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# Optimization of Cropping pattern using Linear Programming Model for Markandeya Command Area

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## ABSTRACT

*Agriculture is one of major activity in INDIA. Overall development depends on food production in service of existing or growing population with maximum benefits and optimal utilization of water and land resources. Management of this water and land resources is also one of the main financial development. Hence there is necessity of implementation of techniques in optimum usage of such available resources. Also Keeping in view of socio economic conditions, the present study makes an attempt to develop optimum cropping pattern with the constraints of available resources like water usage and also labour, fertilizers, seeds, etc., and ultimately getting maximum net benefits. The objective function for multi crop model are formulated using LP for maximizing the net benefits, by keeping all other available resources (such as cultivable land, seeds, fertilizers, human power, pesticides, cash etc) as constraints. Markandeya command area in Karnataka State, India is taken for the study. The study resulted in optimal cropping pattern for different water availabilities ranging from 2000 Ha-m to 5500 Ha-m. The maximum net benefit for the study area varied from Rs. 53.2 Crores for 2000 Ha-m water availability to Rs.78 Crores at 5000 Ha-m Water availability.*

*Index terms: Optimization techniques, Linear Programming, optimal crop pattern, maximum net Benefits, Water Availability.*



## 1. Introduction

Dwindling water resources and increasing food requirements require greater efficiency in water use, both in rain fed and in irrigated agriculture. Regulated irrigation provides a means of reducing water consumption while minimizing adverse effects on yield. CROPWAT model can play a useful role in

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developing practical recommendations for optimizing crop production under conditions of scarce water supply. CROPWAT [1] is a practical tool to help agrometeorologists, agronomists and irrigation engineers to carry out standard calculations for evapotranspiration and crop water use studies, and more specifically the design and management of irrigation schemes. It allows the development of recommendations for improved irrigation practices, the planning of irrigation schedules under varying water supply conditions, and the assessment of production under rainfed conditions or deficit irrigation. Ali Abdzad Gohari adopted the CROPWAT model to appropriately estimate the yield reduction caused by water stress and climatic impacts. The simulation results analysis suggest that in both condition rainfed and irrigated, the largest yield reduction occurred in the stage three (developmental stage) [2]. A study was carried out by Nithya et al to determine the crop water requirement of some selected crops for the command area in Kunigal taluk. These crops include rice, pulses, groundnut, sugarcane and millet (ragi). Crop water requirement for each of the crops was determined using 30-year climatic data in CROPWAT. Reference crop evapotranspiration (ETo) was determined using the FAO Penman Monteith method. [3]. Shreedhar et.al carried out study to review the crop yield responses to deficit irrigation for the major crops in Kunigal command area [4].

To plan the with regard to distribution of water resources to the crop, it is important to optimize the available land and water resources to achieve maximum returns. To solve such problems, the mathematical programming models like linear programming (LP), dynamic programming (DP) and genetic algorithm (GP) are used. It is LP model that is more popular because of the proportionate characteristic of the allocation problem. Linear programming models can handle a large number of constraints and thus, are an effective tool to aid in the optimization process. Hall and Dracup (1970) proposed a linear programming model to maximize the net return and select an optimal cropping pattern [5]. Loucks et al.(1981) discussed in detail about the micro level irrigation planning with detailed examples [6]. Singh et al. (2001) applied linear programming model to Shahi distributory command area to obtain net returns at different water availability levels [7]. Srinivasa Raju et al. (2000) used linear programming models to obtain various possible optimal cropping patterns and optimal operational policies considering different dependability inflow levels. [8].

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## 2. Study area

The area taken for the study is Markandeya Reservoir Project as shown in Figure 1.0. The river Markandeya is a major tributary to Ghataprabha River which is a tributary to river Krishna. It takes its origin near Bailur in the Western Ghats and flows for a length of 66 kms before it joins river Ghataprabha near Gokak. The Markandeya River flows entirely in Belgaum district of Karnataka state with a drainage basin of 432 Sqkms. The project envisages the construction of concrete dam across Markandeya River near Shirur village in Belgaum district to irrigate lands on both banks to an extent of 14850 Hectares of Belgaum, Hukkeri, Gokak, and Saundatti Talukas. The proposed dam site across Markandeya river is located at latitude 16°2´0”N and longitude 74°38´30”E and near Shirur village which is about 10 kms from Pachapur railway station on Miraj-Bangalore section of the South

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Central Railway. The site is 50kms from Belgaum and is approachable by road taking off near Hattargi on Pune- Bangalore road (NH-4) and via Hidkal Dam site. The area is of moderate climate with an average temperature of 26.43°C. The average rainfall in the command is of the order of 48cms to 64cms and unevenly distributed resulting in failure of crops. The soil of this region is fertile and good. Assured crops can be raised in the region by providing irrigation facilities.

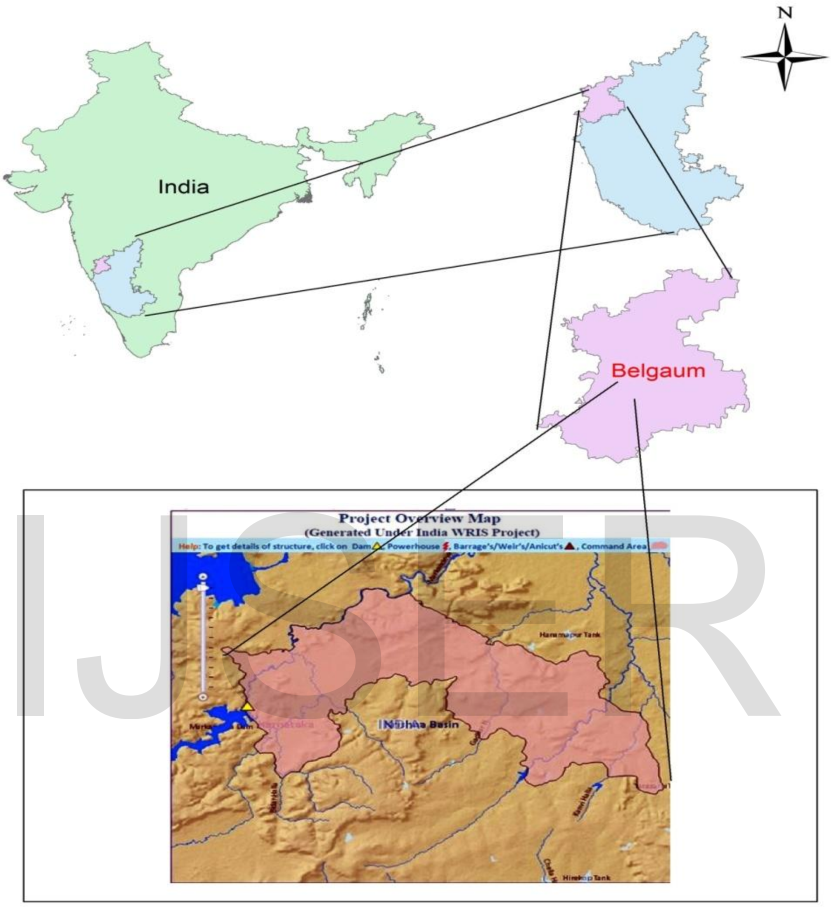




**Figure 1.0 Location Map of Markandeya Study area**

## 3.0 LP Model formulation

The different proposed cropping pattern scenario is formulated for Markandeya command area based on irrigable command area and volume of water at different water availability in the reservoir. The irrigation water requirements of major crops in the study area are estimated. A linear programming model is formulated to suggest the optimal cropping pattern giving the maximum net benefit at different water availability in the reservoir. The objective function of the model is subject to the following constraints: water availability, crop land requirement, Human labour cost, Animal and Machine power cost, Seed cost, Fertlizers and Manure cost, Fixed cost etc.

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### Objective function: Maximize net benefit

$$Z = \sum (Y_i \times A_i (R_i - C_i)$$

where,

Yi=Yield of 'i'th crop in study area in Quintal, Ai= Area of 'i'th crop in study area in Hectare, Ri= Market price of 'i'th crop in Rs/Qtl and Ci= Cost of cultivation in Rs/Qtl

The above objective function is subjected to the following requirements

### Constraints on Water Availability

$$\sum \mathbf{NIR_i \times A_i \leq WA}$$

where, $\mathrm{NIR_i}$=Net Irrigation Requirement for the $\mathrm{i^{th}}$ crop ,WA=Water Availability in Ha-m and $\mathrm{A_i}$=Area of $\mathrm{i^{th}}$ crop in study area

### Constraints on Crop land requirement

$$\sum \mathbf{A_i \leq CCA}$$

where, $\mathrm{A_i}$=Area of $\mathrm{i^{th}}$ crop in Study area in Ha and CCA= Cultivable Command Area in Ha.



### Constraints on Human labour cost

$$\sum \mathbf{CHL_i \times A_i \leq CHL}$$

where, $\mathrm{CHL_i}$=Cost of Human Labour Per Ha in Rs, $\mathrm{A_i}$=Area of $\mathrm{i^{th}}$ crop in Study area in Ha and CHL= Total cost of Human labour for entire CCA in Rs.

### Constraints on Animal and Machine power cost

$$\sum \mathbf{CAMP_i \times A_i \leq CAMP}$$

where, $\mathrm{CHL_i}$=Cost of $\mathrm{i^{th}}$ crop human labour charges Per Ha in Rs. $\mathrm{A_i}$=Area of $\mathrm{i^{th}}$ crop in Study area in Ha and CHL= Total cost of Human labour for entire CCA in Rs.

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### Constraints on seed cost

$$\sum CS_i \times A_i \leq CS$$

Where, $CS_i$=Cost of $i^{th}$ crop seed per Ha in Rs., $A_i$=Area of $i^{th}$ crop in Study area in Ha. and CS= Total cost of seeds per entire CCA in Rs.

### Constraints on Fertilizer and Manure cost

$$\sum CFM_i \times A_i \leq CFM$$

Where, $CFM_i$=Cost of $i^{th}$ crop Fertilizers and Manure per Ha in Rs., $A_i$=Area of $i^{th}$ crop in Study area in Ha.and CFM= Total cost of Fertilizers and Manure per entire CCA in Rs.

### Constraints on Interest on Workmanship cost

$$\sum CIW_i \times A_i \leq CIW$$

Where, $CIW_i$=Cost of $i^{th}$ crop interest on workmanship per Ha in Rs, $A_i$=Area of $i^{th}$ crop in Study area in Ha.and CIW= Total cost of Interest on Workmanship per entire CCA in Rs.



### Constraints on Plant Protection cost

$$\sum CPPC_i \times A_i \leq CPPC$$

Where, $CPPC_i$=Cost of $i^{th}$ crop plant protection charges per Ha in Rs, $A_i$=Area of $i^{th}$ crop in study area in Ha and CPPC= Total cost of plant protection charges per entire CCA in Rs.

### Constraints on Fixed cost

$$\sum CFC_i \times A_i \leq CFC$$

Where, $CFC_i$=Cost of $i^{th}$ crop fixed cost (land revenue, surface water charges) per Ha in Rs. , $A_i$=Area of $i^{th}$ crop in study area in Ha.and CFC= Total amount of fixed cost per entire CCA in Rs.

### Constraints on Unforeseen Expenditure

$$\sum CUFE_i \times A_i \leq CUFE$$

Where, $CUFE_i$=Cost of $i^{th}$ crop unforeseen expenditure per Ha in Rs. $A_i$=Area of $i^{th}$ crop in study area in Ha.and CUFE= Total amount of unforeseen expenditure per entire CCA in Rs.

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## 4.0 Results and discussions

### 4.1 ET0 Calculation using CROPWAT

The CROPWAT software is used to determine the radiation in MJ/m²/day and ETo in mm/day using the average input data of 10 years collected from Hidkal Meteorological station and is presented in Table 1.0. For the area under study, the ETo values varied with minimum value of 3.23 mm/day in December to maximum value of 5.36mm/day in May (Table 1.0).

**Table 1.0: ETo calculations using software CROPWAT**

| Month | Min Temp | Max Temp | Humidity | Wind | Sun | Radiation | ETo |
|---|---|---|---|---|---|---|---|
| | °C | °C | % | m/s | hours | MJ/m²/day | mm/day |
| **January** | 14.9 | 30.1 | 62 | 0.6 | 8.8 | 18.7 | 3.33 |
| **February** | 16.9 | 32.2 | 61 | 0.6 | 9.2 | 21 | 3.91 |
| **March** | 19.9 | 34.6 | 57 | 0.6 | 9.3 | 22.9 | 4.68 |
| **April** | 21.9 | 36.4 | 55 | 0.7 | 8.8 | 23 | 5.15 |
| **May** | 21.8 | 35.8 | 57 | 1 | 8.3 | 22.3 | 5.36 |
| **June** | 20.7 | 30.4 | 62 | 1.6 | 5.4 | 17.7 | 4.55 |
| **July** | 20 | 27.8 | 62 | 1.8 | 2.7 | 13.7 | 3.83 |
| **August** | 20.1 | 28.1 | 65 | 1.5 | 4.1 | 15.7 | 3.84 |
| **September** | 20.3 | 29.3 | 65 | 1.2 | 5.3 | 17 | 3.86 |
| **October** | 20.3 | 31.1 | 65 | 0.8 | 6.9 | 18.1 | 3.83 |
| **November** | 18.5 | 30.1 | 65 | 0.6 | 7.8 | 17.7 | 3.45 |
| **December** | 15.4 | 29.3 | 65 | 0.6 | 8.7 | 18 | 3.23 |



### 4.2 Rainfall

The average rainfall for a 30 year period is calculated and the data on the monthly basis is given in CROPWAT for calculating effective rainfall. Effective rainfall refers to the portion of precipitation that can effectively be used by the plants. Though there are several methods for computing effective rainfall, USDA soil conservation service method is used. The other methods one can decide to use from CROPWAT to find effective rainfall are fixed percentage method, Dependable rainfall formula and Empirical formula.

The effective rainfall per month for the study area using USDA S.C. method is as given in Table 2.0. The average annual rainfall for the study area is 664.4 mm and the effective rainfall used by the crops is 554.6 mm which is 83.5 % of the average annual rainfall.

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**Table 2.0: Rainfall and Effective rainfall in study area**

| Month | Mean Monthly (past 30year data) Rainfall in mm | Effective Rainfall (USDA S.C method) in mm |
|---|---|---|
| Jan | 1.1 | 1.1 |
| Feb | 1 | 1 |
| Mar | 6 | 5.9 |
| Apr | 21 | 20.3 |
| May | 48 | 44.3 |
| Jun | 127 | 101.2 |
| Jul | 144 | 110.8 |
| Aug | 105 | 87.4 |
| Sep | 97 | 81.9 |
| Oct | 90 | 77 |
| Nov | 21 | 20.3 |
| Dec | 3.3 | 3.3 |
| | 664.4 | 554.6 |



## 4.3 Irrigation Requirements for the major crops in study area

Crop water requirement (CWR) refers to the amount of water required to compensate the evapotranspiration loss from the cropped field also synonymously known as crop evapotranspiration (ETc). CWR refers specially to the amount of water to be supplied whereas ETc refers to the amount of water that crop has lost through evapotranspiration. ETc is determined by multiplying the crop co-efficient Kc with the reference crop evapotranspiration ETo. "

ETc is referred to evapotranspiration from disease free, well fertilized crop grown under optimum or standard conditions. These comprises of optimum soil water and achieving full production under given climatic conditions. The effects of characteristics that distinguish field crops from reference grass crop are integrated into the crop co-efficient Kc .The difference in leaf anatomy, stomata characteristics, aerodynamic properties and albedo cause the ETc to differ from ETo. Due to valuations in the crop characteristics throughout its growing cycle, Kc for a given crop changes from sowing till harvest. "

Irrigation requirement is calculated at decade time step. It refers to the amount of water required to be supplied to crop so as to meet CWR. Irrigation requirement is calculated using the formula

$$\mathbf{Irrigation\ requirement} = \mathbf{ET_c} - \mathbf{P_{eff}}$$

where Peff is the effective rainfall.

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**Table 3.0: Net Irrigation requirement for major crops by CROPWAT**

| Season | Crop | NIR in mm |
|---|---|---|
| Kharif | Jowar | 159.9 |
| | Groundnut | 153.8 |
| | Maize | 159.9 |
| | Pulses | 86.01 |
| Rabi | Jowar | 208.6 |
| | Maize | 236.9 |
| | Wheat | 286.3 |
| | Bengal Gram | 272.5 |
| | Green Gram | 207.8 |
| | Sunflower | 184.5 |
| Two Season | Cotton | 183.7 |

## 4.4 Optimization of cropping pattern with different water policies

The linear programming model is run for lowest water availability of 2000 Ha-m and then the model is also run for increased water availability in the increments of 500 Ha-m. For each run, the optimal area of each crop to be allotted shall be less than or equal to total area of land allotted to each of the crops as given by the Irrigation department. The decision variables in each case are the optimal area of land allotted to each of the crops such that maximum net benefit is obtained. However, the study was also carried for each of the water availability case by varying the allotted areas for each crop by ±10 % to ±50%.

The maximum cultivable areas and maximum net benefit obtained for each run in LP model for various water availability in the reservoir is as given in Table 4.0 to 11.0.

**Table 4.0: Optimal Crop area for water availability of 2000 Ha-m**

| Optimal areas in Ha obtained at 2000Ha-m of Water Availability | | | | | | |
|---|---|---|---|---|---|---|
| CROPS | Ai≤TIA | 10% | 20% | 30% | 40% | 50% |
| Kh. Jowar | 2435 | 2205 | 1960 | 1823.07 | 1470 | 1225 |
| Kh. Groundnut | 3910 | 3850.21 | 4692 | 5083 | 5474 | 4643.23 |
| Kh. Maize | 3537 | 3213 | 3815.89 | 4641 | 2784.75 | 1785 |
| Kh. Pulses | 3435 | 3091.5 | 2748 | 2404.5 | 2061 | 1717.5 |
| Rb. Jowar | 0 | 1318.5 | 1172 | 1025.5 | 879 | 732.5 |
| Rb. Maize | 682.06 | 0 | 0 | 0 | 0 | 0 |
| Rb. Wheat | 0 | 0 | 0 | 0 | 0 | 0 |
| Rb. Bengal Gram | 0 | 463.5 | 412 | 360.5 | 309 | 257.5 |
| Rb. Green Gram | 0 | 463.5 | 412 | 360.5 | 309 | 257.5 |
| Rb. Sunflower | 1080 | 0 | 0 | 0 | 648 | 540 |
| Cotton | 0 | 0 | 0 | 0 | 0 | 742.5 |
| | | | | | | |
| CCA | 15112.07 | 14605.21 | 15211.89 | 15698.07 | 13934.76 | 11900.73 |
| | | | | | | |
| Net Benefit in Cr | 54.10 | 43.73 | 49.40 | 53.20 | 54.12 | 46.20 |

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**Table 5.0: Optimized cropping pattern in study area for water availability of 2500 Ha-m**

| Optimal areas in Ha obtained at 2500 Ha-m of Water Availability | | | | | | |
|---|---|---|---|---|---|---|
| CROPS | Ai<=TIA | 10% | 20% | 30% | 40% | 50% |
| Kh. Jowar | 2435 | 2205 | 1960 | 1715 | 1470 | 1225 |
| Kh. Groundnut | 3910 | 4301 | 4692 | 3852.42 | 5474 | 5865 |
| Kh. Maize | 3570 | 3532.98 | 3469.74 | 2499 | 3849.6 | 2268.26 |
| Kh. Pulses | 3435 | 3091.5 | 2748 | 2404.5 | 1374 | 1717.5 |
| Rb. Jowar | 0 | 1318.5 | 1172 | 1025.5 | 879 | 732.5 |
| Rb. Maize | 1955 | 1759.5 | 1564 | 1368.5 | 1173 | 977.5 |
| Rb. Wheat | 148.82 | 0 | 0 | 0 | 0 | 0 |
| Rb. Bengal Gram | 0 | 463.5 | 412 | 360.5 | 309 | 257.5 |
| Rb. Green Gram | 0 | 0 | 412 | 360.5 | 309 | 257.5 |
| Rb. Sunflower | 1080 | 0 | 0 | 756 | 648 | 540 |
| Cotton | 0 | 0 | 0 | 0 | 0 | 742.5 |
| | | | | | | |
| CCA | 16534.82 | 16671.99 | 16429.74 | 14341.92 | 15485.62 | 14583.26 |
| | | | | | | |
| Net Benefit in Cr | 58.35 | 52.54 | 57.80 | 49.60 | 60.14 | 57.90 |

**Table 6.0: Optimized cropping pattern in study area for water availability of 3000 Ha-m**



| Optimal areas in Ha obtained at 3000 Ha-m of Water Availability | | | | | | |
|---|---|---|---|---|---|---|
| CROPS | Ai<=TIA | 10% | 20% | 30% | 40% | 50% |
| Kh. Jowar | 2435 | 2695 | 1960 | 1715 | 1850 | 1225 |
| Kh. Groundnut | 3910 | 4301 | 4103.53 | 3330.1 | 5474 | 4481.45 |
| Kh. Maize | 3570 | 3927 | 2856 | 2499 | 3487.14 | 1785 |
| Kh. Pulses | 3435 | 3778.5 | 2748 | 2404.5 | 2061 | 1717.5 |
| Rb. Jowar | 0 | 1318.5 | 1172 | 1025.5 | 879 | 732.5 |
| Rb. Maize | 1955 | 1759.5 | 1564 | 1368.5 | 1173 | 977.5 |
| Rb. Wheat | 1399.82 | 0 | 0 | 0 | 0 | 1690 |
| Rb. Bengal Gram | 0 | 463.5 | 412 | 360.5 | 309 | 257.5 |
| Rb. Green Gram | 0 | 463.5 | 412 | 360.5 | 309 | 257.5 |
| Rb. Sunflower | 1080 | 343.54 | 0 | 756 | 648 | 540 |
| Cotton | 0 | 0 | 1188 | 1039.5 | 891 | 742.5 |
| | | | | | | |
| CCA | 17784.82 | 19050.05 | 16415.53 | 14859.09 | 17081.8 | 14406.46 |
| | | | | | | |
| Net Benefit in Cr | 6.23 | 5.84 | 5.107 | 4.944 | 6.31 | 5.34 |

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**Table 7.0: Optimized cropping pattern in study area for water availability of 3500 Ha-m**

| Optimal areas in Ha obtained at 3500Ha-m of Water Availability | | | | | | |
|---|---|---|---|---|---|---|
| CROPS | Ai<=TIA | 10% | 20% | 30% | 40% | 50% |
| Kh. Jowar | 2435 | 2695 | 1960 | 3185 | 1470 | 3675 |
| Kh. Groundnut | 3910 | 4301 | 4635 | 5083 | 4216.8 | 5013.8 |
| Kh. Maize | 3570 | 3927 | 2856 | 2950.67 | 2142 | 1785 |
| Kh. Pulses | 3435 | 3328.99 | 2748 | 2404.5 | 2061 | 1717.5 |
| Rb. Jowar | 1022.63 | 1318.5 | 1172 | 1025.5 | 879 | 732.5 |
| Rb. Maize | 1955 | 1759.5 | 1564 | 1368.5 | 1173 | 977.5 |
| Rb. Wheat | 1587.02 | 0 | 0 | 0 | 2028 | 1690 |
| Rb. Bengal Gram | 0 | 463.5 | 412 | 360.5 | 309 | 257.5 |
| Rb. Green Gram | 0 | 463.5 | 412 | 360.5 | 309 | 257.5 |
| Rb. Sunflower | 1080 | 0 | 864 | 990.09 | 648 | 855.93 |
| Cotton | 0 | 1336.5 | 1188 | 1030.5 | 891 | 742.5 |
| | | | | | | |
| CCA | 18994.65 | 19593.5 | 17811 | 18767.77 | 16126.88 | 17704.74 |
| | | | | | | |
| Net Benefit in Cr | 65.00 | 59.00 | 61.50 | 66.90 | 57.03 | 65.18 |



**Table 8.0: Optimized cropping pattern in study area for water availability of 4000 Ha-m**

| Optimal areas in Ha obtained at 4000 Ha-m of Water Availability | | | | | | |
|---|---|---|---|---|---|---|
| CROPS | Ai<=TIA | 10% | 20% | 30% | 40% | 50% |
| Kh. Jowar | 2435 | 2695 | 2940 | 1715 | 3430 | 3675 |
| Kh. Groundnut | 3910 | 4301 | 4146.25 | 3952.3 | 4316.19 | 4070.35 |
| Kh. Maize | 3570 | 3674.72 | 4284 | 2499 | 2142 | 3312.52 |
| Kh. Pulses | 3435 | 3091.5 | 2748 | 2404.5 | 2061 | 1717.5 |
| Rb. Jowar | 1465 | 1318.5 | 1248.69 | 1025.5 | 879 | 732.5 |
| Rb. Maize | 1955 | 1759.5 | 1564 | 1368.5 | 1173 | 977.5 |
| Rb. Wheat | 828.55 | 0 | 0 | 2366 | 2028 | 1690 |
| Rb. Bengal Gram | 0 | 463.5 | 412 | 360.5 | 309 | 257.5 |
| Rb. Green Gram | 0 | 463.5 | 412 | 360.5 | 309 | 257.5 |
| Rb. Sunflower | 1080 | 1027.7 | 1296 | 756 | 1144.47 | 1620 |
| Cotton | 1181.57 | 1336.5 | 1188 | 1039.5 | 891 | 742.5 |
| | | | | | | |
| CCA | 19860.13 | 20131.43 | 20238.94 | 17847.31 | 18682.67 | 19052.87 |
| | | | | | | |
| Net Benefit in Cr | 67.00 | 66.70 | 68.90 | 60.60 | 66.50 | 70.30 |

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**Table 9.0: Optimized cropping pattern in study area for water availability of 4500 Ha-m**

| Optimal areas in Ha obtained at 4500Ha-m of Water Availability | | | | | | |
|---|---|---|---|---|---|---|
| CROPS | Ai<=TIA | 10% | 20% | 30% | 40% | 50% |
| Kh. Jowar | 2435 | 2695 | 2207.69 | 3185 | 3430 | 3675 |
| Kh. Groundnut | 3910 | 3803.8 | 3349.68 | 3547.43 | 3018.47 | 3049.82 |
| Kh. Maize | 3570 | 3927 | 2856 | 2680.88 | 4646.46 | 5244.12 |
| Kh. Pulses | 0 | 3091.5 | 2748 | 2404.5 | 2061 | 1717.5 |
| Rb. Jowar | 1465 | 1611.5 | 1172 | 1025.5 | 1177.58 | 1600.42 |
| Rb. Maize | 1955 | 2150.5 | 1564 | 1368.5 | 1173 | 977.5 |
| Rb. Wheat | 1924 | 0 | 2704 | 2366 | 2028 | 1690 |
| Rb. Bengal Gram | 0 | 463.5 | 412 | 360.5 | 309 | 257.5 |
| Rb. Green Gram | 0 | 463.5 | 412 | 360.5 | 309 | 257.5 |
| Rb. Sunflower | 1080 | 1188 | 864 | 1404 | 1512 | 1620 |
| Cotton | 1485 | 1633.5 | 1188 | 1039.5 | 891 | 742.5 |
| | | | | | | |
| CCA | 17824.78 | 21027.8 | 19477.37 | 19742.32 | 20555.52 | 20831.88 |
| | | | | | | |
| Net Benefit in Cr | 68.40 | 68.40 | 62.80 | 67.70 | 69.75 | 71.71 |



**Table 10.0: Optimized cropping pattern in study area for water availability of 5000 Ha-m**

| Optimal area in Ha obtained at 5000 Ha-m of Water Availability | | | | | | |
|---|---|---|---|---|---|---|
| CROPS | Ai□≤TIA | 10% | 20% | 30% | 40% | 50% |
| Kh. Jowar | 2435 | 2695 | 2607.73 | 3185 | 3430 | 3675 |
| Kh. Groundnut | 3910 | 3803.8 | 3128 | 2971.43 | 3011.44 | 3051.46 |
| Kh. Maize | 3570 | 3927 | 2856 | 3478.82 | 3988.64 | 4498.46 |
| Kh. Pulses | 0 | 3091.5 | 2748 | 2404.5 | 2061 | 1717.5 |
| Rb. Jowar | 1465 | 1611.5 | 1172 | 1904.5 | 2051 | 2197.5 |
| Rb. Maize | 1955 | 2150.5 | 1564 | 1368.5 | 1173 | 977.5 |
| Rb. Wheat | 1924.78 | 0 | 2704 | 2366 | 2028 | 1690 |
| Rb. Bengal Gram | 0 | 463.5 | 412 | 360.5 | 309 | 257.5 |
| Rb. Green Gram | 0 | 463.5 | 412 | 360.5 | 309 | 257.5 |
| Rb. Sunflower | 1080 | 1188 | 1296 | 1404 | 1512 | 1620 |
| Cotton | 1485 | 1633.5 | 1188 | 1211.91 | 1300.8 | 1389.69 |
| | | | | | | |
| CCA | 17824.78 | 21027.8 | 20087.73 | 21015.66 | 21173.89 | 21332.12 |
| | | | | | | |
| Net Benefit in Cr | 68.43 | 68.40 | 66.00 | 68.90 | 78.00 | 72.60 |

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**Table 11.0: Optimized cropping pattern in study area for water availability of 5500 Ha-m**

| Optimal areas in Ha obtained at 5500Ha-m of Water Availability | | | | | | |
|---|---|---|---|---|---|---|
| CROPS | Ai<=TIA | 10% | 20% | 30% | 40% | 50% |
| Kh. Jowar | 2435 | 2695 | 2607.73 | 3185 | 3430 | 3675 |
| Kh. Groundnut | 3910 | 3803.8 | 3128 | 2984 | 3025.1 | 3152.71 |
| Kh. Maize | 3570 | 3927 | 2856 | 2899.37 | 3361.13 | 3628.77 |
| Kh. Pulses | 0 | 3091.5 | 2748 | 2404.5 | 2061 | 1717.5 |
| Rb. Jowar | 1465 | 1611.5 | 1172 | 1904.5 | 2051 | 2197.5 |
| Rb. Maize | 1955 | 2150.5 | 1564 | 1368.5 | 1173 | 977.5 |
| Rb. Wheat | 1924.78 | 0 | 2704 | 2366 | 2028 | 1690 |
| Rb. Bengal Gram | 0 | 463.5 | 412 | 360.5 | 309 | 257.5 |
| Rb. Green Gram | 0 | 463.5 | 412 | 360.5 | 309 | 257.5 |
| Rb. Sunflower | 1080 | 1188 | 1296 | 1404 | 1512 | 1620 |
| Cotton | 1485 | 1633.5 | 1188 | 1930.5 | 2079 | 2227.5 |
| | | | | | | |
| CCA | 17824.78 | 21027.8 | 20087.73 | 21167.41 | 21338.23 | 21401.5 |
| | | | | | | |
| Net Benefit in Cr | 68.40 | 68.40 | 66.10 | 69.30 | 71.30 | 73.14 |



## 5.0 Conclusions

Markandeya reservoir project was designed to irrigate 23760 Ha of land. The maximum capacity of reservoir is 9344 Ha-m. The different proposed cropping pattern scenario is formulated for Markandeya command area based on irrigable command area and volume of water at different water availability in the reservoir Based on the study carried out, the following conclusions are made:

i. The mean monthly rainfall data for about past 30 years and Hydro-Meteorolological data for past 10 years are used n calculating the net irrigation requirements for each of the crops in the study area.
ii. The LP model developed for the study area is run for maximum net benefits using the software LINGO.
iii. The objective function of the model is subject to the following constraints: water availability, crop land requirement, Human labour cost, animal and machine power cost, seed cost, fertlizers and manure cost, fixed cost etc.
iv. The linear programming model is run for lowest water availability of 2000 Ha-m and then the model is also run for increased water availability in the increments of 500 Ha-m.
v. The optimal area of each crop to be allotted by LP model is less than or equal to total area of land allotted to each of the crops as given by the Irrigation department thus meeting the objective of maximum net benefit.

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vi. The study is also carried for each of the water availability case by varying the allotted areas of each crop by ±10 % to ±50%.

vii. The maximum net benefit for 2000 Ha-m availability is 54.12 Crores and increases to 78 Crores for 5000 Ha-m water availability.

viii. The total optimal cultivated area by LP model for 2000 Ha-m water availability is found to be 15485.62 Hectares and is increased to 21173.82 Hectares for 5000 Ha-m water availability.

ix. This different optimum cropping areas and net benefit obtained from LP model for different water availabilities are summarised in Table 12.

**Table 12.0: Optimized cropping pattern in study area for different water availabilities**

| Season | CROPS | EXISTING AREA in Ha | WATER AVAILABILITY | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2000 Ha-m at ±30%Ai | 2500 Ha-m at ±40%Ai | 3000 Ha-m at ±40%Ai | 3500 Ha-m at ±30%Ai | 4000 Ha-m at ±20%Ai | 4500 Ha-m at ±50%Ai | 5000 Ha-m at ±40%Ai | 5500 Ha-m at ±50%Ai |
| KHARIF | JOWAR | 2435 | 1823.07 | 1470 | 1850 | 3185 | 2940 | 3675 | 3430 | 3675 |
| | GROUNDNUT | 3910 | 5083 | 5474 | 5474 | 5083 | 4146.25 | 3049.82 | 3011.44 | 3152.71 |
| | MAIZE | 3570 | 4641 | 3849.6 | 3487.14 | 2950.67 | 4284 | 5244.12 | 3988.64 | 3628.77 |
| | PULSES | 3435 | 2404.5 | 1374 | 2061 | 2404.5 | 2748 | 1717.5 | 2061 | 1717.5 |
| RABI | JOWAR | 1465 | 1025.5 | 879 | 879 | 1025.5 | 1248.69 | 1600.42 | 2051 | 2197.5 |
| | MAIZE | 1955 | 0 | 1173 | 1173 | 1368.5 | 1564 | 977.5 | 1173 | 977.5 |
| | WHEAT | 3380 | 0 | 0 | 0 | 0 | 0 | 1690 | 2028 | 1690 |
| | BENGAL GRAM | 515 | 360.5 | 309 | 309 | 360.5 | 412 | 257.5 | 309 | 257.5 |
| | GREEN GRAM | 515 | 360.5 | 309 | 309 | 360.5 | 412 | 257.5 | 309 | 257.5 |
| | SUNFLOWER | 1080 | 0 | 648 | 648 | 990.09 | 1296 | 1620 | 1512 | 1620 |
| | COTTON | 1485 | 0 | 0 | 891 | 1030.5 | 1188 | 742.5 | 1300.8 | 2227.5 |
| | | | | | | | | | | |
| CCA in Ha | | | 15698.07 | 15485.62 | 17081.8 | 18767.77 | 20238.94 | 20831.88 | 21173.89 | 21401.5 |
| | | | | | | | | | | |
| Maximum Benefit in 10^8 | | | 5.32 | 6.014 | 6.31 | 6.69 | 6.89 | 7.171 | 7.8 | 7.314 |

x. The maximum optimum cropping area and net benefit obtained from LP model for different water availabilities are as given in Figure 2.0.

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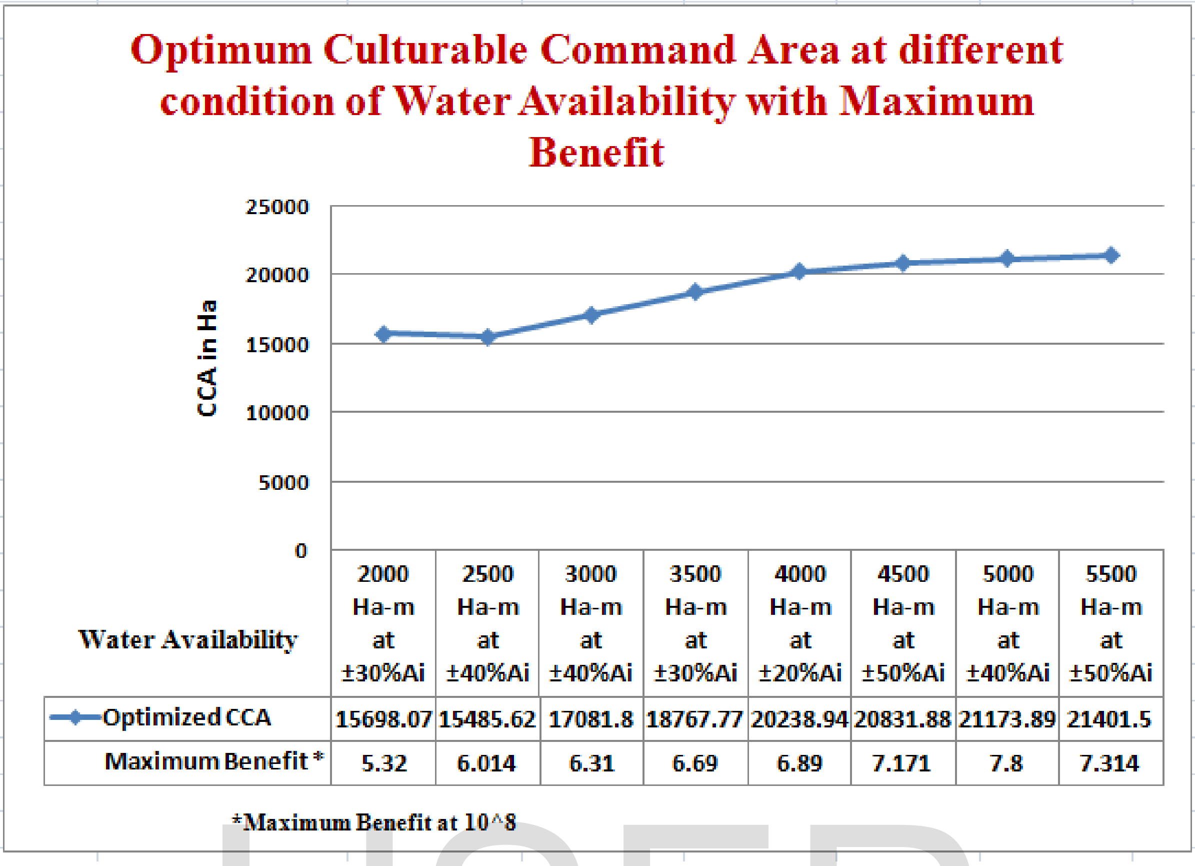


| Water Availability | 2000 Ha-m at ±30%Ai | 2500 Ha-m at ±40%Ai | 3000 Ha-m at ±40%Ai | 3500 Ha-m at ±30%Ai | 4000 Ha-m at ±20%Ai | 4500 Ha-m at ±50%Ai | 5000 Ha-m at ±40%Ai | 5500 Ha-m at ±50%Ai |
|---|---|---|---|---|---|---|---|---|
| Optimized CCA | 15698.07 | 15485.62 | 17081.8 | 18767.77 | 20238.94 | 20831.88 | 21173.89 | 21401.5 |
| Maximum Benefit * | 5.32 | 6.014 | 6.31 | 6.69 | 6.89 | 7.171 | 7.8 | 7.314 |

**Figure 2.0: Maximum Optimized cropping area and Net benefit in study area for different water availabilities**



## 6.0 Recommendations

Farmers are recommended to practice cropping pattern in the study area as suggested in Table 12.0 in order to get maximum net benefit for different water availabilities from the reservoir. The farmers should have adequate knowledge on the crop varieties used so as to know the best time to sow and harvest the crops, expected yield under full irrigation and all proper agronomic practices to be adopted.

Farmers are encouraged to fully protect their crops against diseases, pests and weeds. Diversification and optimum crop production can be practiced in command areas of Markandeya. Agronomic measures such as varying tillage practices and mulching can reduce the demand for irrigation water.

The farmers should be made aware of economic analysis to find out the optimum cropping pattern and profitably use their cropped areas for maximum net returns.

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