OPTIMIZATION OF AREA ALLOCATION STRATEGY FOR IRRIGATION IN COMMAND AREA: A CASE STUDY FOR NATUWADI MEDIUM IRRIGATION PROJECT

A Thesis submitted to the

Dr. BALASAHEB SAWANT KONKAN KRISHI VIDYAPEETH
DAPOLI - 415 712
Maharashtra State (India)

In the partial fulfillment of the requirements for the degree

of
MASTER OF TECHNOLOGY
(AGRICULTURAL ENGINEERING)
in
IRRIGATION AND DRAINAGE ENGINEERING

by

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B. Tech (Agril. Engg.)

DEPARTMENT OF IRRIGATION AND DRAINAGE ENGINEERING

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NOVEMBER, 2013

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CANDIDATE'S DECLARATION

I hereby declare that this thesis or part thereof has not been submitted

by me or any other person to any other

University or Institute

for a Degree or

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CERTIFICATE

This is to certify that the thesis entitled "**Optimization of area allocation strategy for irrigation in command area: A case study for Natuwadi medium irrigation project**", submitted to Faculty of Agricultural Engineering, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Dist. Ratnagiri (M.S.) in partial fulfillment of the requirements for the award of the degree of **Master of Technology (Agricultural Engineering)** in **Irrigation and Drainage Engineering**, embodies the record of a piece of bonafied research work carried out by **Mr. Rupesh Arun Gavit** under my guidance and supervision and that no part of this thesis has been submitted for any other degree, diploma or publication in any other form.

The assistance and help received during the course of this investigation and source of the literature have been duly acknowledged.

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The assistance and help received during the course of this investigation and source of the literature have been duly acknowledged.

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LIST OF SYMBOLS

Symbols		Description
%	:	Per cent
@	:	About
Δ	:	Solar declination angle
Ω	:	Hour angle
Σ	:	Stefan-Boltzmann constant
Φ	:	Latitude
/	:	Division
±	:	Plus or minus
µ	:	Mue
Σ	:	Summation
<	:	Less than
>	:	Greater than
Π	:	Pie
Θ	:	Theta
Ln	:	Natural Logarithm
^{0}C	:	Degree Celsius
=	:	Equal
K	:	Kelvin
‘	:	Minute
Δ	:	Delta
Φ	:	Psi
^{0}	:	Degree
^{0}F	:	Degree Fahrenheit
R	:	Correlation Coefficient
e_a	:	Actual vapour pressure
e_s	:	Saturated vapour pressure
G	:	Soil Heat Flux
J	:	Number of days in the year
K_c	:	Crop coefficient
K_p	:	Pan Coefficient
N	:	Maximum possible duration of sunshine
Rnl	:	Net long wave radiation
Rns	:	Net short wave radiation
Rs	:	Solar radiation
U_2	:	Average wind speed at 2 m height
Ra	:	Extra-terrestrial radiation

LIST OF ABBREVIATIONS

Abbreviations	Meanings
AG	Agriculture
Agril.	Agricultural
Agril. Engg.	Agricultural Engineering
Agromet	Agrometeorology
ASAE	American Society of Agriculture Engineering
Assoc	Association
B:C	Benefit:Cost
CCA	Cultivable Command Area
CEC	Cataion Exchange Capacity
Climatol	Climatological
Deptt.	Department
Dr. BSKKV	Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth
Dy1	Distributory 1
Dy2	Distributory 2
Engg.	Engineering
ET	Evapotranspiration
et al.	And others
Etc	Crop reference evapotranspiration
etc.	Etcetera
ETo	Reference evapotranspiration
FAO	Food Agriculture Organization
FLR	Full Reservoir Level
Fig.	Figure
GCA	Gross Command Area
Ha	Hectare
Hrs	Hours
Hydro	Hydrology
i.e	That is

ICA	Irrigable Command Area
IRR	Internal Rate of Return
J.	Journal
Lab	Laboratory
LBC	Left bank canal
Lit	Liter
LP	Linear programming
Kg	Kilo gram
M cum	Million cubic meter
M. S.	Maharashtra State
M. Tech	Master of Technology
m/s	Meter per second
m^2	Square meter
Meteor.	Meteorology
min.	Minute
mm	Millimeter
mm/day	Millimeter per day
NIN	National Institute of Nutrition
No.	Number
PE	Penman Equation
PET	Potential Evapotranspiration
PM-56	Penman-Monteith 56
Pp	Page number
RBC	Right bank canal
RH	Relative Humidity
Rs.	Rupees
Rs. M	Rupees Million
Sci.	Science
sq.km	Square kilometer
Tech	Technical
temp	Temperature
Univ.	University
Vol.	Volume

ABSTRACT

"OPTIMIZATION OF AREA ALLOCATION STRATEGY FOR IRRIGATION IN COMMAND AREA: A CASE STUDY OF NATUWADI MEDIUM IRRIGATION PROJECT"

BY

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Research Guide	**:**	**Dr. M. S. Mane**
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Land and water are major resources for agriculture. Besides various other uses of water, the largest use of water is made for irrigation. In India, rainfall being erratic and stochastic in nature, agriculture is heavily dependent on irrigation. Thus to meet the food demand of ever increasing population of India, more area needs to be brought under cultivation. However as the productivity of irrigated agriculture is more than thrice the productivity of rainfed agriculture, it is evident that more area should be brought under irrigation. This can be achieved either by developing the new water resources or efficiently utilizing the available water resources.

The present study was under taken with a view, to irrigate more area and maximization of net benefit of command area. A case study was conducted on, Natuwadi medium irrigation project, Natunagar, Khed. Data were collected from field and irrigation department of command area. Water requirement of crops was calculated with the help of FAO Penmen-Monteith method. Food requirement for population of command area was calculated for each canal and distributory. Cost analysis for each crop was done for calculating net benefit at input cost.

A linear programming model was developed considering two specific objectives viz., net benefit maximization and optimal area allocation. Land available, water available, and food requirement are the constraints considered for model. The

model was run at 70 per cent, 80 per cent, 90 per cent and 100 per cent availability levels of storages excluding different water losses.

The optimal cropping pattern indicated that net benefit and area are increased as water availability level increases. For Right bank canal of 965 ha ICA at 70 per cent, 80 per cent, 90 per cent and 100 per cent water availability level, for net benefit maximization, the area brought to be irrigated as 583 ha, 678 ha, 757 ha and 811 ha, respectively. At the same time, the net benefit found to be Rs. 102.69 M, Rs. 129.02 M, Rs. 153.67 M and Rs. 177.66 M, respectively. At this level generation of labor days were 166886, 204579, 227240 and 245006, respectively. Also, for distributory 1 (Dy1) of RBC of 400 ha ICA at different water availability level, the area brought to be irrigated as 221 ha, 240 ha, 274 ha and 308 ha of the ICA, respectively, the net benefit found to be Rs. 46.58 M, Rs. 51.39 M, Rs. 61.09 M and Rs. 71.55 M, respectively. At this level generation of labor days were 61602, 70405, 80694 and 92652, respectively.

Similarly, for distributory 2 (Dy2) of RBC of 405 ha ICA at different water availability level, the area brought to be irrigated as 255 ha, 274 ha, 313 ha and 357 ha of the ICA, respectively, the net benefit found to be Rs. 47.37 M, Rs. 59.14 M, Rs. 70.45 M and Rs. 80.89 M, respectively. At this level generation of labor days were 71928, 81131, 955440 and 109720, respectively. Also, for left bank canal of 280 ha ICA at different water availability level, the area brought to be irrigated as 199 ha, 222 ha, 238 ha and 267 ha of the ICA, respectively, the net benefit found to be Rs. 23.64 M, Rs. 35.96 M, Rs. 41.27 M and Rs. 49.94 M, respectively. At this level generation of labor days were 50908, 57535, 63140 and 73737, respectively.

For Whole command area of Natuwadi dam of 2050 ha ICA at 70 per cent, 80 per cent, 90 per cent and 100 per cent water availability level, for net benefit maximization, the area brought to be irrigated were 1258 ha, 1414 ha, 1582 ha and 1743 ha, respectively having 61.37, 68.97, 77.17 and 85.02 per cent of ICA. At the same time, the net benefit found to be Rs. 220.28 M, Rs. 275.75 M, Rs. 315.17 M and Rs. 380.04 M, respectively, this was much more than existing situation (Rs. 19.56 M). The generations of labor days were 351324, 413650, 466614 and 521115, respectively.

I. INTRODUCTION

Land and water are major resources for agriculture. Besides various other uses of water, the largest use of water is made for irrigation. In India, rainfall being erratic and stochastic in nature, agriculture is heavily dependent on irrigation. Thus to meet the food demand of ever increasing population of India, more area needs to be brought under cultivation. However as the productivity of irrigated agriculture is more than thrice the productivity of rain fed agriculture, it is evident that more area should be brought under irrigation. This can be achieved either by developing the new water resources or efficiently utilizing the available water resources. As tradition the cheap and easily available water resources have been tapped, the efficient utilization of the available water resources is the better solution to bring more area under irrigation.

India shares only 2.4 per cent of the world's geographical area, but support 18 per cent of the population and 15 per cent of the live stock production. In country, Maharashtra is the third largest state in respect of area and second in terms of population. The rural population of the state is 6.158 crore having 54.80 per cent (Census of India, 2011) of the total population. The geographical area of the state is 308 lakh hectares. The total gross cropped area is 224 lakh hectares of which 176 lakh hectares are under net crop. Maharashtra is basically rainfed state with 83.1 per cent area, leaving only 16.9 per cent under irrigation. Limited irrigation is one of the important and critical constraints of Maharashtra State Agriculture. Only 16.9 per cent of the State's net sown area is irrigated as against 41 per cent of country. (Anonymous, 2012).

Thus to meet the requirement of increasing population and to achieve sustainable development, it is necessary to use natural resources very carefully and to check over exploitation of the natural resources for human needs, economic development and the environment. The need for more food had to be met through higher yields per unit land, water, energy and time. Therefore, it is essential to use the land and water resources in the command area of the irrigation project optimally. It is essential to generate comprehensive plans for optimum utilization of land and water resources.

There will be increasing need for more extensive water supply system to meet ever increasing agricultural, domestic and industrial demand due to population pressure. Water is not found when and where it is needed and also it may not be of good quality. Optimum development and efficient utilization of water resources, therefore, assumes great significance in the country. Planning of water resource projects based on scientific data is one of the most important factors of water management. Command area development and management involves knowledge of both the total demand and the distribution of irrigation water over space and time. The major information required for irrigation studies is about soil, crop types, acreage condition and yield. The command area of the medium and major irrigation projects normally ranges from 2000 ha to more than 10000 ha in the country. The soil in the command area is heterogeneous and several crops are grown and irrigated on these soils. The ground water potential also varies. The crop is grown often in two seasons and sometimes in three seasons. The water is distributed with the help of network of canal of varying capacities. This makes management of land and water resources in the command area complex.

The mathematical programming quantifies an optimal way of combining scarce resources to satisfy the proposed goals, that is, they analyze the cases where the available resources must be combined in a way to maximize the profit or minimize the cost. To optimize his decision, the planner must choose among the available production alternatives, the most efficient in the use of productive resources and the one which satisfies the previously-stated goals. In the cases where the decision is related to the allocation of scarce resources, the planner's responsibility is to find efficient methods that can help him to make the right decision. To solve this problem, the mathematical programming models are the most recommended. Several modeling approaches, such as linear programming, non-linear programming, dynamic programming, simulation, and combined optimization-simulation have appeared in the literature. (Singh *et al*. 2001, Khare *et al*. 2006, Mane *et al.* 2010, Pant *et al*. 2010)

For finding optimal crop area under given available water, a different land area, water availability and food requirement is considered as constraints of LP model. The purpose of this study is to propose an allocation LP model that can take into account varied utilized land area and multi-crop water requirements. Linear programming based optimization models are still popular and effective tools in dealing with such allocation problems. These models have been used by many researchers to investigate a variety of water allocation problems.

The Konkan region of Maharashtra having a geographical area of 30,143 sq.km, and has coast length of 720 km. The irrigated area in the region is only 3.81 per cent (Anonymous, 1999) of the total geographical area. Hence, there is strong need of proper planning of irrigation systems. The assessment and the use of available inputs can be better planned by following some modeling techniques and ultimately by increasing the net benefits of the farmers. Due to heavy rainfall rice is the major crop in the *kharif* season i.e. 39 per cent of cultivated area and during rest of period fields remains dry. Horticultural crop like mango, coconut, areca nut, cashew nut, jackfruit, pineapple and banana are grown and spices are also taken in this zone. The crop in *rabbi* and summer season can be planned on the basis of inputs like land, water, labour, finance etc. by using linear programming models. An attempt is made here for integrated analysis of the system and giving proper plan for agriculture development aiming to increase the financial status of the farmer in the command area of the region.

Natuwadi medium irrigation project of South Konkan of Maharashtra was constructed in Natunagar, Tahsil Khed, Ratnagiri district, in the year 1983-84 to utilize the flow of Choriti river. It is project of Govt. of Maharashtra. The gross command area of this project is 2343 ha, cultivable area is 2139 ha and irrigable area is 2050 ha. In which the net irrigated area is only 461 ha, thus there is a gap of more than 75 per cent in adoption of irrigation water of the project. At present, no irrigation planning is being followed for crop production in the command area of Natuwadi irrigation project due to social problems and also uncertain inflow in to the dam. The irrigation department releases irrigation water for crop production without any aim of benefit maximization. Keeping this in view, the present study was under taken with the following objectives:

1. To identify the resource inventory of the command area.
2. To develop a linear programming model for the command area.
3. To derive optimal crop area allocation for irrigation in the command area.

II. REVIEW OF LITERATURE

The canal water is one of the main sources of irrigation for *rabbi* crop or taken two or more crop in same year. The irrigation scenario in India is characterized by poor irrigation system performance, increased demand for higher productivity and improper water management strategies. Due to increasing cost in developing new water resources, the only option left is to enhance the current level of performance. A number of studies have been done by various researchers on the optimal allocation of resources for getting maximum profit.

The literature for the study has been reviewed briefly under the following sub sections.

1. Linear programming model
2. Optimal cropping pattern
3. General models

2.1 Linear programming model:

Stoecker *et al.* (1985) developed a linear dynamic programming (LDP) method and applied to derive optimal temporal investment in the use of stock resources and long term cropping plans for a typical farm situation in the Texas high planes. First, parametric linear programming (PLP) was used to maximize periodic profits subject to specified value of state variables related to animal water use and irrigation system capacity. The PLP results were then used in a dynamic programming model to determine the optimal allocation of water and irrigation resources over time. Result indicated that the economic benefit of modern water and energy efficient irrigation system may come from the expansion of the current irrigation intensity rather than from an extended period of irrigation when water was initially scarce relative to land.

Srivastava and Patel (1992) used an optimization-simulation model for the systems analysis of a water resources system. The Karjan Irrigation reservoir project in India was taken as the system. Two types of optimization models, i.e., linear programming and dynamic programming (continuous and discontinuous) were used for preliminary design purposes. The simulation technique was used for further screening. The linear programming model was most suitable for finding reservoir capacity.

Jothiprakash *et al.* (2004) formulated an optimization model to maximize the net benefit from a tank command with conjunctive use of surface water from the tank and ground water from wells and community well in the tank area. The Kannangudi tank in Pudukkottai district, Tamil Nadu, India had been taken as the case study. Six crops were found in the command area and were considered for revising the optimal cropping pattern. The study result shows that, the wells and community well in a tank command contributes to a sustainable irrigation and apparently maximizes the net benefit from that tank command.

Raju and Kumar (2005) developed Fuzzy Linear Programming (FLP) for the evaluation of management strategies for a case study of Sri Ram Sagar Project, Andhra Pradesh, India. Three conflicting objectives viz. net benefits, crop production and labour employment were considered in the irrigation planning scenario, in which they studied how vagueness and imprecision in the objective function values can be quantified by membership functions in a fuzzy multiobjective framework. Uncertainty in the inflows was considered by stochastic programming. Analysis of results indicated that net benefits, crop production and labour employment in FLP are deviated by 2.38 per cent, 9.6 per cent and 7.22 per cent as compared to ideal values in the crisp Linear Programming (LP) model. Comparison of results indicated that the methodology can be extended to other similar situations.

Khare *et al.* (2006a) studied optimal use of available surface and groundwater. Shortages of surface water supplies have increased the need of groundwater development in many canal commands. The potential of groundwater can be used to develop conjunctive water use management plans for supplementing canal water supplies and to increase agricultural productivity. In this paper, the feasibility of conjunctive water use management was analyzed using a mathematical model in the Sapon irrigation command area of Kulon Progo Regency, Yogyakarta province, Indonesia. The water demand and available water resources in the study area were evaluated considering surface water and groundwater. In the present paper, a simple economic-engineering optimization model was presented to explore the possibilities of conjunctive use of surface and groundwater using linear programming with various hydrological and management constraints, and to arrive at an optimal cropping pattern for optimal use of water resources for maximization of net benefits.

Khare *et al*. (2006b) developed a conjunctive water use planning for Krishna (Nagarjunasagar)–Pennar (Somasila) canal. This link canal has been proposed considering only surface water supplies, neglecting the groundwater potential. Further, water demand and available water resources of the area were evaluated considering both the surface and groundwater resources. A simple economic-engineering optimization model was presented, to explore the potential of conjunctive use of surface and groundwater resources using linear programming with various hydrological and management constraints, and to arrive at an optimal cropping pattern for optimal use of water resources for maximization of net benefits. The LINDO 6.1, optimization package has been used to arrive at optimal allocation plan of surface water and groundwater. The results substantiated that conjunctive water use planning was beneficial and feasible for the proposed canal command. A considerable quantity of surface water (i.e. 43,189 ha m) can be saved for the other needy area as a part of inter-basin water transfer by implementing the proposed conjunctive use of surface and groundwater.

Raju and Kumar (2006) studied application of Data Envelopment Analysis (DEA) as a Multicriterion Decision Making (MCDM) methodology and tested it for Sri Ram Sagar Project, Andhra Pradesh, India. Three different criterion functions of DEA, namely minimizing deviation variable *Dj* (Min*Dj*), minimizing maximum deviation (Minmax), and minimizing the sum of deviations *Dj* (Minsum) were applied for the same DEA constraint set. These criterion functions were evaluated under the framework of Multi Objective Linear Programming (MOLP). Highest efficiency rated irrigation planning alternative was chosen to be the best for each of the above criterion functions. The results were compared with those obtained by discrete MCDM methods, PROMETHEE and EXPROM. It was found that ranks obtained by DEA were reasonably close to those obtained by the above mentioned MCDM methods, PROMETHEE and EXPROM.

Joao *et al.* (2008) developed a multiyear linear programming model to optimize the financial return and water use, at farm level for Jaíba irrigation scheme, Minas Gerais State, Brazil, using data on crop irrigation requirement and yield, obtained from previous simulation with MCID model. The linear programming model outputted a cropping pattern to which a maximum total net present value of Rs. 16.77 million for the four years period, was obtained. Constraints on monthly water availability, labor, land and production were critical in the optimal solution. In relation to the water use optimization, it was verified that an expressive reductions on the irrigation requirements may be achieved by small reductions on the maximum total net present value.

Azamathulla *et al.* (2009) developed a linear programming (LP) model to be applied to real-time reservoir operation in an existing Chiller reservoir system in Madhya Pradesh, India for an increasing awareness among irrigation planners and engineers to design and operate reservoir systems for maximum efficiency to maximize their benefits.

Ayare *et al.* (2010) developed a linear programming (LP) model for the evaluation of irrigation development strategy under coastal conditions and applied to the Natuwadi medium irrigation project, in South Konkan region of Western Maharashtra, India, with objective of maximization of net benefits. The inflows at five levels of water availability viz.70 per cent, 80 per cent, 90 per cent, 100 per cent and 110 per cent were considered, to obtain various possible optimal cropping pattern and optimal operating policies. It was observed that, net benefits of Rs 130.5 million were obtained at 110 per cent water availability levels, which was 42 per cent more than that at 70 per cent availability levels.

Ouda and Bardossy (2010) studied multi objectives optimization model (MOM) based on linear programming techniques aimed to optimize the treated waste water use under the consideration of biophysical and socio-economic conditions in Gaza strip was implemented for wet, dry and average rainfall years. The available agriculture area, available groundwater, crop water change, available treated waste water and local agriculture products demand were considered as constraints. Irrigation water demand for each crop and average product prices were considered as input. Three single objective models were implemented for the three meteorological conditions. The first two maximize the treated water reuse, second to minimize the treated water reuse and the third to maximize the treated water.

Bhuvandas *et al.* (2010) studied a Linear Programming (LP) model for obtaining optimized cropping area in the command of Ukai reservoir. The objective was to maximize the sum of the relative yields from all crops in the irrigated area for specific range of water availability like 100 per cent, 90 per cent, 80 per cent and 70 per cent. The study was aimed to get the optimal allocation of irrigation water depending upon the availability of water from the source. The net revenue from agricultural production was maximized, for available irrigation water taking into account the sets of constraints like crop area, cropping pattern and water requirement.

The model was applied to a part of Ukai reservoir system namely Ukai Right Bank Main Canal (URBMC), in Gujarat state, India.

Mane *et al.* (2010) developed a linear programming model for the left Dadupur and its associated distributaries and minor in Bulandshahar district of Uttar Pradesh State of India. Result indicated that in *kharif* season, the current net benefits of Rs. 69.88 million could be increase to Rs. 107.79 million. For *rabi* season, different scenarios like meeting food requirement of the population residing in the area, meeting food, oil seed plus cash crop requirement and meeting food, oil seed, cash crop and fodder requirement of the area were generated. For scenario of meeting the food requirement, the net benefit could be increased to Rs. 89.91 million by allocating 48 per cent area to wheat crop. In the scenario of meeting food, oil seed plus cash crop requirement, the net benefit could be raised to Rs. 82.81 million and generating the employment potential of 3.39 million of working hrs.

Regulwar and Gurav (2010) made an attempt to develop the irrigation planning model and to apply the same in the form of Multi Objective Fuzzy Linear Programming (MOFLP) approach for crop planning in command area of Jayakwadi Project Stage I, Maharashtra State, India. To formulate MOFLP model various Linear Programming (LP) models were developed to optimize the Net Benefits (NB), Crop/Yield Production (YP), Employment Generation (EG) and Manure Utilization (MU) for which the objective function and constraints were crisp in nature. From the results of these LP models the linear membership function for each individual objective function had been developed. Considering the decision makers satisfaction level (λ), all the four objectives were maximized simultaneously. The results of the MOFLP and LP were compared. The MOFLP model concentrates on satisfying four objectives simultaneously. The degree of satisfaction λ, works out to be 0.58. Compromised solution provides net benefits Rs. 1503.73 Million, crop production 319563.50 Tons, Employment Generation/Labor Requirement 29.74 Million Man days and Manure Utilization 154506.50 Tons, respectively.

Zeng *et at.* (2010) studied multi objective linear programming (MOLP) model, which was not suitable for such decision making in such fuzzy environment. In this study, they proposed the fuzzy multi objective linear programming (FMOLP) model with triangular fuzzy numbers and transformed the FMOLP model and its corresponding fuzzy goal programming (FGP) problem to crisp ones which can be solved by the convectional programming method. The FMOLP model was applied to crop area planning of Liang Zhou region Gansu province of North West China and then the optimal cropping patterns under different water saving levels and satisfaction grades for water resources availability of the decisions makers (DM) were obtained compared to the MOLP model.

Gadge *et al.* (2011) developed mathematical approach for techno-economic feasibility study towards adoption of micro irrigation methods in areas bestowed with good quality surface water under rotational distribution of canal network. The approach involves water requirement, scheduling of crops using FAO Penman-Monteith method and optimal allocation of available resources i.e. land and water using linear programming technique among the crops selected on the basis of farmers preference and productivity in the area. The another module determines the minimum reservoir capacity and design a dug out type surface storage reservoir using linear programming technique to store water for use during the “OFF” time period of the canal operation. The Pipe Network Design Model gave optimal design of conveyance piping system based on the optimization technique with an objective of minimum total cost. Studied command area was Direct minor no. 3 of the Mula Irrigation Project, Ahmednagar, Maharashtra, indicated 3.5 times higher net benefits due to adoption of microirrigation methods using field reservoir and pump for an individual field and 2.8 times higher net benefits due to micro irrigation methods using single common reservoir and pumping unit as compared to the surface irrigation method.

Hosseinpourtehrani and Ghahraman (2011) developed a Fuzzy based model using non linear programming to obtain optimal reservoir operation for irrigation of multiple crop. Result show that the changing trend of water releases in both model was the same with R^2 =0.97. Over the 12 months period, both trends had risen from October to May but since then they had fallen gradually. In general the amount of annual released water in Fuzzy model was almost less than NLP, especially in comparative months, May and June. The percentage of water deficit to the percentage of annual mean water deficit was respectively, 0.57 and 0.81 in training and 0.93 and 1.145 in the test stage. In addition, the water deficit compared with the amount of cultivated crops acreage has more impact on the net benefit.

Keramatzadeh *et al.* (2011) discussed the optimal allocation of water to agriculture, the relatively true economic value of water as well as the cropping patterns for the Shirvan Barzo (SB) dam area in North Khorasan Province of Iran. The analysis was based on linear programming (LP) and on multi goal linear programming

(MGLP) models for determining solutions that can maximize net return to farmers. The results indicated that optimizing the cropping patterns along with proper allocation of irrigation water has yet substantial potential to increase the net return from agriculture. It has already decreased the applied water as much as 19 percent. The results show that the economic value of each unit of agricultural water is estimated to be between 107 to 1296 IRR$\times^{104}$ per cubic meter. This suggests managing the allocation of water based on optimal models and bring water prices close to its true economic value to motivate the farmers to economize in the applied water.

Noory *et al.* (2011) studied to maximize net benefit for all cultivated crops within irrigated areas in a reservoir-irrigation system in Iran. The linear model was optimized with linear programming (LP) method and continuous particle swarm optimization (CPSO) algorithm to make a detailed comparison between the LP method and CPSO algorithm results. The optimal solution obtained by the CPSO algorithm and LP method in the linear model were comparable. However, the optimal allocated areas for both crops and orchards in the linear model obtained by the LP method and CPSO algorithm were not directly applicable in real crop planning situations. The results showed that the discrete nature of cropping area variables in the MIL model had a significant effect on assigned areas and reservoir operation policies. It was found that the inapplicable assigned area by the LP method and CPSO algorithm for some crops was eliminated from optimum selected cropping areas by the DPSO algorithm. The statistical assessment showed that the CPSO and DPSO algorithms were both able to limit the variations of annual net benefit within the acceptable range of no more than 2 per cent. The number of function evaluations for obtaining optimal annual net benefit and the standard deviation of the results in 50 independent runs in the MIL model was 167,000 and 0.81, respectively by the DPSO algorithm as compared with 200,000 and 1.09 by the CPSO algorithm in the linear model.

Tzimopoulos *et al.* (2011) developed a linear programming model for to determine the minimum possible usage of the available water resources. The record of annual flow, irrigated areas, crop water requirements, evapotranspiration and effective rainfall of the region were used for this application. The constraints were formulated taking in to consideration several economic factors such as water costs, production costs and agricultural prices. The profit resulting from all three different scenario was calculated about a raise close to 285 per cent, 182 per cent and 168 per cent and also saving of irrigation water about 70 per cent,23 per cent and 66 per cent respectively. Result showed that the proposed linear programming model gave the optimum crop pattern for the region, obtaining the higher profit both for the cultivator and the water resources.

Mirajkar and Patel (2012) used crisp linear programming approach to get the individual solutions of three conflicting objectives: maximization of net benefit, maximization of employment generation and minimization of cost of cultivation. These crisp solutions were, then, solved together to obtain the solution under fuzzy multi-objective environment with maximum–minimum operators. Also, an effort has been made to improve the solution from maximum-minimum operator approach using two-phase as well as compromised fuzzy approaches. The applicability of the aforesaid algorithms was demonstrated through a case study of Kakrapar Right Bank Main Canal (KRBMC) under Ukai command area in India. The linear programming model for each objective function resulted in maximum net benefit of Rs. 5593.77 million, employment generation of 14.82 million man-days and a minimum cost of cultivation of Rs. 1076.75 million over the planning year.

Pradhan (2012) analyzed profitability and constraints of mixed cropping pattern (i.e. the production of fruit, vegetable and other non-cereal crop along with the basic rice crop) in the area under study. An attempt has been made with Linear programming Model to compare the profitability of actual and suggested (optimum) production mix farming method considering the primary data collected from 400 sample farm households of three different villages (irrigated, tailed-irrigated and non-irrigated) located in three different blocks of Bargarh district of Orissa. Despite the profitability nature of the mix-cropping pattern the farmers in the area under study are not in a position to adopt and adapt this type of cropping, they are highly concentrating on the rice based and biased cropping as evident from the research result; this may be due to certain constraints that discourage them to go for mix-cropping.

Rani and Rao (2012) developed different crop planning strategies which increases the productivity with minimum input cost with the constraints of available resources like water usage and also labour, fertilizers, seeds, etc., and ultimately getting maximum net benefits. Multi objectives were framed by formulating three single objective functions for multi crop model and for two seasons were formulated in LP for maximizing the net benefits, minimizing the cost and minimizing the water usage by keeping all other available resources as constraints. RDS Rajoli Banda Diversion scheme area, Mahaboobnagar, AP, India was taken, and solved through optimization techniques linear programming and was solved with Lingo software. The results revealed that optimization approach will significantly improve the annual net benefits with optimal crop areas allocation.

2. Optimal cropping pattern:

Maqsood *et al.* (1994) formulated a linear programming model to develop an optimal cropping pattern within the available resources and constraints of the study area at Dijkot distributary. The objective function was to maximize the net returns of the farmers and to make the best use of the available water resources. The proposed optimal cropping pattern eliminated cotton and reduced the cropped area of sugarcane and wheat to 50 per cent and 36 per cent, respectively. The area under *kharif* fodder however remained the same. The adoption of the proposed optimal cropping pattern promised an increase of net returns by 27 per cent.

Paul *et al.* (2000) developed optimal resource allocation strategies for a canal command in the semiarid region of Indian Punjab. The proposed strategies were divided into two modules using a multilevel approach. The first module determines the optimal seasonal allocation of water as well as optimal cropping pattern. This module was subdivided into two stages. The first stage was a single crop intraseasonal model that employs a stochastic dynamic programming algorithm. The second stage was a deterministic dynamic programming model that takes into account the multi crop situation. An exponential seasonal crop-water production function was used in this stage. The second module was a single crop stochastic dynamic programming intraseasonal model that takes the output of the first module and gave the optimal weekly irrigation allocations for each crop by considering the stress sensitivity factors of crops.

Singh *et al.* (2001) estimated the irrigation water requirements of major crops and the total available water through canal and ground water in the command of Shahi distributory. A linear programming model was formulated to suggest the optimal cropping pattern giving the maximum net return at different water availability levels. The objective function of the model was subject to the following constrains: total available water and land during different seasons, the minimum area under wheat and rice for local food requirements, farmer's socio – economic conditions, and preference to grow a particular crop in a specific area. Optimally, the total available water can support 42, 30, 15, 5, 3, 1 and 31 per cent of the command area under cultivation for wheat, sugarcane, mustard, lentil, potato, chickpea and rice, respectively, to achieve self-sufficiency in food and optimal utilization of resources. At reduced water availability levels area under mustard may be increased while the area under sugarcane and rice may be decreased.

Benli and Kodal (2003) developed a non-linear optimization model for the determination of optimum cropping pattern, water amount and farm income under adequate and limited water supply conditions. The objective function of the model was based on crop water-benefit functions. The model was solved using MS Excel Solver package for conditions existing in South-East Anatolian Region of Turkey. The model gave the optimal distribution of crop areas, irrigation water needs of crops and total profit for the farm under adequate and limited water supplies. The problem was also solved by a linear programming (LP) model, in order to indicate the difference between non-linear programming (NLP) and linear programming models. After the examination of NLP and LP model solutions, it can be seen that, the NLP model can gave higher farm income values than the LP model under deficit irrigation conditions.

Singh *et al.* (2003) formulated linear programming (LP) model to develop optimal cropping pattern for producing minimum food requirement in relation minimum investment during drought year in Mahi command area. The study revealed that by judiciously using minimum quantum (58.7 per cent of normal usage) of irrigation water in drought year feeding 58 per cent of area grown with optimal cropping pattern incurring minimum investment (less by 40.9 per cent). It would be possible to achieve the food security. The investment although made in drought condition, has not involved any financial risk and also provided considerable employment (10 per cent of total man-days). Further envisage strengthening of co-operative societies, promoting shearing of benefits, creditors like SHG (self help group) and voluntary regulatory bodies for water distributaries for the success of proposed activities.

Montazar *et al.* (2007) developed a nonlinear model for determining optimal cropping pattern under different water regimes for Ghazvin irrigation network located in a semi-arid region in Iran. The objective function of the model was the water productivity index defined as the net profit to the volume of water used. The results showed that among the crop types grown in the region, sunflower had the highest water productivity value while tomato had the lowest. These values under drought conditions for optimal cropping pattern of the two crops were estimated at 1778.96 and 353.22 Rials/m^3. The overall water productivity of the irrigation network with relevant cropping pattern management can rise to as high as 504.38 Rials/m^3 under drought conditions. This was while in normal and wetty years, depending on the water available and the optimal cropping pattern, the values for this index were estimated to be 535.352 and 667.13 Rials/m^3, respectively. Investigations show that under drought conditions, the water productivity of the irrigation network could be raised to as high as the value in normal years.

Reddy and Kumar (2008) formulated multi-objective differential evolution (MODE) approach for the simultaneous evolution of optimal cropping pattern and operation policies for a multi-crop irrigation reservoir system. Under varying hydrological conditions, the fixed cropping pattern with conventional operating rule curve policies may not yield economically good results. The developed model was applied for ten-daily reservoir operation to a case study in India. The model results suggest that changes in the hydrologic conditions over a season had considerable impact on the cropping pattern and net benefits from the irrigation system. Towards this purpose, the proposed MODE model can be used to evolve different strategies for irrigation planning and reservoir operation policies, and to select the best possible solution appropriate to the forecasted hydrologic condition.

Vasan and Raju (2007) developed an evolutionary based optimization algorithm Differential Evolution (DE) and applied it as case study of Bisalpur project, Rajasthan, India. The objective of DE based planning model was to determine suitable cropping pattern which yields maximum net benefits. Ten different strategies (variations) of DE were analyzed with various population sizes, crossover constants and weighting factors. Results of DE were compared with solution of Linear Programming (LP). Minimum and maximum CPU elapsed time was also analyzed. It was concluded that DE/rand-to-best/1/bin was the best strategy for the planning problem with maximum net benefits of 95.1903 crores of rupees taking minimum CPU time of 2.844 seconds.

Kangrang *et al.* (2008) proposed an allocation LP model that can account heterogeneity of the land area. The divided scenario into several subareas based on the suitable soil type for each crop was used to represent the heterogeneous character in term of water requirement crop yield. The proposed model was applied to find the dry season cropping pattern of the Nong Wei irrigation project which is located in the North-East region of Thailand. The record of seasonal flow, requested area, crop water requirement, evaporation and effective rainfall of the project were used for this illustrative application. Result showed that the proposed LP model gave the optimal cropping pattern with net seasonal profit, with corresponding seasonal available water and required area. It provided the highest profit as compared to the existing LP model that considering homogeneous project.

Boustani and Mohammadi (2010) studied optimal cropping pattern for arid and semiarid regions with deficit water resources. Fars province is located in the southern part of I.R. of Iran with mean annual precipitation from 50 to 1000 mm. Jahrom region with semi-arid climate is located in Fars province with mean annual rainfall of 373 mm. In this study optimal cropping pattern was determined for this region based on water deficit condition. For this purpose, multi-objective programming approach was applied in order to reduce water consumption use. The results of this study showed that, there was tradeoffs among reduce water use, reduce risk and getting a specific gross margin. Also, the results showed that, wheat tended to increase, causing from price supporting program, indicating the government intervention trace in farmers cropping pattern. Therefore sustainable use of resources was affected by output condition in the market. Furthermore, the area of maize and vegetables were increased in all of selected solutions as compared to their current area.

Kangrang and Compliew (2010) studied a sensitivity analysis of irrigation efficiency in the modified LP model, the proposed model was applied to find the optimal crop pattern of the Huai-Ang irrigation project where located in North-East region of Thailand during dry season. The records of seasonal flow, requested and actual irrigation areas, crop water requirement, crop yield, evaporations and effective rainfall of the project were used for this illustrative application. Results show that the modified LP model was feasible for finding the optimal crop pattern. Heterogeneous character in allocation LP model provided the cropping pattern suitable for cultivating crop on actual land area. The consideration of vary irrigation efficiency in irrigation planning provided the optimal cropping pattern that can be given higher gross benefit.

Pant *et al.* (2010) studied irrigation management for optimal allocation of water for irrigation purposes, optimal cropping pattern for a given land area and water availabilities with an objective to maximize economic returns. In this study they formulated an optimization model based on linear programming for determining optimal crop plan for command area of Pamba-Achankovil-Vaippar (PAV) link project, Kerala, India. The crop planning model considers various resource constraints (land area, seeds, manure, fertilizers etc.) availability adaptive to national conditions with the objective to maximize net irrigation benefits.

Montazar and Snyder (2012) developed a comprehensive multi-criteria model for selecting adequate cropping pattern in an irrigation district under water scarcity condition. Eleven and nine attribute decisions were considered in ranking the type of crop and determination of the percentage of crop cultivation area as an optimal irrigated crop planning system, respectively. The results indicate that the proposed multi-attribute preference approach can synthesize various sets of criteria in the preference elicitation of the crop type and cultivated area. The predictive validity analysis shows that the preferences acquired by the proposed model were evident in reasonable accordance with those of the conjunctive water use model. Consequently, the model may be used to aggregate preferences in order to obtain a group decision, improve understanding of the choice problem, accommodate multiple objectives and increase transparency and credibility in decision making by actively involving relevant criteria in the crop planning.

Raul and Panda (2013) studied on rice dominated cropping system of the Hirakud canal command (eastern India). These were able to meet only 54 per cent of the irrigation demands at 90 per cent probability of exceedance. Further, optimal land and water resources allocation model was developed to determine the optimal cropping pattern for maximizing net annual return. The modeling results suggested that 2.0 and 2.3 million m^3 of groundwater can be pumped from the bottom aquifer during monsoon and non-monsoon seasons, respectively, at 90 per cent probability of exceedance of rainfall and canal water availability (PERC). Optimal cropping patterns and pumping strategies can lead to about 12.5 to 51.3 per cent increase in net annual return from the area at 10 to 90 per cent PERC. The sensitivity analysis of the model indicated that the variation in the market price of crops has very high influence on the optimal solution followed by the cost of cultivation and cultivable area. Finally, different future scenarios of land and water use were formulated for the command area.

3. General models:

Kuo *et al.* (2000) developed a genetic algorithm model to an irrigation project located in Delta, Utah of 394.6 ha in area, for optimizing economic profits, simulating the water demand, crop yields, and estimating the related crop area percentages with specified water supply and planted area constraints. The generated daily weather data were then applied to simulate the daily crop water demand and relative crop yield for seven crops within two command areas. Information on relative crop yield and water demand allows the genetic algorithm to optimize the objective function for maximizing the projected benefits. Optimal planning for the 394.6 ha irrigation project can be summarized as follows: (1) projected profit equals US$ 114,000, (2) projected water demand equals 3.03_106 M^3, (3) area percentages of crops within UCA#2 command area were 70.1, 19, and 10.9 per cent for alfalfa, barley, and corn, respectively, and (4) area percentages of crops within UCA#4 command area were 41.5, 38.9, 14.4, and 5.2 per cent for alfalfa, barley, corn, and wheat, respectively. Simulation results also demonstrate that the most appropriate parameters of GA for this study were as follows: (1) number of generations equals 800, (2) population sizes equal 50, (3) probability of crossover equals 0.6, and (4) probability of mutation equals 0.02.

Kuo and Liu (2002) formulated a simulation and optimization model for an irrigated area in Delta, Utah to optimize the economic benefit, simulate the water demand, and search the related crop area percentages with specified water supply and planted area constraints. To simulate the daily crop water demand and relative crop yield for seven crops in two command areas, to optimize the project benefit by searching for the best allocation of planted crop areas given the constraints of projected water supply. The results were employed in the genetic algorithm submodel. Optimal planning for the 394.6-ha area of the Delta irrigation project was projected to produce the maximum economic benefit. That is, projected profit equals US$113 826 and projected water demand equals 3.03×10^6 m^3. Also, area percentages of crops within UCA#2 command area are 70.1 per cent, 19 per cent and 10.9 per cent for alfalfa, barley and corn, respectively, and within UCA#4 command area are 41.5 per cent, 38.9 per cent, 14.4 per cent and 5.2 per cent for alfalfa, barley, corn and wheat, respectively.

Raju and Kumar (2004) used Genetic Algorithms (GA) for irrigation planning. In which constraints include continuity equation, land and water requirements, crop diversification and restrictions on storage. Penalty function approach was used to convert constrained problem into an unconstrained one. For fixing GA parameters the model was run for various values of population, generations, cross over and mutation probabilities. It was found that the appropriate parameters for number of generations, population size, crossover probability, and mutation probability are 200, 50, 0.6 and 0.01, respectively for the present study. Results obtained by GA are compared with linear programming solution and found to be reasonably close. GA is found to be an effective optimization tool for irrigation planning and the results obtained can be utilized for efficient planning of any irrigation system.

Raju *et al.* (2006) developed best compromise irrigation planning strategy for Jayakwadi irrigation project, Maharashtra, India. Four-phase methodology was employed. In phase 1, separate linear programming (LP) models were formulated for the three objectives, namely, net economic benefits, agricultural production and labour employment. In phase 2, nondominated (compromise) irrigation planning strategies were generated using the constraint method of the multiobjective optimization. In phase 3, Kohonen neural networks (KNN) based classification algorithm was employed to sort nondominated irrigation planning strategies into smaller groups. In phase 4, multicriterion analysis (MCA) technique, namely, compromise programming was applied to rank strategies obtained from phase 3. It was concluded that the above integrated methodology was effective for modeling multiobjective irrigation planning problems.

Wen *et al.* (2007) studied a novel spatial scenario based planning framework, with a database, model base, and scenario-setting modules, to generate flexible spatial planning scenarios for improving irrigation water-demand planning. Possible demand planning scenarios for irrigation managers were discussed. A prototype of the proposed scenario-based framework was implemented on a geographic information system platform to assist in spatial decision making. Demand planning during a drought period for the Chia-Nan irrigation command area, the largest one in Taiwan, was adopted as a case study to demonstrate the proposed framework for spatial scenario analysis.

Rao and Rajput (2009) developed demand-based optimal canal water releases for reducing the gap between canal supplies and demands for increasing the water-use efficiency in canal command areas. The developed decision support system (DSS) was evaluated under different situation of the command area of Guvvalagudem major distributary of the Nagarjunasagar left bank canal, Andhra Pradesh, India. Results indicated that the CWREDSS was capable of developing releases under different scenarios of varying cropping patterns, groundwater use situations and different rainfall probability levels of the study area, and reduce the gap between demands and supply considerably.

Venot *et al.* (2010) studied continuous upstream water development in the South Indian Krishna Basin in declining water availability downstream conditions. Upstream water use was not adjusted to reflect rainfall fluctuations, and downstream farmers of the Nagarjuna Sagar irrigation project in the state of Andhra Pradesh were increasingly vulnerable to water supply shocks. Primary and secondary data indicated managerial adjustments such as rotational and timely water supplies to meet critical water demands of standing crops. Farmers responded to changing conditions through :(a) crop diversification, (b) shifting calendars, (c) conjunctive use, (d) suspending cultivation, (e) sale of livestock, (f) out- irrigation and (g) tampering with the irrigation system. Adaptive strategies were more diverse in the tail-end than in the head-end of the canal network and local adjustments were often uncoordinated and may degrade the resource base. A better understanding of the practices induced by changes in water availability was needed to refine current water allocation and management in large surface irrigation projects.

Annepu *et al* (2011) developed different agriculture strategies and accordingly, single objective optimization models were formulated with net profit, production of crops and fertilizer consumption as objectives and availability of cultivable land, agriculture labor, agriculture machinery and water as constraints. To illustrate the models a case study of Visakhapatnam district, Andhra Pradesh, India was presented and were solved through Genetic Algorithm. This model was based on single objective optimization depending on the strategy of the agriculture planners subject to the resource and conditional constraints. By using this model the cultivated land can be reorganized to get maximum satisfaction of the stakeholders of the rural area and hence lead to sustainable development in agriculture.

Pant *et al.* (2011) studied an application of Differential Evolution (DE) to determine optimal crop plan for command area of Pamba-Achankovil-Vaippar (PAV) link project, so as to maximize the net irrigation benefit. The mathematical model of the problem was linear in nature subject to various constraints due to availability of total land area, water, fertilizers, seeds and manure, etc. Numerical results show that DE gives a better performance in comparison to the usual software tools used for solving such problems.

Hong *et al.* (2012) analyzed water distribution issues at a secondary sector of the Gignac Canal, these developed an approach to optimize water delivery of on demand distribution policies. Mixed integer quadratic programming (MIQP) was used to solve such problem. Within irrigation network, water resources and manpower for gate operation constraints, these built an objective function for dual goal: as close as possible to demand load profile and less manpower work. This method would be illustrated for scheduling off-take turnouts of an example chosen from a secondary command area of the Gignac Canal.

Montazar and Gaffari (2012) developed a multi-criteria technique, an analytical hierarchy process (AHP), a promising framework for selecting adequate cropping patterns in an irrigation command area of the Varamin Irrigation Network in I.R. Iran. Ten attribute decisions were considered for ranking the type of crop in the cropping system. These criteria were assumed nine attributes for determination of the crop cultivation area. The results show that the AHP can synthesize various sets of criteria in the preferred elicitation of the type and the cultivated area. It was concluded that AHP can be used to aggregate preferences in order to obtain a group decision, improve understanding of the choice problem, accommodate multiple objectives and increase transparency and credibility in decision making by actively involving relevant criteria in the crop planning.

Palanisami *et al.* (2012) suggested an improvement in subsidy estimation methods by adjusting the operating and maintenance cost of projects to multiple benefits of projects using the Separable Cost Remaining Benefits (SCRB) methods in three multipurpose irrigation projects in the state of Andhra Pradesh. The study had revealed that currently irrigation was over estimated. For example, the estimated average irrigation subsidy in Nagarjunsagar Project (NRSP) right bank canal based on currently practiced method, work out to be Rs 428 per ha, whereas using the SCRB approach, it come to be Rs 111 per ha. The irrigation subsidy for NRSP was thus being that time over estimated to the tune of almost 286 per cent. Similar was the case with other two projects studied. The inference of this paper was that reliable information about subsidies actually going to the irrigation sector could help in framing better pricing policies for irrigation water and in promoting more efficient use of irrigation water and utilization of subsidies.

Satiskhumar *el al.* (2012) formulated an optimization model to maximize the net benefit from a cascade of tank system and ground water from wells in northern Karnataka. The paddy being traditional and priority crop of the tank command area farmers, its optimal water allocation plans had been proposed for paddy along with alternative light irrigated groundnut and sunflower crops. The cropping pattern was derived commensurating with the tank inflow quantity at 10 per cent, 45 per cent, 70 per cent and 90 per cent probability levels in all the four tanks and groundwater that could be pumped from the existing wells to the limit of sustainable draw down. The minimum water productivity of Rs. 1.34 m^{-3} would be assured in the command areas of all the tanks of the cascade system whenever they receive inflows recurrently beyond their capacities and paddy crop would be cultivated alone. The maximum productivity that could be achieved at very low inflows was in the range of Rs.3.77 m^{-3} to Rs.4.61 m^{-3}, provided light irrigated crops namely, sunflower and groundnut were practiced.

Montazar (2013) developed an integrated soil water balance algorithm and coupled it to a non-linear optimization model in order to carry out water allocation planning in complex deficit agricultural water resources systems based on an economic efficiency criterion for Koohdasht Irrigation District (KID), a semi-arid region in I.R. Iran. The results revealed that the proposed model, as a decision tool for optimal irrigated crop planning and water resources sustainability, may be used for maximizing the overall net benefits and global water productivity of an irrigation district considering an allowable annual recharge of groundwater. Findings indicated the importance of the conjunctive water management modeling, which can be easily implemented and would enhance the overall benefits from cropping activities in the study area.

The review presented in above sections revealed that a large number of studies had been carried out for the allocation of land as well as to maximize the net benefit by using limited water resources. The optimal plan for the overall Natuwadi command area was done in the past (Ayare *et al*, 2010), however the spatial optimal plan for

RBC, two distributaries of RBC and LBC was not done so far. Hence the present attempt has been made. This is the need of time for proper water management to suit the local requirement aspects of the people in the command area.

III. MATERIALS AND METHODS

The present study was undertaken to determine optimal cropping pattern for maximization of the net returns in the command area of Natuwadi Medium Irrigation project of Konkan region of Maharashtra. The chapter includes the detailed methodology adopted to carry the present study.

3.1 Profile of the Study Area

The dam is constructed on Choriti river, it's located in southern Konkan region of Maharashtra between the latitude $17^{0}50'$ N and $73^{0}24'$E. The location map of Natuwadi medium irrigation project is shown in Plate No. 1 and the command area map is shown in Plate No. 2. The project was established in year 1983. The project commanded 2343 ha area in 16 villages of Khed tahasil. The catchments area of the Natuwadi dam is 16.32 sq.km. The area is mostly hilly with steep slopes and covered with dense forest. There are no tanks in Natuwadi medium irrigation project catchments. At present there is no planning for irrigation development. The irrigation department releases water for crop production without any aim of benefit maximization.

The river inflow up to this dam is virgin. In the data used in this study have been taken for this virgin inflow, which for all practical purposes in an unrestricted and natural inflow and can be used for linear programming model building. The salient features of Natuwadi medium irrigation project are presented in Table 3.1. The general view of Natuwadi medium irrigation project is shown in Plate No. 3 and the three dimensional view of dam is shown in Plate No. 4.

<u>Table 3.1 Salient features of Natuwadi Medium Irrigation project, Ratnagiri</u>

a	**Value**
n	
p	
a	
r	
a	

neter	
ocation	Village – Natuwadi, Tal- Khed, Dist-Ratnagiri, State of Maharashtra.
ype of dam	Earthen dam
CI	47/G-5 and 6
Top	

osheet No.

$17^{0}50'$ N

atitude

$73^{0}24'$E

ongitude

16.32 sq. km

atch

ments area

3632 mm

)

Mean annual rainfall

l

49.98 M cum.

i)

Average annual runoff

36.3 M cum.

ii)

75

% dependable runoff am and Reserv

oir

28.08 M. cum

)

Gross capacity of reservoir

0.85 M. cum

i) Capacity of dead storage

27.23 M.cum

ii)

Capacity of live storage 7.6 M.cum

v)

Evapo

l

ration losses) 8.33 M. cum

Seepage losses 217.2 ha

i)

li

Area under submergence at FRL

45.27 m

ii

)

Maximum height of dam	900 m

iii) Tota

l length of dam x)	Masonry gated ogee type spillway on left bank
Type of spillw	

ay anals

Left bank canal, 12 km.

)

Length of canal

Right bank canal, 24 km.

Distributory 1 (DY1), 7.43 km

Distributory 2 (DY2), 3.75 km

Left bank canal, 0.88 cum./sec

i)

Discharge at head	Right bank canal,5.66 cum./sec
ommand area)	2390 ha.

Gross command area

2139 ha.

i) Cultivable

area 2050 ha.

iii) Irrigable area 76.17%

ntensit

y of irrigation of gross command

area	
ost of scheme	Rs. 37.62 M
ost of M. cu	Rs.13.4 M /M. cum

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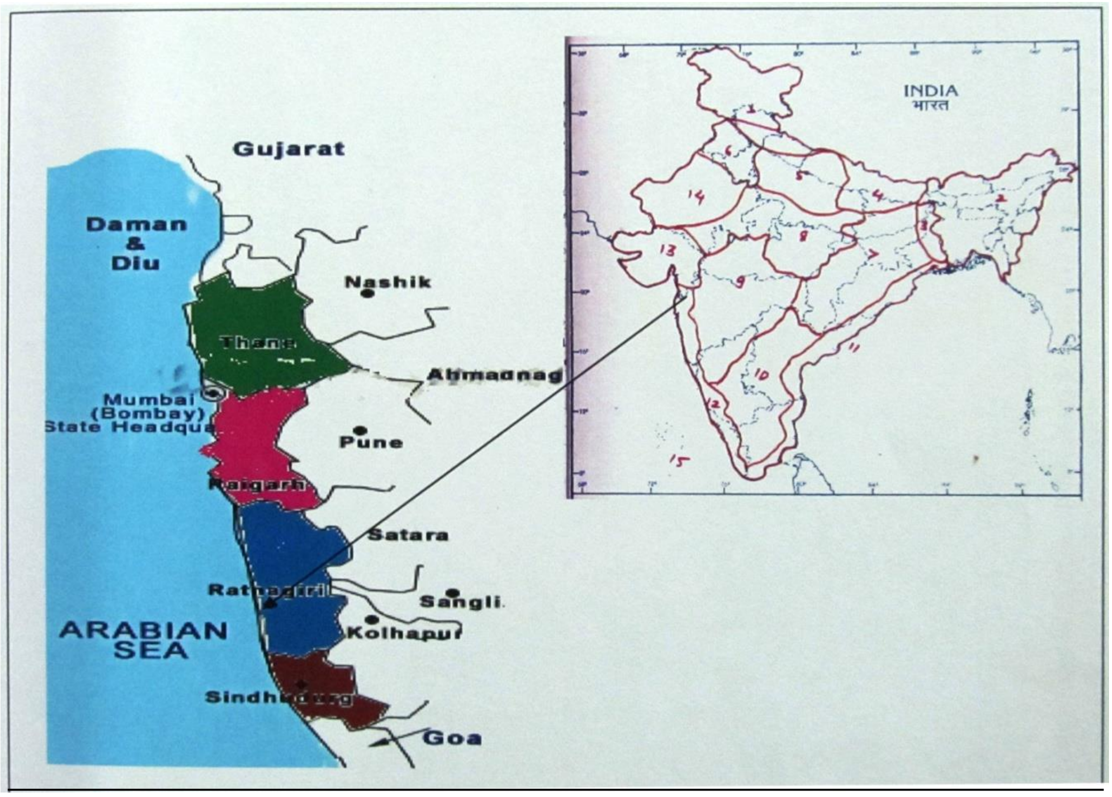

Plate No.1 The location map of Natuwadi medium irrigation project, Khed

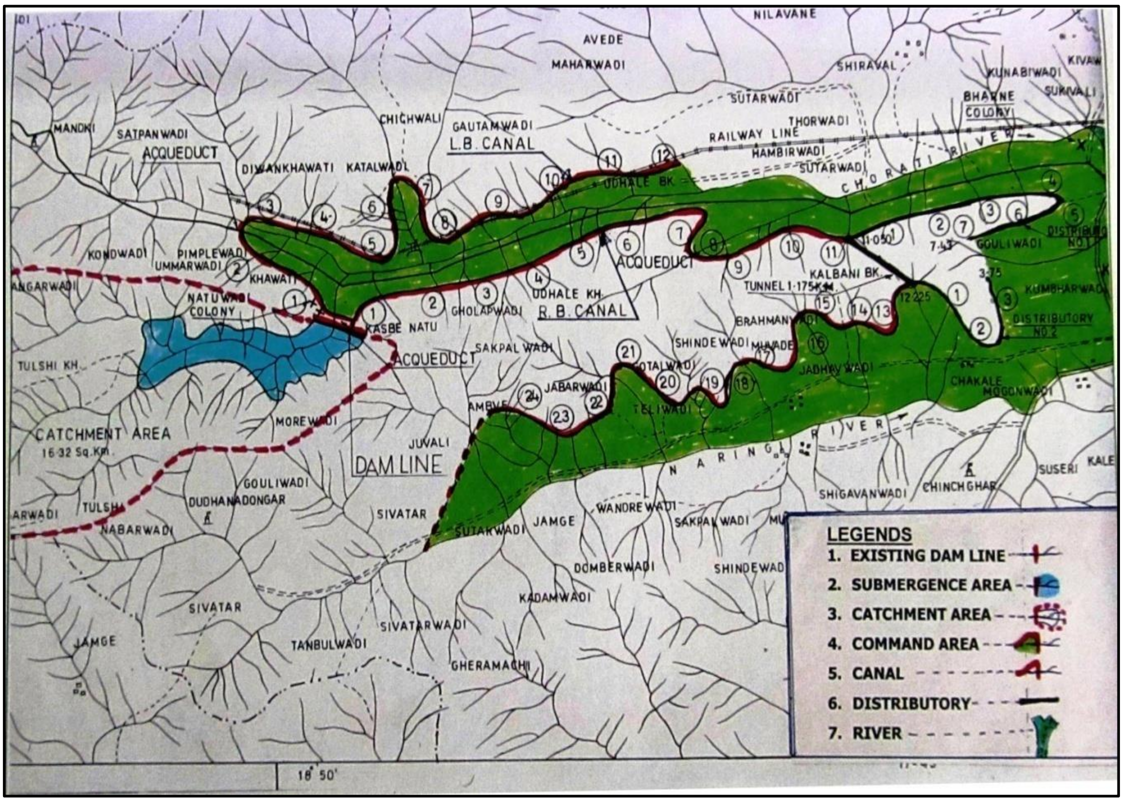

Plate No. 2 Command area map of Natuwadi medium irrigation project, Khed

3.2 Command Information

3.2.1 Irrigation information

The information of Natuwadi irrigation project was collected from Irrigation Department, Dam site, Sub Divisional Office Natunagar, Khed, Dist- Ratnagiri. The data like yearly inflow, rainfall, evaporation, canal system, canal releases, GCA, CCA, ICA, number of beneficiaries were collected.

3.2.1.1 Canal network

There are two main canals, Right Bank Canal (RBC) having length of 24 km and left bank canal (LBC) having length of 12 km. The discharge of right bank canal is 5.66 cu.m/sec and the discharge of left bank canal is 0.88 cu.m/sec. there are two distributaries of RBC namely Distributory 1 (Dy1) and Distributory 2 (Dy2). Detail of canal network is given in Table 3.2. Plate No. 5 shows the flow measurement using Parshall flume on right bank canal and Plate No. 6 shows the gated outlet on right bank canal.

Table 3.2: Details of canal networks:

Name of canal	ICA (ha)	Discharge capacity	Names of villages benefited

		(cumec)	
Right bank canal (RBC)	965	5.66	Natunagar, Borghar, Udhale (K), Kalambani (B), Murde, Ambaye, Tise
Left bank canal (LBC)	280	0.88	Khavati, Divan khavati, Chinchvali, Udhale (B)
Distributory 1 (Dy1) of RBC	400	0.7	Bharane
Distributory 2 (Dy2) of RBC	405	0.8	Bhadgaon, Chakale

3.2.1.2 River inflow data

The daily river inflow data for 25 years i.e. from year 1988 to year 2012 was collected from Irrigation Department. The average monthly inflow discharges were obtained from daily inflow data and it's used for model development. The water year was considered from June to May, with June, July, August, September and October as wet season and November to May as dry season. The mean monthly values of river inflow for wet season are depicted in Appendix-A.

3.2.1.3 Availability of water for irrigation:

Water available for irrigation was calculated by considering different losses and the dead storage. The gross storage, net storage and dead storage of reservoir was 28.08 M cum, 27.23 M cum and 0.85 M cum, respectively. Evaporation losses of reservoir was 7.6 M cum and by measuring flow reading on parshall flume the seepage losses were found out and they were used for calculating seepage losses. Excluding all losses from the net storage, remaining water available for irrigation. Table 3.3 shows the storage and release data (ha-cm) of Natuwadi medium irrigation project.

Table 3.3 Storage and release data (ha-cm) of the Natuwadi irrigation project.

Sr.No.	Month	Storage (ha-cm)	Release (ha-cm)
1.	January	194120	49520
2.	February	150190	43930
3.	March	114020	36170
4.	April	46470	67550
5.	May	24010	22460

6.	June	88890	11370
7.	July	198000	-
8.	August	280800	-
9.	September	280800	-
10.	October	280800	-
11.	November	276460	4340
12.	December	243640	32820

(Release water (ha-cm) was including seepage losses)

Plate No. 3 General view of Natuwadi medium irrigation project, Khed

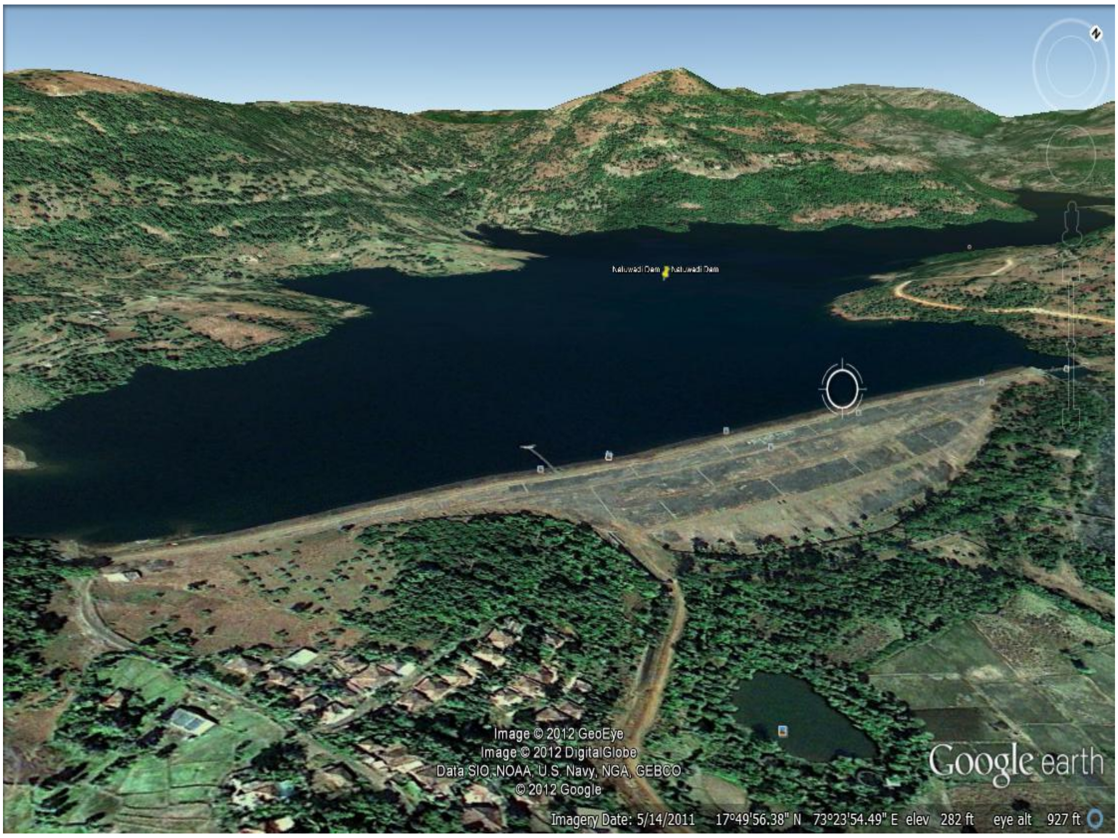

Plate No. 4 Three dimensional view of Natuwadi medium irrigation project

(**Source**: www.googleearth.com)

Plate No. 5 Flow measurement using Parshall flume on right bank canal

Plate No. 6 Gated outlets on right bank canal

3.3 Soil Information

The soils of the study area were lateritic sandy clay loam, having acidic in nature. The CEC ranges between 8.1 to 23.55 cmol kg^{-1}. The soils are medium to low in nitrogen, low in phosphorus and medium to high in potassium content. The lateritic soils are dominant in the region having field capacity of 28% and wilting point 17.4%. Table 3.4 shows the physico-chemical properties of soils of the study area.

Table 3.4 Physico-chemical properties of soils of the study area (Ayare, 2010)

Particulars			
	Mechanical analysis		

	Chemical properties		

			DTPA extractable micronutrients (ppm):

3.4 Climatic and Topographic Conditions

The climate of the area is characterized by humid sub-tropical monsoon climate with three-distinct season i.e. summer (March to May), rainy (June to October) and winter (November to February). According to agro climatic zones of Maharashtra, the Ratnagiri district comes under high rainfall zone with lateritic soil type. The study area is located in Khed tahasil of Ratnagiri district, which is near to the Wakawali meteorological observatory. On an average annual precipitation is 3600 mm, of which about 95% of the rainfall occurs during June to September. Pre-monsoon and widely distributed post monsoon showers contribute to the remaining rainfall. Mean monthly relative humidity is as lies between 31 to 95 per cent. The mean monthly minimum and maximum temperature varies between 13 ^{0}C to 36 ^{0}C, respectively. The topography is slightly undulating with small hillocks.

3.5 Meteorological Information

The latest 23 years i.e. year 1990 to year 2012, data on temperature, humidity, radiation and wind speed were collected from Meteorological Observatory, AICRP on Water Management, Wakawali, Dr. BSKKV, Dapoli. As this was the nearest meteorological observatory from the Natuwadi dam at present. Table 3.5 shows mean monthly climatic parameter.

Table 3.5: Mean monthly climatic parameter (Year 1990 to 2012)

						Evap o-ration mm/day

3.5.1 Rainfall

The daily rainfall data for last 23 years (1990-2012) was collected from the meteorological observatory of the catchment area and enclosed in Appendix-B.

3.6 Crop water requirement

The estimation of water requirement is one of the basic needs for crop planning on the farm and for planning of any irrigation project. The amount of water required to compensate the evapotranspiration loss from the cropped field is defined as water requirement.

3.6.1 Evapotranspiration (ET)

Evaporation and transpiration occurs simultaneously and there is no easy way of distinguishing between the two processes. At sowing nearly 100% of ET comes from the evaporation from soil while at full crop cover more than 90% of ET comes from transpiration.

3.6.2 Reference crop Evapotranspiration (ET_0)

The evaporation rate from the reference surface, not short of water, is called the reference crop evapotranspiration (ET_0) and computed from meteorological data.

3.6.3 Crop evapotranspiration under standard conditions (ET_c)

It is the evapotranspiration from the disease free, well fertilized crops, grown in large fields, under optimum soil conditions and achieving full protection under given climatic conditions. It can be calculated from climatic data and by integrating directly the crop resistance, albedo and air resistance factors in the Penman-Monteith approach.

3.6.4 Reference Surface

The FAO Expert Consultation on Revision of FAO Methodologies for crop Water Requirements accepted the following unambiguous definition for the reference surface (Smith, 1991). "A hypothetical reference crop with an assumed crop height of 0.12m, a fixed canopy resistance of 70 sm^{-1} and an albedo of 0.23".

3.6.5 FAO Penman-Monteith equation

A consultation of experts and researchers was organized by FAO in May 1990, in collaboration with the International Commission for Irrigation and Drainage and with the World Metrological Organization, to review the FAO methodologies on crop water requirements and to advise the revision and updating of procedures.

The panel of experts recommended the adoption of the Penman-Monteith combination method as a new standard for reference evapotranspiration and advised on procedures for calculation of the various parameters. By defining the reference crop, as described earlier, the FAO Penman-Monteith method was developed. The method overcomes shortcomings of the previous FAO Penman method and provides values more consistent with actual crop water use data worldwide.

From the original Penman equation, aerodynamic equation and surface resistance equation, the FAO Penman-Monteith method to estimate ET_0 was derived which is

$$ETo = \frac{0.408 * \Delta * (R_n - G) + \gamma * \left(\frac{900}{T + 273}\right) * U_2 * (e_s - e_a)}{\Delta + \gamma * (1 + 0.34 * U_2)} \quad \text{.....(3.1)}$$

Where,

ETo = reference evapotranspiration (mm/day),

λ = latent heat of vaporization (KJ/Kg),

Δ = slope of saturation vapour pressure temperature curve ($kPa/^0C$),

γ = psychometric constant ($kPa/^0C$),

T = mean air temperature (^0C),

e_s = saturated vapour pressure (kPa),

e_a = actual vapour pressure (kPa),

R_n = net radiation ($MJ/m^2/day$),

G = soil heat flux density (KJ/m^2s),

U_2 = wind speed at 2m height (m/s),

(e_s-e_a) = saturated vapour pressure deficit (kPa).

3.6.6 Selection of crop coefficients

Change in vegetation and ground cover mean that, the crop coefficient (Kc) varies during the growing period. To account for effect of crop characteristics on crop water requirement, crop coefficients (Kc) were adopted from FAO-56 (Allen *et.al*. 1998).

The Kc value relate to evapotranspiration of a disease free crop grown in large fields under optimum soil water and fertility conditions and achieving full production potential under the given growing environment.

ET_{crop} was estimated by:

ET_{crop} = Kc.ETo .....(3.2)

Factors affecting the value of the crop coefficient (Kc) are mainly the crop characteristics, crop planting and sowing date, rate of crop development, length of growing season and climatic conditions. Particularly following sowing and during the early growth the frequency of rain or irrigation is important. The crop planning and sowing date will affect the length of growing season, the rate of crop development to full ground cover and onset of maturity. For selecting the appropriate Kc value for each period and month in the growing season for given crop, the rate of crop development was considered. General climatic conditions, especially wind and humidity, were considered. The crop-growing season was divided into four stages as suggested in FAO-56 (Allen *et.al.*1998).

1. Initial stages: Germination and early growth when the soil surface is not or is hardly covered by the crop (ground cover <10%)

2. Crop development: From end of initial stage to attainment of effective full ground cover (ground cover = 70-80%)
3. Mid – season stage: From attainment of effective full ground cover to time of start of maturity as indicated by discoloring of leaves (beans) or leaves falling off (cotton). For some crops this may extend to near harvest (sugar beets) unless irrigation is not applied. At late season and reduction in ET crop is induced to increase yield and or quality (sugarcane, cotton, some things).
4. Late season stage: From the end of mid- season stage until full maturity of harvest.

FAO Irrigation and Drainage paper No. 24 provides a general length for four distinct growth stages and total period for various type of climates and locations. The Kc value for three stages viz. Kc initial, Kc mid and Kc end were selected from FAO 56 (Allen *et al.* 1998). Length of growing season, sowing date and crop development stage of common *rabi* crops in the command area are presented in Table No. 3.6 and for *rabi* / annual season crops, crop coefficient values are presented in Table 3.7. Plate No. 7 shows the field visit and collection of information from farmers. Rice transplanting and wal crop in command area is shown in Plate No. 8 and Plate No. 9, respectively.

Table 3.6: Length of growing season, sowing date and crop development stage of common *rabi* / annual crops in the command area

r. No.			Length of Stages

.	*Rabi* rice						
.	Groundnut						
.							

.	Ghewada						
.							
.							
.	Green Chilli						

.							
.	Sugarcane						
0.	Cucumber						
1.	Watermelon						
2.	Fodder maize						

(**Source**: FAO 56 Allen *et al*.1998 and Irrigation Department, Khed)

Table 3.7: Crop Coefficients for *Rabi* / annual Crops

		Growth stages		

(Source: FAO 56,Allen *et al*.1998)

Plate No. 7 Field visit and collection of information from farmers

Plate No. 8 Rice transplanting in command area

Plate No. 9 Wal crop in command area

3.7 Agricultural Information

The agricultural information like *rabi* crops, sowing date, growth stages, growth periods, were used as prescribed in FAO 56 and irrigation department, Khed. Agricultural inputs, yields, labour requirements etc. were collected from Department of Agriculture Economics, and profit per animal were collected from Department of Animal Husbandry, Dr. BSKKV, Dapoli.

3.7.1 Existing cropping pattern:

The rainfall in the command area is too high hence limited crops are grown in *kharif*. At present crops are mainly rice, finger millet, vari, tur etc. in *kharif* and rice, groundnut, wal, ghewada, brinjal, green chilli, pavata, fodder maize etc. in *rabi*. The mango, cashew nut, coconut and areca nut horticultural crop are also grown in this area. There are two cropping season in the area viz; *kharif* season (Monsoon season: June to October) and *rabi* season (Irrigation season: November to March). The canal wise irrigated cropped area is shown in Table 3.8

Table 3.8: Existing cropping pattern of Natuwadi command area

Canal	Existing area under various crop (ha)						Total Area (ha)
	Rice	Groundnut	Wal	Vegetable	Banana	Fodder maize	
RBC	126	56	28	13	12	17	252
LBC	44	21	6	5	0	8	84
DY1	0	25	10	6	0	5	46
DY2	0	37	17	9	5	11	79
Total	**170**	**139**	**61**	**33**	**17**	**41**	**461**

(**Source**: Irrigation Department, Khed)

3.8 Cost of Cultivation of Crops:

Cost of cultivation of crop i.e. *rabi* rice, ground nut, wal, ghewada, tomato, brinjal, green chilli, banana, sugarcane, cucumber, water melon and fodder maize were estimated. The following parameters were considered in the cost of cultivation.

3.8.1 Cost A:

3.8.1.1 Hired human labour: Hired human labour cost was estimated at their actual wages paid in cash. The wages paid in kind were calculated at prevailing price in the market on an average basis.

3.8.1.2 Bullock labour: Hired and owned bullock labour cost was estimated at the actual rate period for hiring of bullock labour in local market from time to time.

3.8.1.3 Machinery charges: Machineries are required for ploughing, sowing, harvesting, threshing, transporting of seed, fertilizers etc, Machinery charges were taken into consideration on the basis of actual expenditure incurred by the growers.

3.8.1.4 Seed: The actual cost paid for purchasing of seed from the market was taken into account for its evaluation.

3.8.1.5 Manures: The cost of farm yard manure produced on the farm was estimated at the prevailing rates in the locality. In case of purchased farm yard manure the actual price paid was taken into account.

3.8.1.6 Fertilizers: The actual price paid for the fertilizers was taken into account.

3.8.1.7 Plant Protection: Actual cost for purchase of insecticides and pesticides was taken into account.

3.8.2 Cost B:

3.8.2.1 Interest on working capital: The interest on working capital was worked out @ 6 per cent per six month for the entire life period of crop as per prevailing rate of interest.

3.8.2.2 Land Revenue: It includes actual land revenue paid by the farmers.

3.8.2.3 Depreciation: Include depreciation on implements and farm buildings.

3.8.2.4 Imputed value of family labour: Wages for the work done by the family labour should be imputed on the basis of average wages rate of permanent labour. However in view of the difficulties in calculating average wage rate of permanent farm labour, the family labour was imputed on the basis of wage rate of casual labour prevailing in the locality for various farm operations.

3.8.3 Gross return: It comprises of value of main product and byproducts.

3.8.4 Net return: Net return was computed by deducting respective costs viz. Cost A and Cost B from the gross return.

All the relevant data like prices of input and output of agricultural products were collected from beneficiaries of command area as well as Agricultural Prices Scheme, Department of Agriculture Economics of Dr. BSKKV, Dapoli.

3.9 Canal Water Rates: The water charges prevailing in the command varies with the crops. The crop wise water rates are given in Table 3.9

Table 3.9: Water rates for different crops

Sr.No.	Crop	Water rate Rs /ha
1	*Rabi* rice	840/-
2	Groundnut	1225/-
3	Pulses	525/-
4	Vegetable	2100/-
5	Horticultural crop	2755/-

(**Source:** Irrigation Department, Khed)

3.10 Population of Natuwadi Command Area

Total population of Natuwadi irrigation command area is 22,554. It includes two canal and two distributory i.e. Right bank canal, left bank canal, distributory 1 (Dy1) of RBC and distributory 2 (Dy2) of RBC having population 10063, 4977, 3531, 3983 respectively. Population data were collected from Extension Department, Panchayat Samiti Khed, Tahsil Khed of Ratnagiri district. The details of population and nutrition requirement are given in Table 3.10 and Table 3.11, respectively.

Table 3.10: Number of Populations including Children in command area

Sr.	Canal	Populations	Grant Total

No.		Male	Female	
1	Right bank canal	4694	5369	10063
2	Left bank canal	2331	2646	4977
3	Distributory 1 (DY1)	1772	1759	3531
4	Distributory 2 (DY2)	1963	2020	3983
	Total	**10760**	**11794**	**22554**

(**Source**: Extension Department, Panchayat Samiti ,Khed)

Table 3.11 Nutritional requirement for adult persons:

Sr. No.	Food item	Population		Average (gm)
		Male (gm)	Female (gm)	
1.	Cereals	360	300	330
2.	Pulses	60	60	60
3.	Vegetables	350	250	300
4.	Oil	40	30	35
5.	Milk	250	250	250

(**Source**: National Institute of Nutrition, Hyderabad)

3.11 Theoretical Consideration:

3.11.1 Formulation of general linear programming model

Linear Programming deals with that class of programming problems for which the constraints as well as the function to be optimized are linear relations among the variables. When the resources are scarce, there is a need for allocation of limited resources to priorities the activities. Linear Programming is a technique of allocation of scarce resources for completing activities under the assumption of linearity. This technique is used either to maximize or minimize a given objective functions. The general linear programming problem can be stated in the following form:

1. In scalar form

Maximize (or minimize):

$Z = C_1 X_1 + C_2 X_2 + \ldots\ldots\ldots\ldots + C_n X_n.$ ….(3.3)

Subject to constraints

$a_{11} X_1 + a_{12} X_2 + \ldots\ldots\ldots\ldots + a_{1n} X_n (\leq, = \text{ or } \geq) b_1$

$a_{21} X_1 + a_{22} X_2 + \ldots\ldots\ldots\ldots + a_{2n} X_n (\leq, = \text{ or } \geq) b_2$

….. ……… ………

$a_{m1} X_1 + a_{m2} X_2 + \ldots\ldots\ldots. + a_{mn} X_n$ (≤, = or ≥) b_m and ….(3.4)

$X_1 \geq 0, X_2 \geq 0, \ldots\ldots, X_n \geq 0$ ….(3.5)

2. The linear programming model in scalar form may also be stated in compact form by using summation sign as:

Maximize (or minimize) $Z = \sum_{j=1}^{n} C_j X_j$ ....(3.6)

Subject to the constraints:

$\sum_{j=1}^{n} a_{ij} X_j$ (≤, = or ≥) b_i i = 1, 2, …………..,m ….(3.7)

and $X_j \geq 0$, j = 1, 2,…………...,n .... (3.8)

Where,

C_j = cost coefficient of X_j

X_j = decision variable

a_{ij} = Coefficient for i^{th} resource and j^{th} variable

b_i = Total available resource

3. In a more convenient matrix notation, a typical LP problem can be written as

Maximize (or minimize) $Z = C^T x$ …. (3.9)

Subject to constraints Ax = B …. (3.10)

and x ≥ 0 ..... (3.11)

$$x = \begin{vmatrix} x1 \\ x2 \\ . \\ . \end{vmatrix} \quad B = \begin{vmatrix} B1 \\ B2 \\ . \\ . \end{vmatrix} \quad C = \begin{vmatrix} C1 \\ C2 \\ . \\ . \end{vmatrix}$$ …. (3.12)

Where,

$$A = \begin{vmatrix} a_{11} & a_{12} & a_{13} & --- & --- & a_{1n} \\ a_{21} & a_{22} & a_{23} & --- & --- & a_{2n} \\ --- & --- & --- & --- & --- & --- \\ --- & --- & --- & --- & --- & --- \\ a_{m1} & a_{m2} & a_{m3} & --- & --- & a_{mn} \end{vmatrix}_{mxn}$$ .... (3.13)

All the notations are same and the superscript ‘T’ is used to indicate the transpose. C is the vector of known constants. x is a vector of decision variables. The problem is to find a set of X, the decision variables, that maximize the objective function Z (equation 3.9) and satisfies the equations 3.4 and 3.5. We used scalar form of linear programming model, because of its more convenient and easy for calculation on personal computer with appropriate optimization package.

3.11.2 Assumptions

The following assumptions were considered in developing the model.

1. The relationship between the variables in the objective function and the constraints are linear.
2. All parts of the land under consideration have same management practices.
3. All inputs other than water, viz. seeds, fertilizers, weedicides, labours and pesticides of desired quality are available in adequate quantities.
4. Time and period of crop sown is same in every year.
5. Crop yield considered is constant throughout the command area.

3.11.3 Development of linear programming model

Linear programming is a versatile tool in system analysis and it finds application whenever two or more activities are competing for limited resources. Basically it is an optimizing technique with an objective function consisting of variables subject to number of constraints. It incorporates stochastic nature of variables like rainfall and inflows. A linear programming model is developed for command area of Natuwadi medium irrigation project. For the development of LP model, the subscripts used are ‘j’ represents crop and animal activity. Particulars of the subscripts are given in the Table 3.12.

Table 3.12: Subscript used in the development of the model

Sr. No.	Subscript	Crop/Animal	Sr. No.	Subscript	Crop/Animal
1	X_1	*Rabi* rice	9	X_9	Banana
2	X_2	*Kharif* rice	10	X_{10}	Sugarcane
3	X_3	Groundnut	11	X_{11}	Cucumber
4	X_4	Wal	12	X_{12}	Water melon
5	X_5	Ghewada	13	X_{13}	Fodder maize
6	X_6	Tomato	14	X_{14}	No. of bullock
7	X_7	Brinjal	15	X_{15}	No. of buffalos
8	X_8	Green chilli	16	X_{16}	No. of cows

3.11.3.1 Objective function

In order to maximize the net benefit, a mathematical model is developed for optimal allocation of land for the command area.

1. Net benefit maximization

Net benefit is to be maximized in order to consider the economic upliftment of the farming community in the project area.

$$\text{Max. } Z_N = \sum_{\substack{i=1 \\ j=1}}^{N,M} NBij.Xij$$

Where,

Z_N = total net return from all the crops, Rs

NBij = net benefit from the j^{th} crop activity in i^{th} area, Rs/ha

Xij = area under j^{th} crop at i^{th} location, ha (Decision variable)

i = 1,2,3…………m different areas and

j = 1,2,3………....n different crops.

3.11.3.2 Constraints

The following constraints were used for formulation of linear programming model.

3.11.3.2.1 Land area constraints

The area under each crop during the growing season should not exceed total area available for cultivation in the command area.

$$\sum Xij \leq A$$

Where,

A = the area available for cultivation in given season, ha

3.11.3.2.2 Water availability constraints

The water requirement of all crops in the area is fulfilled by the existing water resources in the command area.

$$\sum WijXij \leq Wt$$

Where,

Wij = Water requirement of j^{th} crop in i^{th} area, cm

Wt = total water delivered at outlet, ha-cm.

3.11.3.2.3 Food production constraint

Food available from the crops grown in the command area should fulfill the actual food and nutritional requirement of people in the command area.

$$\sum Yij\,Xij \geq Fij$$

Where,

Yij = yield of j^{th} crop in i^{th} area, quintal/ha.

Fij = total food requirement of j^{th} crop in i^{th} area, quintal

3.11.3.2.4 Affinity constraints

$$Eij \leq Xij \leq Mij$$

Where,

Eij = existing area under j^{th} crop,ha.

Mij = maximum area, which may be kept under cultivation of j^{th} crop in i^{th} area, ha

3.12 Software Used

3.12.1 LINDO 7.1

The Hyper LINDO 7.1 optimization package was used to solve the linear optimization model. The Hyper LINDO 7.1 package (Thompson, 2012) is capable of solving linear, integer and quadratic optimization models. The Hyper LINDO 7.1 uses the revised simplex method to solve the linear optimization models, using personal computer.

IV. RESULTS AND DISCUSSIONS

The main objective of the present study was to formulate appropriate linear programming model for determining optimal cropping pattern and reservoir release. The data obtained from various sources have been analyzed using techniques described in chapter 4. In this chapter, the result along with the discussion has been presented for achieving the objectives under the following heads.

4.1 Cost of Cultivation of Different Crops:

Cost estimation of *rabi* rice, groundnut, wal/pavata, ghewada, tomato, brinjal, green chilli, banana, sugarcane, cucumber, water melon and fodder maize crop were done as per procedure mentioned in chapter 4. At input cost banana crop has maximum net benefit of Rs. 448272/- per hectare followed by Rs. 282055/-, Rs. 206001/-, Rs. 166998/-, Rs. 161458/-, Rs. 156787/-, Rs. 102400/-, Rs. 77834, Rs. 51079/-, Rs. 24950/- Rs. 12857/- and Rs. 10797/- for cucumber, water melon, green chilli, tomato, brinjal, ghewada, sugarcane, fodder maize, wal, groundnut and *rabi* rice, respectively. The investment in, banana, cucumber, water melon, green chilli, tomato, brinjal, ghewada, sugarcane, fodder maize, wal, groundnut and *rabi* rice was Rs. 511728/-, Rs. 117945/-, Rs. 93999/-, Rs. 133002/-, Rs. 138542/-, Rs. 143213/-, Rs. 137600/-, Rs. 132166/-, Rs. 36421/-, Rs. 35050/-, Rs. 69143/- and Rs. 79203/-, respectively and corresponding yield or production in qt/ha was 800, 200, 300, 100, 200, 200, 100, 1000, 350, 10, 20 and 60, respectively. The minimum support prize by Govt. of India for banana, cucumber, water melon, green chilli, tomato, brinjal, ghewada, sugarcane, fodder maize, wal, groundnut and *rabi* rice was Rs. 1200/-, 2000/-, 1000/-, 3000/-, 1500/-, 1500/-, 2400/-, 170/-, 250/-, 6000/-, 3700/- and 1250/-, respectively. Detail calculations are shown in Appendix-C and detail cost of cultivation is given in Table 4.1

Table 4.1: Cost of cultivation of crop

Crop	Investment (Rs)	Yield (qt/ha)	Minimum support prize (Rs)	Net benefit (Rs)
***Rabi* rice**				
a) Main	79203/-	60	1250/-	10797/-
b) By product	-	75	200/-	
Ground nut				
a) Main	69143/-	20	3700/-	12857/-
b) By product	-	40	200/-	
Wal/Pavata	35050/-	10	6000/-	24950/-
Ghewada	137600/-	100	2400/-	102400/-
Tomato	138542/-	200	1500/-	161458/-
Brinjal	143213/-	200	1500/-	156787/-
Green chilli	133002/-	100	3000/-	166998/-
Banana	511728/-	800	1200/-	448272/-
Sugarcane				
a) Main	132166/-	1000	170/-	77834/-
b) By product	-	200	200/-	
Cucumber	117945/-	200	2000/-	282055/-
Water Melon	93999/-	300	1000/-	206001/-
Fodder maize	36421/-	350	250/-	51079/-

(**Source**: Agricultural Prices Scheme, Department of Agriculture Economics, Dr.BSKKV, Dapoli)

4.2 Irrigation Water Requirement:

The irrigation water requirement was calculated with help of the FAO Penman-Monteith method as mentioned in Chapter 3. The net irrigation requirement of *rabi* rice for December to April was 137.9 cm. The net irrigation requirement of groundnut, wal/pavata, ghewada, tomato, brinjal, green chilli, banana, sugarcane, cucumber, water melon and fodder maize crop were 37.5 cm, 17.3 cm, 41.9 cm, 64.3 cm, 55.7 cm, 43 cm, 72.2 cm, 97.5 cm, 41.8 cm, 31.1 cm and 35.2 cm, respectively, application efficiency was considered 70 per cent (Hamdy, 2007), the gross irrigation requirement of different crops are given in Table 4.2. The monthly irrigation water requirements of crops (cm) were tabulated in the form enclosed in Appendix-D. The water requirements of human as well as animals residing in the command area were fulfilled by seepage water losses (8.33 M cum.) in the canal command area which ultimately contributed to the ground water.

Table 4.2 Gross water requirement of different crops

Sr. No.	Crop	ETc (cm)	Gross water requirement (cm)
1.	*Rabi* rice	137.90	197.00
2.	Groundnut	37.50	53.57
3.	Wal	17.30	24.71
4.	Ghewada	41.90	59.85
5.	Tomato	64.30	91.85
6.	Brinjal	55.70	79.57
7.	Green chilli	43.00	61.42
8.	Banana	72.20	103.14
9.	Sugarcane	97.50	139.28
10.	Cucumber	41.80	59.71
11.	Water melon	31.10	44.42
12.	Fodder maize	35.20	50.28

4.3 Actual available water for irrigation (ha-cm):

Water available for irrigation was calculated by considering different losses, reservation of water for drinking purpose and the dead storage. Evaporation losses of reservoir was 76000 ha-cm and by measuring flow reading on parshall flume the seepage losses were found out and they were used for calculating seepage losses, the seepage losses were 42 per cent having 83299 ha-cm. Net storages at 70 per cent, 80 per cent, 90 per cent and 100 per cent levels are 190610 ha-cm, 217840 ha-cm, 245070 ha-cm and 272300 ha-cm, respectively. By excluding different losses the actual available water for irrigation in command area was estimated as 79100.7 ha-cm, 90399 ha-cm, 101699 ha-cm and 113001 ha-cm, respectively. The available water for right bank canal of 965 ha ICA at 70 per cent, 80 per cent, 90 per cent and 100 per cent availability level was estimated to be 38586 ha-cm, 44098 ha-cm, 49610 ha-cm and 55123 ha-cm, respectively having 34.14 per cent, 39.02 per cent, 43.90 per cent and 48.78 per cent of total actual available water for irrigation. Also, the water available for distributory 1 (Dy1) of RBC of 400 ha ICA at 70 per cent, 80 per cent, 90 per cent and 100 per cent level was to be 13505 ha-cm, 15434 ha-cm, 17363 ha-cm and 19293 ha-cm, respectively having 11.95 per cent, 13.66 per cent, 15.36 per cent and 17.07 per cent of actually available water for irrigation. Similarly, for distributory 2 (Dy2) of RBC of 405 ha ICA at 70 per cent, 80 per cent, 90 per cent and 100 per cent availability level was to be 15434 ha-cm, 17639 ha-cm 19844 ha-cm and 22049 ha-cm, respectively having 13.65 per cent, 15.61 per cent, 17.56 per cent and 19.51 per cent of actually available water for irrigation. Also, the water available for left bank canal of 280 ha ICA at 70 per cent, 80 per cent, 90 per cent and 100 per cent level was estimated to be 11575 ha-cm, 13228 ha-cm, 14882 ha-cm and 16536 ha-cm, respectively having 10.24 per cent, 11.70 per cent, 13.16 per cent and 14.63 per cent of actually available water for irrigation. Table No. 4.3 shows the actual available water for irrigation (ha-cm). Detail calculation of actual available water for irrigation is given in Appendix-E.

Table 4.3: Actual available water for irrigation (ha-cm)

Canal	70 per cent	80 per cent	90 per cent	100 per cent
Right bank canal (RBC)	38586	44098	49610	55123
Distributory 1 of RBC	13505	15434	17363	19293
Distributory 2 of RBC	15434	17639	19844	22049
Left bank canal (LBC)	11575	13228	14882	16536

4.4 Food Requirement:

In order to achieve self sufficiency in food production, minimum requirement of the crops were estimated as per demand of the population. Food requirement for different canal were calculated as per norms prescribed by National Institute of Nutrition, Hyderabad. The cereal requirement is fulfilled by rice crop, pulse requirement by wal/pavata crop, oil requirement by groundnut and vegetable requirement by ghewada, tomato, brinjal and green chilli crop. For right bank canal rice requirement was 12121 qt/year. While wal/pavata, groundnut, vegetable and Milk requirement was 2204 qt/year, 1286 qt/year, 11019 qt/year and 918249 lit/year, respectively. For left bank canal rice, wal/pavata, groundnut, vegetable and milk requirement was 5995 qt/year, 1089 qt/year, 636 qt/year, 5450 qt/year and 454152 lit/year, respectively. For distributory 1 (Dy1) of RBC, rice, wal/pavata, groundnut, vegetable and milk requirement was 4253 qt/year, 774 qt/year, 452 qt/year, 3867 qt/yea and 322204 lit/year, respectively. For distributory 2 (Dy2) of RBC rice, wal/pavata, groundnut, vegetable and milk requirement was 4798 qt/year, 873 qt/year, 509 qt/year, 4362 qt/year and 363449 lit/year, respectively. Total food requirement for command area in respect of different crop was estimated as rice 27167 qt/yr, wal/pavata 4940 qt/yr, groundnut 2883 qt/yr, vegetable 24698 qt/yr and milk 2058054 lit/yr. Detail food requirement of all canal networks are shows in Table 4.4 and The detail calculations are shown in Appendix-F.

Table 4.4: Estimated food requirement for the reference year 2012.

Canal	Rice (qt/yr)	Wal/Pavata (qt/yr)	Groundnut (qt/yr)	Vegetable (qt/yr)	Milk (lit/yr)
RBC	12121	2204	1286	11019	918249
Dy1 of RBC	4253	774	452	3867	322204
Dy2 of RBC	4798	873	509	4362	363449
LBC	5995	1089	636	5450	454152
Total	**27167**	**4940**	**2883**	**24698**	**2058054**

(**Source**: National Institute of Nutrition, Hyderabad)

4.5 Formulation of Linear Programming Model:

A linear programming model is most widely used tool, for optimal allocation of land to various crop activities in a command area. The linear programming model developed for the command area of Natuwadi medium irrigation project is given below.

4.5.1 Linear programming model for Right bank canal (RBC)

4.5.1.1 Objective function

The objective function for this study is to maximize the net benefit of command area and it is given as;

$$\text{Max } Z = 10797X_1 + 0X_2 + 12857X_3 + 24950X_4 + 102400X_5 + 161458X_6 + 156787X_7 + 166998X_8 + 448272X_9 + 77834X_{10} + 282055X_{11} + 206001X_{12} + 51079X_{13} + 15000X_{14} + 35000X_{15} + 23000X_{16}$$

Where, the coefficients are the profits/ha for the crops X_1 to X_{13} and for the profits per animals X_{14} to X_{16}

4.5.1.2 Constraints

The constraints to the model developed are

4.5.1.2.1 Land area constraints

The area under different crops during the *rabi* / annual season in the RBC should not exceed the total ICA.

$$X_1 + X_3 + X_4 + X_5 + X_6 + X_7 + X_8 + X_9 + X_{10} + X_{11} + X_{12} + X_{13} <= 965$$

Here the area for only *rabi* / annual season was taken

4.5.1.2.2 Water availability constraints

The seasonal gross requirement of water is considered.

$197X_1+0X_2+53X_3+24X_4+59X_5+91X_6+79X_7+61X_8+103X_9+139X_{10}+59X_{11}+44X_{12}+50X_{13} <= WA$

Where, WA = water available at 70 per cent, 80 per cent, 90 per cent and 100 per cent availability level, and the coefficients are the gross water requirement in cm.

4.5.1.2.3. Food requirement constraints

The crop should be grown on least area to meet the actual demand of population in command area of RBC.

(a) Meeting cereal requirement

$60X_1+40X_2>=12121$

The area for growing *kharif* rice was obtained by excluding the area of annual crops like banana and sugarcane from the command area of RBC. The condition of meeting the cereal requirement was checked on this *kharif* rice area.

(b) Meeting pulse requirement

$10X_4>=661.2$

Here considered only 30 per cent of pulse requirement, for fulfillment the remaining requirement pulses will be purchased from the market

(c) Meeting oil requirement

$12X_3>=1286$

Where, the coefficient is groundnut production in qts/year, here groundnut production is considered without shell

(d) Meeting vegetable requirement

$100X_5+200X_6+200X_7+100X_8>=11019$

Where, the coefficients are vegetables production in qts/year

(e) Meeting milk requirement

$2000X_{15}+1400X_{16}>= 918249$

Where, the coefficients are the milk production in lit/year

4.5.1.2.4. Non-negativity constraints

$X_1>=0$, $X_2>=0$, $X_3>=0$, $X_4>=0$, $X_5>=0$, $X_6>=0$, $X_7>=0$, $X_8>=0$, $X_9>=0$, $X_{10}>=0$, $X_{11}>=0$, $X_{12}>=0$, $X_{13}>=0$, $X_{14}>=0$, $X_{15}>=0$, $X_{16}>=0$

4.5.2 Linear programming model for Distributory 1 (DY1) of RBC

4.5.2.1 Objective function

The objective function for this study is to maximize the net benefit of command area and it is given as;

$$\text{Max } Z = 10797X_1 + 0X_2 + 12857X_3 + 24950X_4 + 102400X_5 + 161458X_6 + 156787X_7 + 166998X_8 + 448272X_9 + 77834X_{10} + 282055X_{11} + 206001X_{12} + 51079X_{13} + 15000X_{14} + 35000X_{15} + 23000X_{16}$$

Where, the coefficients are the profits/ha for the crops X_1 to X_{13} and for the profits per animals X_{14} to X_{16}

4.5.2.2 Constraints

The constraints to the model developed are

4.5.2.2.1 Land area constraints

The area under different crops during the *rabi* / annual season in the command area of Dy1 should not exceed the total CCA.

$$X_1 + X_3 + X_4 + X_5 + X_6 + X_7 + X_8 + X_9 + X_{10} + X_{11} + X_{12} + X_{13} <=400$$

Here the area for only *rabi* / annual season was taken

4.5.2.2.2 Water availability constraints

The seasonal requirement of water is considered.

$$197X_1+0X_2+53X_3+24X_4+59X_5+91X_6+79X_7+61X_8+103X_9+139X_{10}+59X_{11}+44X_{12}+50X_{13} <=WA$$

Where, WA = water available at 70 per cent, 80 per cent, 90 per cent and 100 per cent availability level, and the coefficients are the gross water requirement in cm.

4.5.2.2.3 Food requirement constraints

The crop should be grown on least area to meet the actual demand of population in command area.

(a) Meeting cereal requirement

$$60X_1+40X_2>=4253$$

The area for growing *kharif* rice was obtained by excluding the area of annual crops like banana and sugarcane from the command area of LBC. The condition of meeting the cereal requirement was checked on this *kharif* rice area.

(b) Meeting pulse requirement

$$10X_4>=232.2$$

Here considered only 30 per cent of pulse requirement, for fulfillment the remaining requirement pulses will be purchased from the market

(c) Meeting oil requirement

$$12X_3>=452$$

Where, the coefficient is groundnut production in qts/year, here groundnut production is considered without shell

(d) Meeting vegetable requirement

$100X_5+200X_6+200X_7+100X_8>=3867$

Where, the coefficients are vegetables production in qts/year

(e) Meeting milk requirement

$2000X_{15}+1400X_{16}>= 322205$

Where, the coefficients are the milk production in lit/year

4.5.2.2.4 Non-negativity constraints

$X_1>=0$, $X_2>=0$, $X_3>=0$, $X_4>=0$, $X_5>=0$, $X_6>=0$, $X_7>=0$, $X_8>=0$, $X_9>=0$, $X_{10}>=0$, $X_{11}>=0$, $X_{12}>=0$, $X_{13}>=0$, $X_{14}>=0$, $X_{15}>=0$, $X_{16}>=0$

4.5.3 Linear programming model for Distributory 2 (DY2) of RBC

4.5.3.1 Objective function

The objective function for this study is to maximize the net benefit of command area and it is given as;

$\text{Max } Z = 10797X_1 + 0X_2 + 12857X_3 + 24950X_4 + 102400X_5 + 161458X_6 + 156787X_7 + 166998X_8 + 448272X_9 + 77834X_{10} + 282055X_{11} + 206001X_{12} + 51079X_{13} + 15000X_{14} + 35000X_{15} + 23000X_{16}$

Where, the coefficients are the profits/ha for the crops X_1 to X_{13} and for the profits per animals X_{14} to X_{16}

4.5.3.2 Constraints

The constraints to the model developed are

4.5.3.2.1 Land area constraints

The area under different crops during the *rabi* / annual season in the command area of Dy2 should not exceed the total ICA.

$X_1 + X_3 + X_4 + X_5 + X_6 + X_7 + X_8 + X_9 + X_{10} + X_{11} + X_{12} + X_{13} <=405$

Here the area for only *rabi* / annual season was taken

4.5.3.2.2 Water availability constraints

The seasonal requirement of water is considered.

$197X_1+0X_2+53X_3+24X_4+59X_5+91X_6+79X_7+61X_8+103X_9+139X_{10}+59X_{11}+44X_{12}+50X_{13} <=WA$

Where, WA = water available at 70 per cent, 80 per cent, 90 per cent and 100 per cent availability level, and the coefficients are the gross water requirement in cm.

4.5.3.2.3 Food requirement constraints

The crop should be grown on least area to meet the actual demand of population in command area.

(a) Meeting cereal requirement

$60X_1+40X_2>=4798$

The area for growing *kharif* rice was obtained by excluding the area of annual crops like banana and sugarcane from the command area of Dy1. The condition of meeting the cereal requirement was checked on this *kharif* rice area.

(b) Meeting pulse requirement

$10X_4>=261.9$

Here considered only 30 per cent of pulse requirement, for fulfillment the remaining requirement pulses will be purchased from the market

(c) Meeting oil requirement

$12X_3>=509$

Where, the coefficient is groundnut production in qts/year, here groundnut production is considered without shell

(d) Meeting vegetable requirement

$100X_5+200X_6+200X_7+100X_8>=4362$

Where, the coefficients are vegetables production in qts/year

(e) Meeting milk requirement

$2000X_{15}+1400X_{16}>= 363449$

Where, the coefficients are the milk production in lit/year

4.5.3.2.4 Non-negativity constraints

$X_1>=0$, $X_2>=0$, $X_3>=0$, $X_4>=0$, $X_5>=0$, $X_6>=0$, $X_7>=0$, $X_8>=0$, $X_9>=0$, $X_{10}>=0$, $X_{11}>=0$, $X_{12}>=0$, $X_{13}>=0$, $X_{14}>=0$, $X_{15}>=0$, $X_{16}>=0$

4.5.4 Linear programming model for Left bank canal (LBC)

4.5.4.1 Objective function

The objective function for this study is to maximize the net benefit of command area and is given as;

$$\text{Max } Z = 10797X_1 + 0X_2 + 12857X_3 + 24950X_4 + 102400X_5 + 161458X_6 + 156787X_7 + 166998X_8 + 448272X_9 + 77834X_{10} + 282055X_{11} + 206001X_{12} + 51079X_{13} + 15000X_{14} + 35000X_{15} + 23000X_{16}$$

Where, the coefficients are the profits/ha for the crops X_1 to X_{13} and for the profits per animals X_{14} to X_{16}

4.5.4.2 Constraints

The constraints to the model developed are

4.5.4.2.1 Land area constraints

The area under different crops during the *rabi* /annual season in the command area of LBC should not exceed the total ICA.

$X_1 + X_3 + X_4 + X_5 + X_6 + X_7 + X_8 + X_9 + X_{10} + X_{11} + X_{12} + X_{13} <=280$

Here the area for only *rabi* / annual season was taken

4.5.4.2.2 Water availability constraints

The seasonal requirement of water is considered.

$197X_1+0X_2+53X_3+24X_4+59X_5+91X_6+79X_7+61X_8+103X_9+139X_{10}+59X_{11}+44X_{12}+50X_{13} <=WA$

Where, WA = water available at 70 per cent, 80 per cent, 90 per cent and 100 per cent availability level, and the coefficients are the gross water requirement in cm.

4.5.4.2.3 Food requirement constraints

The crop should be grown on least area to meet the actual demand of population in command area.

(a) Meeting cereal requirement

$60X_1+40X_2>=5995$

The area for growing *kharif* rice was obtained by excluding the area of annual crops like banana and sugarcane from the command area of Dy2. The condition of meeting the cereal requirement was checked on this *kharif* rice area.

(b) Meeting pulse requirement

$10X_4>=326.6$

Here considered only 30 per cent of pulse requirement, for fulfillment the remaining requirement pulses will be purchased from the market

(c) Meeting oil requirement

$12X_3>=636$

Where, the coefficient is groundnut production in qts/year, here groundnut production is considered without shell

(d) Meeting vegetable requirement

$100X_5+200X_6+200X_7+100X_8>=5450$

Where, the coefficients are vegetables production in qts/year

(e) Meeting milk requirement

$2000X_{15}+1400X_{16}>= 454152$

Where, the coefficients are the milk production in lit/year

4.5.4.2.4 Non-negativity constraints

$X_1>=0$, $X_2>=0$, $X_3>=0$, $X_4>=0$, $X_5>=0$, $X_6>=0$, $X_7>=0$, $X_8>=0$, $X_9>=0$, $X_{10}>=0$, $X_{11}>=0$, $X_{12}>=0$, $X_{13}>=0$, $X_{14}>=0$, $X_{15}>=0$, $X_{16}>=0$

4.6 Optimal area allocation and net benefit maximization

4.6.1 Right bank canal (RBC):

In case of existing cropping pattern, the total area irrigated was 252 ha, in which *rabi* rice crop covers maximum area about 126 ha, followed by groundnut, wal, fodder maize, banana, ghewada, brinjal, green chilli and tomato is 56 ha, 28 ha, 17 ha, 12 ha, 7 ha, 3 ha, 2 ha and 1 ha, respectively. After excluding the area covered by annual crop like banana and sugarcane of 118 ha and 20 ha, respectively, at 100 per cent water availability level. The minimum area remains for *kharif* rice of 827 ha, this will fulfill cereal requirement of command area people. The net return in existing conditions was Rs. 10.85 M. The proposed cropping pattern for right bank canal of 935 ha ICA is given in Table 4.5.

For net benefit maximization, at 70 per cent water availability level, it shows that fodder maize crop allotted maximum area about 155 ha which was 16.06 per cent of ICA of RBC, for fulfillment of fodder requirement of rearing milk cattle and draft animal. For meeting food requirement of people, area under *rabi* rice, groundnut, wal, tomato, ghewada, brinjal, green chilli were allocated as 35 ha, 99 ha, 66 ha, 25 ha, 20 ha, 20 ha and 18 ha, respectively, having 3.63, 10.26, 6.84, 2.59, 2.07, 2.07 and 1.87 per cent of ICA of RBC, due to seepage problem in front end of canal rice was default crop having less net benefit and need more water. Banana, sugarcane, cucumber and water melon are cash crop, in which banana crop having maximum net benefit but due to shortage of water only 30 ha area was allotted for it. Due to the more water requirement and non-availability of sugar factories in the nearby locality, sugarcane crop was fixed at 2.07 per cent of ICA and hence it allotted 20 ha area, the area under cucumber and water melon were 69 ha and 26 ha, respectively having 7.15 and 2.69 per cent of ICA. At this level 583 ha area was irrigated, which was 60.41 per cent of ICA, the income at this level was found to be Rs. 102.69 M. The generations of labor days at this level was 166886.

For 80 per cent water availability level, the area under rice, groundnut, wal, ghewada, tomato, brinjal, green chilli, banana, sugarcane and fodder maize crop were remains the same. It is seen that the increase in availability level of water the area under cucumber and water melon crop increases up to 160 ha and 30 ha, respectively having 16.58 per cent and 3.11 ha of ICA. It has more net benefit, less water requirement and short duration crop as compared to the banana and sugarcane. At this level 678 ha area was irrigated, which was 70.26 per cent of ICA, the net benefit at this level was found to be Rs. 129.02 M. The generations of labor days at this level was 204579.

For 90 per cent water availability level the area under rice, groundnut, wal, ghewada, tomato, brinjal, green chilli, sugarcane and fodder maize were remain the same. It is seen that the increase in availability level of water the area under cucumber, water melon and banana crop were increased up to 160 ha, 75 ha and 64 ha respectively having 16.58, 7.77 and 6.63 per cent of ICA. At this level 757 ha area was irrigated, which was 78.45 per cent of ICA, the net benefit at this level was Rs. 153.67 M. The generations of labor days at this level was 227240.

For 100 per cent water availability level the area under *rabi* rice, groundnut, wal, ghewada, tomato, brinjal, green chilli, sugarcane, water melon and fodder maize were remains the same, cucumber crop occupied maximum area about 160 ha, having 16.58 per cent of ICA. It is seen that the increase in availability level of water the area under banana crop increased up to 118 ha having more net benefit, which was 12.23 per cent of the ICA. At this level 811 ha area was irrigated, which was 84.04 per cent of ICA, the net benefit at this level was Rs. 175.05 M. It was much more than existing situation. The generations of labor days at this level was 245006. Figure 4.1 shows the graphical representation of allotted area at different water availability level in ha of RBC and Figure 4.2 shows the maximum net benefit at different water availability in Rs. M of RBC.

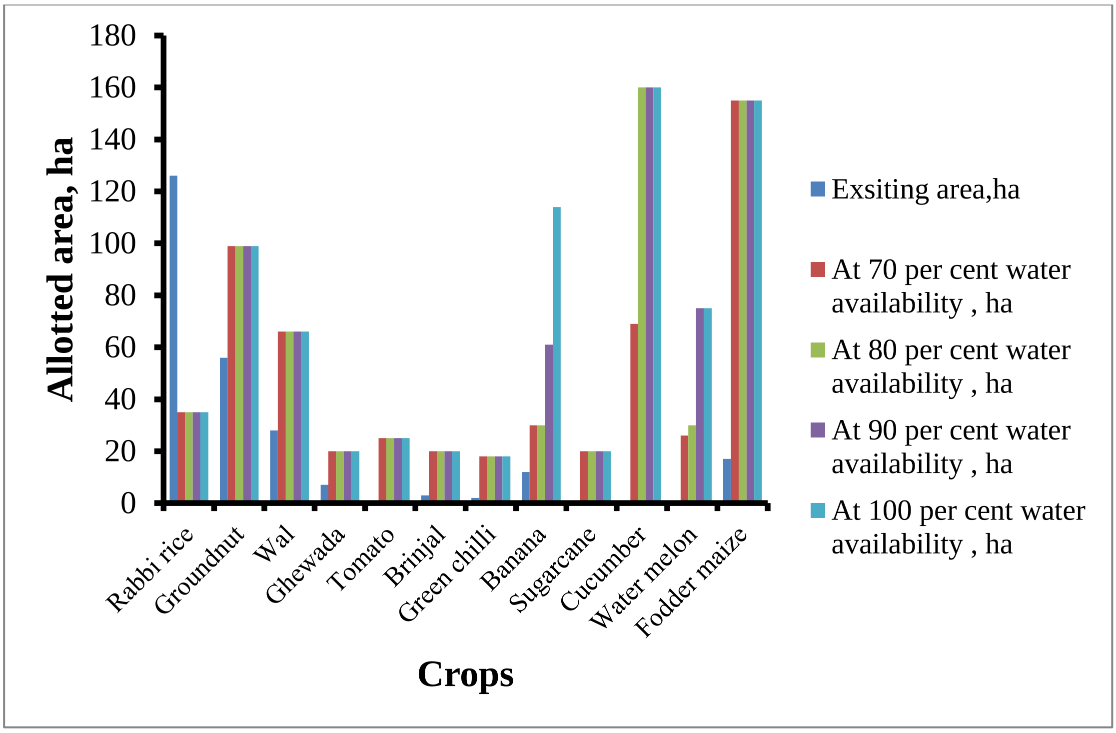

Figure 4.1 Allotted area at different water availability level in ha of RBC

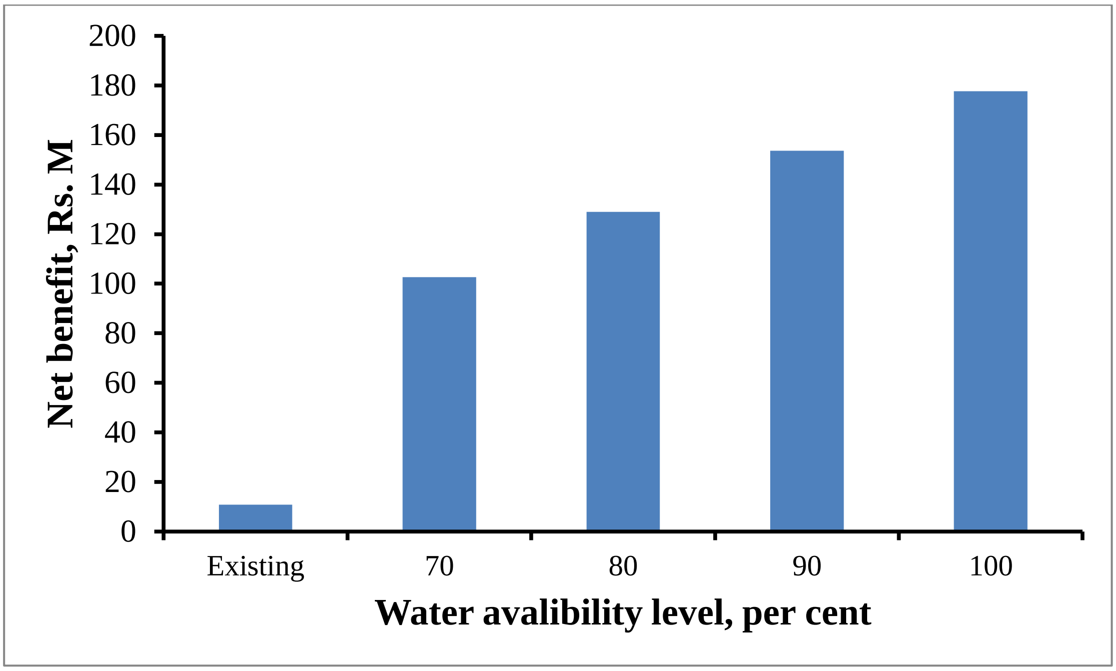

Figure 4.2 Maximum net benefit at different water availability, Rs. M of RBC

Table 4.5: Proposed cropping pattern for Right bank canal of 965 ha ICA

Sr. No.	Crop	Existing crop area, ha	Allotted area to different water availability level, ha			
			70 (*)	**80 (*)**	**90 (*)**	**100 (*)**
1.	*Rabi* rice	126.00	35	35	35	35
2	Groundnut	56.00	99	99	99	99
3	Wal	28.00	66	66	66	66
4	Ghewada	07.00	20	20	20	20
5	Tomato	01.00	25	25	25	25
6	Brinjal	03.00	20	20	20	20
7	Green chilli	02.00	18	18	18	18
8	Banana	12.00	30	30	64	114
9	Sugarcane	-	20	20	20	20
10	Cucumber	-	69	160	160	160
11	Water melon	-	26	30	75	75
12	Fodder maize	17.00	155	155	155	155
Total	**Max. area (ha)**	**252**	**583**	**678**	**757**	**811**
	Generated labor days		**166886**	**204579**	**227240**	**245006**
	Net benefit in Rs. M	**10.85**	**102.69**	**129.02**	**153.67**	**177.66**

(*): Water availability level in per cent

4.6.2 Distributory 1 (DY1) of RBC:

In case of existing cropping pattern, the total area irrigated was 45 ha, in which groundnut crop covers maximum area about 25 ha, followed by wal, fodder maize, ghewada, brinjal, tomato and green chilli is 25 ha, 10 ha, 2 ha, 2 ha, 1 ha and 1 ha, respectively. After excluding the area covered by annual crop like banana and sugarcane of 30 ha and 15 ha, respectively, at 100 per cent water availability level. The minimum area remains for *kharif* rice of 355 ha, this will fulfill cereal requirement of command area people. The net return in existing conditions was Rs. 01.69 M. The proposed cropping pattern for distributory 1 (Dy1) of 400 ha ICA is given in Table 4.6.

For net benefit maximization, at 70 per cent water availability level, it shows that fodder maize crop allotted maximum area about 72 ha, having 18 per cent of ICA for fulfillment of fodder requirement of rearing milk cattle and draft animal. For meeting food requirement of command area people, area under groundnut, wal, ghewada, brinjal, tomato and green chilli were allocated as 38, 23 ha, 9 ha, 9 ha, 8 ha and 6 ha, respectively having 9.50, 5.75, 2.25, 2.25, 2 and 1.50 per cent of ICA. Banana, sugarcane, cucumber and water melon are cash crop, in which banana crop having maximum net benefit but due to shortage of water only 25 ha area was allotted for it having 6.25 per cent of ICA. Due to the more water requirement and non-availability of sugar factories in the nearby locality, sugarcane crop was fixed at 2.50 per cent of ICA and hence it allotted 10 ha area, the area under cucumber and water melon were 11 ha and 10 ha, respectively having 2.75 and 2.50 per cent of ICA, no area allotted to the rice crop because of less net benefit and need of more water. At this level 221 ha area was irrigated, which was 55.25 per cent of ICA, the income at this level was found to be Rs. 46.58 M. The generations of labor days at this level was 61602.

For 80 per cent water availability level, the area under groundnut, wal, cucumber, water melon and fodder maize crop were remains same. It is seen that the increase in availability level of water the area under banana, sugarcane, tomato, brinjal, ghewada and green chilli crop increased up to 30 ha, 15 ha, 12 ha, 11 ha, 10 ha and 9 ha, respectively having 7.50, 3.75, 3, 2.75, 2.50 and 2.25 per cent of ICA, no area allotted to the rice crop. At this level 240 ha area was irrigated, which was 60 per cent of ICA, the net benefit at this level was found to be Rs. 51.39 M. The generations of labor days at this level was 70405.

For 90 per cent water availability level the area under groundnut, wal, banana and sugarcane were remains the same, because of banana and sugarcane are the annual crop and having high water requirement. When the increase in availability level of water the area under fodder maize, water melon, tomato, brinjal, ghewada, cucumber and green chilli crop were increased up to 89 ha, 15 ha, 15 ha, 15 ha, 12 ha, 12 ha and 10 ha, respectively having 22.25, 3.75, 3.75, 3.75, 3, 3 and 2.50 per cent of ICA, having less water requirement and short duration crop as compare to the banana and sugarcane crop, no area was allotted to the rice crop. At this level 274 ha area was irrigated, which was 68.50 per cent of ICA, the net benefit at this level was Rs. 61.09 M. The generations of labor days at this level was 80694.

For 100 per cent water availability level the area under groundnut, wal, ghewada, tomato, brinjal, green chilli, banana, sugarcane and water melon were remains the same. It is seen that the increase in availability level of water the fodder maize crop allotted maximum area about 97 ha, having 24.25 per cent of ICA, area under cucumber crop increased up to 38 ha having more net benefit, which was 4.25 per cent of the ICA, no area was allotted to the rice crop. At this level 308 ha area was irrigated, which was 77 per cent of ICA, the net benefit at this level was Rs. 71.55 M. It was much more than existing situation. The generations of labor days at this level was 92652. Figure 4.3 shows the graphical representation of allotted area at different water availability level in ha of Dy1 and Figure 4.4 shows the maximum net benefit at different water availability in Rs. M of Dy1.

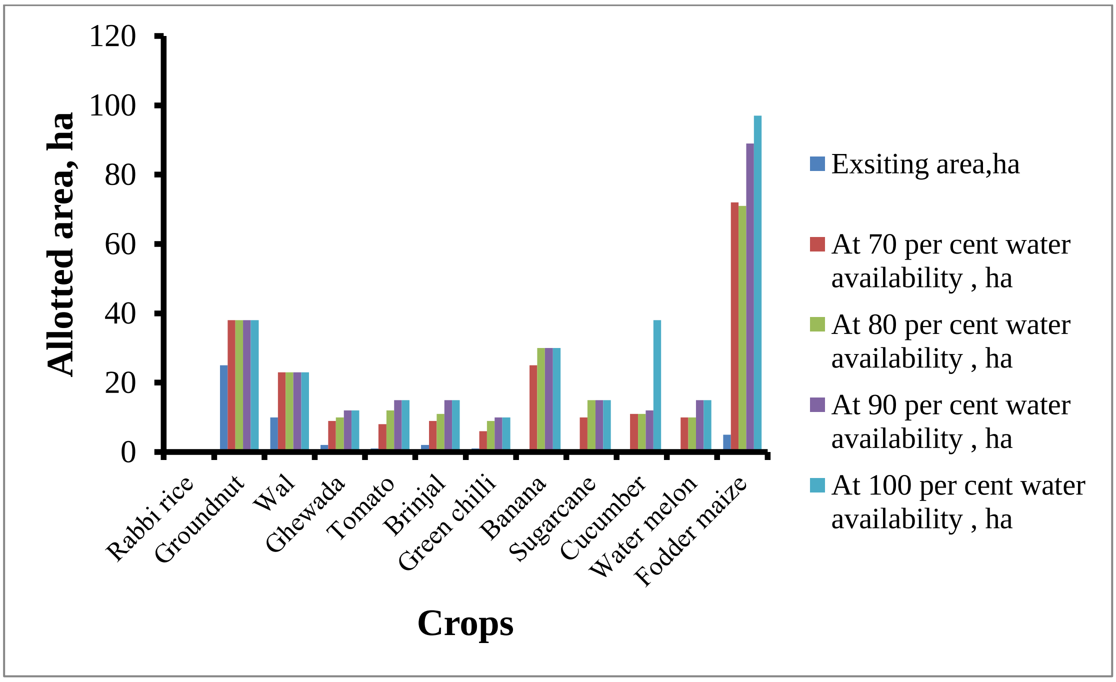

Figure 4.3 Allotted areas at different water availability level in ha of Dy1 of RBC

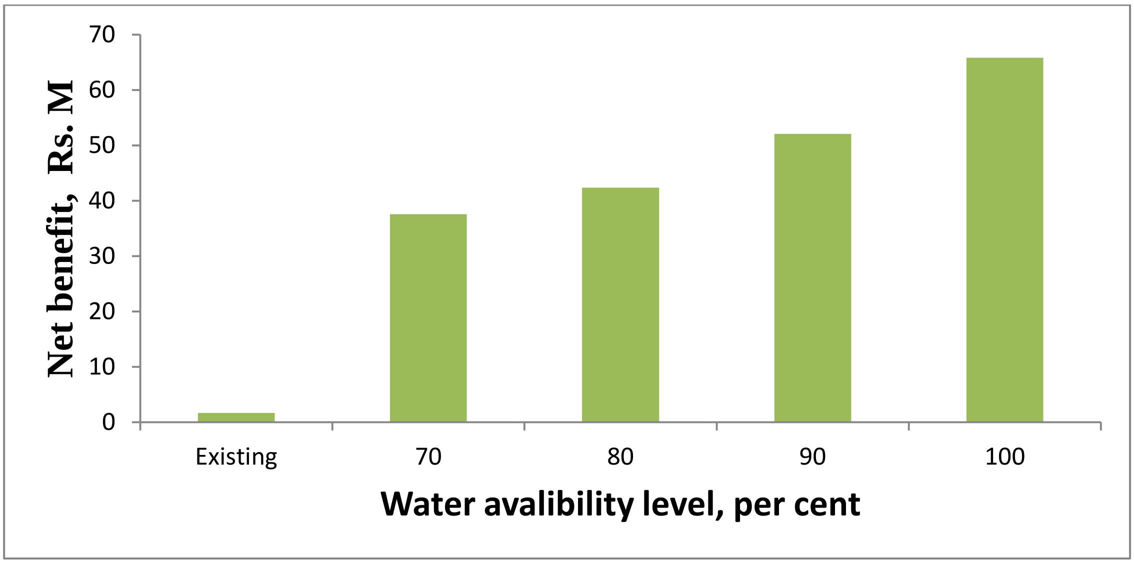

Figure 4.4 Maximum net benefits at different water availability, Rs. M of Dy1

Table 4.6: proposed cropping pattern for distributory 1 (Dy1) of 400 ha ICA

Sr. No.	Crop	Existing crop area, ha	Allotted area to different water availability level, ha			
			70 (*)	**80 (*)**	**90 (*)**	**100 (*)**
1.	*Rabi* rice	00	00	00	00	00
2	Groundnut	25	38	38	38	38
3	Wal	10	23	23	23	23
4	Ghewada	02	09	10	12	12
5	Tomato	01	08	12	15	15
6	Brinjal	02	09	11	15	15
7	Green chilli	01	06	09	10	10
8	Banana	-	25	30	30	30
9	Sugarcane	-	10	15	15	15
10	Cucumber	-	11	11	12	38
11	Water melon	-	10	10	15	15
12	Fodder maize	05	72	71	89	97
Total	**Max. area (ha)**	**45**	**221**	**240**	**274**	**308**
	Generated labor days		**61602**	**70405**	**80694**	**92652**
	Net benefit in Rs. M	**01.69**	**37.53**	**42.36**	**52.04**	**65.79**

(*): Water availability level in per cent

4.6.3 Distributory 2 (DY2) of RBC:

In case of existing cropping pattern, the total area irrigated was 79 ha, in which groundnut crop covers maximum area about 37 ha, followed by wal, fodder maize, banana, ghewada, brinjal, tomato and green chilli is 17 ha, 11 ha, 5 ha, 4 ha, 3 ha, 1 ha and 1 ha, respectively. After excluding the area covered by annual crop like banana and sugarcane of 35 ha and 15 ha, respectively, at 100 per cent water availability level. The minimum area remains for *kharif* rice of 355 ha, this will fulfill cereal requirement of command area people.The net return in existing conditions was Rs. 4.94 M. The proposed cropping pattern for distributory 2 (Dy2) of 405 ha CCA is given in Table 4.7.

For net benefit maximization, at 70 per cent water availability level, it shows that fodder maize crop allotted maximum area about 87 ha which was 21.48 per cent of ICA, for fulfillment of fodder requirement of rearing milk cattle and draft animal. For meeting food requirement of command area people, area under groundnut, wal, tomato, ghewada, brinjal, green chilli were allocated as 43 ha, 26 ha, 14 ha, 11 ha, 10 ha and 9 ha, respectively having 10.62, 6.42, 3.46, 2.72, 2.47 and 2.22 per cent of ICA. Banana, sugarcane, cucumber and water melon are cash crop, in which banana crop having maximum net benefit but due to shortage of water only 24 ha area was allotted for it, having 5.93 per cent of ICA. Due to the more water requirement and non-availability of sugar factories in the nearby locality, sugarcane crop was fixed at 2.47 per cent of ICA and hence it occupies 10 ha area, the area under cucumber and water melon were 11 ha and 10 ha, respectively having 2.72 and 2.47 per cent of ICA, no area allotted to the rice crop because of less net benefit and need of more water. At this level 255 ha area was irrigated, which was 62.96 per cent of ICA, the income at this level was found to be Rs. 47.37 M. The generations of labor days at this level was 71928.

For 80 per cent water availability level, the area under groundnut, wal and water melon crop were remains the same. It is seen that the increase in availability level of water the area under banana, tomato, sugarcane, brinjal, cucumber, ghewada, water melon and green chilli crop increased up to 35 ha, 16 ha, 15 ha, 14 ha, 12 ha, 12 ha, 10 ha and 10 ha, respectively having 8.64, 3.95, 3.70, 3.46, 2.96, 2.96, 2.47 and 2.47 per cent of ICA, area under fodder maize crop was decease up to the 81 ha having 20 per cent of ICA, no area allotted to the rice crop because of less net benefit and need of more water. At this level 274 ha area was irrigated, which was 67.65 per cent of ICA, the net benefit at this level was found to be Rs. 59.14 M. The generations of labor days at this level was 81131.

For 90 per cent water availability level the area under groundnut, wal, tomato, banana, sugarcane, brinjal, ghewada, green chilli and watermelon were remains the same. When the increase in availability level of water the area under fodder maize and cucumber crop were increased up to 87 ha and 45 ha, respectively having 21.48 and 11.11 per cent of ICA, no area was allotted to the rice crop. At this level 313 ha area was irrigated, which was 75.56 per cent of ICA, the net benefit at this level was Rs. 70.45 M. The generations of labor days at this level was 95540.

For 100 per cent water availability level the area under groundnut, wal, ghewada, tomato, brinjal, green chilli, banana, sugarcane and fodder maize were remains the same. It is seen that the increase in availability level of water the cucumber and water melon crop increased up to 65 ha and 34 ha area, respectively having 16.05 and 8.40 per cent of ICA, these both crops having less water requirement and short duration crops as compared to the banana and sugarcane. No area was allotted to the rice crop. At this level 357 ha area was irrigated, which was 88.15 per cent of ICA, the net benefit at this level was found Rs. 80.89 M. It was much more than existing situation.

The generations of labor days at this level was 109720. Figure 4.5 shows the graphical representation of allotted area at different water availability level in ha of Dy2 and Figure 4.6 shows the maximum net benefit at different water availability in Rs. M of Dy2.

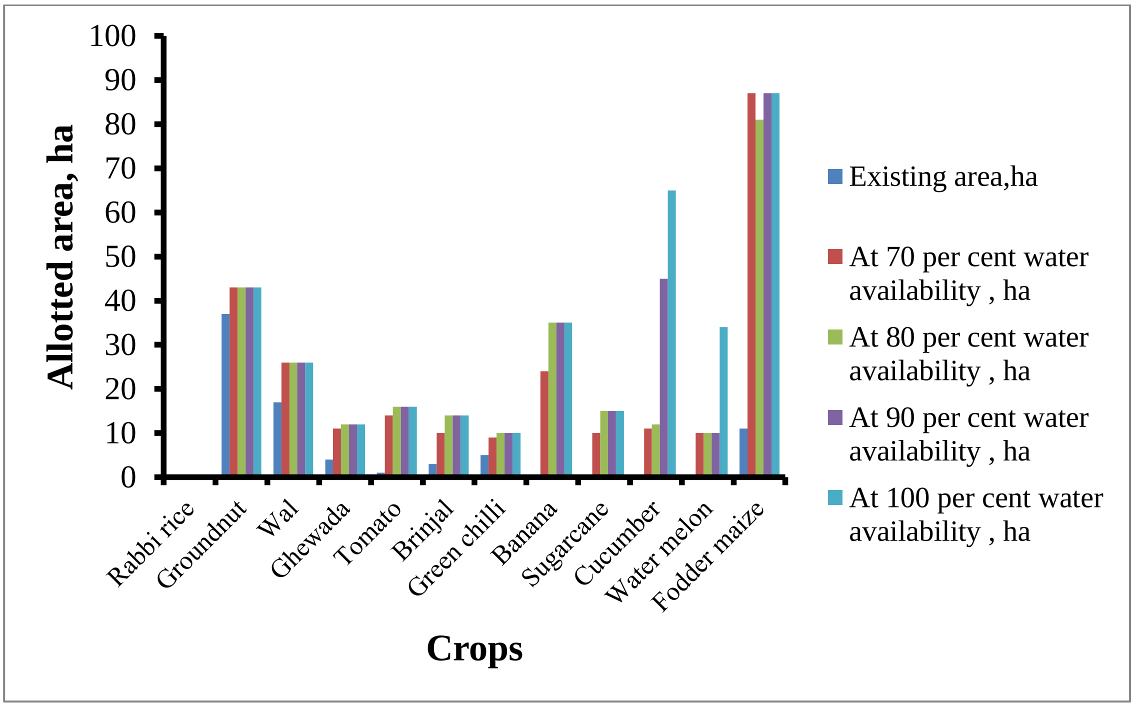

Figure 4.5 Allotted areas at different water availability level, ha of Dy2 of RBC

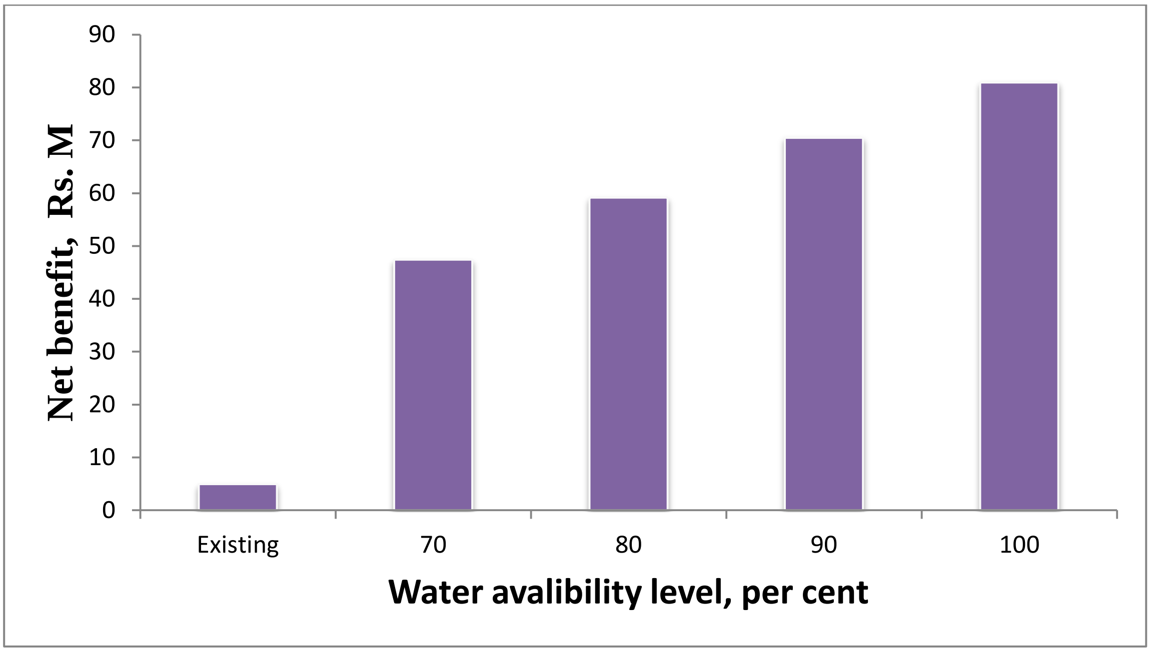

Figure 4.6 Maximum net benefits at different water availability, Rs. M of Dy2

Table 4.7: proposed cropping pattern for distributory 2 (Dy2) of 405 ha ICA

Sr. No.	**Crop**	**Existing crop area, ha**	**Allotted area to different water availability level, ha**			
			70 (*)	**80 (*)**	**90 (*)**	**100 (*)**
1.	*Rabi* rice	00	00	00	00	00
2	Groundnut	37	43	43	43	43
3	Wal	17	26	26	26	26
4	Ghewada	04	11	12	12	12
5	Tomato	01	14	16	16	16
6	Brinjal	03	10	14	14	14
7	Green chilli	05	09	10	10	10
8	Banana	-	24	35	35	35
9	Sugarcane	-	10	15	15	15
10	Cucumber	-	11	12	45	65
11	Water melon	-	10	10	10	34
12	Fodder maize	11	87	81	87	87
Total	**Max. area (ha)**	**79**	**255**	**274**	**313**	**357**
	Generated labor days		**71928**	**81131**	**95540**	**109720**
	Net benefit in Rs. M	**04.94**	**47.37**	**59.14**	**70.45**	**80.89**

(*): Water availability level in per cent

4.6.4 Left bank canal (LBC):

In case of existing cropping pattern, the total area irrigated was 84 ha, in which *rabi* rice crop covers maximum area about 44 ha, followed by groundnut, fodder maize, wal, ghewada and brinjal was 21 ha, 8 ha, 6 ha, 2 ha, 2 ha and 1 ha, respectively. After excluding the area covered by annual crop like banana and sugarcane of 15 ha and 7 ha, respectively, at 100 per cent water availability level. The minimum area remains for *kharif* rice of 827 ha, this will fulfill cereal requirement of command area people. The net return in existing conditions was Rs. 2.08 M. The proposed cropping pattern for left bank canal of 280 ha ICA is given in Table 4.8.

For net benefit maximization, at 70 per cent water availability level, it shows that fodder maize and groundnut crop allotted maximum area about 62 ha and 53 ha, respectively having 22.14 and 18.93 per cent of ICA, for fulfillment of fodder requirement of rearing milk cattle and draft animal and meeting oil requirement of command area people, respectively. For meeting other food requirement of people area under wal, tomato, *rabi* rice, brinjal, green chilli and ghewada were allocated as

33 ha, 12 ha, 10 ha, 10 ha, 5 ha and 5 ha, respectively, having 11.79, 4.29, 3.57, 3.57, 1.79 and 1.79 per cent of ICA, due to seepage problem in front end of canal rice was default crop having less net benefit and need more water. Banana, sugarcane, cucumber and water melon are cash crop, the area under cucumber and water melon were 5 ha and 4 ha, respectively having 1.79 and 1.43 per cent of ICA. Due to shortage of water at this level no area was allotted for banana and sugarcane crop. At this level 199 ha area was irrigated, which was 71.07 per cent of ICA, the net benefit at this level was found to be Rs. 23.64 M. The generations of labor days at this level was 50908.

For 80 per cent water availability level, the area under rice, groundnut, wal, ghewada and green chilli crop remains the same. It is seen that the increase in availability level of water the area under fodder maize, brinjal, banana, cucumber and water melon crop increased up to 69 ha, 14 ha, 10 ha, 8 ha, and 7 ha having 24.64, 5, 3.57, 2.86, and 2.5 per cent of ICA. The area under tomato crop was decreased up to 8 ha having 2.86 per cent of ICA, due to shortage of water and for getting feasible solution no area was allotted to the sugarcane crop. At this level 222 ha area was irrigated, which was 79.29 per cent of ICA, the net benefit at this level was found to be Rs. 35.96 M. The generations of labor days at this level was 57535.

For 90 per cent water availability level the area under rice, groundnut, wal, ghewada, green chilli remain the same. It is seen that the increase in availability level of water the area under fodder maize, brinjal, banana, cucumber, water melon and sugarcane crop were increased up to 71 ha, 16 ha, 15 ha, 9 ha, 8 ha and 7 ha respectively having 25.36, 5.71, 5.36, 3.21 and 2.50 per cent of ICA. The area under tomato crop was decreased up to 6 ha having 2.14 per cent of ICA. At this level 238 ha area was irrigated, which was 85 per cent of ICA, the net benefit at this level was found to be Rs. 41.27 M. The generations of labor days at this level was 63140.

For 100 per cent water availability level the area under rice, groundnut, wal, ghewada, brinjal, green chilli, tomato, banana, sugarcane and water melon remain the same. It is seen that the increase in availability level of water the area under fodder maize and cucumber crop increased up to 76 ha and 33 ha, respectively having 27.14 and 11.79 per cent of the ICA. At this level 267 ha area was irrigated, which was 95.36 per cent of ICA, the net benefit at this level was found to be Rs. 44.41 M. It was much more than existing situation. The generations of labor days at this level was 73737. Figure 4.7 shows the graphical representation of allotted area at different water availability level in ha of LBC and Figure 4.8 shows the maximum net benefit at different water availability in Rs. M of LBC.

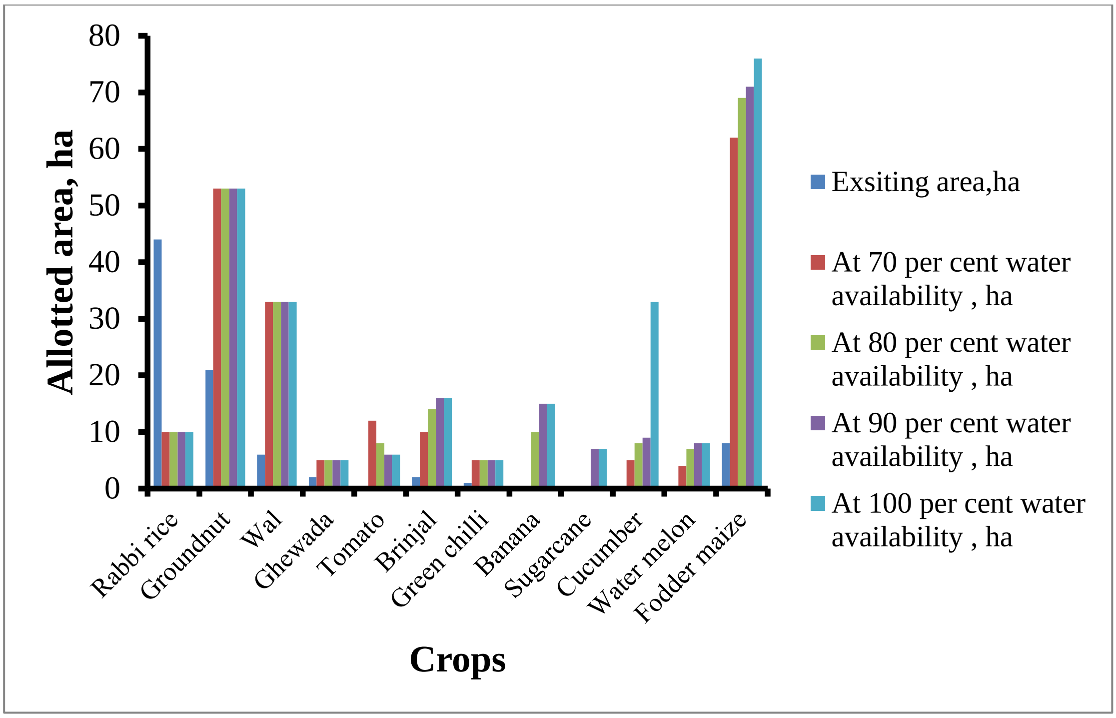

Figure 4.7 Allotted areas at different water availability level, ha of LBC

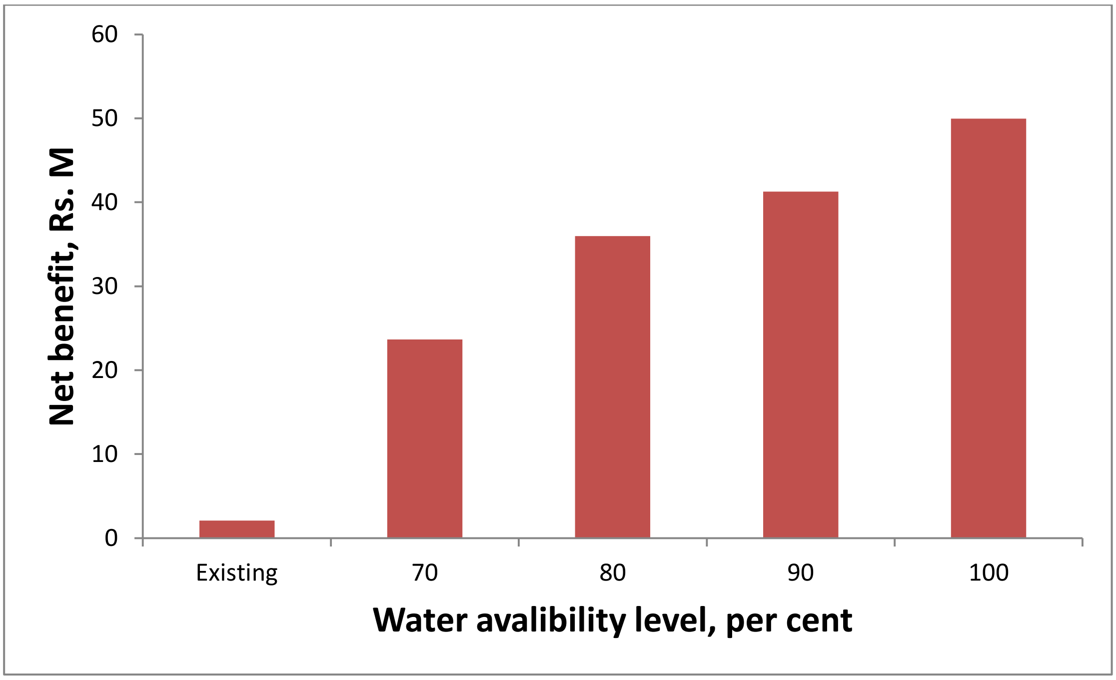

Figure 4.8 Maximum net benefits at different water availability, Rs. M of LBC

Table 4.8: proposed cropping pattern for left bank canal of 280 ha ICA

Sr. No.	**Crop**	**Existing crop area, ha**	**Allotted area to different water availability level, ha**			
			70 (*)	**80 (*)**	**90 (*)**	**100 (*)**
1.	*Rabi* rice	44	10	10	10	10
2	Groundnut	21	53	53	53	53
3	Wal	06	33	33	33	33
4	Ghewada	02	05	05	05	05
5	Tomato	-	12	08	06	06
6	Brinjal	02	10	14	16	16
7	Green chilli	01	05	05	05	05
8	Banana	-	00	10	15	15
9	Sugarcane	-	00	00	07	07
10	Cucumber	-	05	08	09	33
11	Water melon	-	04	07	08	08
12	Fodder maize	08	62	69	71	76
Total	**Max. area (ha)**	**84**	**199**	**222**	**238**	**267**
	Generated labor days		**50908**	**57535**	**63140**	**73737**
	Net benefit in Million rupees	**02.08**	**23.64**	**35.96**	**41.27**	**49.94**

(*): Water availability level in per cent

V. SUMMARY AND CONCLUSIONS

A study entitled "optimization of area allocation strategies for irrigation in command area: A case study of Natuwadi medium irrigation project" was undertaken for obtaining optimal crop plan for maximization of net benefits. The study area of Natuwadi irrigation project is located in Khed tahasil of Ratnagiri district.

A linear programming model was developed for each canal and distributory of Natuwadi medium irrigation project. Inflow data of last 25 year were collected from Natuwadi dam site, for knowing storages situation in reservoir. 70 per cent, 80 per cent, 90 per cent and 100 per cent water availability levels were selected for irrigation. The crops viz. *rabi* rice, groundnut, wal/pavata, ghewada, tomato, brinjal, green chilli, banana, sugarcane, cucumber, water melon and fodder maize were selected for cropping pattern.

Water requirement of crops was calculated with the help of FAO Penmen-Monteith method. Food requirement for population of command area was calculated for each canal and distributory, as per the sample meal plan by National Institute of Nutrition, Hyderabad. Cost analysis for each crop was done for calculating net benefit at input cost.

The required data were collected from the State Irrigation Department Khed, Agricultural Prices Scheme, and Department of Agricultural Economics of this university and from beneficiary farmer of command area.

Net storages at 70 per cent, 80 per cent, 90 per cent and 100 per cent levels are 190610 ha-cm, 217840 ha-cm, 245070 ha-cm and 272300 ha-cm, respectively. By excluding the losses and reservation for non- agricultural purposes the water availability for irrigation in command area was estimated as 79100.7 ha-cm, 90399 ha-cm, 101699 ha-cm and 113001 ha-cm, respectively. At 70 per cent, 80 per cent, 90 per cent and 100 per cent level, water available for right bank canal was 38586 ha-cm, 44098 ha-cm, 49610 ha-cm and 55123 ha-cm, respectively. Also, the water available for left bank canal was to be 11575 ha-cm, 13228 ha-cm, 14882 ha-cm and 16536 ha-cm respectively. Similarly the water available for distributory 1 (DY1) of RBC was to be 13505 ha-cm, 15434 ha-cm, 17363 ha-cm and 19293 ha-cm, respectively, Also water availability for distributory 2 (DY2) of RBC was to be 15434 ha-cm, 17639 ha-cm 19844 ha-cm and 22049 ha-cm, respectively.

Gross irrigation requirements (considering application efficiency of 70 per cent) for *rabi* rice, groundnut, wal/pavata, ghewada, tomato, brinjal, green chilli, banana, sugarcane, cucumber, water melon and fodder maize are 197 cm, 53.5 cm, 24 cm, 59.8 cm, 91.8 cm, 79.5 cm, 61.4 cm, 103.1 cm, 139.2 cm, 59.7 cm, 44.4 cm and 50.2 cm respectively.

For Right bank canal of 965 ha ICA at 70 per cent, 80 per cent, 90 per cent and 100 per cent water availability level, for net benefit maximization, the area brought to be irrigated were 583 ha, 678 ha, 757 ha and 811 ha, respectively having 60.41, 70.26, 78.45 and 84.04 per cent of ICA. At the same time, the net benefit found to be Rs. 102.69 M, Rs.129.02 M, Rs. 153.67 M and Rs. 177.66 M, respectively, which was much more than existing situation (Rs. 10.85 M). The generations of labor days were 166886, 204579, 227240 and 245006, respectively.

For distributory 1 (Dy1) of RBC of 400 ha ICA at 70 per cent, 80 per cent, 90 per cent and 100 per cent water availability level, for net benefit maximization, the area brought to be irrigated were 221 ha, 240 ha, 274 ha and 308 ha, respectively having 55.25, 60, 68.50 and 77 per cent of ICA. At the same time, the net benefit found to be Rs. 46.58 M, Rs. 51.39 M, Rs. 61.09 M and Rs. 71.55 M, respectively, which was much more than existing situation (Rs. 1.69 M). The generations of labor days were 61602, 70405, 80694 and 92652, respectively.

For distributory 2 (Dy2) of RBC of 405 ha ICA at 70 per cent, 80 per cent, 90 per cent and 100 per cent water availability level, for net benefit maximization, the area brought to be irrigated were 255 ha, 274 ha, 313 ha and 357 ha, respectively having 62.96, 67.65, 77.28 and 88.15 per cent of ICA. At the same time, the net benefit found to be Rs. 47.37 M, Rs. 59.14 M, Rs. 70.45 M and Rs. 80.89 M, respectively, which was much more than existing situation (Rs. 4.94 M). The generations of labor days were 71928, 81131, 95540 and 109720, respectively.

For left bank canal of 280 ha ICA at 70 per cent, 80 per cent, 90 per cent and 100 per cent water availability level, for net benefit maximization, the area brought to be irrigated were 199 ha, 222 ha, 238 ha and 267 ha, respectively having 71.07, 79.29, 85 and 95.36 per cent of ICA. At the same time, the net benefit found to be Rs. 23.64 M, Rs. 35.96 M, Rs. 41.27 M and Rs. 49.94 M, respectively, this was much more than existing situation (Rs. 2.08 M). The generations of labor days were 50908, 57535, 63140 and 73737, respectively.

For Whole command area of Natuwadi dam of 2050 ha ICA at 70 per cent, 80 per cent, 90 per cent and 100 per cent water availability level, for net benefit maximization, the area brought to be irrigated were 1258 ha, 1414 ha, 1582 ha and 1743 ha, respectively having 61.37, 68.97, 77.17 and 85.02 per cent of ICA. At the same time, the net benefit found to be Rs. 220.28 M, Rs. 275.75 M, Rs. 315.17 M and Rs. 380.04 M, respectively, this was much more than existing situation (Rs. 19.56 M). The generations of labor days were 351324, 413650, 466614 and 521115, respectively.

Based on the results of study the following conclusions are drawn.

1. With increasing availability of water, area under different crops and generation of labor days have also increased for maximize net benefit of the command area.
2. *Rabi* rice is inevitable at some location of RBC and LBC due to excessive seepage.
3. Optimization of resources restricts banana cultivation to certain limit due to high water requirement and yearlong cycle of crop, although it gives high net returns.
4. Net benefit from command area of Natuwadi dam can be increased up to Rs.220.28 M, from existing net benefit of Rs. 19.56 M at 70 per cent water availability by optimization of water resources and proper crop planning.

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APPENDICES VII

APPENDIX-A

Measured Historical Mean Monthly Inflow Series of Choriti River in M cu.m.

Sr.No.	Year	June	July	August	September	October
1.	1988	12.43	18.35	18.75	18.80	20.72
2.	1989	10.64	18.39	21.69	24.88	24.65
3.	1990	5.47	18.39	20.70	26.36	27.06
4.	1991	6.69	16.53	23.12	27.10	27.23
5.	1992	3.63	6.88	21.92	27.18	27.23
6.	1993	4.18	15.42	23.27	27.15	27.23
7.	1994	3.98	16.91	22.18	27.14	27.23
8.	1995	2.83	8.98	20.69	27.08	23.23
9.	1996	3.82	10.52	22.48	27.93	28.08
10.	1997	2.87	17.46	23.74	27.92	28.08
11.	1998	2.68	13.18	24.76	28.08	28.08
12.	1999	4.69	16.42	22.56	27.30	28.08
13.	2000	5.84	17.30	23.50	27.93	28.08
14.	2001	2.96	12. 26	24.63	28.08	28.08
15.	2002	2.86	11.22	24.43	27.95	28.08
16.	2003	5.43	17.12	25.29	28.08	28.08
17.	2004	5.30	16.99	24.83	28.00	28.08
18.	2005	3.48	16.54	23.19	27.92	28.08
19.	2006	15.18	19.65	24.98	28.08	28.08
20.	2007	3.32	19.35	24.78	28.08	28.08

21.	2008	7.54	19.62	27.63	28.08	28.08
22.	2009	6.54	19.31	27.74	28.08	28.08
23.	2010	7.19	19.74	27.07	28.08	28.08
24.	2011	8.89	19.80	28.08	28.08	28.08
25.	2012	3.54	18.40	28.08	28.08	28.08
	Average	**5.68**	**16.19**	**24.00**	**27.25**	**27.45**

(**Source**: Natuwadi dam site, Natunagar, Khed)

APPENDIX-B

Mean monthly rainfall (mm) of 23 year viz. Year 1990 to 2012

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1990	00	00	00	00	54	1058	1007	1260	372	295	38	00	4085
1991	00	00	00	00	03	1088	1850	705	68	09	00	04	3726
1992	00	00	00	00	03	304	854	1438	241	87	00	00	2927
1993	00	00	00	00	02	726	2023	868	770	141	04	03	4535
1994	00	00	00	00	12	753	1081	582	515	136	09	00	3087
1995	00	00	00	00	38	349	1337	668	438	193	20	00	3042
1996	00	00	00	00	00	425	1510	639	215	183	14	07	2993
1997	05	00	00	00	00	1041	1420	929	106	09	51	51	3613
1998	00	00	00	00	16	780	923	1016	367	366	66	00	3534
1999	00	00	00	00	133	1141	1314	352	307	207	00	00	3453
2000	00	00	03	10	194	815	1438	1061	130	131	00	00	3778
2001	06	00	00	00	46	482	1028	815	216	68	00	00	2661
2002	00	00	02	00	00	1128	703	915	237	53	00	00	3036
2003	00	07	00	00	00	999	1338	702	303	41	01	00	3391
2004	00	00	00	00	48	916	1159	1009	291	60	13	00	3495
2005	00	00	00	00	00	629	1734	1016	528	15	00	00	3921
2006	00	00	06	00	131	918	1330	1007	481	113	23	00	4018
2007	00	00	00	00	00	1257	1218	1255	822	01	11	00	4565
2008	00	00	43	01	00	1453	939	943	597	79	00	09	4063
2009	00	00	38	00	03	247	1549	470	582	227	123	00	3237
2010	00	00	00	00	09	830	1616	652	663	139	148	00	4057
2011	00	00	00	02	00	1106	1575	1359	447	164	00	00	4653
2012	00	00	00	00	00	740	1123	987	541	167	00	00	3559
Avg	**0.48**	**0.30**	**04**	**0.56**	**30**	**834**	**1307**	**898**	**402**	**125**	**23**	**03**	**3627**

APPENDIX-C

a) Cost of cultivation of Hybrid rice

Sr. No.	Particulars	Unit	Quantity	Rate (Rs.)	Amount (Rs.)
1	Labour---- Male	Days	93	145	13485
	Female	Days	194	145	28130
	Bullock	P. days	24	250	6000
2	Seed material	kg.	20	120	2400
3	F.Y.M.	Tone	8.5	2500	21250
4	Fertilizers i) Urea	kg.	261	6	1566
	ii) Single Super Phosphate	kg.	313	9	2817
	iii) Muriate of potash	kg.	83	15	1245
5	Plant protection a) Nursary				
	i) Phorate 10%	kg.	1	75	75
	b) Need based				
	i) Phorate 10%	kg.	10	75	750
	ii) Monocrotophos	lit.	1.5	430	645
6	Irrigation (Water charges)				840
	Input Cost				**79203**
7	Deperciation on implements and Machinery				400
8	Land revenue & Other cesses				100
9	Interest on working capital (@ 6% for 6 Months)				2376
10	Interest on fixed capital				800
11	Rental value of land (1/6th of the gross value - Land revenue)				14900
12	Supervision charges (@10% input cost)				7920
	Total Cost				**105699**
13	Yield & Gross returns				
	i) Main Product	Q.	60	1250	75000
	ii) By Product	Q.	75	200	15000
	Gross returns				**90000**

14	Net returns at: i) Input cost				10797
	ii) Total cost				-15699
15	Cost benefit ratio				0.85

b) Cost of cultivation of Ground nut

Sr. No.	Particulars	Unit	Quantity	Rate (Rs.)	Amount (Rs.)
1	Labour---- Male	Days	98	145	14210
	Female	Days	165	145	23925
	Bullock	P.days	20	250	5000
2	Seed material	kg.pods	125	72	9000
3	F.Y.M.	Tone	4.5	2500	11250
4	Fertilizers				
	i) Urea	kg.	55	6	330
	ii) Single Super Phosphate	kg.	312	9	2808
5	Plant protection				
	i) Cypermethrin	lit.	1	550	550
	i) Monocrotophos	Lit	1	430	430
	iii) Bavistin	kg.	0.25	660	165
	iv) Tricoderma	kg.	2.5	100	250
6	Irrigation (Water charges)				1225
	Input Cost				**69143**
7	Deperciation on implements and Machinery				500
8	Land revenue & Other cesses				100
9	Interest on working capital (@ 6% for 6 Months)				2074
10	Interest on fixed capital				500
11	Rental value of land (1/6th of the gross value - Land revenue)				13567
12	Supervision charges (@10% input cost)				6914
	Total Cost				**92798**
13	Yield & Gross returns				
	i) Main Product	Q	20	3700	74000
	ii) By Product	Q	40	200	8000
	Gross returns				**82000**
14	Net returns at:				
	i) Input cost				12857
	ii) Total cost				-10798
15	Cost benefit ratio				0.88

c) **Cost of cultivation of Wal**

Sr. No.	**Particulars**	**Unit**	**Quantity**	**Rate (Rs.)**	**Amount (Rs.)**
1	Labour---- Male	Days	25	145	3625
	Female	Days	58	145	8410
	Bullock	P.days	12	250	3000
2	Seed material	kg.	50	71	3550
3	F.Y.M.	Tone	5	2500	12500
4	Fertilizers				
	i) Urea	kg.	50	6	300
	ii) Single Super Phosphate	kg.	240	9	2160
5	Plant protection				
	i) Blitox	kg.	1	550	550
	ii) Monocrotophos	Lit	1	430	430
6	Irrigation (water charges)				525
	Input Cost				**35050**
7	Deperciation on implements and Machinery				250
8	Land revenue & Other cesses				50
9	Interest on working capital (@ 6% for 6 Months)				1052
10	Interest on fixed capital				300
11	Rental value of land (1/6th of the gross value - Land revenue)				9950
12	Supervision charges (@10% input cost)				3505
	Total Cost				**50157**
13	Yield & Gross returns				
	i) Main Product	Q.	10	6000	60000
	Gross returns				**60000**
14	Net returns at:				
	i) Input cost				24950
	ii) Total cost				9844

15	Cost benefit ratio				1.20

d) Cost of cultivation of Ghewada

Sr. No.	Particulars	Unit	Quantity	Rate (Rs.)	Amount (Rs.)
1	Labour---- Male	Days	210	145	30450
	Female	days	340	145	49300
	Machine (Tractor)	hours	18	400	7200
2	Seed material	kg.	30	160	4800
3	F.Y.M.	Tone	15	2500	37500
4	Fertilizers				
	i) Urea	kg.	195	6	1170
	ii) Single Super Phosphate	kg.	375	9	3375
	iii) Muriate of potash	kg.	50	15	750
5	Plant protection				
	i) Rogar	lit.	0.5	330	165
	i) Monocrotophos	Lit	1	430	430
	iii) Diathene M - 45	kg.	1	360	360
6	Irrigation (Water charges)				2100
	Input Cost				**137600**
7	Deperciation on implements and Machinery				400
8	Land revenue & Other cesses				50
9	Interest on working capital (@ 6% for 6 Months)				4128
10	Interest on fixed capital				600
11	Rental value of land (1/6th of the gross value - Land revenue)				39950
12	Supervision charges (@10% input cost)				13760
	Total Cost				**196488**
13	Yield & Gross returns				

	i) Main Product	Q	100	2400	240000
	Gross returns				**240000**
14	Net returns at:				
	i) Input cost				102400
	ii) Total cost				43512
15	Cost benefit ratio				1.30

e) Cost of cultivation of Tomato

Sr. No.	Particulars	Unit	Quantity	Rate (Rs.)	Amount (Rs.)
1	Labour---- Male	Days	164	145	23780
	Female	Days	346	145	50170
	Tractor	hours	15	400	6000
2	Seed material	kg.	0.5	1420	710
3	F.Y.M.	Tone	20	2500	50000
4	Fertilizers				
	i) Urea	kg.	215	6	1290
	ii) Single Super Phosphate	kg.	313	9	2817
	iii) Muriate of potash	kg.	83	15	1245
5	Plant protection				
	ii) Lindane-6.5%	kg.	2	35	70
	ii) Dithene M-45	kg.	1	360	360
6	Irrigation (Water charges)				2100
	Input Cost				**138542**
7	Deperciation on implements and Machinery				600
8	Land revenue & Other cesses				50
9	Interest on working capital (@ 6% for 6 Months)				4156
10	Interest on fixed capital				800
11	Rental value of land (1/6th of the gross value - Land revenue)				49950
12	Supervision charges (@10% input cost)				13854
	Total Cost				**207952**
13	Yield & Gross returns				

	i) Main Product	Q.	200	1500	300000
	Gross returns				**300000**
14	Net returns at:				
	i) Input cost				161458
	ii) Total cost				92048
15	Cost benefit ratio				1.44

f) Cost of cultivation of Brinjal

Sr. No.	Particulars	Unit	Quantity	Rate (Rs.)	Amount (Rs.)
1	Labour---- Male	Days	187	145	27115
	Female	Days	340	145	49300
	Tractor	hours	18	400	7200
2	Seed material	kg.	0.8	870	696
3	F.Y.M.	Tone	20	2500	50000
4	Fertilizers				
	i) Urea	kg.	325	6	1950
	ii) Single Super Phosphate	kg.	313	9	2817
	iii) Muriate of potash	kg.	83	15	1245
5	Plant protection				
	i) Dithane M – 45	kg.	2	360	720
	ii) Lindane-6.5%	kg.	2	35	70
6	Irrigation (Water charges)				2100
	Input Cost				**143213**
7	Deperciation on implements and Machinery				600
8	Land revenue & Other cesses				50
9	Interest on working capital (@ 6% for 6 Months)				4296
10	Interest on fixed capital				800
11	Rental value of land (1/6th of the gross value - Land revenue)				49950
12	Supervision charges (@10% input cost)				14321
	Total Cost				**213231**

13	Yield & Gross returns				
	i) Main Product	Q	200	1500	300000
	Gross returns				**300000**
14	Net returns at:				
	i) Input cost				156787
	ii) Total cost				86769
15	Cost benefit ratio				1.41

g) Cost of cultivation of Green chilli

Sr. No.	Particulars	Unit	Quantity	Rate (Rs.)	Amount (Rs.)
1	Labour---- Male	Days	192	145	27840
	Female	Days	351	145	50895
	Tractor	hours	15	400	6000
2	Seed material	kg.	1.5	980	1470
3	F.Y.M.	Tone	15	2500	37500
4	Fertilizers				
	i) Urea	kg.	325	6	1950
	ii) Single Super Phosphate	kg.	313	9	2817
	iii) Muriate of potash	kg.	83	15	1245
5	Plant protection				
	i) Sulphar 80 W	kg.	1.5	200	300
	ii) Dithene M-45	kg.	2	360	720
	iii) Rogar	lit.	0.5	330	165
6	Irrigation (Electricity charges)				2100
	Input Cost				**133002**
7	Deperciation on implements and Machinery				600
8	Land revenue & Other cesses				50
9	Interest on working capital (@ 6% for 6 Months)				3990
10	Interest on fixed capital				800
11	Rental value of land (1/6th of the gross value - Land revenue)				49950

12	Supervision charges (@10% input cost)				13300
	Total Cost				**201692**
13	Yield & Gross returns				
	i) Main Product	Q.	100	3000	300000
	Gross returns				**300000**
14	Net returns at:				
	i) Input cost				166998
	ii) Total cost				93308
15	Cost benefit ratio				1.49

h) Cost of cultivation of Banana

Sr. No.	Particulars	Unit	Quantity	Rate (Rs.)	Amount (Rs.)
1	Labour---- Male	days	243	145	35235
	Female	days	86	145	12470
	Tractor	hours	20	500	10000
2	Seed material (Tissue Culture Seedling)		3268	18	58824
3	F.Y.M.	Tone	15	2500	37500
4	Fertilizers				
	i) Urea	kg.	13072	6	78432
	ii) Single Super Phosphate	kg.	19608	9	176472
	iii) Muriate of potash	kg.	6536	15	98040
5	Plant protection				2000
6	Irrigation (Water charges)				2755
	Input Cost				**511728**
7	Deperciation on implements and Machinery				23000
8	Land revenue & Other cesses				100
9	Interest on working capital (@ 6% for 12 Months)				30704
10	Interest on fixed capital				12000
11	Rental value of land (1/6th of the gross value - Land revenue)				159900
12	Supervision charges (@10% input cost)				51173
	Total Cost				**788605**

13	Yield & Gross returns				
	i) Main Product	Qtl.	800	1200	960000
	Gross returns				**960000**
14	Net returns at:				
	i) Input cost				448272
	ii) Total cost				171395
15	Cost benefit ratio				1.22

i) Cost of cultivation of Sugarcane

Sr. No.	Particulars	Unit	Quantity	Rate (Rs.)	Amount (Rs.)
1	Labour---- Male	Days	190	145	27550
	Female	Days	224	145	32480
	Bullock	P.days	45	250	11250
2	Seed material	Sets	3000	2	6000
3	F.Y.M.	Tone	15	2500	37500
4	Fertilizers				
	i) Urea	kg.	544	6	3264
	ii) Single Super Phosphate	kg.	780	9	7020
	iii) Muriate of potash	kg.	200	15	3000
5	Plant protection				
	i) Thayram	kg.	0.3	230	69
	i) Monocrotophos	Lit	2.5	430	1075
	iii) Bavistin	kg.	0.5	406	203
6	Irrigation (Electricity charges)				2755
	Input Cost				**132166**
7	Deperciation on implements and Machinery				1000
8	Land revenue & Other cesses				150
9	Interest on working capital (@ 6% for 12 Months)				7930
10	Interest on fixed capital				1500
11	Rental value of land (1/6th of the gross value - Land revenue)				34850

12	Supervision charges (@10% input cost)				13217
	Total Cost				**190813**
13	Yield & Gross returns				
	i) Main Product	Q.	1000	170	170000
	ii) By Product	Q.	200	200	40000
	Gross returns				**210000**
14	Net returns at:				
	i) Input cost				77834
	ii) Total cost				19187
15	Cost benefit ratio				1.10

j) Cost of cultivation of Cucumber

Sr. No.	Particulars	Unit	Quantity	Rate (Rs.)	Amount (Rs.)
1	Labour---- Male	Days	125	145	18125
	Female	Days	278	145	40310
	Machine Tractor	hours	11	400	4400
2	Seed material	kg.	2.5	1090	2725
3	F.Y.M.	Tone	15	2500	37500
4	Fertilizers				
	i) Urea	kg.	293	6	1758
	ii) Single Super Phosphate	kg.	375	9	3375
	iii) Muriate of potash	kg.	50	15	750
5	Plant protection				
	i) Cypermethrin	lit.	1	550	550
	ii) Rogar	lit.	0.5	330	165
	iii) Diathene M-45	kg.	2.5	360	900
	ii) Lambdacynalothrin	lit.	0.5	574	287
6	Cost of support material				5000
7	Irrigation (Water charges)				2100
	Input Cost				**117945**
8	Deperciation on implements and Machinery				400
9	Land revenue & Other cesses				50
10	Interest on working capital (@ 6% for 6				3538

	Months)				
11	Interest on fixed capital				600
12	Rental value of land (1/6th of the gross value - Land revenue)				66616
13	Supervision charges (@10% input cost)				11795
	Total Cost				**200944**
14	Yield & Gross returns				
	i) Main Product	Q.	200	2000	400000
	Gross returns				**400000**
15	Net returns at:				
	i) Input cost				282055
	ii) Total cost				199056
16	Cost benefit ratio				2

k) Cost of cultivation of Water melon

Sr. No.	Particulars	Unit	Quantity	Rate (Rs.)	Amount (Rs.)
1	Labour---- Male	Days	221	145	32045
	Female	Days	34	145	4930
	Tractor	hours	18	400	7200
2	Seed material	kg.	2.5	810	2025
3	F.Y.M.	Tone	15	2500	37500
4	Fertilizers				
	i) Urea	kg.	325	6	1950
	ii) Single Super Phosphate	kg.	313	9	2817
	iii) Muriate of potash	kg.	85	15	1275
5	Plant protection				
	i) Diathene M – 45	kg.	2	360	720
	ii) Lambdacynalothrin	lit.	0.3	574	172
	iii) Blitox	kg.	2	550	1100
	iv) Rogar	lit.	0.5	330	165
6	Irrigation (Water charges)				2100
	Input Cost				**93999**
7	Deperciation on implements and Machinery				500

8	Land revenue & Other cesses				100
9	Interest on working capital (@ 6% for 6 Months)				2820
10	Interest on fixed capital				1000
11	Rental value of land (1/6th of the gross value - Land revenue)				49900
12	Supervision charges (@10% input cost)				9400
	Total Cost				**157719**
13	Yield & Gross returns				
	i) Main Product	Q.	300	1000	300000
	Gross returns				**300000**
14	Net returns at:				
	i) Input cost				206001
	ii) Total cost				142281
15	Cost benefit ratio				1.90

l) Cost of cultivation of Fodder maize

Sr. No.	Particulars	Unit	Quantity	Rate (Rs.)	Amount (Rs.)
1	Labour---- Male	days	102	145	14790
	Female	Days	83	145	12035
	Bullock	P. days	10	180	1800
2	F.Y.M.	Tone	2	2500	5000
3	Fertilizers (100 kg N. per ha.)				
	i) Urea	kg.	326	6	1956
4	Irrigation (Water charges)				840
	Input Cost				**36421**
5	Deperciation on implements and Machinery				400
6	Land revenue & Other cesses				50
7	Interest on working capital (@ 6% for 06 Months)				1093
9	Interest on fixed capital				100
9	Rental value of land (1/6th of the gross value - Land revenue)				14533.3
10	Supervision charges (@10% input cost)				3642

	Total Cost				**56239**
11	Yield & Gross returns				
	Main Producrt (Green fodder)	Q	350	250	87500
	Gross returns				**87500**
12	Net returns at:				
	i) Input cost				51079
	ii) Total cost				31261
13	Cost benefit ratio				1.49

APPENDIX-D

Monthly Irrigation Water requirement of crop in cm

Crop / month	Rabbi rice	Groundnut	Wal	Ghewada	Tomato	Brinjal	Green chilli	Banana	Sugarcane
January	29.4	11.7	11.4	10.6	11.7	11.2	9.4	5.1	4.1
February	30.3	13.4	5.9	12.2	13.4	13.5	11.6	5.8	8.3
March	31.2	6.8	00	10.6	16.5	14.8	13.8	7.2	17.9
April	15.3	00	00	00	14.3	7.8	00	13.7	19.7
May	00	00	00	00	00	00	00	17.8	20.3
June	00	00	00	00	00	00	00	11.7	13.2
July	00	00	00	00	00	00	00	9.3	10.6
August	00	00	00	00	00	00	00	9.3	10.5
September	00	00	00	00	00	00	00	9.9	9.1
October	00	00	00	00	00	00	00	10.9	7.9
November	5.3	2.0	2.0	3.0	3.0	3.0	3.4	7.2	5.6
December	26.4	3.6	7.3	5.5	5.4	5.4	4.8	4.5	3.7
Total	**137.9**	**37.5**	**26.6 (17)[a]**	**41.9**	**64.3**	**55.7**	**43.0**	**112.4 (72.2)[b]**	**130.9 (97.5)[b]**

a = water requirement of wal excluding the residual moisture. b = water requirement of banana and sugarcane excluding the effective rainfall.

APPENDIX- E

Calculation of actual available water for irrigation in command area:

Gross storage = 28.08 M cum.

Net storage = 27.23 M cum

Dead storage = 0.85 M cum

Evaporation losses = 7.6 M cum

Seepage losses = 42 per cent

Irrigation days = 55 days (irrigation days taken from the canal release roaster of dam)

Flow rate :

RBC = 3.5 cumec (For Dy1 = 0.7 cumec and Dy2 = 0.8 cumec)

LBC = 0.6 cumec

1) Actual available water for irrigation on RBC at 3.5 cumec flow rat including Dy1 and Dy2

= Flow rate × irrigation days

= 3.5 × 60 × 60 × 24 × 55

= 16632000 m^3

To reduce seepage losses of 42 per cent from it.

= 9646560 m^3

RBC = 96465.6 ha-cm (including Dy1 and Dy2)

a) Actual available water for irrigation in Dy1 at 0.7 cumec flow rate

= 0.7 × 60 × 60 × 24 × 55

= 3326400 m^3

To reduce seepage losses of 42 per cent from it.

Dy1 = 19293 ha-cm

b) Actual available water for irrigation in Dy2 at 0.8 cumec flow rate

= 0.8 × 60 × 60 × 24 × 55

= 3801600 m^3

To reduce the seepage losses of 42 per cent on it.

Dy2 = 22049 ha-cm

c) Actual available water for irrigation in RBC excluding Dy1 and Dy2.

= 96465.6 - 19293.12 - 22049.28

RBC = 55123 ha-cm

2) Actual available water for irrigation in LBC at the flow of 0.6 cumec.

$= 0.6 \times 60 \times 60 \times 24 \times 55$

$= 2851200\ m^3$

LBC = 16536 ha- cm

APPENDIX- F

Food Requirement of People in Natuwadi Command Area

a) Food requirement for right bank canal

Food requirement / year = per head need x population x days

1) Cereal requirement = (0.33 x 10063 x 365)

   = **12120.8 qtl/yr**

2) Pulses requirement = (0.06 x 10063 x 365)

   = **2203.8 qtl/yr**

   Wal requirement = 30 per cent of total pulses requirement

   = **661.4 qtl/yr**

3) Oil/ Oilseeds requirement = (0.035x10063 x 365)

   = **1285.54 qtl/yr**

4) Vegetable requirement = (0.3 x 10063 x 365)

   = 11018.98 qtl/yr

5) Milk = (0.25 x 10063 x 365)

   = **918248.75 lit/yr**

b) Food requirement for left bank canal

Food requirement / year = per head need x population x days

1) Cereal requirement = (0.33 x 4977 x 365)

   = **5994.8 qtl/yr**

2) Pulses requirement = (0.06 x 4977 x 365)

   = **1089.96 qtl/yr**

   Wal requirement = 30 per cent of total pulses requirement

= **326.98 qtl/yr**

3) Oil requirement = (0.035 x 4977 x 365)

= **635.81 qtl/yr**

4) Vegetable requirement = (0.3 x 4977 x 365)

= **5449.81 qtl/yr**

5) Milk = (0.25 x 4977 x 365)

= **454151.25 lit/yr**

c) Food requirement for distributory 1 (Dy1) of RBC

Food requirement / year = per head need x population x days

1) Cereal requirement = (0.33 x 3531 x 365)

= **4253.08 qtl/yr**

2) Pulses requirement = (0.06 x 3531 x 365)

= **773.28 qtl/yr**

Wal requirement = 30 per cent of total pulses requirement

= **231.98 qtl/yr**

3) Oil requirement = (0.035 x 3531 x 365)

= **451.08 qtl/yr**

4) Vegetable requirement = (0.3 x 3531 x 365)

= **3866.44 qtl/yr**

5) Milk = (0.25 x 3531 x 365)

= **322203.75 lit/yr**

d) Food requirement for Distributory 2 (Dy2) of RBC

Food requirement / year = per head need x population x days

1) Cereal requirement = (0.33 x 3983 x 365)

= **4797.52 qtl/yr**

2) Pulses requirement = (0.06 x 3983 x 365)

= **872.37 qtl/yr**

Wal requirement = 30 per cent of total pulses requirement

= **261.68 qtl/yr**

3) Oil requirement = (0.035 x 3983 x 365)

= **508.82 qtl/yr**

4) Vegetable requirement = (0.3 x 3983 x 365)

= **4361.385 qtl/yr**

5) Milk = (0.25 x 3983 x 365)

= **363448.75 lit/yr**