that rainfall is quite low during the period November to May. Maximum amount of rainfall (1089 mm) occurred during the monsoon months i.e., June-September. Post-monsoon (Oct-Dec) rainfall was 173 mm. 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 the 42 through 52 SMW in the year 2014.

10.4 Study on the rainfall-runoff relationship and seepage losses

Runoff is a major component in hydrologic cycle. It has been estimated for Kuanria irrigation project of Daspalla in Nayagarh district of Odisha. Runoff characteristics and the estimation of runoff were analyzed by using 20 years (1995-2014) meteorological rainfall data of the study area. The area receives an average annual rainfall of 1532 mm. Soil property is the primary parameter that influences the amount of runoff. The soil property of the study area was found to be in hydrological soil group C. 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. Curve number method being used for measuring the depth of runoff from rainfall depth developed by Soil Conservation Service. The initial accumulation of rainfall represents interception, depression storage and infiltration before the start of runoff which is called as initial abstraction. After the runoff started additional runoff started in form of infiltration is called as actual retention. With increase in rainfall actual retention also increases up to the maximum value: potential maximum retention.

Curve Number method mathematically is the ratio of actual retention to potential maximum retention equal to the ration of actual runoff to potential maximum runoff.

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

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. This relationship is

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

Curve number was decided relating to land use cover, land treatment or practice, hydrologic condition and hydrological soil group. These parameters together called as Hydrological Soil-cover Complex. The CN value varies from 0 to 100. As per the field survey, it was observed that farmers grow paddy and legumes in *kharif* and *rabi* season respectively. Mostly fallow lands were found during summer season due to non-availability of sufficient amount of water. Generally, conventional straight row method is being adopted by the farmers. The curve number (CN) values were decided based on this field condition (Table 4.1).

Table 4.1 CN values for command area soil condition relating to different crop growing seasons

Crop growing season	Land use	Treatment/ Practices	Hydrological condition	Hydrological soil group	CN value	*S*
Kharif (June- September)	Paddy	Straight row	Poor	C	84	48.3
Rabi (October-February)	Legumes	Straight row	Poor	C	85	44.8
Summer (March-May)	Fallow	Straight row	Poor	C	91	25.1

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. The detail distribution is presented in Table 4.2. It also showed that pre-monsoon rainfall contributed maximum rainfall (89%) as effective rainfall followed by monsoon and winter rainfall.

Table 4.2 Rainfall, effective rainfall distribution in Daspalla, Nayagarh district of Odisha

Seasons	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

Based on the assigned CN value, surface runoff was estimated. For every rainfall event recorded for 20 years in daily basis runoff was estimated. Then annual rainfall and runoff on depth basis is presented in Table 4.3. Similarly monthly average rainfall, runoff depth with the runoff percentage of rainfall is shown in Table 4.4. On an average, the area receives 1532 mm of rainfall annually; out of this 386 mm (25%) is lost due to runoff. Runoff during post monsoon and summer season is nearly 12% and 14% of rainfall received during that season respectively (Fig. 4.1).

Table 4.3 Annual rainfall and runoff analysis for the year 1995-2014

Year	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

Table 4.4 Monthly average rainfall and runoff in the command area (1995-2014)

Months	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

The analysis revealed that the monsoon rainfall was about 73% of annual rainfall whereas the respective runoff during the monsoon period was about 70% of annual runoff which was in higher amount than the other seasons. Monsoon runoff could be stored for future purposes. During the *kharif* season, paddy is a major crop. As paddy utilizes the rainwater effectively, but apart from the effective rainfall the overflowing runoff was about 24% of its rainfall. Hence, it is justified that the conservation of monsoon runoff would be helpful for the post- monsoon cropping system.

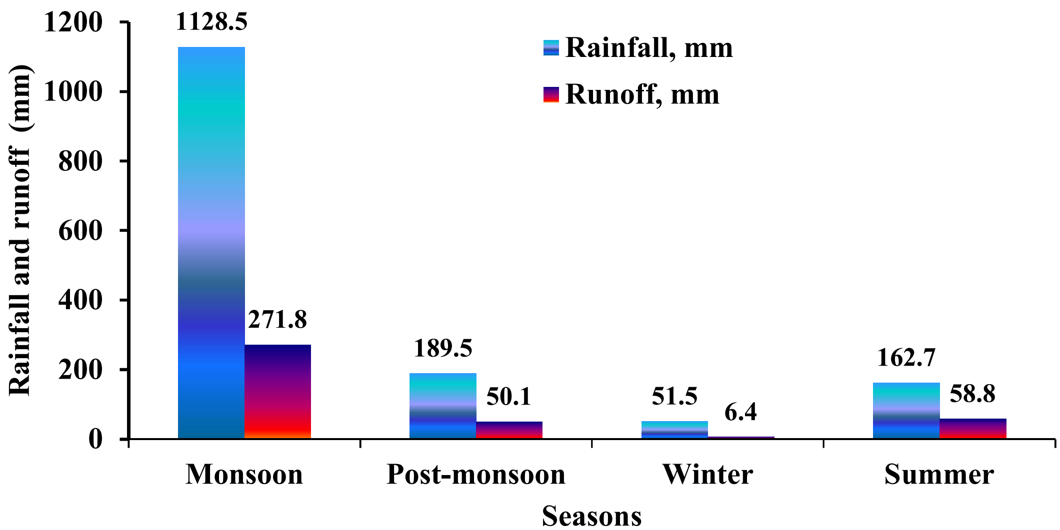


Fig. 4.1 Average rainfall and runoff during monsoon (Jun-Sep), post-monsoon (Oct-Dec), winter (Jan-Feb) and pre-monsoon or summer (Mar-May) seasons in years 1995-2014 in Kuanria canal command area in Daspalla, Nayagarh district, Odisha

The annual rainfall varies between 994 and 1902 mm with an average of 1532 mm. On an average, runoff was calculated as 386 mm (25% of the average annual rainfall). 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. Hence, annually 13.3-32.5% of rainfall goes as runoff in the study area, which indicated that the construction of water conservation structures was appropriate to reduce the runoff and increase the recharge to the groundwater. This would facilitate increase the crop coverage during post-monsoon and summer season.

Seepage losses during 2011-2013

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 (Fig. 4.2). 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.

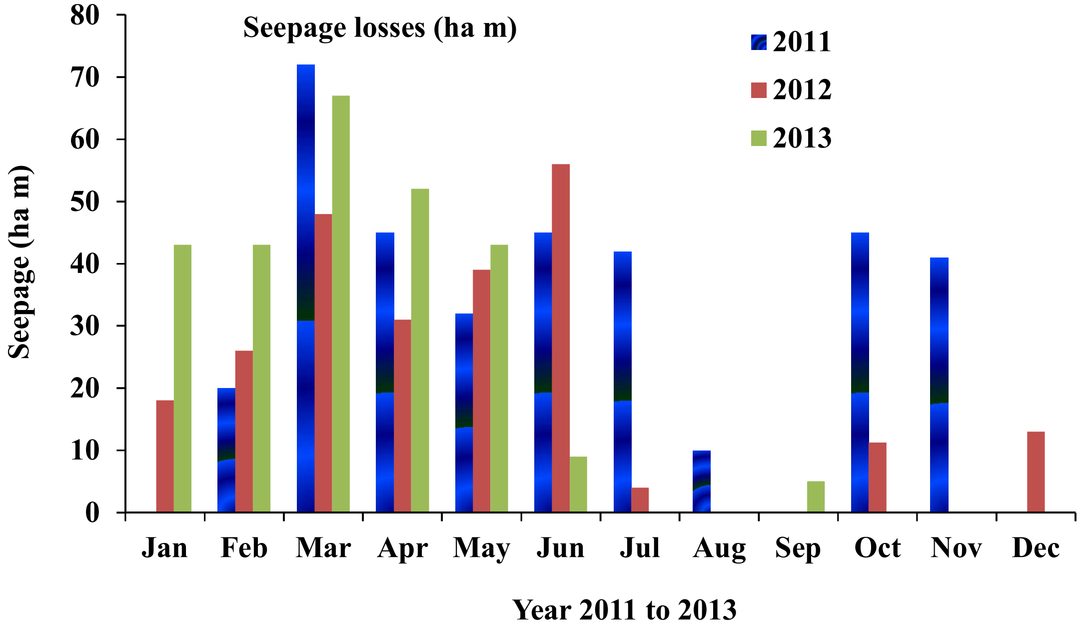


Fig. 4.2 Month-wise seepage losses of water from the dam and canal distributaries in the year 2011-2013

Monthly seepage losses from the reservoir and canal during the year 2014-15 show that it was the maximum during the months of January to May (Fig. 4.3). 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.

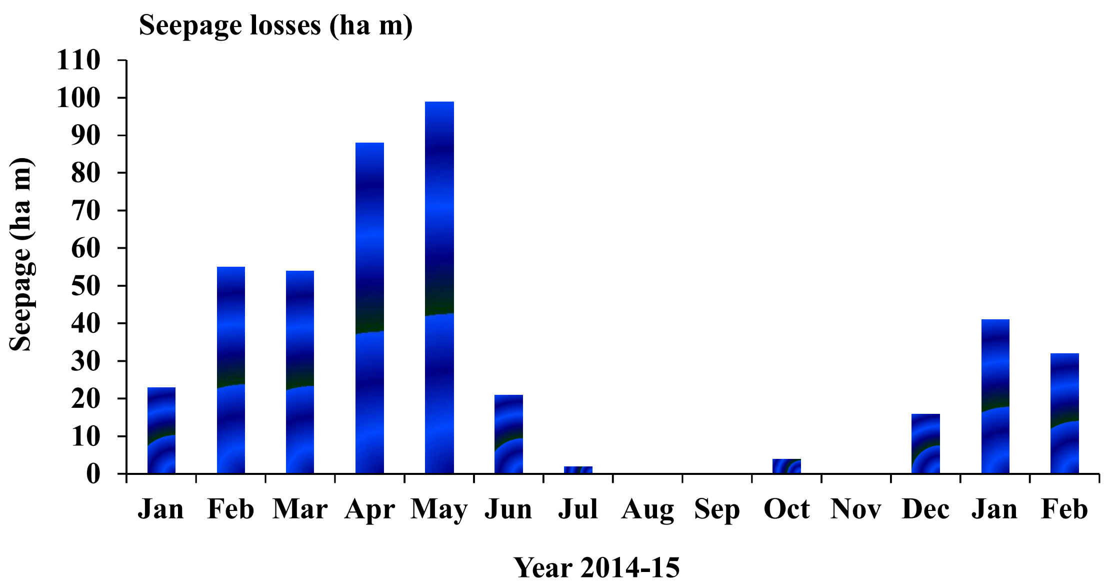


Fig. 4.3 Month-wise seepage losses of water from the dam and canal distributaries in the year 2014-15

10.5 Studies on canal water availability, water supply, time schedule and discharge rate

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, at the latitude 20°20' N and longitude 84°28' E. KIP is a medium irrigation project. The earth dam is 1576 m long with maximum height of 21 m at deepest section (Table 5.1). 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. The name of all minors and sub-minors are mentioned in this section. 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.

Table 5.1 Salient features of the Kuanria irrigation project (KIP)

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 and 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

The picture shows the 'Kuanria dam' and also supply of water through left distributary. Intercepting river is 'Kuanria', a right tributary of river Mahanadi and a nallah named 'Khalakhala' by an earth dam form the reservoir of KIP. The catchment area of the reservoir is 124 sq km.

Picture of Kuanria dam, water supply through left distributary, visit of Director, ICAR-IIWM (formerly DWM), Bhubaneswar

Monthly mean reservoir water level

Mean monthly reservoir water level for the year 2011-2013 is presented in Fig. 5.1. 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 (Fig. 5.2). Reservoir level in January and February 2015 was much lower than those of January-February 2014 because of more canal water supply during 2015.

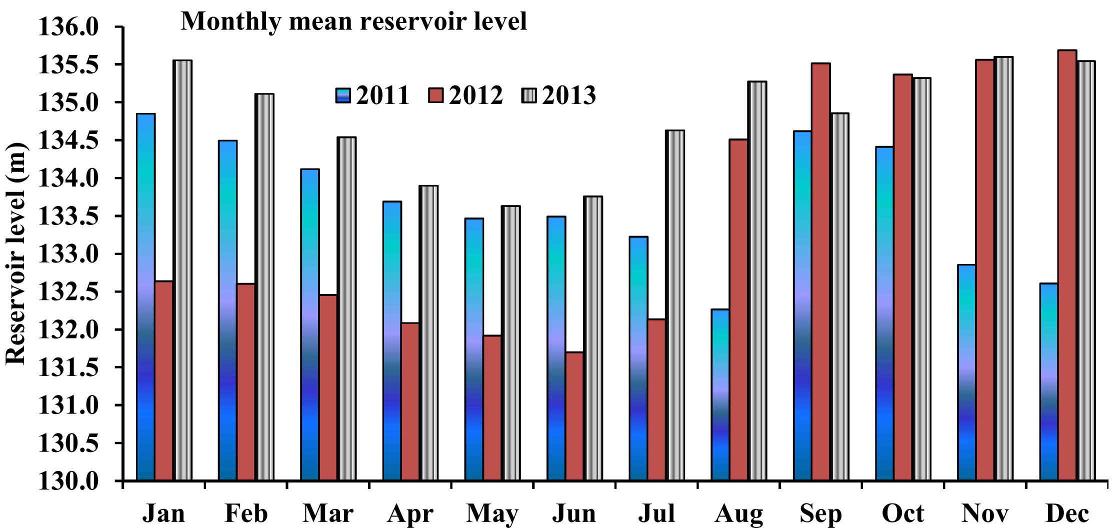


Fig. 5.1 Monthly mean reservoir level during the year 2011, 2012 and 2013

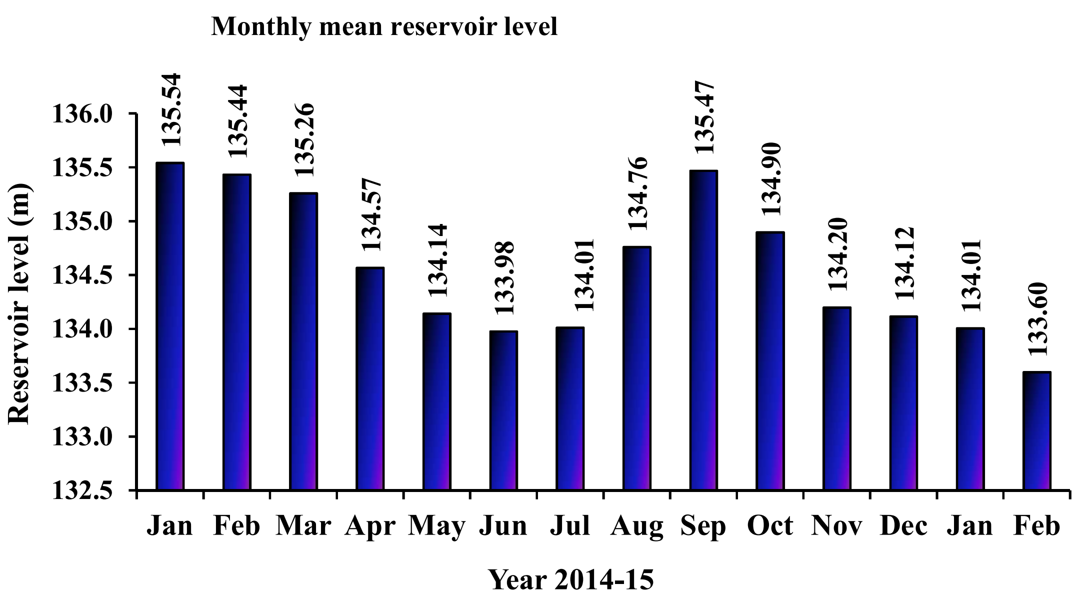


Fig. 5.2 Monthly average reservoir level in the Kuanria dam at Daspalla during the year 2014-15

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 in the diagram (Fig. 5.3). The deficiencies were: supply of irrigation water was not possible at the tail-end of the left distributary. Farmers in the tail-end area were deprived of getting irrigation water by putting temporary earthen bunds across the canal by head-end farmers.

FLOW DIAGRAM OF KUANRIA IRRIGATION PROJECT , DASPALLA

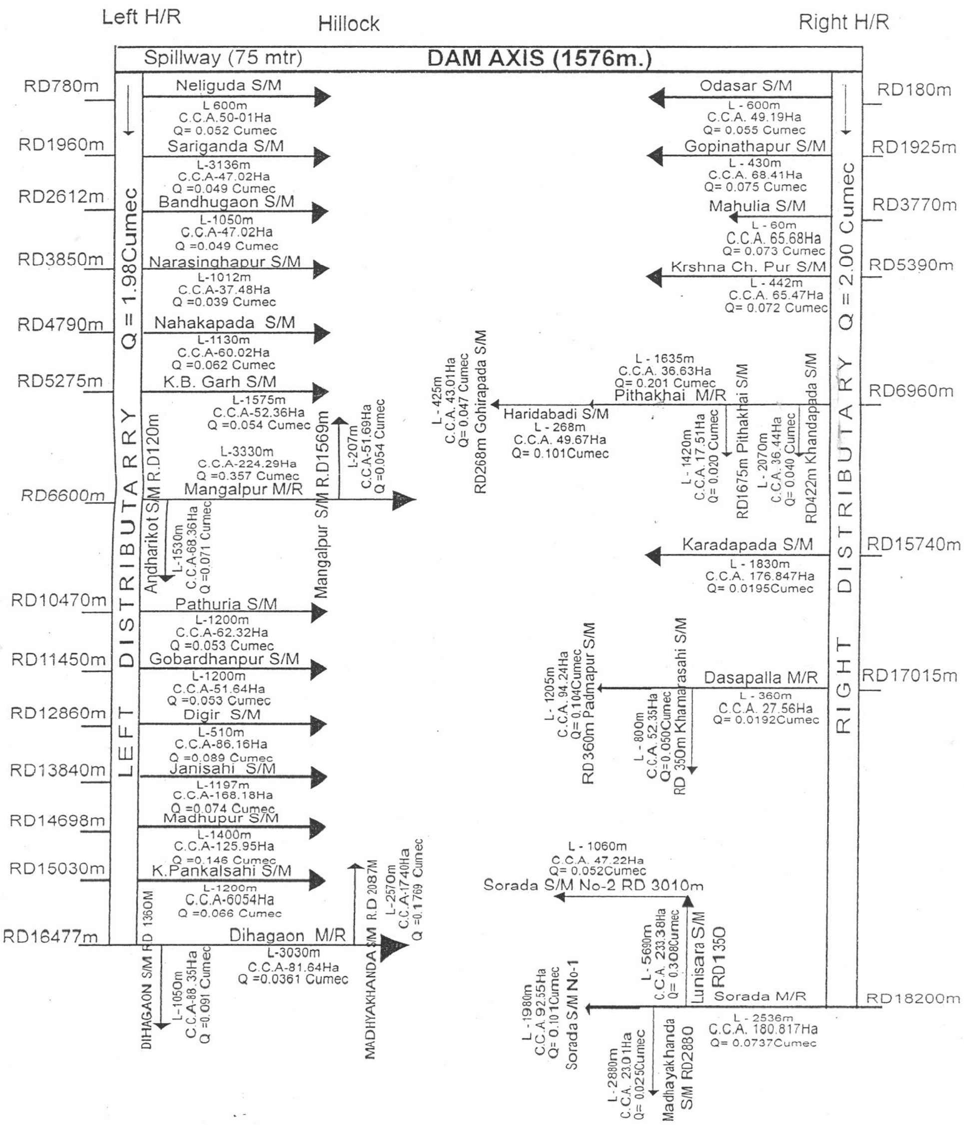


Fig. 5.3 Flow diagram of Kuanria irrigation project; discharge capacity of various minors and sub-minors is also presented in the flow diagram

Available water resources at project head

Distributary wise distribution / allocation of water are given in Table 5.2 and the month wise water account is given in Table 5.3 and 5.4. Maximum water is available during July, August, September and October, and the minimum in April and May. Canal-wise details of allocation of water for irrigation at the head as detailed below:

Table 5.2 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 5R	0.015
14	Direct 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	0.019
23	Direct water course 12R	0.015
24	Pathuria s/m	0.050
25	Direct outlet 5R	0.017
26	Gobardhanpur s/m	0.053
27	Direct outlet 6R	0.020
28	Direct water course 14R	0.015
29	Direct s/m	0.030
30	Janisahi s/m	0.174
31	Madhupur s/m	0.146
32	Direct outlet HR	0.015
33	Khairapankalsahi s/m	0.066
34	Direct outlet 12R	0.007
35	Direct water course 15R	0.010
36	Dihagaon minor	0.361
37	Dihagaon s/m	0.091
38	Direct outlet 1R, 2R and 3R of Dihagaon minor	0.015
39	Madhyakhanda s/m	0.177
40	Direct water course 16 tail	0.015

Table 5.3 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

Canal water supply and its schedule

The water released data through left and right distributary of Kuanria Dam was collected for last 15 years. Table 5.5 shows the month-wise average water supply from left and right distributaries of Kuanria dam.

Table 5.4 Month-wise canal water availability in Kuanria irrigation system

Sl. No.	Month-wise canal water availability (ha.m)		
Months	**Left distributary (LD)**	**Right distributary (RD)**	**Total**
July	466.6	503.5	970.1
August	129.9	143.2	273.1
September	280.0	332.4	612.4
October	239.2	235.4	474.6
November	71.5	56.8	128.3
December	133.0	109.5	242.5
January	104.9	83.1	188
February	123.8	93.2	217
March	53.9	33.6	87.5
April	18.4	11.9	30.3
May	13.3	10.6	23.9
June	3.2	2.5	5.7
Design Q (in cumec)	1.98	2.00	

Amount of water released was highest in the month of October (i.e. 354.3 and 314.2 ha.m for LD and RD, respectively) was highest. During the period of July to October major amount of water was released from the Kuanria dam which is sufficient to irrigate 3780 ha of cultivable command area. Amount of released water was 1967.5 ha m during monsoon (Jul-Oct) and 703.1 ha m during dry period (Nov-Jun). The released amount of water was much less during lean period in comparison to the same during monsoon.

Table 5.5 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	0.0	0.5	0.5
July	150.1	131.6	281.7
August	277.6	218.1	495.7
September	262.0	259.6	521.6
October	354.3	314.2	668.5
November	62.0	55.0	117.1
December	6.8	5.8	12.6

The water availability, water released and water required (ha-m) during different months in the command area are presented in Table 5.6. It may be 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 is 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.

Table 5.6 Total water availability, water release and water requirement (ha-m) during different months in the command area of Kuanria Irrigation Project

Months	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

Month-wise discharge (cumec) and canal water supply for the year 2103 are presented in Fig. 5.4 and 5.5. In the month of June there was no discharge or supply of water. 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 it was no supply in the month of December. There was also supply during the period of January through May 2013, however the amount was less than July to November 2013 period. During the period of July to October major amount of water was released which was sufficient to irrigate 3780 ha of cultivable 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. There was a demand-supply gap during every month (Table 5.7).

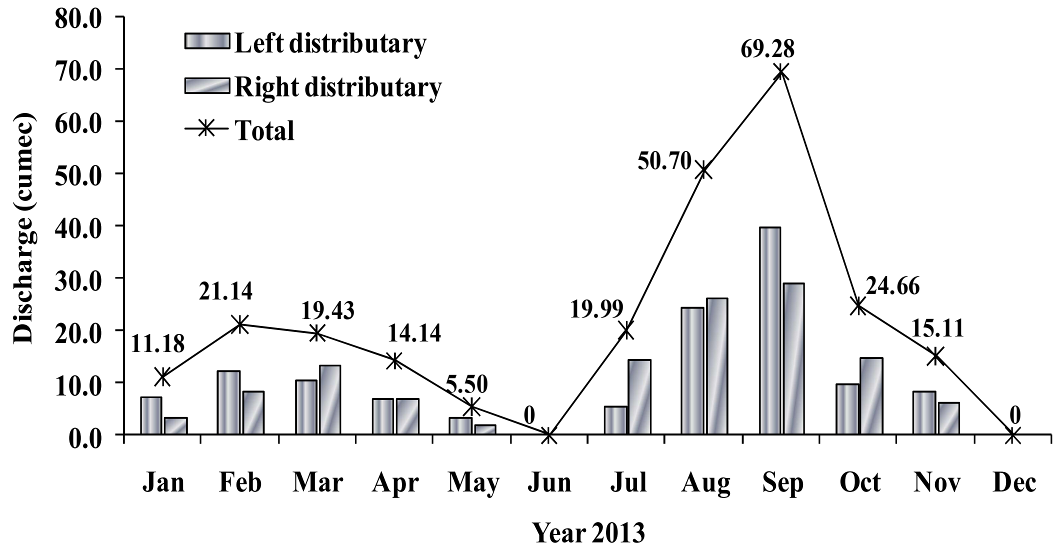


Fig. 5.4 Monthly discharge (cumec) pattern of water from the reservoir through left and right distributary (LD & RD) and the total discharge (cumec) during the year 2013

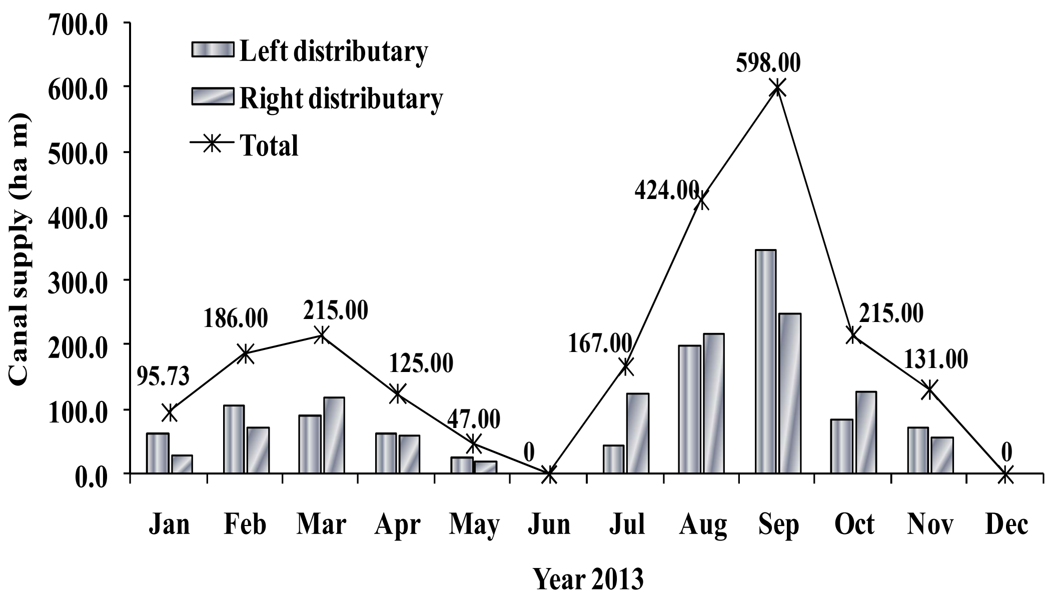


Fig. 5.5 Variation in monthly canal water supply (ha m) through left and right distributary (LD & RD) and the total supply (ha m) during the year 2013

Month-wise canal water supply for the year 2014-15 is presented in Fig. 5.6. In the month of June 2014 there was very less supply of water. In 2014, 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 it was no supply in the month of December. There was also supply during the period of January and February in 2015. The released amount of water was much less during lean period in comparison to the same during monsoon. There was inconsistent supply of canal water; excess supply during monsoon months, hence, there was a demand-supply gap during every month.

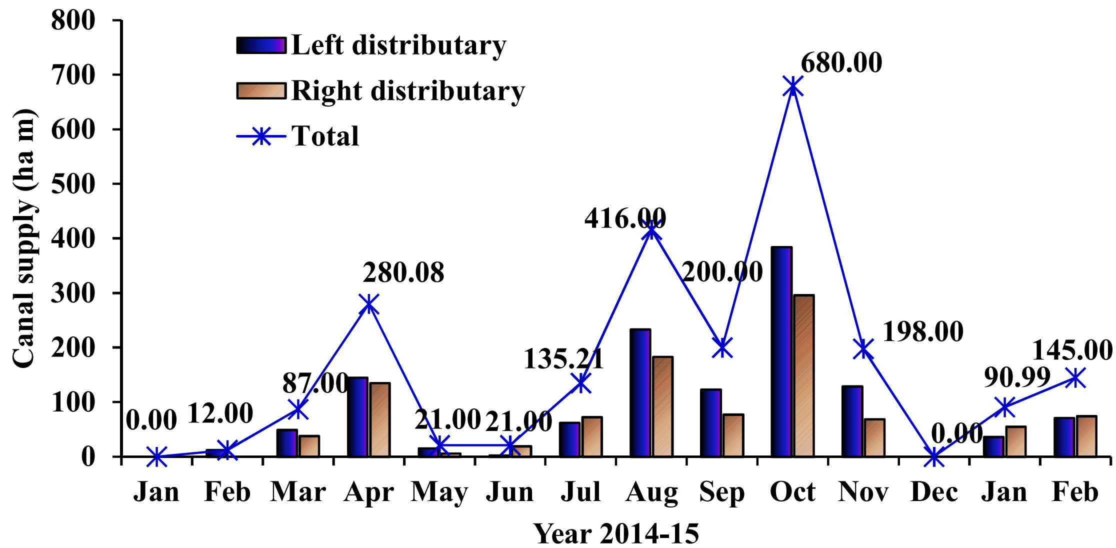


Fig. 5.6 Monthly canal water supply (ha m) through left and right distributaries and the total supply (ha m) during the year 2014-15

Table 5.7 Month-wise irrigation water demand, canal water supply through distributaries, minors and sub-minors and demand-supply gap (ha m)

Months	Demand (ha m)			Supply (ha m)			Gap (Demand-supply)		
	LD	RD	Total	LD	RD	Total	LD	RD	Total
Jan	110.9	86.1	197.0	65.5	30.9	96.4	45.4	55.2	100.6
Feb	132.7	85.6	218.3	107.6	74.7	182.3	25.1	10.9	36.0
Mar	135.6	128.5	264.1	93.3	119.6	212.8	42.3	8.9	51.3
Apr	74.5	66.8	141.3	65.0	60.0	125.0	9.5	6.8	16.3
May	34.6	18.9	53.5	27.6	20.0	47.6	7.0	-1.1	5.9
Jun	10.6	8.9	19.5	0.0	0.0	0.0	10.6	8.9	19.5
Jul	122.6	102.3	224.9	46.8	124.5	171.3	75.8	-22.2	53.6
Aug	129.8	135.2	265.0	201.7	219.4	421.1	-71.9	-84.2	-156.1
Sep	280.8	232.4	513.2	349.0	249.0	598.0	-68.2	-16.6	-84.8
Oct	52.3	48.6	100.9	85.0	130.0	215.0	-32.7	-81.4	-114.1
Nov	71.5	56.8	128.3	73.8	56.5	130.3	-2.3	0.3	-2.0
Dec	14.5	12.6	27.1	0.0	0.0	0.0	14.5	12.6	27.1

LD = left distributary, RD = right distributary

Canal delivery opening schedule

The canal has been opened and closed at the head regulator end of the two distributaries, i.e. left and right distributaries. The schedule of opening of head regulatory is given in Table 5.8.

Table 5.8 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

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 that the opening and closing of the canal system depend upon frequency and intensity of monsoon rainfall in the command area. No rotational supply of water was made in the canal network.

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. 5.7 and 5.8 and Table 5.9 and 5.10. It is observed that, in all the minors and sub minors of right and left distributaries, the carrying capacities (i.e. measured discharge) have 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 is reduced and ultimately the carrying capacity is reduced.

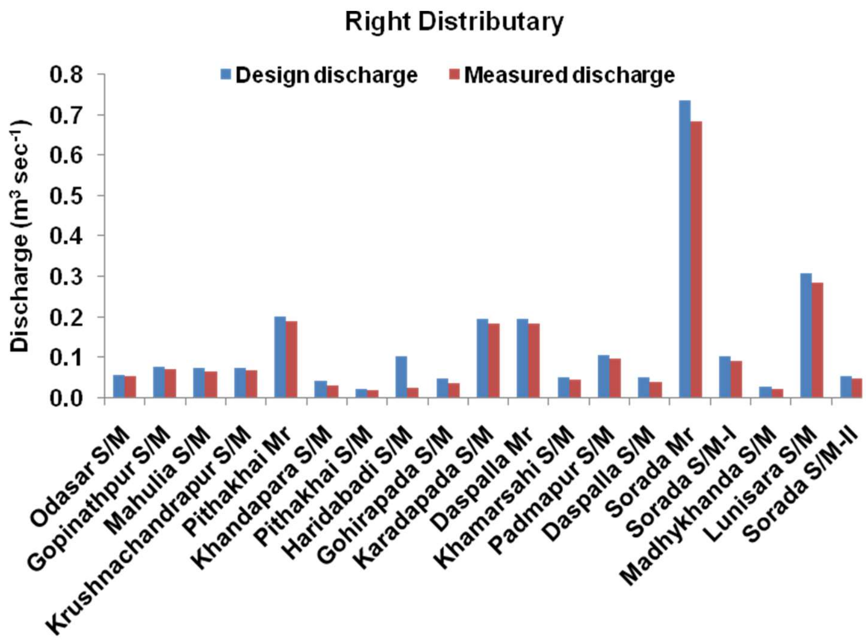


Fig. 5.7 Comparison of design and measured discharge rates of minors and sub-minors in right distributaries

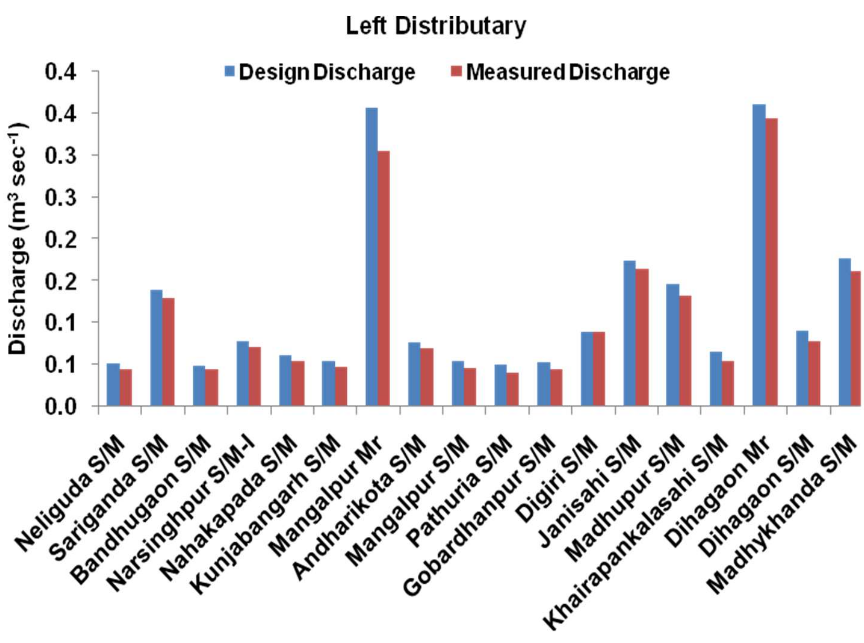


Fig. 5.8 Comparison of design and measured discharge rates of minors and sub-minors in left distributaries

Table 5.9 Comparison of design and measured discharge of minors and sub minors for right distributary

Canal system (minors and sub minors)	Design discharge in m^3/s	Measured discharge in m^3/s	Difference (m^3/s)
Odasar S/M	0.055	0.051	0.004
Gopinathpur S/M	0.075	0.071	0.004
Mahulia S/M	0.073	0.065	0.008
Krushnachandrapur S/M	0.072	0.066	0.006
Pithakhai Minor	0.201	0.188	0.013
Khandapara S/M	0.040	0.028	0.012
Pithakhai S/M	0.020	0.016	0.004
Haridabadi S/M	0.101	0.024	0.077
Gohirapada S/M	0.047	0.034	0.013
Karadapada S/M	0.195	0.183	0.012
Daspalla Minor	0.195	0.183	0.012
Khamarsahi S/M	0.050	0.044	0.006
Padmapur S/M	0.104	0.095	0.009
Daspalla S/M	0.050	0.039	0.011
Soroda Minor	0.737	0.684	0.053
Soroda S/M-I	0.101	0.090	0.011
Madhyakhanda S/M	0.025	0.020	0.005
Lunisara S/M	0.308	0.285	0.013
Soroda S/M-II	0.052	0.047	0.005

Table 5.10 Comparison of design and measured discharge of minors and sub minors for left distributary

Canal system (minors and sub minors)	Design discharge in m^3/s	Measured discharge in m^3/s	Difference (m^3/s)
Neliguda S/M	0.052	0.044	0.008
Sariganda S/M	0.140	0.129	0.011
Bandhugaon S/M	0.049	0.045	0.004
Narsinghpur S/M	0.078	0.071	0.007
Nahakapada S/M	0.062	0.055	0.007
Kunjabangarh S/M	0.054	0.048	0.006
Mangalpur Minor	0.357	0.305	0.052
Andharikote S/M	0.076	0.069	0.007
Mangalpur S/M	0.054	0.046	0.008
Pathuria S/M	0.050	0.040	0.010
Gobardhanpur S/M	0.053	0.045	0.008
Digiri S/M	0.089	0.088	0.001
Janisahi S/M	0.174	0.164	0.010
Madhupur S/M	0.146	0.133	0.013
Khairapnkalsahi S/M	0.066	0.055	0.011
Dihagaon Minor	0.361	0.344	0.017
Dihagaon S/M	0.091	0.078	0.013
Madhyakhanda S/M	0.177	0.162	0.015

Studies on authorized and unauthorized outlets

Authorized and unauthorized outlets of minors and sub minors for right and left distributaries are presented in Tables 5.11 and 5.12. 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.

Table 5.11 Authorized and unauthorized outlets of right distributaries, its minors and sub minors

Canal system	Authorized outlets	Unauthorized outlets
Right distributaries (A)	16	20
Minors and sub minors (B)	85	18
Odasar sub-minor	3	4
Gopinathpur sub-minor	4	1
Mahulia sub-minor	3	Nil
Krushnachandrapur sub-minor	4	Nil
Pithakhai minor	5	1
Khandapara sub-minor	6	Nil
Pithakhai sub-minor	5	Nil
Haridabadi sub-minor	2	Nil
Gohirapada sub-minor	1	1
Karadapada sub-minor	6	2
Daspalla minor	2	Nil
Khamarsahi sub-minor	3	Nil
Padmapur sub-minor	5	Nil
Daspalla sub-minor	2	Nil
Soroda minor	7	3
Soroda sub-minor –I	3	2
Madhyakhanda sub-minor	9	1
Lunisara sub-minor	11	1
Soroda sub-minor –II	4	2
Total (A+B)	101	38

Table 5.12 Authorized and unauthorized outlets of minors and sub minors for left distributaries

Canal system	Authorized outlets	Unauthorized outlets
Left distributaries (A)	4	22
Minors and sub minors (B)	87	52
Neliguda sub-minor	1	3
Sariganda sub-minor	8	4
Bandhugaon sub-minor	16	3
Narsinghpur sub-minor	10	5
Nahakapada sub-minor	2	4
Kunjabangarh sub-minor	9	2
Mangalpur minor	1	4
Andharikote sub-minor	2	2
Pathuria sub-minor	2	1
Gobardhanpur sub-minor	5	3
Digiri sub-minor	5	3
Janisahi sub-minor	5	2
Madhupur sub-minor	5	4
Khairapankalsahi sub-minor	3	2
Dihagaon minor	9	2
Dihagaon sub-minor	3	3
Madhyakhanda sub-minor	1	5
Total (A+B)	91	74

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

Groundwater fluctuation in the canal command

Groundwater fluctuation data were collected and it was observed that groundwater fluctuation varied in different observation wells (Table 6.1).

Table 6.1 Groundwater fluctuation in different observation wells under different villages in the command area

Observation well no.	Village	Water level in m			
		August	November	January	April
73D-3C1	Banigocha	4.83	6.04	7.80	8.50
73D-3C2A	Takara	2.87	5.34	6.92	8.72
73D-3D1	Daspalla-I	0.22	0.16	2.89	1.25
73D-3D2	Nuagaon	7.28	3.91	4.35	4.47
73D-3D3	Daspalla-II	5.46	6.82	6.32	6.80
73D-3D4	Subalaya	0.40	2.84	6.06	6.47

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 6.1). Overall trend is that the depth of groundwater decreases during rainy season due to monsoon rainfall. Then, its depth increases in 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.

Studies on groundwater quality in the command area

A study was carried out on chemical quality parameters of groundwater in Kuanria command area. Chemical parameters were determined in the laboratory, as listed in Table 6.2, based on the water samples collected randomly from well water after monsoon season from different sites. It indicated 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.

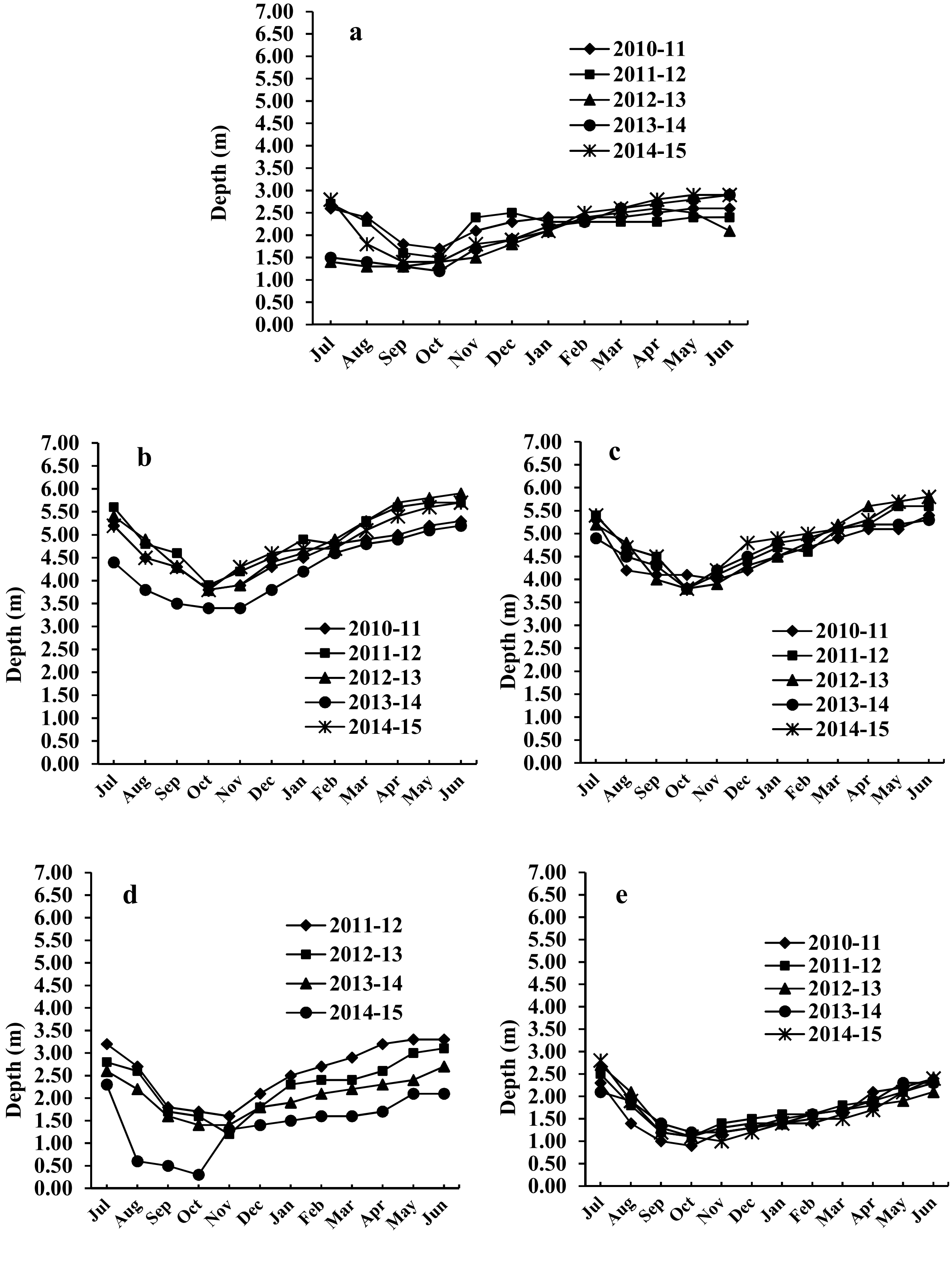


Fig. 6.1 Groundwater fluctuation over the year in the command area, a) head reach in the RD at Odasar s/m, b) mid-reach in the RD at Khamarsahi s/m, c) mid-reach in the LD at Mangalpur s/m, d) tail-end in the RD at Soroda s/m-II and e) tail-end in the LD at Madhyakhanda s/m

Table 6.2 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 (μS 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

s.d. is standard deviation

10.7 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 less 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. Based on experiences from watershed management research and large-scale development efforts, practical harvesting of runoff is possible only when the harvestable amount is more than 50 mm or greater than 10% of the seasonal rainfall. In this study area, as runoff amount was more than 10% of the seasonal rainfall, therefore practical harvesting of runoff was possible. In order to conserve the rainfall, seepage and excess canal water ponds are constructed within the Kuanria irrigation command area under beneficiary farmers (photo plates). The intervention was made in eight sites under eight sub-minors as indicated in Table 1.4, Table 7.1 & 7.2. The corresponding name of village, distributary and jurisdiction of the WUA is mentioned.

Table 7.1 Intervention sites in different head, mid- and tail ends under different water users' association (WUA) jurisdictions

Sl. No.	Name of the village	Name of sub-minor canal	WUA No.	Distributary	Canal reach
1	Odasar	Odasar S/M	6	RD	Head reach
2	Kunjabanagarh	Mangalpur S/M	2	LD	Middle reach
3	Paikabaghuarani	Khamarasahi S/M	8	RD	Middle reach
4	Malisahi	Khairapankalsahi S/M	4	LD	Tail- end
5	Dwargaon	Madhyakhand S/M	5	LD	Tail- end
6	Dendabhuin	Madhyakhand S/M-2	9	RD	Tail- end
7	Soroda	Lunisara S/M	10	RD	Tail- end
8	Subalaya	Soroda S/M-II	10	RD	Tail- end

The list of beneficiary farmers, name of villages, exact location with respect to longitude and latitude and the capacity of rain/ runoff water storage tanks developed in different minor/ sub-minors under the Kuanria canal command area is furnished also in the Table 7.2.

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

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


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


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


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

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

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

Construction of open wells

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 7.2 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	Distri butary	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^{0}18′52″N	84^{0}55′59″E	1630	2.02

10.8 Study on the cropping pattern, agricultural practices and socio-economic status of the farmers in the command

Cropping pattern, agricultural practices and productivity levels

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 8.1 and Fig. 8.1, 8.2 and 8.3. 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. Cropping pattern in the right and left distributary. The major cropping systems are presented with detailed information on agricultural practices, productivity levels etc. (Table 8.2).

Table 8.1 Area occupied by different crops under existing 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

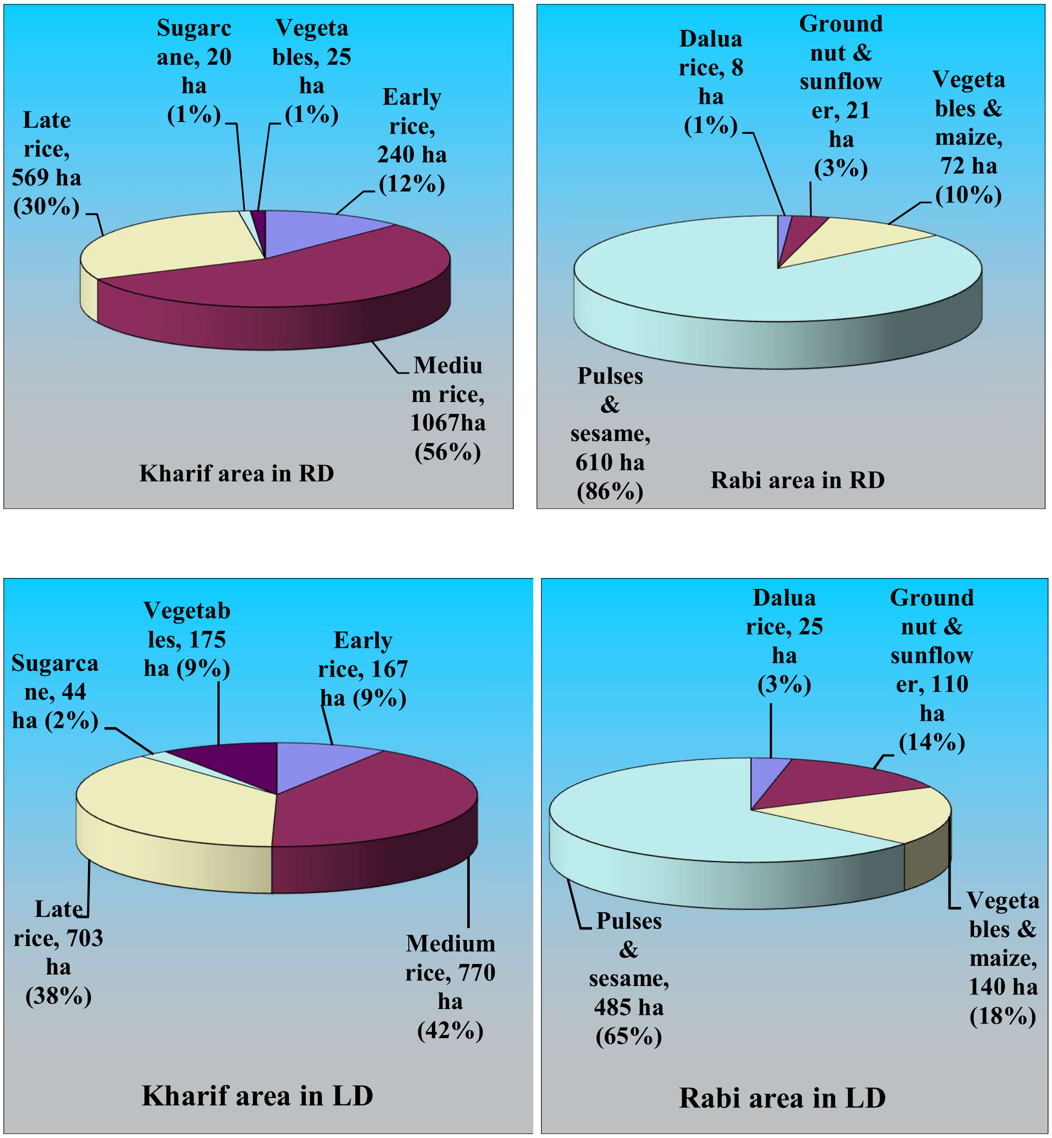


Fig. 8.1 Cropping pattern in right and left distributaries (RD & LD) during kharif and rabi seasons

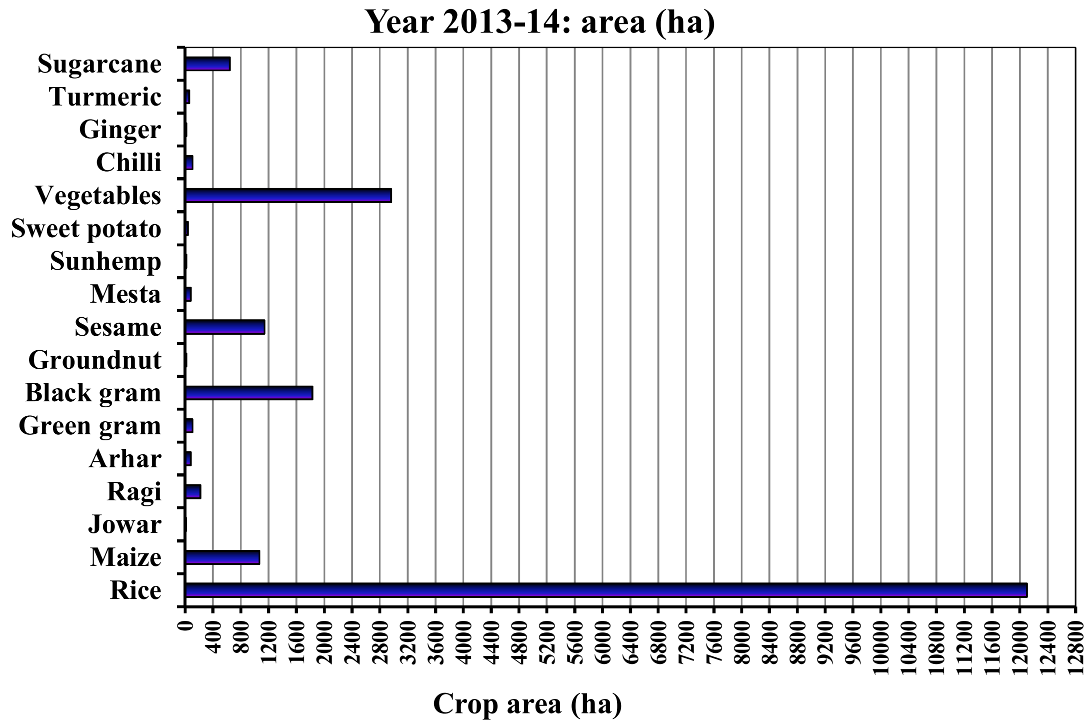


Fig. 8.2. Cropping pattern in the Kuanria canal command in the year 2013-14

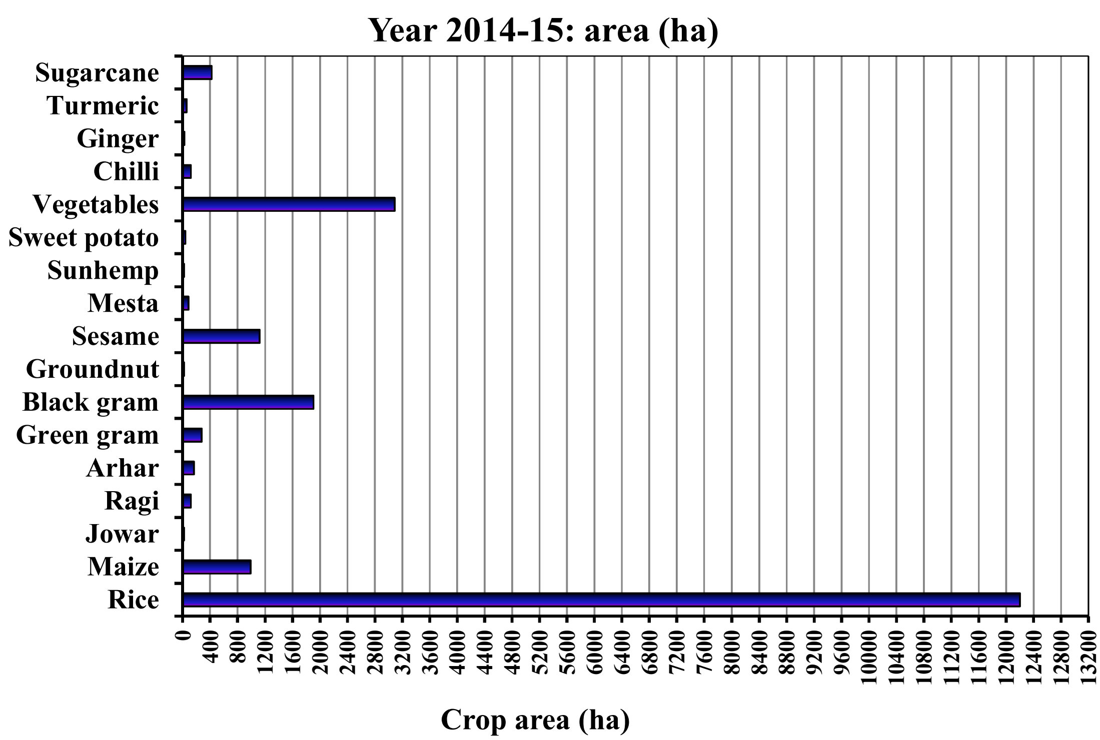


Fig. 8.3. Cropping pattern in the Kuanria canal command in the year 2014-15

Table 8.2 Major cropping systems- agricultural practices and productivity levels

Cropping systems, location	Cropping period	Crop variety, duration & spacing	Land preparation/ tillage operations	Manure and fertilizer application	Irrigation	Productivity levels
Rice-fallow system (20° 18' to 20° 21' N, 84° 53' to 84° 55' E)	Rice (mid-Jun to end of Oct) in rainy season	Rice var. 'Pratikshya (125 d) with 20x10 cm, 'MTU 1001' (120 d) with 20x10 cm	One summer ploughing and puddling before transplanting of rice	Farmyard manure (FYM) @ 3-5 t $ha^{-1}yr^{-1}$, N-P_2O_5-K_2O @ 60-30-30 kg ha^{-1}	Supplemental irrigation 2-3 times during dry spells	2.8-3.2 t ha^{-1}
Rice-sugarcane-2 years rotation (20° 20' N, 84° 54' E)	Rice (Jul-Nov) in rainy season; sugarcane (mid April-Feb/Mar)	Rice var. 'Pratikshya (125 d), 'Swarna' (140-145 d), 'MTU 1001' (120 d) with 20 x 10 cm & sugarcane var. 'Co 87044 (Uttara) Co 86249 (Bhavani) with 60-75 cm	One summer ploughing and puddling before transplanting of rice; ploughing and trenching while planting of sugarcane	FYM @ 3-5 t ha^{-1}; N-P_2O_5-K_2O @ 80-40-40 kg ha^{-1}; FYM @ 5-7 t ha^{-1}; N-P_2O_5-K_2O @ 200-80-60 kg ha^{-1} in splits for sugarcane	Supplemental irrigation 4-5 times to rice; need periodical based irrigation to sugarcane	Rice yield 3-4.5 t ha^{-1} & sugarcane 80-100 t ha^{-1}
Rice-greengram system (20° 20' N, 84°52' E)	Rice (Jul-Oct/Nov) in rainy & green gram (second fortnight of Nov-early Feb)	Rice var. Pratikshya (125 d), 'Swarna' (140-145 d), 'MTU 1001' (120 d) with 20 x 10 cm and mung bean var. 'Sujata' (65-70 d), 'Samrat' (75-80 d) with broadcasting	One summer ploughing and puddling before transplanting of rice, one ploughing for mung bean	FYM @ 3-5 t ha^{-1} for rice; N-P_2O_5-K_2O @ 60-30-30 kg ha^{-1} for rice and 20-40-20 kg ha^{-1} for mung bean	Supplemental irrigation 3-4 times to rice and residual moisture or one irrigation to mung bean	Rice yield 3.0-3.5 t ha^{-1} & mung bean 0.5-0.7 t ha^{-1}

Study on socio-economic status of farmers and water users' association (WUA)

According to the information, it is revealed that 90% of the farmers belong to marginal and small farmers while remaining 10% belongs to medium and large farmers (Table 8.3). 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%.

Table 8.3 Percentage distribution of area under different category of size of holdings

Size of holdings	Number percentage (%)	Area (%)
0-1 ha	84.9	43.0
1-4 ha	12.0	34.6
4-10 ha	2.9	18.1
> 10 ha	0.2	4.3

A total of 10 numbers Pani Panchayats have been operational under the command area. The jurisdiction area of the Pani Panchayats varies from 274.95 ha to 501.70 ha (Table 8.4). 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. Cultivable command area (CCA) for different WUAs under KIP is presented in Table 8.5. The composition of WUAs indicates that it 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 8.4 Pani Panchayats under Kuanria Irrigation Project, Daspalla, Nayagarh

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


Dr. Ashwani Kumar, Director, ICAR-IIWM (formerly DWM) interacted with the farmers of the command area

The study was conducted to survey of existing socio economic status for around 64 farmers by using a pre-tested questionnaire, which covered eight gram panchayat and 30 villages. Out of 64 farmers 60 farmers belong to Daspalla block and remaining 4 farmers in

Nuagaon block. 23.4, 57.8 and 3.1 percent of the farmers belong to general, other backward caste and schedule class category respectively. Main occupation is agriculture for all the farmers. Maximum percentage (i.e. 56.3) of farmers has passed high school. Similarly 10.9 and 31.3% of farmers have passed college level and primary. Average annual income of the farmer was Rs 31,484/- with maximum and minimum income of about Rs 90,000 and 5,000 respectively. Average farm size of the farmer was 3.6 acre. 76.6 percent of total farmers belong to medium household and remaining farmers belong to small (i.e. 14.1%), large (i.e. 6.3%) and very large (i.e. 3.1%) household. Main occupation is agriculture for all the farmers; 84.4, 9.4, 4.7 and 1.6 percent of total farmers adopting agriculture, business, diary and fishery, respectively as their secondary occupation.

Table 8.5 Detail of WUAs composition and jurisdiction area

Particular of WUA	Members	Male members	Female members	Executive Committee members	Location	CCA (ha)
WUA 1	889	792	97	14	LD, Head	351.96
WUA 2	752	648	104	24	LD, Head	436.74
WUA 3	620	526	94	17	LD, Middle	274.95
WUA 4	808	734	74	20	LD, Middle	366.82
WUA 5	1037	935	102	20	LD, Tail	428.82
WUA 6	410	354	56	10	RD, Head	287.01
WUA 7	910	727	183	23	RD, Head	313.25
WUA 8	1254	1111	143	21	RD, Middle	501.7
WUA 9	1592	1363	229	16	RD, Tail	491.67
WUA 10	318	281	37	11	RD, Tail	327.08

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

10.9 Soil fertility and water quality in the command area

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. The data on the parameters have been presented along with WUA jurisdiction (Table 9.1). 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 9.1 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 9.2).

Table 9.2 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

Studies on 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 9.3, based on the water samples collected from pond water after monsoon season from different sites. It indicated 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. In the year 2014-15 also, water quality of the rain/ runoff water storage tanks was monitored. 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. All the parameters in pond and the open well water were in permissible limits for irrigation to crops.

Table 9.3 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

10.10 Development of appropriate cropping systems and economic assessment of benefit due to pond-based intervention

Due to our 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 10.1.

Across the sites, the cost of cultivation (operational cost) varied from Rs 131003 to Rs 154064 per ha depending upon the variation in input costs including fish feed, fertilizer, irrigation and seeds etc. The benefit i.e., the net income from the whole systems including fish culture varied from Rs 157 224 to Rs 199776 per ha. The integrated farming systems under pond command 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) +vegetable (on dyke) -greengram and rice + (fish in pond) + banana/ papaya (on-dyke)- pigeonpea (on dyke); rice+(fish in pond) –vegetable (on-dyke)-vegetable.

Table 10.1 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	
Pond command areas i.e. 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
Non-pond command areas i.e. 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 is not applicable; kharif vegetable was not grown in non-pond command area

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 showing the diversification in cropping under different intervention sites

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

Sunflower crop is 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 showing the diversification in cropping under different intervention sites

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. The construction costs etc. have been ignored for the sake of comparison in the long-run. For the current year 2013-14, the data on assessment for the complete year is not presented because of the reason that the final fish harvest and harvesting and marketing of rabi and summer crops occurred beyond reporting period i.e., up to March 2014.

However, the economic assessment of kharif crop cultivation (kharif rice and kharif vegetables) has been made and presented. It is revealed from the data up to kharif season 2013 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 sub-minor, Khairapankalsahi sub-minor, Madhyakhanda sub-minor, Odasar sub-minor, Khamarsahi sub-minor, Madhyakhanda sub-minor-2, Lunisara sub-minor and Soroda sub-minor. 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

10.11 Studies on multiple uses of stored water, conjunctive use and development of pond-based integrated farming system

Rain/ runoff water storage tanks and open wells were constructed for conservation of rainfall and runoff water to ensure water availability and dependability to the farmers. The list of beneficiary farmers, name of the village and the respective sub-minors etc are mentioned in the Table 7.2 and in photo plates in the succeeding pages in this report.

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, 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 attributed by increased level of metabolites and organic matter. At any given point of time, other water quality parameters and plankton did not register any specific trend. 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 11.1, 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}.

During 2013-14, fish fingerlings of IMCs (*Catla, Labeo rohita* and *C. mrigala*) were stocked in the first week of September @ 5,000/ha with a stocking composition of 30:30:40 (MBW- 20, 14 & 12 g for catla, rohu & mrigala, respectively) in each pond of 1630 m^3 each. 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 DO concentration showed a decreasing trend with the advancement of rearing period while, gradual increase in nitrite, nitrate, ammonia were attributed by increased level of metabolites and organic matter. At any given point of time, other water quality parameters and plankton did not register any specific trend. After 210 days of rearing, harvesting was carried out. The recorded fish production ranged between 2.56-3.06 t ha^{-1} 210d^{-1}. Species-wise production-size index and performance index is presented in Table 11.2, indicating the normal growth performance of the cultured species. Pond-wise gross water productivity ranged between 6.64-8.05 Rs m^{-3} while the net water productivity ranged between 4.7-5.98 Rs m^{-3}.

Fish water productivity: To evaluate the efficiency of water management, the gross water productivity (GWP), net water productivity (NWP) was calculated (Rs. m^{-3}) keeping the total volume of water used into account as shown below: GWP = total economic value of the produce (Rs.) / total volume of water used (m3), NWP = total economic value of the produce (Rs.) - production cost (Rs.) / total volume of water used (m3),

Total volume of water use (precipitation + runoff + canal addition) and consumptive water use (evaporation + seepage + irrigation + water in harvest biomass) was estimated. Average water in harvest biomass is about 0.75 m3/t, was taken into account. To estimate the water use, a recording water level gauge was installed in each pond to measure the water loss, the inflow and outflow during the experimental period. Further, to separate the evaporation from the total loss, evaporation was estimated using the following equation: pond evaporation (mm) = pond-pan coefficient × class-A pan evaporation (mm), pond pan coefficient of 0.8, most appropriate for ponds, was used in the above equation.

Example: For Mangalpur S/M (Table 11.1)

GWP (Rs.m^{-3}) = 7.09

NWP (Rs.m^{-3}) = 5.25

PSI = production-size index, PI- performance index, AFCR- apparent feed conversion ratio, FE- feeding efficiency

PSI = (Per day increment in g) x (survival rate in %) = 541.6

PI = (Production in kg/ha) x (mean body weight in g)/1000 = 273.2

AFCR = (Total feed used in kg)/ (total harvested biomass in kg) = 1.41

FE% = (Biomass gain in kg/ feed used in kg) x 100 = 50.7

Table 11.1 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 S/M	Catla	22.0	555.2	541.6/ 273.2	2.65	1.41/ 50.7	7.09	5.25
	Rohu	15.5	466.5	241.7/ 195.9				
	Mrigala	12.0	480.5	324.4/ 200.6				
Khairapankal sahi S/M	Catla	22.0	545.0	540.7/ 274.2	2.58	1.33/ 62.3	6.94	5.10
	Rohu	15.5	462.5	241.1/ 196.7				
	Mrigala	12.0	485.5	338.6/ 200.1				
Madhyakhan da S/M	Catla	22.0	510.0	536.7/ 270.5	2.72	1.49/ 61.6	7.37	5.35
	Rohu	15.5	436.5	239.1/ 193.7				
	Mrigala	12.0	455.5	328.6/ 197.1				
Odasar S/M	Catla	22.0	553.2	522.7/ 264.2	2.45	1.45/ 55.5	6.47	4.60
	Rohu	15.5	476.2	238.1/ 194.7				
	Mrigala	12.0	498.5	333.4/ 200.0				
Khamarsahi S/M	Catla	22.0	565.0	542.6/ 274.8	2.96	1.62/ 58.3	7.85	5.86
	Rohu	15.5	482.5	242.6/ 197.7				
	Mrigala	12.0	500.0	344.6/ 205.5				
Madhyakhan da S/M -2	Catla	22.0	585.0	606.8/ 305.5	2.75	1.44/ 70.7	7.54	5.44
	Rohu	15.5	492.5	282.2/ 211.9				
	Mrigala	12.0	470.0	385.4/ 207.8				
Lunisara S/M	Catla	22.0	572.5	611.2/ 302.0	2.84	1.37/ 67.3	7.66	5.61
	Rohu	15.5	470.0	265.5/ 208.4				
	Mrigala	12.0	485.0	359.2/ 204.4				
Soroda S/M-II	Catla	22.0	590.0	612.5/ 288.2	2.62	1.45/ 57.8	6.98	5.13
	Rohu	15.5	510.5	247.1/ 202.9				
	Mrigala	12.0	520.0	376.7/ 211.5				

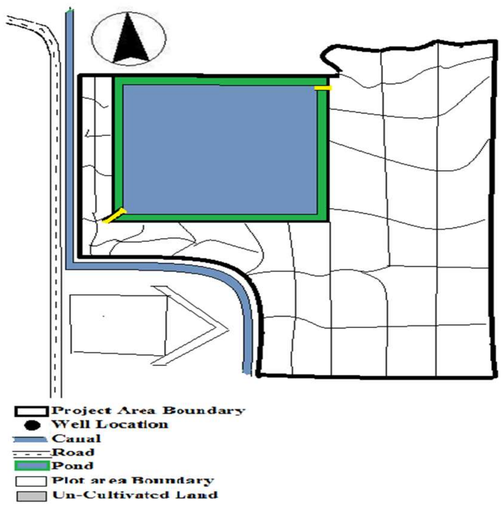
Fish productivity (t ha^{-1} per 210 days), PSI- production-size index, PI- performance index, AFCR- apparent feed conversion ratio, FE- feeding efficiency, Fish sold @ Rs.90 kg^{-1}, GWP- gross water productivity, NWP- net water productivity

Table 11.2 Production performance of IMCs in water harvesting structures (2013-14)

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

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

Multiple uses of water, conjunctive use, and integrated farming systems under different sites



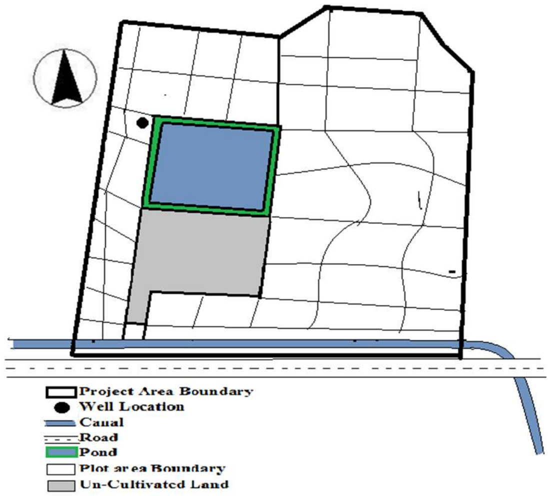
Location map of the study site under Khamarsahi sub-minor in the mid-end

Rain/ runoff water storage structures has been developed in the Khamarsahi sub-minor and rice crop in its command

Field operation and cleaning of weeds in the okra crop in the pond command under Khamarsahi sub-minor

Initial stage of spinach crop grown in between okra rows as intercrop in the pond command under Khamarsahi sub-minor

Integrated farming system in Khamarsahi sub-minor



Location map of the study site under Mangalpur sub-minor in the mid-end

Rain/ runoff water storage structures was developed in Mangalpur sub-minor

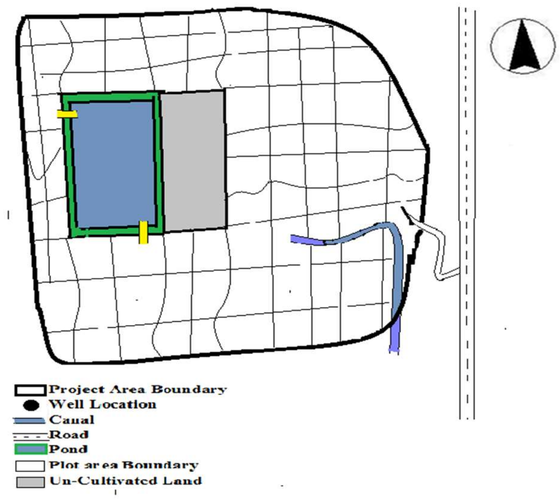
New crop of sweet corn was introduced in the pond-command under Mangalpur sub-minor

Paired-row cultivation of sunflower in the pond-command with irrigation from constructed tank and open well in Mangalpur sub-minor

Integrated farming system in Mangalpur sub-minor

Table 11.3 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)	Total command (ha)
1	Mrs. Jyotsnamai Nanda	Kunjabanagarh	Mangalpur S/M	LD	2	20° 20' N	84° 52' E	1630	2.83
2	Sh. Banamali Mishra	Malisahi	Khairapankalsahi S/M	LD	4	20° 21' N	84° 53' E	1630	2.02
3	Mr. Balakrusna Pradhan	Dwargaon	Madhyakhand S/M	LD	5	20° 20' N	84° 54' E	1630	1.82
4	Mrs. Itishree Mishra	Dendabhuin	Odasar S/M	RD	6	20° 17' N	84° 50' E	1630	2.43
5	Mr. Sudarsan Das	Paikabaghuarani	Khamarasahi S/M	RD	8	20° 18' N	84° 53' E	1630	2.43
6	Mr. Banbihari Muduli	Dendabhuin	Madhyakhand S/M	RD	9	20° 19' N	84° 55' E	1630	2.43
7	Mr. Hadia Nayak	Sorada	Lunisara S/M	RD	10	20° 19' N	84° 55' E	1630	1.01
8	Mr. Bhagirathi Nayak	Subalaya	Soroda S/M-II	RD	10	20° 18' N	84° 55' E	1630	2.02



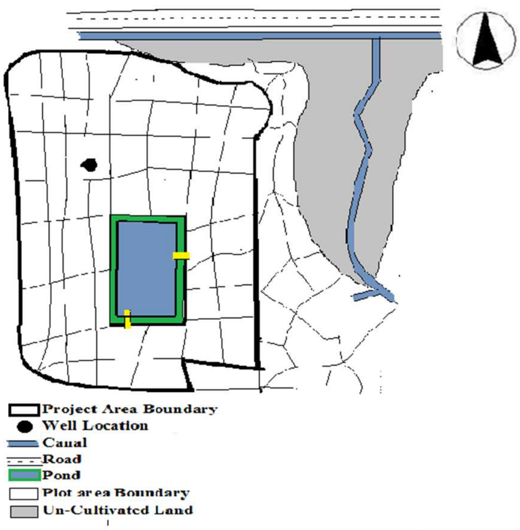
Location map of the study site under Khairapankalsahi sub-minor in the tail-end

Rain/ runoff water storage structures has been developed in Khairapankalsahi sub-minor

Rice is the predominant crop which is grown in the command during kharif season

Kharif vegetable viz. bitter gourd was grown in the pond-command area

Integrated farming system in Khairapankalsahi sub-minor



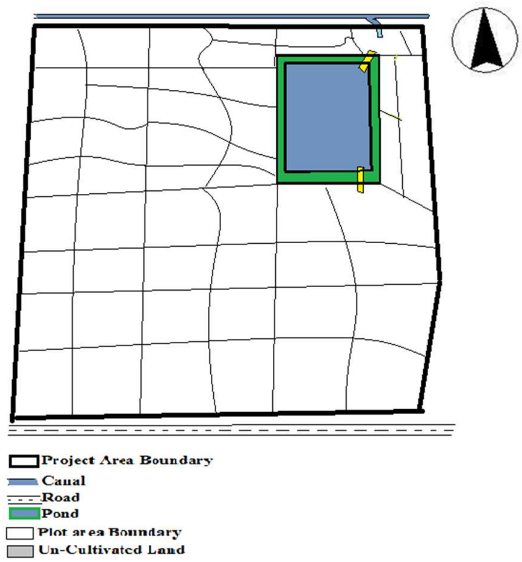
Location map of the study site under Madhyakhanda sub-minor in the tail-end

Rain/ runoff water storage structures developed in the Madhyamkhanda sub-minor

Okra was grown in rabi and summer season using irrigation water from open wells and constructed 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

Integrated farming system in Madhyakhanda sub-minor



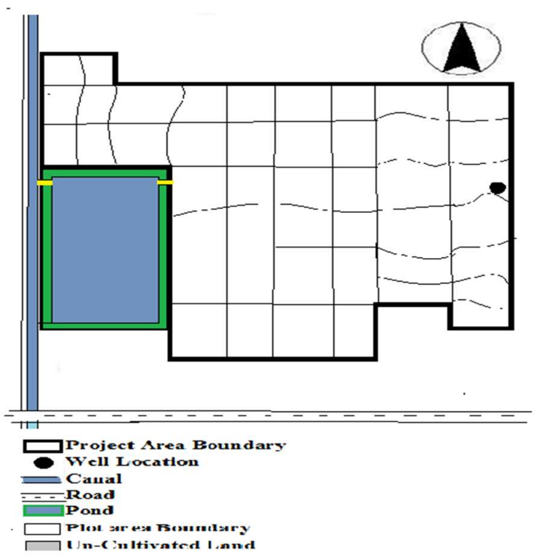
Location map of the study site under Odasar sub-minor in the head-reach

Fish culture was profitable in the constructed water storage tank in the Odasar 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

Integrated farming system in Odasar sub-minor



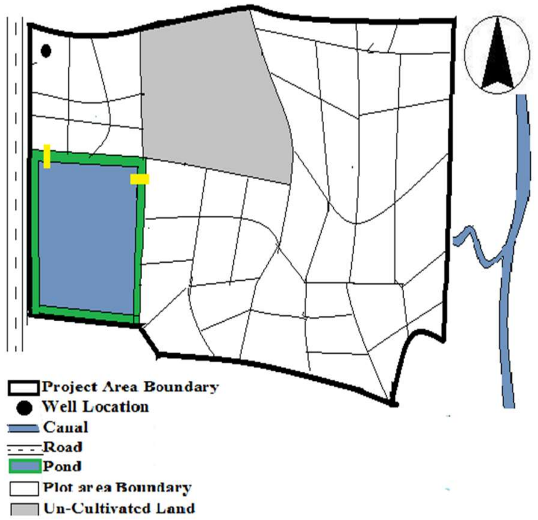
Location map of the study site under Madhyakhanda sub-minor in the tail-end

Rain/ runoff water storage structures was developed under Madhyakhand sub-minor, & on-dyke pigeonpea cultivation

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

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

Integrated farming system in Madhakhanda (2) sub-minor

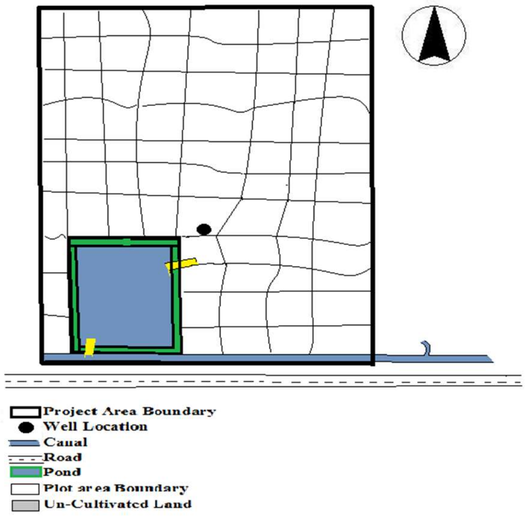


Location map of the study site under Lunisara sub-minor in the tail-end

Rain/ runoff water storage structures has been developed in Lunisara sub-minor

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

Integrated farming system in Lunisara sub-minor



Location map of the study site under Sorada sub-minor II in the tail-end

Rain/ runoff water storage structures developed in the Sorada sub-minor-II

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

Integrated farming system in Sorada sub-minor-II

Table 11.4 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)		
			Kharif crop*	Rabi crop	Fish$
	Pond-command areas i.e. with water storage tank				
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*; in the year 2011-12 tank could not be made in sub-minors with blank data.

Table 11.5 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
	Non-pond command areas i.e. without water storage tank				
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.

Table 11.6 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	Tank command area (ha)	Yield (kg/ha)		
			Kharif crop*	Rabi Crop#	Fish$
	Pond-command areas i.e. with water storage tank				
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 11.7 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
	Non-pond command areas i.e. without water storage tank				
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.

Table 11.8 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
	Pond command areas i.e. with water storage tank				
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 11.9 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*,$
	Non-pond command areas i.e. without water storage tank				
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 non-pond command area

The integrated farming systems were developed under different sites (head-, mid- and tail end) of the canal command. The sites belong to the 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 for improving farm income.

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 11.4 and 11.5). 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 11.6 & 11.7). During rabi season (2011-12), greengram, blackgram and chickpea were grown, after harvesting of kharif rice, 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. Supplementary irrigation could not be given. 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 with Sh. Banabihari Muduli of village Dendabhuin under Madhyakhanda sub-minor in the right distributaries, 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 with residual soil moisture only. Supplementary irrigation could not be given. 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, the rain/ runoff water storage tank was constructed in the field, near the main roadside, of a beneficiary farmer, Sh. Hadia Nayak of village Soroda under Lunisara sub-minor in the right distributaries. One irrigation could not be given to kharif season rice during 2011 though there was dry spell. In 2012, irrigation was not required due to optimum distribution of rainfall. Pond command area was compared with the non-command area of the same farmer. 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 from the pond. In the non-command area, greengram was grown with residual soil moisture only. Supplementary irrigation could not be given. There was no crop during rabi season.

In Soroda sub-minor-II, the rain/ runoff water storage tank was constructed in the field, near roadside, of a beneficiary farmer, Sh. Bhagirathi Nayak of village Subalaya under Soroda sub-minor-II in the right distributaries of KIP. The area comes under the jurisdiction of WUA 10. 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. Pond command area was compared with the non-command area of the same farmer. 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 utilizing the residual soil moisture. 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.

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; moong bean and arhar for Khairapankalsahi S/M; maize, vegetables and moong bean for Madhyakhand S/M; maize and vegetables for Odasar; maize, vegetables, sunflower for Khamarasahi S/M; maize, arhar, moong, vegetables for Madhyakhand S/M-2; moong, arhar for Lunisara S/M and moong, 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. There was no much difference in rice yield due to having water storage structure or not because no irrigation to kharif rice was required to be provided during kharif season 2012. 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 as indicated in the Table 7. The cumulative fish yield ranged from 2.45 to 2.96 t ha^{-1}. 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}.

For the year 2013-14, paddy yield ranged from 2740 to 3360 kg ha^{-1} under the pond command (Table 11.8 and 11.9), 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 reported under impact assessment section.

11. Field Tests/ Impact Assessment Conducted

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

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 under the command area. The availability of water throughout the year has been depicted through water depths in the tanks as presented in the Fig. 12.1 and 12.2.

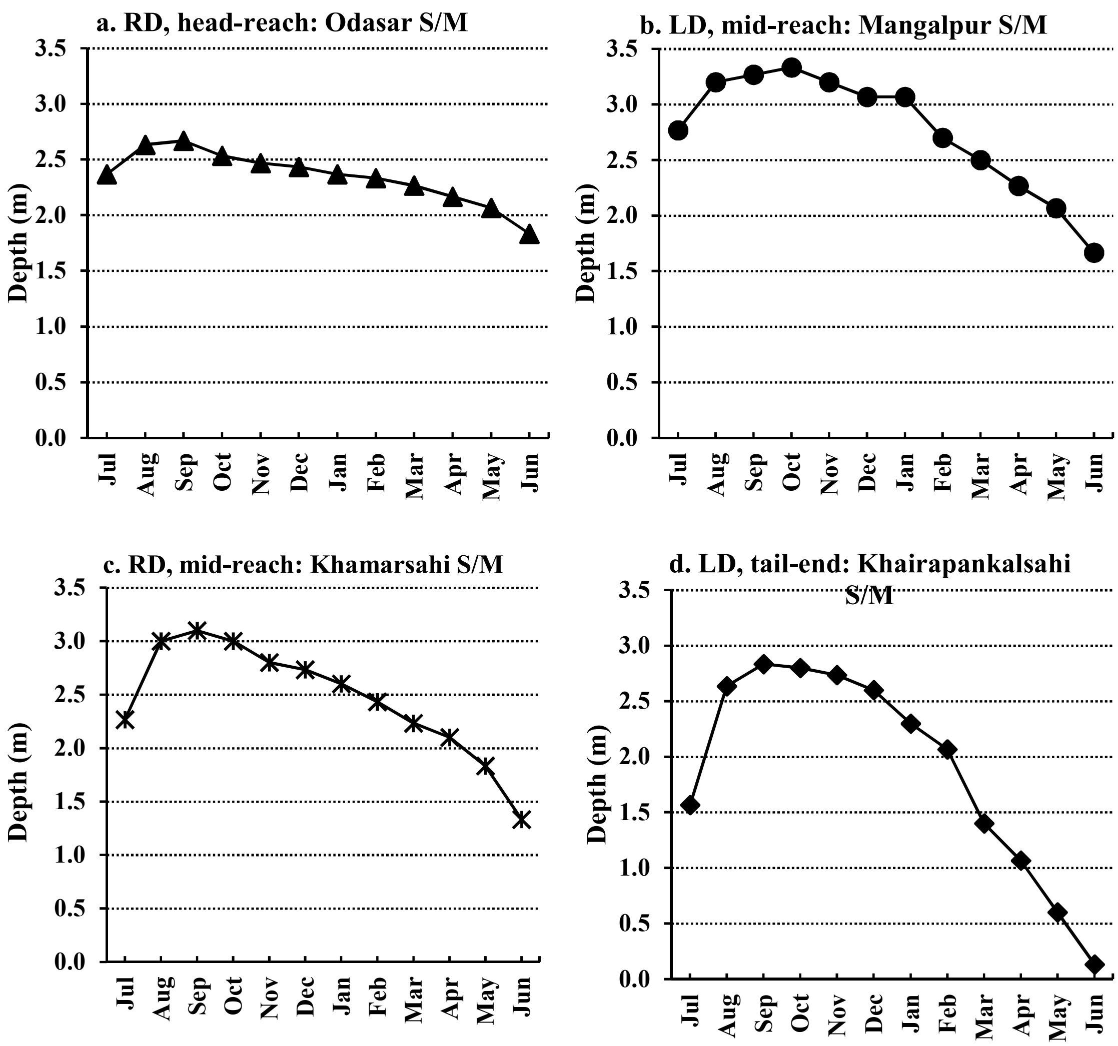


Fig. 12.1 Fluctuation of pond water depth (mean of 3 years, 2011-12 to 2014-15) in different sites in the KIP command, a) RD, head-reach under Odasar s/m, b) LD, mid-reach under Mangalpur s/m, c) RD, mid-reach under Khamarsahi s/m, d) LD, tail-end under Khairapankalsahi s/m

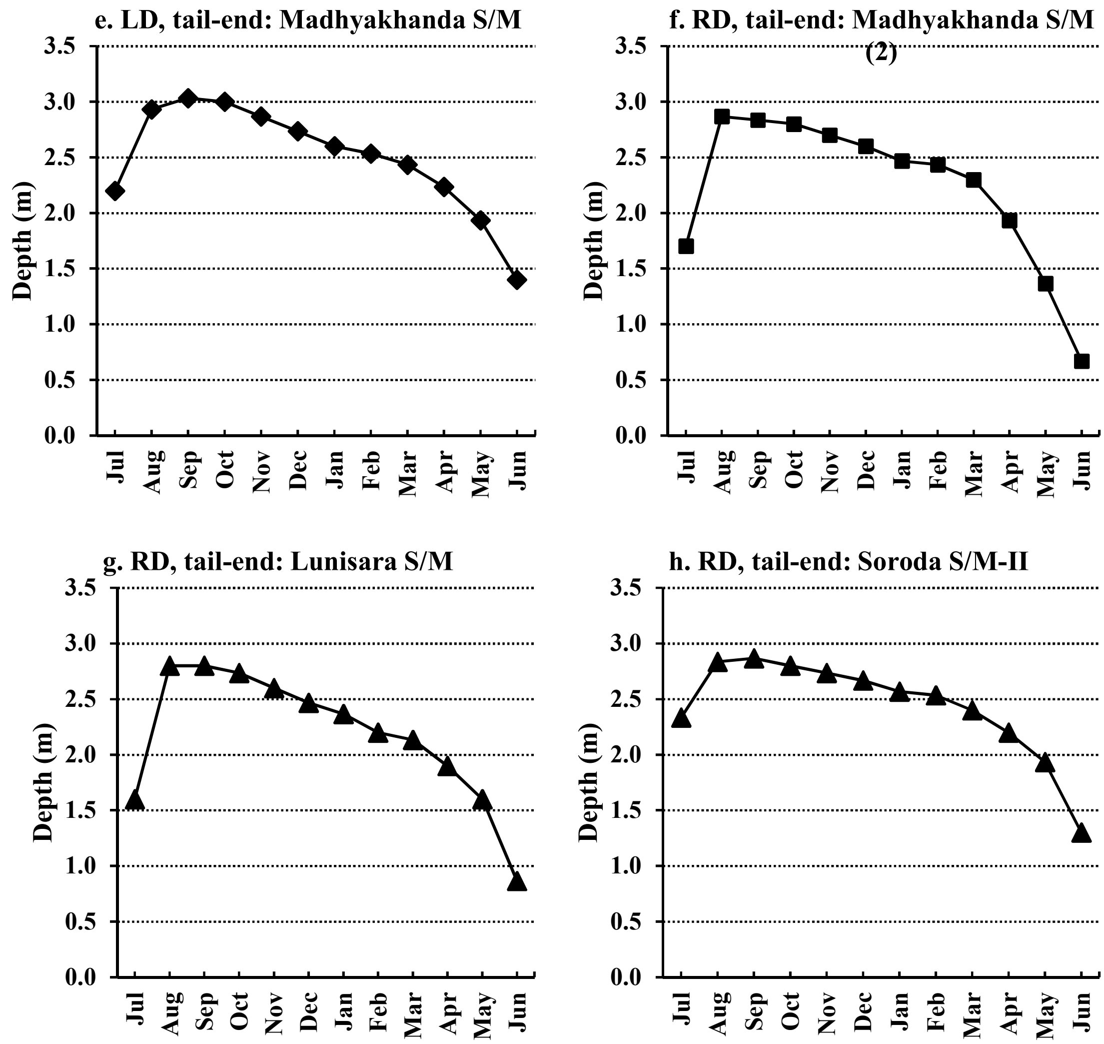


Fig. 12.2 Fluctuation of pond water depth (mean of 3 years, 2011-12 to 2014-15) in different sites in the KIP command, e) LD, tail-end under Madhyakhanda s/m, f) RD, tail-end under Madhyakhanda s/m (2) g) RD, tail-end under Lunisara s/m, h) RD, tail-end under Soroda s/m-II

Crop and fish production

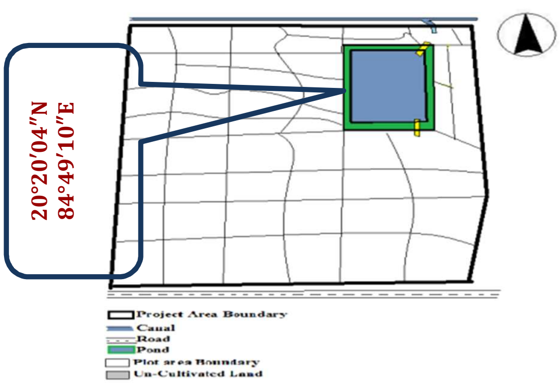
There has been a significant impact on the crop and fish production due to intervention through the project activities. The integrated farming systems were developed under different sites (head-, mid- and tail end) of the canal command. The sites belong to the Odasar S/M, Mangalpur S/M, Khamarasahi S/M, 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.

Physical water productivity (PWP) = (Produce in kg from the area)/ (water used in m^3)
Economic water productivity (EWP) = (Gross return in Rs from the area)/ (water used in m^3)

Example (Table 12.1)
Fish- physical water productivity (PWP) = 510/2930 = 0.17 kg/m^3
Fish- economic water productivity (EWP) = 51000/2930 = 17.40 Rs/m^3
Brinjal- physical water productivity (PWP) = 1800/700 = 2.57 kg/m^3
Brinjal- economic water productivity (EWP) = 27000/700 = 38.57 Rs/m^3

Similarly, PWP and EWP have been calculated for other sub-minors viz. Table 12.2, 12.3, 12.4, 12.5, 12.6, 12.7 & 12.8

Crop and fish production due to intervention under Odasar sub-minor in the head-reach of the canal command



The site showing location of constructed water storage tank at the head-reach

A view of the constructed water storage tank at the head-reach under Odasar sub-minor

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

Table 12.1 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 (m³)	Phy. water productivity (kg/m³)	Eco. water productivity (Rs/m³)
Fish (IMC)	0.098	510	5204	51000	2930	0.17	17.40
Rice	1.5	4200	2800	57120	-	-	-
Moong	1.0	525	525	24150	600	0.88	40.25
Brinjal	0.2	1800	9000	27000	700	2.57	38.57
Tomato	0.2	2000	10000	40000	800	2.50	50.00
Cauliflower	0.1	1200	12000	24000	450	2.67	53.33
Total				223270			

IMC is Indian major carps i.e., *Labeo rohita*, *Catla catla* and *C. mrigala*

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 12.1. 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.

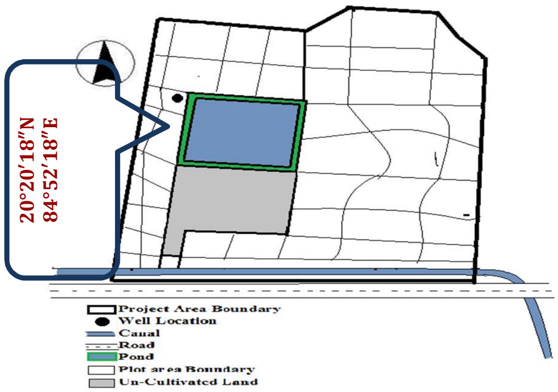
Table 12.2 Crop & fish production and water productivity the site under Mangalpur sub-minor in the mid-reach

Fish/ Crops	Area (ha)	Production (kg)	Yield (kg/ha)	Gross return (Rs)	Water used (m³)	Phy. water productivity (kg/m³)	Eco. water productivity (Rs/m³)
Fish (IMC)	0.098	240	2449	24000	2744	0.09	8.74
Coconut (on-dyke)		27 plants	-	-	-	-	-
Rice	2.2	6500	2955	88400	-	-	-
Arhar	0.2	180	900	7830	130	1.38	60.23
Moong	2.0	1100	550	50600	1320	0.83	38.33
Vegetables	0.02	-	-	3500	70	-	50.00
Total				174330			

IMC is Indian major carps i.e., *Labeo rohita*, *Catla catla* and *C. mrigala*

Fish, crop production, conjunctive use of water used from storage tank and open well, water productivity are presented in Table 12.2. 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.

Crop and fish production due to intervention under Mangalpur sub-minor in the mid-reach of the canal command



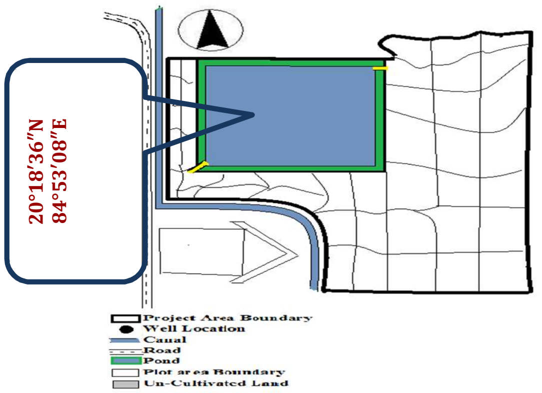
The site showing location of constructed water storage tank and open well under Mangalpur sub-minor

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

A team of Scientists from the Institute and State Govt. Officials visited the site during July 2014

A pulse crop, moong i.e., green gram was grown with irrigation in the pond command

Crop and fish production due to intervention under Khamarsahi sub-minor in the mid-reach of the canal command



The site map showing location of constructed water storage tank under Khamarsahi sub-minor

A view during monsoon season of the constructed pond at the mid-reach under Khamarsahi sub-minor

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 with irrigation from storage water

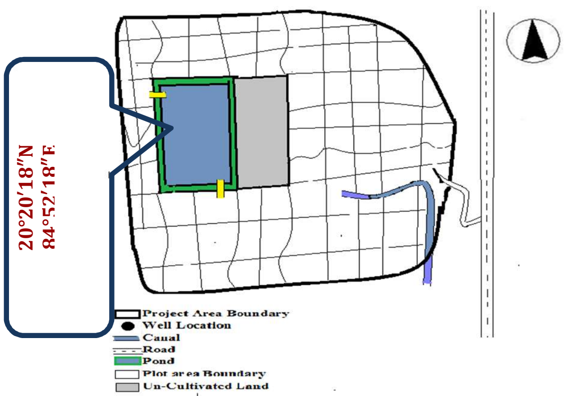
Table 12.3 Crop & fish production and water productivity in the site under Khamarasahi sub-minor in the mid-reach

Fish/ Crops	Area (ha)	Production (kg)	Yield (kg/ha)	Gross return (Rs)	Water used (m3)	Phy. water productivity (kg/m3)	Eco. water productivity (Rs/m3)
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	1.08	39.81
Bhindi	0.08	550	6875	11000	256	2.15	42.97
Total				163675			

IMC is Indian major carps i.e., *Labeo rohita*, *Catla catla* and *C. mrigala*

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 12.3. 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.

Crop and fish production due to intervention under Khairapankalsahi sub-minor in the tail-end of the canal command



The site map showing location of constructed water storage tank under Khairapankalsahi sub-minor

A view during summer of the constructed tank at the tail-end under Khairapankalsahi sub-minor

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 12.4 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)	Phy. water productivity (kg/m^3)	Eco. water productivity (Rs/m^3)
Fish (IMC)	0.098	130	1327	13000	2455	0.05	5.29
Rice	1.5	4200	2800	57120	-	-	-
Moong	0.2	130	650	5980	110	1.18	54.36
Sesame	0.05	40	800	1840	35	1.14	52.57
Total				77940			

IMC is Indian major carps i.e., *Labeo rohita*, *Catla catla* and *C. mrigala*

Fish, crop production, water used from storage tank and open well and water productivity are presented in Table 12.4. 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.

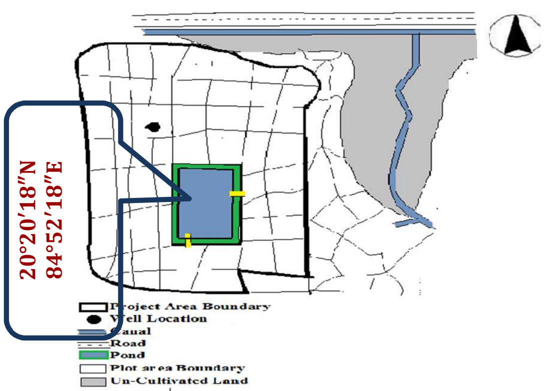
Table 12.5 Crop & fish production and water productivity in the site under Madhyakhand sub-minor in the tail-end

Fish/ Crops	Area (ha)	Production (kg)	Yield (kg/ha)	Gross return (Rs)	Water used (m^3)	Phy water productivity (kg/m^3)	Eco water productivity (Rs/m^3)
Fish (IMC)	0.098	260	2653	26000	2680	0.09	9.7
Rice	1.4	4500	3214	61200	-	-	-
Banana (on-dyke)	0.02	40 bunch	-	3000	-	-	-
Papaya (on-dyke)	0.01	180	18000	1800	-	-	-
Vegetables (on-dyke)	0.01	-	-	3500	-	-	-
Maize	0.2	1000	5000	13100	560	1.79	23.39
Bhindi	0.2	1100	5500	22000	800	1.38	27.50
Pumpkin	0.6	7000	11667	70000	2250	3.11	31.11
Total				200600			

IMC is Indian major carps i.e., *Labeo rohita*, *Catla catla* and *C. mrigala*

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 12.5. 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.

Crop and fish production due to intervention under Madhyakhanda sub-minor in the tail-end of the canal command



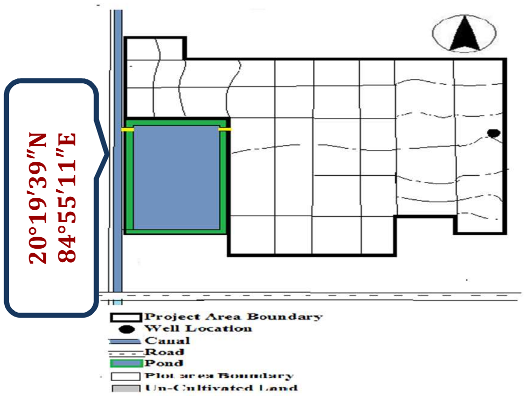
The site map showing location of constructed water storage tank under Madhyakhanda sub-minor

A view during monsoon season of the constructed tank at the tail-end under Madhyakhanda sub-minor

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

Crop and fish production due to intervention under Madhyakhand sub-minor (2) in the tail-end of the canal command



The site map showing location of constructed water storage tank and open well under Madhyakhand sub-minor (2)

On-dyke arhar cultivation on the constructed tank is economical under Madhyakhand sub-minor (2)

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

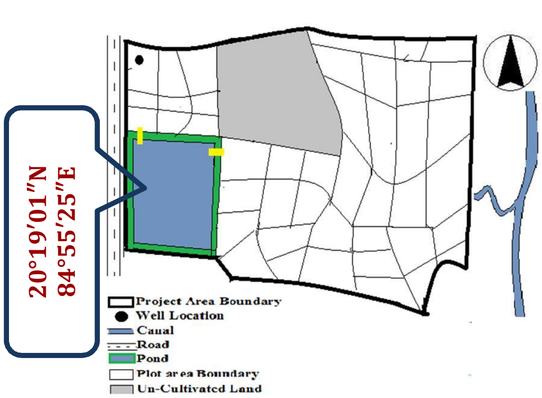
Fish and crop production, crop diversification, water used from storage tank and open well, water productivity for various components of the integrated farming system under Madhyakhand sub-minor (2) in the tail-end are presented in Table 12.6. Fish production was 2.60 t ha^{-1} with fish water productivity 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.

Table 12.6 Crop & fish production and water productivity in the site under Madhyakhand sub-minor (2) in the tail-end

Fish/ Crops	Area (ha)	Prod (kg)	Yield (kg/ha)	Gross return (Rs)	Water used (m³)	Phy. water productivity (kg/m³)	Eco. water productivity (Rs/m³)
Fish (IMC)	0.098	255	2602	25500	2722	0.09	9.36
Rice	2.1	6200	2952	84320	-	-	-
Arhar (on-dyke)	0.05	80	1600	3480	-	-	-
Moong	0.4	250	625	11500	240	1.04	47.92
Pointed gourd	0.4	3000	7500	60000	1600	1.88	37.50
Total				184800			

IMC is Indian major carps i.e., *Labeo rohita*, *Catla catla* and *C. mrigala*

Crop and fish production due to intervention under Lunisara sub-minor in the tail-end of the canal command



The site map showing location of constructed water storage tank and open well under Lunisara sub-minor

A view during summer of the constructed tank at the tail-end under Lunisara sub-minor

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

Fish, crop production, water used from storage tank and open well and water productivity in the Lunisara sub-minor are presented in Table 12.7. 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 12.7 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)	Phy. water productivity (kg/m^3)	Eco. water productivity (Rs/m^3)
Fish (IMC)	0.098	170	1735	17000	2485	0.07	6.84
Rice	0.41	1150	2805	15640	-	-	-
Arhar (on-dyke)	0.03	35	1167	1523	-	-	-
Moong	0.04	25	625	500	20	1.25	25.00
Total				34663			

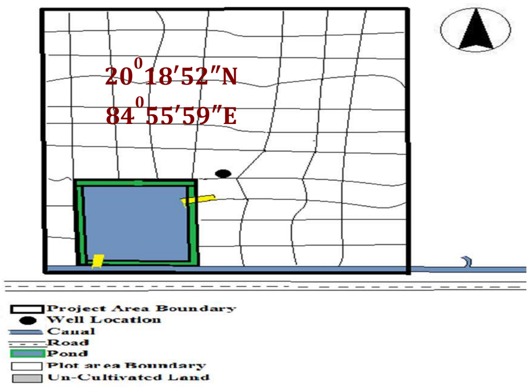
IMC is Indian major carps i.e., *Labeo rohita*, *Catla catla* and *C. mrigala*

Table 12.8 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)	Phy. water productivity (kg/m^3)	Eco. water productivity (Rs/m^3)
Fish (IMC)	0.098	230	2347	23000	2854	0.08	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	2.05	31.70
Onion	0.09	850	9444	12750	212	4.01	60.28
Bhindi	0.04	250	6250	5000	92	2.72	54.35
Total				112515			

IMC is Indian major carps i.e., *Labeo rohita*, *Catla catla* and *C. mrigala*

Crop and fish production due to intervention under Soroda sub-minor-II in the tail-end of the canal command



The site map showing location of the constructed water storage tank and open well under Soroda sub-minor (II)

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

View of the constructed open well and the farmer; conjunctive use of water for irrigation to post-monsoon crops

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

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 12.8. 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.

Groundwater dynamics

The dynamics of groundwater was assessed periodically for all sites under our intervention. This has been presented within groundwater fluctuation section.

Environmental impact- soil water retention characteristics, soil environment and other issues

Soil samples were collected from different sites of head, mid- and tail reaches, and two sites of each of rice-fallow, rice-sugarcane and rice-green gram cropping system. Samples were collected with the help of auger and down to the profile depth up to 90 cm from 5 different locations within one representative in a zig-zag pattern and also from four depth increments (i.e. 0-15, 15-30, 30-60 and 60-90 cm) from the soil profile to study the soil properties. After collection, soil samples were processed properly for analyses. Field capacity (FC) and permanent wilting point (PWP) have been presented in Table 12.9. The range of permanent wilting point (PWP), irrespective of sites, was 0.161-0.308, 0.158-0.272, 0.222-0.279, 0.198-0.302, 0.163-0.254 and 0.169-0.236 $cm^3.cm^{-3}$ in sites 1 through 6, respectively (Table 13.9). Similar to the trends in FC values, PWP increased significantly with the increase in soil depth for every site. The average values of PWP were greater in site 3 and 4 under rice-sugarcane crop rotation that other sites. The AWC was slightly greater in the soils of site 3, 4 in the rice-sugarcane system than other systems; it showed higher values in the deeper soil layers (Fig. 12.3). The difference in available water capacity (AWC) was governed by the difference in FC and PWP values; and basically, it is the clay fractions in the soils of different sites which determined the higher FC, and in turn the higher AWC of soils.

Table 12.9 Field capacity and permanent wilting point of soils in different depths at different sites/ cropping systems under the Kuanria command area

Soil depth (cm)	Site-1 (Rice-fallow cropping)	Site-2 (Rice-fallow cropping)	Site-3 (Rice-sugarcane crop rotation)	Site-4 (Rice-sugarcane crop rotation)	Site-5 (Rice-greengram cropping)	Site-6 (Rice-greengram cropping)
Field capacity (at -33 kPa) (cm^3cm^{-3})						
0-15	0.228b	0.236c	0.331c	0.286c	0.255d	0.231c
15-30	0.278b	0.348b	0.368b	0.370b	0.300c	0.297b
30-60	0.403a	0.393ab	0.406a	0.449a	0.339b	0.374a
60-90	0.464a	0.409a	0.423a	0.465a	0.371a	0.392a
$LSD_{5\%}$	0.077	0.057	0.220	0.033	0.023	0.028
Permanent wilting point (-1500 kPa) (cm^3cm^{-3})						
0-15	0.161c	0.158c	0.222d	0.198c	0.163d	0.169c
15-30	0.211b	0.239b	0.257c	0.245b	0.194c	0.192b
30-60	0.285a	0.270a	0.272b	0.289a	0.227b	0.229a
60-90	0.308a	0.272a	0.279a	0.302a	0.254a	0.236a
$LSD_{5\%}$	0.026	0.018	0.007	0.025	0.023	0.010

Mean values with same letter within a column are not significantly different according to DMRT at $P < 0.05$.

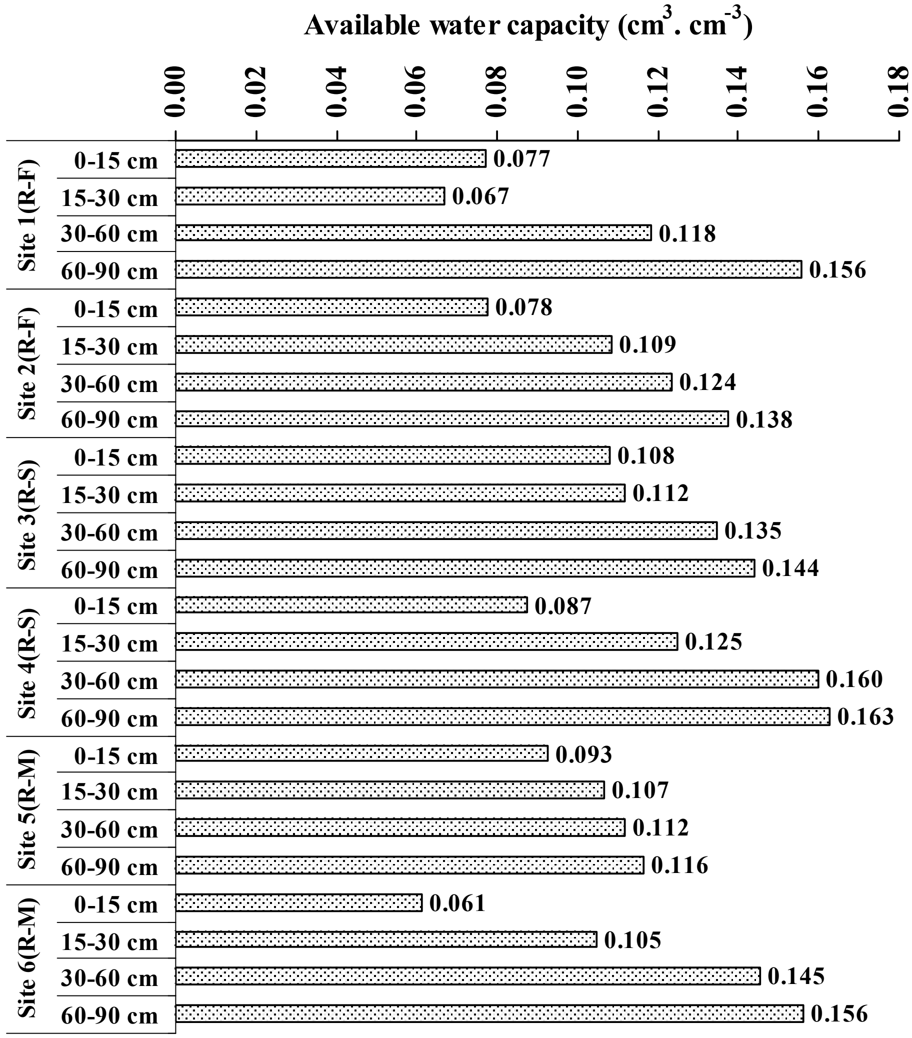


Fig. 12.3 Available water capacity (AWC) of soils in depth increments under different sites; R-F indicates rice-fallow system, R-S rice-sugarcane rotation and R-M is rice-greengram cropping.

Soil organic carbon (SOC) content and storage

Soil organic carbon (SOC) content varied from 0.34 to 0.95% depending upon the cropping systems/ sites and the soil layer (Fig. 12.4). The SOC was highest in surface (0-15 cm) layer and then decreased down to the soil profile in every site. There was no sharp difference of SOC due to difference in cropping systems for every soil depths. However, one trend was clearly emerged out of the results that is, soils of site 3 and 4 under rice-sugarcane crop rotation had greater SOC content compared to other rice-based systems.

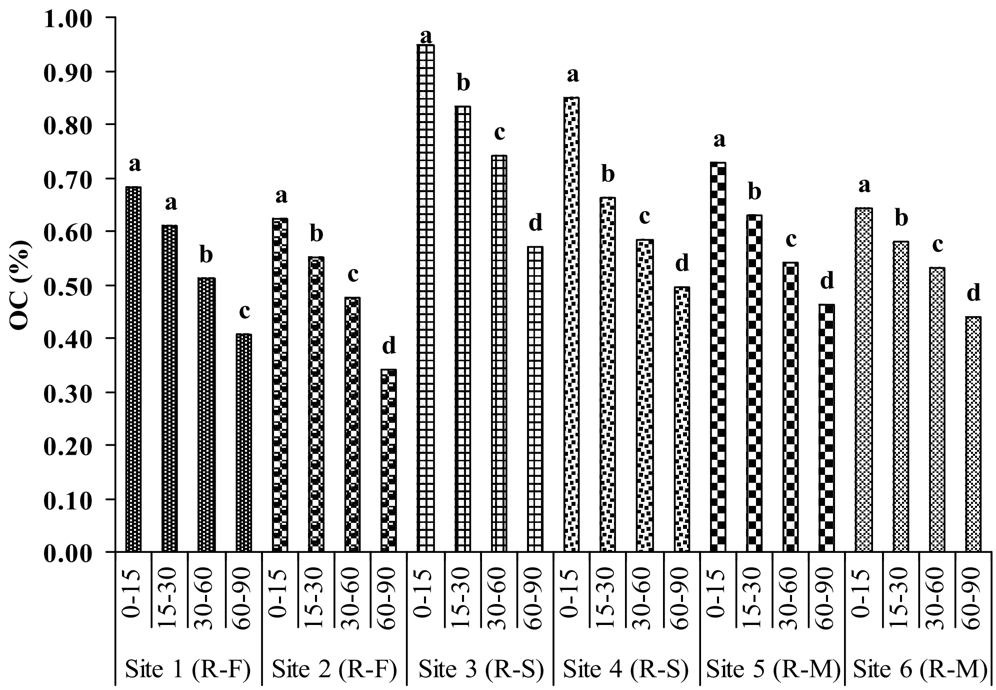


Fig. 12.4 Organic carbon content of soils in different depths under different sites; R-F indicates rice-fallow, R-S rice-sugarcane rotation and R-M is rice-greengram cropping; vertical bars with same letter are not significant at $p<0.05$ in a site as per DMRT.

The organic carbon in the surface soil i.e., 0-15 cm is more susceptible to be released into the environment through CO_2. Hence, its quantification was made with the help of bulk density, depth, area and organic carbon content data (Fig. 12.5). It was estimated that SOC storage was higher in rice-sugarcane crop rotation systems, 18.90 and 20.53 Mg ha^{-1} in the sites 3 and 4, respectively. However, other sites also had the organic carbon storage to amount of 14.68, 16.16, 14.58 and 15.70 Mg ha^{-1} in the site 1 (rice-fallow) and site 2 (rice-fallow), site 5 (rice-greengram) and site 6 (rice-greengram), respectively. Depth-wise soil organic carbon (SOC) storage shows highest in the first 30 cm soil depth (0-30 cm) and gradually decreased significantly with depth increments in each site (Fig. 12.6).

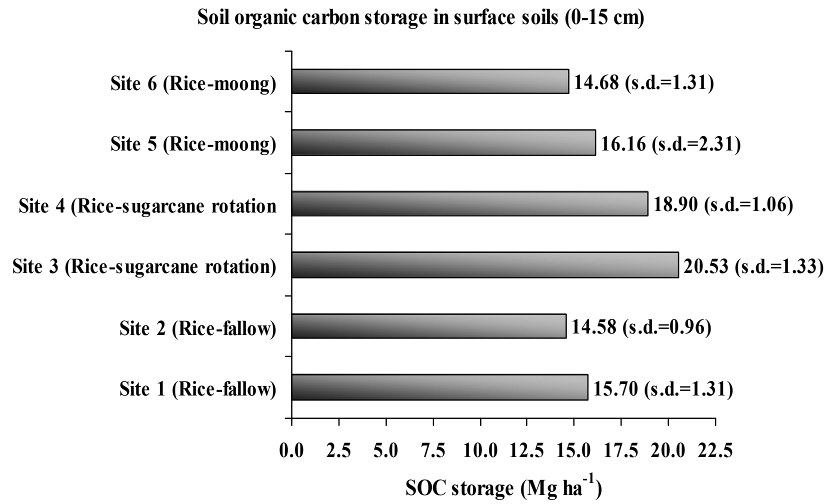


Fig. 12.5 Soil organic carbon (SOC) storage in surface soil (0-15 cm depth) in different soil sites/ cropping systems; mean values with standard deviation (s.d.) are presented against each horizontal bar

In the 0-30 cm soil layer, SOC storage ranged from 27.77 Mg ha^{-1} under rice-fallow system in site 2 to 39.44 Mg ha^{-1} under rice-sugarcane in site 3. In the 30-60 cm soil layer, SOC storage ranged from 23.06 Mg ha^{-1} under rice-fallow system in site 2 to 34.15 Mg ha^{-1} under rice-sugarcane in site 3. In the 60-90 cm soil layer, SOC storage ranged from 16.67 Mg ha^{-1} under rice-fallow system in site 2 to 26.83 Mg ha^{-1} under rice-sugarcane in site 3. The SOC storage significantly decreased towards greater depth of soils as evident from estimated values. The SOC storage in the profile (0-90 cm) varied from 67.51 Mg ha^{-1} under rice-fallow system in site 2 to 100.43 Mg ha^{-1} under rice-sugarcane in site 3. Rice-sugarcane system has greater SOC storage in the profile. The greater organic carbon content (SOC) in rice-sugarcane was might be due to the continuous cropping with higher rates of fertilizer, year round cropping practice for sugarcane that might have sequestered greater SOC in sites 3 and 4. Moreover, sugarcane crop residues viz. trashes and greater root biomass from a long duration crop might have favoured higher organic carbon content in these soils. The comparatively greater SOC in the soils of rice-greengram system might be ascribed to greater soil organic matter in the soil and lesser loss of carbon through CO_2 into the atmosphere.

Impact on the activities of soil enzymes

Studies on activities of soil enzymes viz. dehydrogenase, phosphatase and urease were made for surface soil (0-15 cm) (Table 12.10 to 12.12). Dehydrogenase activity showed a range of 283.52 to 313.31 µg TPF g^{-1}soil $24h^{-1}$ with the coefficient of variation (CV) ranged from 8.36 to 9.22%; the highest value was obtained at site 5 under rice-moong cropping system and the lowest at site 2 under rice-fallow system. Soil phosphatase activity ranged from 280.58 to 480.28 µg phenol g^{-1}soil h^{-1} with the CV ranged from 9.24 to 11.93%; the highest value was obtained at site 5 under rice-moong cropping system and the lowest at site 6 under another rice-moong system. Soil urease activity ranged from 38.36 to 67.75 µg NH_4^+-N g^{-1}soil $2h^{-1}$ with the CV ranged from 9.73 to 11.08%; the highest value was obtained at site 1 under rice-fallow system and the lowest at site 6 under rice-moong cropping system. Impact on the soil environment in different head, mid- and tail end commands have been presented in Table 12.13

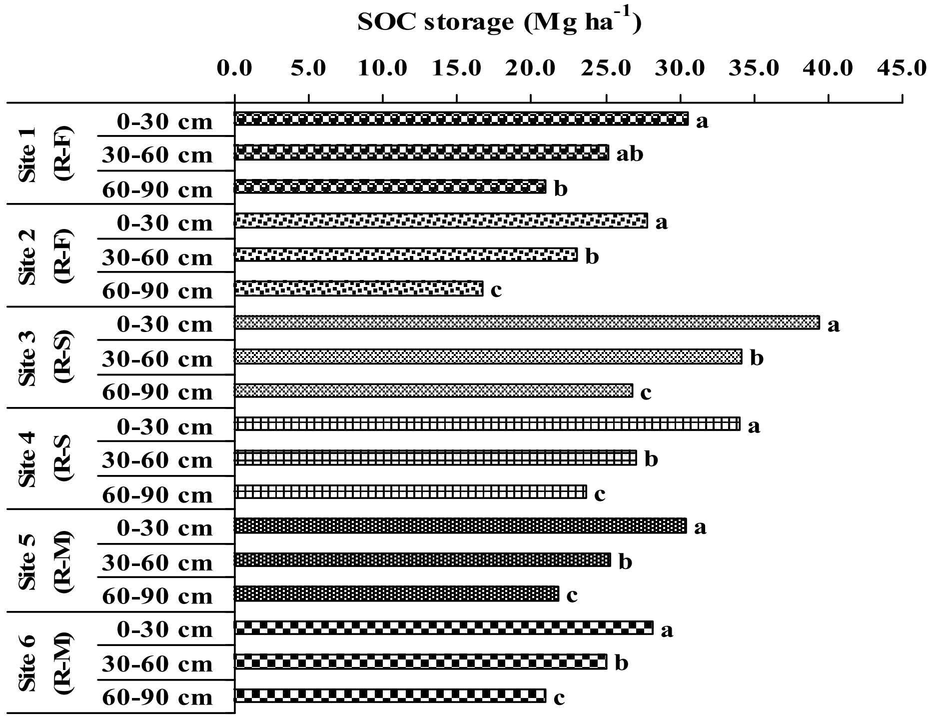


Fig. 12.6 Soil organic carbon (SOC) storage in different depths under different sites; R-F indicates rice-fallow, R-S rice-sugarcane rotation and R-M is rice-greengram cropping; vertical bars with same letter are not significant at p<0.05 in a site as per DMRT.

Table 12.10 Soil dehydrogenase activity in the surface soils in different sites/ cropping systems

Site/ Cropping system	Dehydrogenase activity (µg TPF.g^{-1}soil. 24h^{-1}		
	Mean	s.d.	c.v. (%)
Site-1 (Rice-fallow cropping)	343.73	31.68	9.22
Site-2 (Rice-fallow cropping)	283.52	23.91	8.43
Site-3 (Rice-sugarcane rotation)	302.68	27.09	8.95
Site-4 (Rice-sugarcane rotation)	311.24	24.23	8.42
Site-5 (Rice-moong cropping)	313.31	27.36	8.73
Site-6 (Rice-moong cropping)	300.18	25.08	8.36

Table 12.11 Soil phosphatase activity in the surface soils in different sites/ cropping systems

Site/ Cropping system	Phosphatase activity (μg phenol g^{-1}soil h^{-1})		
	Mean	s.d.	c.v. (%)
Site-1 (Rice-fallow cropping)	413.08	44.50	10.77
Site-2 (Rice-fallow cropping)	315.64	32.89	10.42
Site-3 (Rice-sugarcane rotation)	441.94	40.84	9.24
Site-4 (Rice-sugarcane rotation)	452.35	42.51	10.16
Site-5 (Rice-moong cropping)	480.28	57.28	11.93
Site-6 (Rice-moong cropping)	280.58	30.50	10.87

Table 12.12 Soil urease activity in the surface soils in different sites/ cropping systems

Site/ Cropping system	Urease activity (μg NH_4^+-N g^{-1}soil $2h^{-1}$)		
	Mean	s.d.	c.v. (%)
Site-1 (Rice-fallow cropping)	67.75	7.02	10.36
Site-2 (Rice-fallow cropping)	42.66	4.15	9.73
Site-3 (Rice-sugarcane rotation)	56.95	5.85	10.27
Site-4 (Rice-sugarcane rotation)	54.47	5.13	10.23
Site-5 (Rice-moong cropping)	64.21	6.88	10.71
Site-6 (Rice-moong cropping)	38.36	4.25	11.08

Table 12.13 Impact on the soil environment in different head, mid- and tail end commands

Sl. No.	Name of sub-minor canal command	Dehydrogenase activity (μg TPF.g^{-1}soil. $24h^{-1}$)	Phosphatase activity (μg phenol.g^{-1}soil. h^{-1})	Urease activity (μg NH_4-N.g^{-1}soil. $2h^{-1}$)
1	Odasar S/M	262	286	59.77
2	Mangalpur S/M	332	389	78.39
3	Khamarasahi S/M	318	347	43.49
4	Khairapankalsahi S/M	312	319	65.21
5	Madhyakhand S/M	300	417	92.74
6	Madhyakhand S/M (II)	298	348	73.18
7	Lunisara S/M	287	368	82.68
8	Soroda S/M-II	306	397	50.47

Impact on availability of soil micronutrients

Availability of soil micronutrient was assessed and presented in the Table 12.14. It indicates that available Zn and B were deficient by about 25-30% of the samples; Fe, Mn and Cu were not deficient.

Table 12.14 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

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 = $\Sigma P_i / N$ and $P_i = \Sigma PP_j$

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.

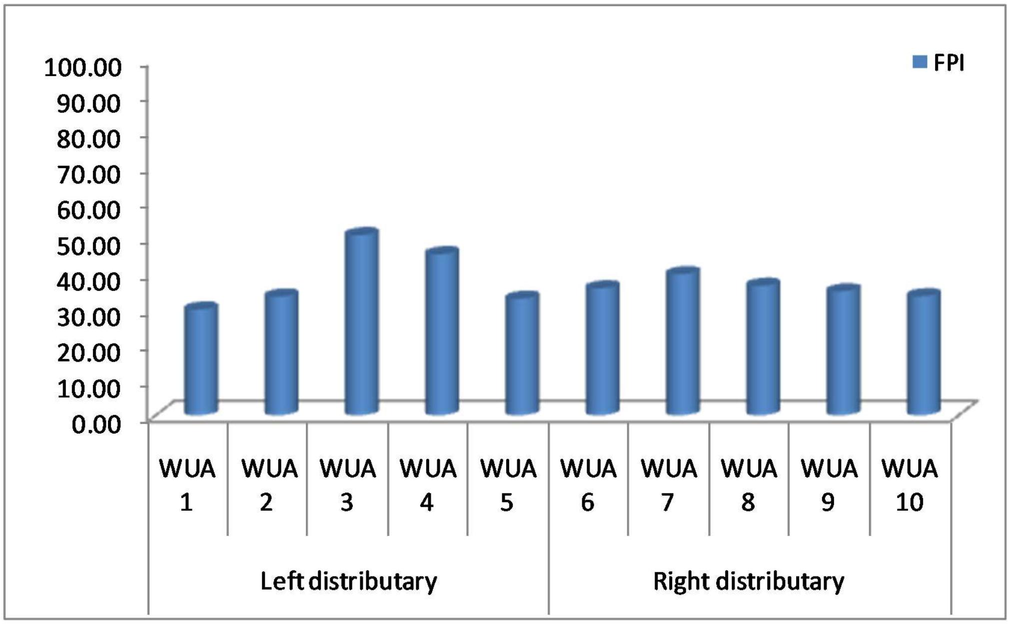


Fig. 12.7 Farmers' participation in different activities undertaken by WUA depicted by FPI

The farmers' participation in different WUA activities is indicated through farmers participation index (FPI) (Fig. 12.7). 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.

12. Conclusions/ Recommendations

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 enhanced compared to the non-pond command area i.e. without water storage tank.

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 is 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.

13. How do the conclusions/ recommendations compare with current thinking

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. Our work and intervention with infrastructure development, on farm water management and improving water productivity under Kuanria Medium Irrigation Project command at Daspalla block of Nayagarh district, has 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.

Our work has been proven to be highly beneficial to the farmers of the canal command area and the work has become a model kind of pond-based integrated farming in the canal command. 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 subminors, 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. The transfer of technology has happened to other researchers, stake holders/development agencies, water resources departments, WUAs/ farmers, field assistants under agricultural extension and to all those who would be interested for management of water in the canal command. The following key points are:

1. Construction of water storage tanks facilitate storage of rainwater and excess canal water; for providing irrigation, fish culture, on-dyke horticulture, and conjunctive use of water for post-rainy season crops under Kuanria medium irrigation command in Odisha.

2. Participatory development of integrated crop & fish culture systems accrue greater economic returns 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.

3. This pond-based integrated farming technology has potential to increase cropping intensity involving remunerative diversified crops, land and water productivity in canal commands through augmented water resources.

Training Programmes Organized

1. Farmers' Training Programme (One)

One 7-day (15-21 Jan 2011) Farmers' Training Programme was organized at the project site at Daspalla block of Nayagarh district, Odisha on '*Scaling up of water productivity in agriculture for livelihoods*'. There were 67 nos of participating farmers. Out of the total 67 farmers, all were male. Among the trainees, 13 belonged to general caste, 49 OBC, 4 SC and 1 ST. Based on poverty level, there were 32 farmers in the category of APL and 35 in BPL. This was organized under the SWPA scheme of the Institute.

One 7-day Farmers Training Programme at the project site at Daspalla block of Nayagarh district, Odisha under SWPA scheme of the Institute

2. Trainers' Training Programme (One)

One 14-day (24th Aug- 6th Sept, 2011) Trainers' Training Programme was organized at the project site at Daspalla block of Nayagarh district, Odisha on '*Scaling up of water productivity in agriculture for livelihoods*'. There were 25 nos of trainees: 20 from pani panchayat functionaries viz. Presidents and Secretaries of 10 Water Users' Association, 2 trainees were Jr. Engineers from Kuanria Irrigation Sub-division, 3 trainees were Village Agricultural Workers, Assistant Agricultural Office, Govt. of Odisha, Daspalla. This was organized under the SWPA scheme of the Institute.

One 14-day Trainers' Training Programme at the project site at Daspalla block of Nayagarh district, Odisha under SWPA scheme of the Institute

3. Interface Meeting with Farmers (One)

One Interface Meeting with the farmers was organized. Selected farmers were invited from the project site i.e., from Daspalla, Nayagarh district for participation in the '*Interface Meeting on Monsoon Preparedness and Contingency Planning in 2015*', which was organized at the ICAR-Indian Institute of Water Management, Bhubaneswar on 08.07.2015. Farmers actively interacted and discussed various aspects of contingency planning for kharif season farming practices.

Farmers participated in the Interface Meeting on '*Monsoon Preparedness and Contingency Planning*', held at ICAR-IIWM, Bhubaneswar on 08.07.2015

LIST OF PUBLICATIONS

Full length papers in peer reviewed journals (5)

1. Mandal, K.G., Majhi, P., Sahoo, D.K., Rout, R., Kumar, A., Ghosh, S., Mohanty, R.K. and Raychaudhuri, M. 2013. Assessing the soil environment under major cropping systems in Kuanria canal command. *Ecology, Environment & Conservation*, 19 (2): 509-513
2. Mandal, K.G., Kundu, D.K., Singh, R., Kumar, A., Rout, R., Padhi, J., Majhi, P. And Sahoo, D.K. 2013. Cropping practices, soil properties, pedotransfer functions and organic carbon storage at Kuanria canal command area in India. *SpringerPlus* 2: 631, 1-14, DOI: 10.1186/2193-1801-2-631.
3. Mandal, K.G., Padhi, J., Kumar, A., Sahoo, D.K., Majhi, P., Ghosh, S., Mohanty, R.K. and Raychaudhuri, M. 2013. Analyzing rainfall events and soil characteristics for water resources management in a canal irrigated area. *Journal of Water Resources and Ocean Science* 2 (1): 1-8.
4. Mandal, K.G., Kumar Ashwani, Padhi, J., Ghosh, S., Mohanty, R.K., Majhi, P. and Raychaudhuri, M. 2015. Improving water productivity in a canal command through conservation of surface and ground water using tanks and wells. *IWRA (India) Journal*, 4 (1): 3-10.
5. Mandal, K.G., Padhi, J., Kumar, A., Ghosh, S., Panda, D.K., Mohanty, R.K. and Raychaudhuri, M. 2015. Analyses of rainfall using probability distribution and Markov chain models for crop planning in Daspalla region in Odisha, India. *Theoretical and Applied Climatology* (Springer) 121: 517–528, *DOI 10.1007/s00704 -014-1259-z*.

Research bulletin (1)

1. Mandal, K.G., Kumar, Ashwani, Ghosh, S., Kundu, D.K., Panda, R.K., Mohanty, R.K., Raychaudhuri, M., Padhi, J., Majhi, P. and Sahoo, D.K. 2013. Analyses of Rainfall and Soil Characteristics of Kuanria Canal Command for Water Resources Management. Research Bulletin No. 57, DWM (ICAR), Bhubaneswar, Odisha, India, 43p.
2. Mandal K.G., Mohanty R.K., Ghosh S., Kundu D.K., Raychaudhuri M., Padhi J., Majhi P., Sahoo D.K., Kumar Ashwani and Ambast S.K. 2016. Participatory Water Management and Integrated Farming in a Canal Command. Research Bulletin No. 75, IIWM (ICAR), Bhubaneswar, Odisha, India, 64p.

E-publication (1)

1. Mandal, K.G., Kumar, A., Padhi, J., Ghosh, S., Mohanty, R.K., Majhi, P. and Raychaudhuri, M. 2012. Improving water productivity in a canal command through conservation of surface and ground water using tanks and wells, Proc. IWW 2012 on Water, Energy and Food Security: Call for Solutions, MoWR, GoI, pp. 1-14.

Contribution to ICAR-IIWM (formerly DWM) Annual Report (3)

1. Mandal, K.G., Ghosh, S., Mohanty, R.K., Raychaudhuri, M. and Kumar, A. 2013. Improving water productivity under canal irrigation command through conservation

of surface and ground water using tanks and wells. In: DWM Annual Report 2012-13, Directorate of Water Management (ICAR), Bhubaneswar, pp. 32-34.

2. Mandal, K.G., Ghosh, S., Mohanty, R.K., Raychaudhuri, M. and Kumar, A. 2014. Improving water productivity under canal irrigation command through conservation of surface and ground water using tanks and wells. In: DWM Annual Report 2013-14, Directorate of Water Management (ICAR), Bhubaneswar, pp. 32-35.
3. Mandal, K.G., Ghosh, S., Mohanty, R.K., Raychaudhuri, M. and Kumar, A. 2015. Improving water productivity under canal irrigation command through conservation of surface and ground water using tanks and wells. In: ICAR-IIWM Annual Report 2014-15, Indian Institute of Water Management (ICAR), Bhubaneswar, pp. 26-28.
4. Mandal, K.G., Mohanty, R.K., Raychaudhuri, M. 2016. Improving water productivity under canal irrigation command through conservation of surface and ground water using tanks and wells. In: ICAR-IIWM Annual Report 2015-16, Indian Institute of Water Management (ICAR), Bhubaneswar, pp. 11-12.

Published as Proceedings (4)

1. Mandal, K.G., Kumar, A., Padhi, J., Ghosh, S., Mohanty, R.K., Majhi, P. and Raychaudhuri, M. 2012. Participatory water management in a medium irrigation command for multiple uses and enhancing livelihood of farmers. Extended Summaries Vol 3: 3rd International Agronomy Congress on Agriculture Diversification, Climate Change Management and Livelihoods, Nov. 26-30, 2012, New Delhi, India, Indian Soc. Agronomy, p. 1290-1291.
2. Mandal, K.G., Kumar, A., Ghosh, S., Mohanty, R.K., Padhi, J., Biswal, A.R. and Raychaudhuri, M. 2013. Participatory water management in canal commands for improving productivity. In: Proc. of the 100th Session of The Indian Science Congress, Section of Agriculture and Forestry Sciences, held at Calcutta University, Kolkata, during 3-7 Jan 2013, Published by The Indian Science Congress Association, Kolkata, pp. 68-69.
3. Mandal, K.G., Kumar, A., Ghosh, S., Mohanty, R.K., Padhi, J., Biswal, A.R. and Raychaudhuri, M. 2014. Multiple use of water through pond-based integrated crop and fish farming in a canal command. In: Proc. of the 101st Session of The Indian Science Congress, Section of Agriculture and Forestry Sciences, held at University of Jammu, Jammu, during 3-7 Feb 2014, published by The Indian Science Congress Association, Kolkata, pp. 48-49.
4. Mandal K.G., Kumar Ashwani, Mohanty R.K., Raychaudhuri, M. and Sahoo, D.K. 2015. Water resource management in a medium irrigation command and integrated crop-fish farming. In: Proc. 102nd Indian Science Congress (102nd ISC), Section of Agriculture and Forestry Sciences held in the University of Mumbai, Mumbai during 3-7 January, 2015, pp. 43-44.

Presentation in Seminar/ Conference/ Symposia etc.

1. K.G. Mandal presented the progress of the scheme 'Improving water productivity under canal irrigation command through conservation and recycling of runoff, seepage, rainwater and ground water using tanks and wells' at the 9th R & D Session of INCID, Central Water Commission at R.K. Puram, New Delhi on 13 Dec 2010.
2. K.G. Mandal presented the progress of the scheme 'Improving water productivity under canal irrigation command through conservation and recycling of runoff, seepage, rainwater and ground water using tanks and wells' in the 10th R&D Session of INCID, CWC at New Delhi on 23.3.2012.
3. K.G. Mandal presented on 'Improving water productivity in a canal command through conservation of surface and ground water using tanks and wells' in the India Water Week on Water, Energy and Food Security: Call for Solutions, under the theme: Water and Infrastructure Development, held during 10-14 April 2012 at Vigyan Bhavan, New Delhi.
4. K.G. Mandal presented on 'Multiple use of water through pond-based integrated crop and fish farming under Kuanria canal command in Odisha' in National Level Workshop on 'Water quality issues, opportunities and socio-cultural concerns of wastewater use in agriculture, supported by the USIEF Alumni Award 2013, held during 7-8 August 2013 at DWM (ICAR), Bhubaneswar.
5. K.G. Mandal presented on 'Participatory water management in canal commands for improving productivity' in the 100th Session of The Indian Science Congress, Section of Agriculture and Forestry Sciences, during 3-7 Jan 2013, at Calcutta University, Kolkata.
6. K.G. Mandal presented a paper on 'Water resource management in a medium irrigation command and integrated crop-fish farming' under the Section of Agriculture and Forestry Sciences in the 102nd Indian Science Congress (102nd ISC) held at the University of Mumbai, Mumbai during 3-7 January, 2015.
7. K.G. Mandal presented a paper on 'Participatory water management and integrated farming systems in a medium irrigation command' in the 17th Annual Conference on 'Statistics & information for smart decisions in managing resources: issues and challenges' at Birla Institute of Management and Technology, Bhubaneswar during 23-25 February, 2015.

Awards and Recognitions

❖ Dr. K.G. Mandal has received the DWM PROFICIENCY AWARD 2011 of the Institute in recognition of his good work under Scientific category.

❖ Dr. K.G. Mandal has become Elected Member of the Sectional Committee of the Section of Agriculture and Forestry Sciences for the year 2013-14 (101^{th} Session of the Indian Science Congress) of the ISCA, Kolkata.

❖ Dr. K.G. Mandal, has been elected as Sectional Recorder for the Section of Agriculture and Forestry Sciences of The Indian Science Congress Association (ISCA) for the year 2014-15 & 2015-16 i.e. 102^{nd} and 103^{rd} Sessions of the Indian Science Congress.

❖ Dr. K.G. Mandal has been selected as Editorial Board Member of the '*International Journal of Agronomy*', Hindawi Publishing Corporation, USA., and for the '*Journal of Food, Agriculture and Environment*', published by WFL Publisher, Helsinki, Finland.

Invited lecture on the theme '*Water & Infrastructure Development*' in IWW 2012

❖ K.G. Mandal delivered on 'Improving water productivity in a canal command through conservation of surface and ground water using tanks and wells' in the *India Water Week* during 10-14 April 2012 at Vigyan Bhavan, New Delhi.

DWM Progressive Farmer Honour 2012

- One farmer from INCID project site, Daspalla, Nayagarh district, Odisha was nominated and received *DWM Progressive Farmer Honour 2012* on the Institute's Silver Jubilee Foundation Day on 12th May 2012. Dr. A.K. Singh, former DDG (NRM), ICAR kindly handed over the citations to the awardees.

Research Work for M.Sc. by a student from Utkal University, Odisha

- Guided and supervised for M.Sc. research work on "*Soil properties, organic carbon storage, and development of Pedotransfer functions for Kuanria irrigation command in Odisha*" submitted by a M.Sc. Student, 70p.

14. Software generated, if any: Nil

15. Possibilities of any patents/ copyrights: Nil

16. Suggestions for further work

The following key points may be considered for further work in future:

i) Participatory integrated water resource management in canal commands

ii) Infrastructure development in construction of series of auxiliary ponds in canal commands for storage of runoff water, seepage and excess canal water delivered

iii) Development of pond-based integrated farming systems to increase the farmers income

iv) Micro-irrigation or pipe irrigation in the canal commands to increase water use efficiency

v) Capacity building of farmers through training and demonstration of existing technologies for enhancing agricultural productivity and increasing water use efficiency.

Acknowledgement

Investigators are thankful to the former and present Director of the Institute for providing facilities and appropriate guidance to carry out the project activities; thanks to the beneficiary farmers, other associated farmers in the command area and stake holders from Govt. of Odisha, water users associations, KIP staffs of Daspalla for cooperation and successful implementation of the scheme. The financial support by INCSW (formerly INCID), Central Water Commission, Ministry of Water Resources, Govt. of India is duly acknowledged for smoothly carrying out the project activities. The investigators acknowledge the help and cooperation rendered by research associate and fellows, friends and colleagues, staffs of administration and finance & accounts section, technical personnel of the ICAR-Indian Institute of Water Management (formerly Directorate of Water Management), Bhubaneswar.

Signature 17.2.2021	**Signature**
(Head of the Institute)	**(Principal Investigator)**
Name: A. MISHRA	**Name:** K. G. MANDAL
Date: 17/02/2021	**Date:** 17/02/2021

निदेशक/Director
भाकृअनुप-भारतीय जल प्रबंधन संस्थान
ICAR-Indian Institute of Water Management
चन्द्रशेखरपुर, भुवनेश्वर-751023
C.S.Pur, Bhubaneswar-751023

Financial Details

(Sanction cost; amount released; expenditure; unspent balance (if any) and return of unspent balance)

R&D Scheme: 'Improving Water Productivity under Canal Irrigation Command through Conservation and Recycling of Runoff, Seepage, Rainwater and Groundwater using Tanks and Wells'

Sanction Cost	Rs 45,49,000/-
Amount Released	Rs 36,46,700/- (in two instalments i.e. total of Rs 22,20,000/- & Rs 14,26,700/-)
Expenditure	Rs 33,72,929/-
Unspent balance (if any)	Rs 2,73,771/-
Return of Unspent balance	Rs 2,73,771/- [Returned on 15.03.2018 Bank UTR No. PUNBH18074035783 dt. 15.03.2018]

17/02/2021
Principal Investigator

17/02/2021
Finance & Accounts Officer
वित्त एवं लेखा अधिकारी
Finance & Accounts Officer
भाकृअनुप-भारतीय जल प्रबंधन संस्थान
ICAR-Indian Institute of Water Management
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17.2.2021
Head of the Institute
निदेशक/Director
भाकृअनुप-भारतीय जल प्रबंधन संस्थान
ICAR-Indian Institute of Water Management
चन्द्रशेखरपुर, भुवनेश्वर-751023
C.S.Pur, Bhubaneswar-751023

Appendix 6 Utilization certificate

FORM GFR 19-A
Utilization Certificate
[See Rule 212 (1)]

2015 - 16

SL No.	Letter No. and date	Amount
	Revalidation Letter No.21/108//2009-R&D/22-30 Dated 06.01.2016	**₹12,54,665.00**
	Total	**₹12,54,665.00**

Certified that out of **₹12,54,665/- (Rupees Twelve lakhs Fifty four thousand Six hundred Sixty Five)** only of grants-in-aid brought forward from the previous financial year 2014-15 in favour of "Improving Water Productivity under Canal Irrigation Command through Conservation and Recycling of Runoff, Seepage, Rain water and Ground Water using Tanks and Wells, operating in ICAR-IIWM, Bhubaneswar" under the Ministry of Water Resources /Department Letter No. 21/108/2009-R&D/22-30 dt. 06.01.2016 given in the margin, a sum of **₹9,20,098/- (Rupees Nine lakhs twenty thousand Ninety eight)** only has been utilized for the purpose of grants-in-aid for which it was sanctioned and that the balance of **₹ 3,34,567/- (Rupees Three lakhs Thirty four thousand Five hundred Sixty seven)** only remaining unutilized at the end of the year has been adjusted towards grants-in-aid during the next year 2016-17.

2. Certified that I have satisfied myself that the conditions on which the grant-in-aid was sanctioned have been duly fulfilled and that I have expressed the following checks to see that the money actually utilized for the purpose for which it was sanctioned.

Kinds of checks exercised

1. Above amount has been incurred under the head Experimental charges, TA, Infrastructure, Contigencies and Overhead

17/02/2021 | 17/02/2021 | 17.2.2021

Principal Investigator | Finance & Accounts Officer | Head of the Institute

वित्त एवं लेखा अधिकारी
Finance & Accounts Officer
भाकृअनुप-भारतीय जल प्रबंधन संस्थान
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C.S.Pur, Bhubaneswar-751023

निदेशक/Director
भाकृअनुप-भारतीय जल प्रबंधन संस्थान
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Appendix 6 Utilization certificate

FORM GFR 19-A
Utilization Certificate
[See Rule 212 (1)]

2016 - 17

SL No.	Letter No. and date	Amount
	Nil	₹3,34,567.00
	Total	₹3,34,567.00

Certified that out of **₹3,34,567/- (Rupees Three lakhs thirty four thousand Five hundred Sixty seven)** only of grants-in-aid brought forward from the previous financial year 2015-16 in favour of "Improving Water Productivity under Canal Irrigation Command through Conservation and Recycling of Runoff, Seepage, Rain water and Ground Water using Tanks and Wells, operating in ICAR-IIWM, Bhubaneswar" under the Ministry of Water Resources /Department Letter No. Nil given in the margin, a sum of **₹60,796- (Rupees Sixty thousand seven hundred ninety six)** only has been utilized for the purpose of grants-in-aid for which it was sanctioned and that the balance of **₹ 2,73,771/- (Rupees Two lakhs Seventy three thousand Seven hundred Seventy one)** only remaining unutilized at the end of the year has been surrendered to Ministry of Water Resources, Government of India during the next year 2017-18.

2. Certified that I have satisfied myself that the conditions on which the grant-in-aid was sanctioned have been duly fulfilled and that I have expressed the following checks to see that the money actually utilized for the purpose for which it was sanctioned.

Kinds of checks exercised

1. Above amount has been incurred under the head Overhead

17/02/2021
Principal Investigator

17/02/2021
Finance & Accounts Officer
वित्त एवं लेखा अधिकारी
Finance & Accounts Officer
भाकृअनुप-भारतीय जल प्रबंधन संस्थान
ICAR-Indian Institute of Water Management
चन्द्रशेखरपुर, भुवनेश्वर-751023
C.S.Pur, Bhubaneswar-751023

17.2.2021
Head of the Institute
निदेशक/Director
भाकृअनुप-भारतीय जल प्रबंधन संस्थान
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C.S.Pur, Bhubaneswar-751023

Appendix 6 Utilization certificate

FORM GFR 19-A
Utilization Certificate
[See Rule 212 (1)]

2017 - 18

SL No.	Letter No. and date	Amount
	Nil	₹ 2,73,771.00
	Total	₹ 2,73,771.00

Certified that out of **₹2,73,771/- (Rupees Two lakhs Seventy three thousand Seven hundred Seventy one)** only of grants-in-aid brought forward from the previous financial year 2016-17 in favour of "Improving Water Productivity under Canal Irrigation Command through Conservation and Recycling of Runoff, Seepage, Rain water and Ground Water using Tanks and Wells, operating in ICAR-IIWM, Bhubaneswar" under the Ministry of Water Resources /Department Letter No. Nil given in the margin remaining unutilized at the end of the year has been surrendered to Ministry of Water Resources, Government of India during the year 2017-18 (to A/c. No.11084278321) vide this Office letter No.124/A&A/INCID/2010-11/921(4) Dated 16.03.2018

2. Certified that I have satisfied myself that the conditions on which the grant-in-aid was sanctioned have been duly fulfilled and that I have expressed the following checks to see that the money actually utilized for the purpose for which it was sanctioned.

Kinds of checks exercised

17/02/2021
Principal Investigator

17/02/2021
Finance & Accounts Officer
वित्त एवं लेखा अधिकारी
Finance & Accounts Officer
भाकृअनुप-भारतीय जल प्रबंधन संस्थान
ICAR-Indian Institute of Water Management
C.S.Pur, Bhubaneswar-751023

17.2.2021
Head of the Institute
निदेशक/Director
भाकृअनुप-भारतीय जल प्रबंधन संस्थान
ICAR-Indian Institute of Water Management
चन्द्रशेखरपुर, भुवनेश्वर-751023
C.S.Pur, Bhubaneswar-751023

Appendix 6 Utilization certificate

FORM GFR 19-A
Utilization Certificate
[See Rule 212 (1)]

Final Utilization certificate

Sl. No.	Letter No. and date	Amount
1	**No.21/108/2009-R&D/777 Dated: March 12, 2010**	**₹22,20,000.00**
2	**No.21/108/2000-R&D/707-719 Dated: September 18, 2014**	**₹14,26,700.00**
	Total	**₹36,46,700.00**

Certified that out of **₹36,46,700/- (Rupees Thirty six lakh Forty six thousand Seven hundred)** only of grants-in-aid sanctioned/**released** in favour of the project titled "Improving Water Productivity under Canal Irrigation Command through Conservation and Recycling of Runoff, Seepage, Rain water and Ground Water using Tanks and Wells" operating in ICAR-IIWM, Bhubaneswar under the Ministry of Water Resources /Department Letter No. given in the margin, a sum of **₹33,72,929/- (Rupees Thirty three lakh Seventy two thousand nine hundred twenty nine)** only has been utilized for the purpose of grants-in-aid for which it was sanctioned/**released** and that the balance of **₹ 2,73,771/- (Rupees Two lakhs Seventy three thousand Seven hundred Seventy one)** only remaining unutilized at the end of the Project has been surrendered to Ministry of Water Resources, Government of India during the year . 2017-18 (to A/c. No.11084278321) vide this Office letter No.124/A&A/INCID/2010-11/921(4) Dated 16.03.2018

2. Certified that I have satisfied myself that the conditions on which the grant-in-aid was sanctioned have been duly fulfilled and that I have expressed the following checks to see that the money actually utilized for the purpose for which it was sanctioned.

Kinds of checks exercised

1. Above amount has been incurred under the head Experimental charges, TA, Infrastructure, Contigencies and Overhead charges.

17/02/2021
Principal Investigator

Vinod
17/02/2021
Finance & Accounts Officer

वित्त एवं लेखा अधिकारी
Finance & Accounts Officer
भाकृअनुप-भारतीय जल प्रबंधन संस्थान
ICAR-Indian Institute of Water Management
चन्द्रशेखरपुर, भुवनेश्वर-751023
C.S.Pur, Bhubaneswar-751023

17-2-2021
Head of the Institute

निदेशक/Director
भाकृअनुप-भारतीय जल प्रबंधन संस्थान
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STATEMENT OF EXPENDITURE

Name of the Institute : **ICAR- Indian Institute of Water Management, Bhubaneswar**

Title:	**Improving Water Productivity under Canal Irrigation Command through Conservation and Recycling of Runoff, Seepage, Rainwater and Ground water using Tanks and Wells.**
Funding Agency	**Ministry of Water Resources, PP Wing,- R & D Division, Government of India, New Delhi**
Letter No.	**21/108/2009-R & D/432-440 Dated February 18, 2010**
Name of the PI	**Dr. K.G.MANDAL**

SL. No.	Particulars/Head	Amount Sanctioned (₹)	Funds received as 1st Installment (₹)	Funds received as 2nd Installment (₹)	Total Funds received (₹)	Actual Expenditure (₹)	Closing Balance (₹)
1	2	3	4	5	6	7	8
1	Salary	14,68,800	22,20,000	14,26,700	36,46,700	14,35,694	2,73,771
2	Travel Expenditure	3,70,000				2,79,980	
3	Insfracture/Equipment	17,64,400				10,80,809	
4	Experimental charges	4,43,500				2,03,695	
5	Contingency	2,02,335				72,751	
6	Overhead charges	3,00,000				3,00,000	
	Grand Total	**45,49,035**	**22,20,000**	**14,26,700**	**36,46,700**	**33,72,929**	**2,73,771**
	Or Say	**45,48,000**					

17/02/2021
Principal Investigator

17.2.2021
Head of the Institute
निदेशक/Director
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Appendix-7 Statement of Equipment Purchased

Assets acquired wholly or substantially out of the Government grants register maintained by grantee Institution

Name of Sanctioning Authority: Ministry of water Resources, Govt. of India

Sl. No.	
Name of Grantee Institution	Indian Institute of Water Management (Formerly Directorate of water management), Bhubaneswar
No. and date of Sanction	No. 21/108/2009-R&D/432-440 dt. 18.02.2010
Amount of the Sanctioned Grant	Rs 45,49,000
Brief purpose of the Grant	R&D Scheme: 'Improving Water Productivity under Canal Irrigation Command through Conservation and Recycling of Runoff, Seepage, Rainwater and Groundwater using Tanks and Wells'
Whether any condition regarding the right of ownership of government in the property or other assets acquired out of the grant was incorporated in the grant-in aid sanction	The equipment purchased with the funds remain as the property of the Govt. of India
Particulars of assets actually credited or acquired	1) Construction of rain/run off water storage tank, 2) Data acquisition system
Value of assets developed	Rs 10,80,809
Purpose for which utilized at present	Project work
Encumbered or not	No
Reasons, if encumbered	NA
Disposed off or not	No
Reasons and authority, if any, for disposal	NA
Amount realized on disposal	NA
Remarks	Rain/run off water storage tanks: constructed at the project site, about 9 years old as on date- farmers are using those; Data acquisition system: about 10 years old as on date; at present- working but not satisfactorily.

17/02/2021

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17.2.2021

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Response to Views/ Suggestions of Reviewer

Sl. No.	Views/ Suggestions of Reviewer	Response by PI
1.	Crop & fish production and water productivity at the sites under various sub minors area given in Tables 13.1, 13.2, 13.3, 13.4, 13.5, 13.6, 13.7 and 13.8, whereas detailed calculation of physical water productivity (PWP) and economic water productivity (EWP) are not given in the report.	Now, in the Final Report, physical water productivity (PWP) have been included in addition to economic water productivity (EPW); now all those can be seen in revised Tables (with changed numbers) viz. 12.1, 12.2, 12.3, 12.4, 12.5, 12.6, 12.7 and 12.8. One sample calculation have also been included in the text preceding to the Table 12.1 (please refer page no. 93 in the Final Report)
2.	At page No. 5 (para 3), it is stated that water productivity is enhanced in ponds commands area than the non-pond commands area. The comparison of cost benefit for the ponds commands and non-pond commands area needs to enclose in the report	'Without water storage tank' as was reported in the DFR (within Table 11.1) is actually the 'non-pond commands' area. Accordingly it was summarised (page No. 5, para 3 in DFR); Now, we have revised as per suggestions received; please find the comparison in Tables 10.1, 11.5, 11.7, 11.9 in the Final Report.
3.	A brief write up on data collection (primary & secondary), frequency of observations, methods of observations, points of observation, and sample calculations for finding values of different parameters may be included in the report for better understanding.	Now, we have included the data collection (primary & secondary), frequency of observations, methods of observations etc. in the Final Report, under the sub-head 9 (page no. 7-8) for better understanding; we have specified the page numbers for detailed methods for different parameters.

17/02/2021
(K.G. Mandal)
Principal Investigator