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Optimization Modelling For Crop Planning of Hasdeo Bango Command

S. K. Shrivastava[1], M. K. Verma[2], Mrs. C. P. Devatha[3],

Abstract

Optimal cropping pattern is one of the essential tasks for obtaining the benefit from an irrigation command with the available water resources, this task can be achieved by using optimization model, which plays a vital role in planning and management of water resource system.

An application of nonlinear optimization methodology has been developed for solving the NLP models.

Banahil distributary covers 22no. of benefitted villages to irrigate CCA of 11106.43hectare in Janjgir-Champa District Chhattisgarh India. The data on crops weather, soils, canal supply, and cost of cultivation pertaining to the study area have been collected from various Govt. departments, organisations & personal contact from the farmers of the command.

The wheat is the most profitable crop followed by sunflower. Sensitivity analysis has been carried out to study the effect of -20 to 20% change in sale price of crop, cost of cultivation and cost of canal water on the optimal solution. The present target summer paddy is about 20 % of CCA that means, if water supply on turn basis each cultivar field can get canal water after 5 years.

Keywords

Nonlinear programming, optimal cropping pattern, optimization, sensitivity analysis, water production function, water supply-demand.

S.K. Shrivastava

Research Scholar Department of Civil Engineering, National Institute of Technology,

Raipur, Chhattisgarh, PIN 492010, India

M.K. Verma

Department of Civil Engineering, National Institute of Technology,

Raipur, Chhattisgarh, PIN 492010, India

Mrs. C.P. Devatha

Department of Civil Engineering, National Institute of Technology,

Raipur, Chhattisgarh, PIN 492010, India

1. Introduction

Irrigation is the science of artificial application of water to land in accordance with the crop requirements throughout the crop period for full-fledged nourishment of crops. According to the N.D. Gulhati Irrigation is the "Science of Survival" for the main kind. Land and water are most important natural resources. Efficient use of this two are necessary for maximum benefit. The scarcity of water in the many parts of the world leads to the need of optimizing the benefits from the field of irrigation system by adopting effective & efficient water management. Our aim is to use water economically to get maximum crop output, for that optimization models are most widely accepted in the field of irrigation system planning and management.

In the present study, irrigation system planning for Rabi summer season at Banahil distributary of A. B.C. which is situated in R.B.C. of the Hasdeo Bango major irrigation project, Chhattisgarh selected.

A decrease in 10% of rainfall causes 5.8% loss in food grain production with the variation in its impact from region to region (Parthsarathy et al. 1988). In India water demand is shooting up with the growth of agriculture, industries and population. Moreover, due to growing population of India, which will be expected to reach 1395 million by 2025 (United Nation, 2005), increasing municipal, industrial and hydropower sectors need the share of water available for irrigation. In India, the irrigated areas are likely to go down from the present 93% to 83% by 2025 A.D. (Biswas, 1994).

Objective:

The implicit objectives associated in the present study are as follows:

(i) To develop an optimization model to determine the optimal Rabi cropping for maximizing the net seasonal return, a distributary of Hasdeo Bango, Chhattisgarh state.
(ii) To maximize the total net economic benefits from major irrigation project of Chhattisgarh.

The poor irrigation system performance, water management may be due to faulty irrigation scheduling which leads to mismatch between the supply and demand and thus impacts on crops yield due to shortage or excess of water at their critical growth stages, which also causes water logging, salinity and other environmental hazards in the command area Hence the proper irrigation scheduling and crop planning are required to achieve the maximum benefit.

Consider afore mentioned issues, several optimization models of irrigation system have been developed for obtaining optimal cropping pattern. Mainuddin et al. (1997) formulated a monthly irrigation planning model for determining the optimal cropping pattern and the groundwater abstraction requirement in an existing groundwater development project. Carvallo et al. (1998) developed a nonlinear model for determining optimal cropping pattern in irrigated agriculture.

Benli and Kodal (2003) NLP model developed based on crop water benefit function, Hasan et al. (2005) LP model was selected for optimal cropping pattern under various price option, Reis et al. (2006) Optimization model for optimal cropping pattern with different irrigation levels, Georgiou and Popamichali (2008) NLP optimization model to maximized the total farm income based on crop water production function, Salami et al. (2009) LP model to estimate agriculture cost, Panigrahi et al. (2010) Mathematical model developed using LGP technique for optimal area allocation, minimization of soil loss, investment and maximization of net return from agriculture.

Many of these models are developed for specific conditions and cannot be used directly in all irrigation system.

2. Study Area

Minimata (Hasdeo) Bango multipurpose project (Irrigation & Hydel Project) is located near village Bango on Hasdeo river, the largest tributary of Mahanadi river in Korba District of Chhattisgarh State, India, lies between21^{o} 30' to 22^{o} 45' north latitude and 82^{o} 15' to 83^{o} 15' east longitude with mean altitude of 350m above mean sea level. Index map of Hasdeo Bango Irrigation Project is shown in figure 1.

Banahil distributary (R.D.) 23.10 KM of Akaltara Branch Canal has been selected for present study is situated in RBC of Hasdeo Bango Command and lies between 21^{o} 51' to 21^{o} 59' north latitude and 82^{o} 17' to 82^{o} 26' east longitude, to irrigate 11,106.43 hectare, benefited villages 22 no. of Kharif rice, covers 8 villages of Akaltara Block & 14 villages of Pamgarh Block in Janjgir-Champa District, design discharge of distributary is 10.43m^{3}/ sec. The map of Banahil distributary with benefited village boundary is shown in figure 2.

The climate of the study area is hot and sub-humid. Normally, the temperature is maximum in the month of May and minimum in the month of January. The monthly average maximum and minimum temperature varies from 27.3°C to 41.7°C and the relative humidity of the area varies from 25.3 to 95.1% and its average value is always greater than 38%. The area receives more than 72% of rainfall during monsoon (June to September). The months of July and August, receive highest amount of rainfall. The average annual rainfall of the area for 10 years is 1350 mm in Janjgir-Champa District. The type of soil in study area is clay soil, sandy clay soil and sandy clay loam soil.

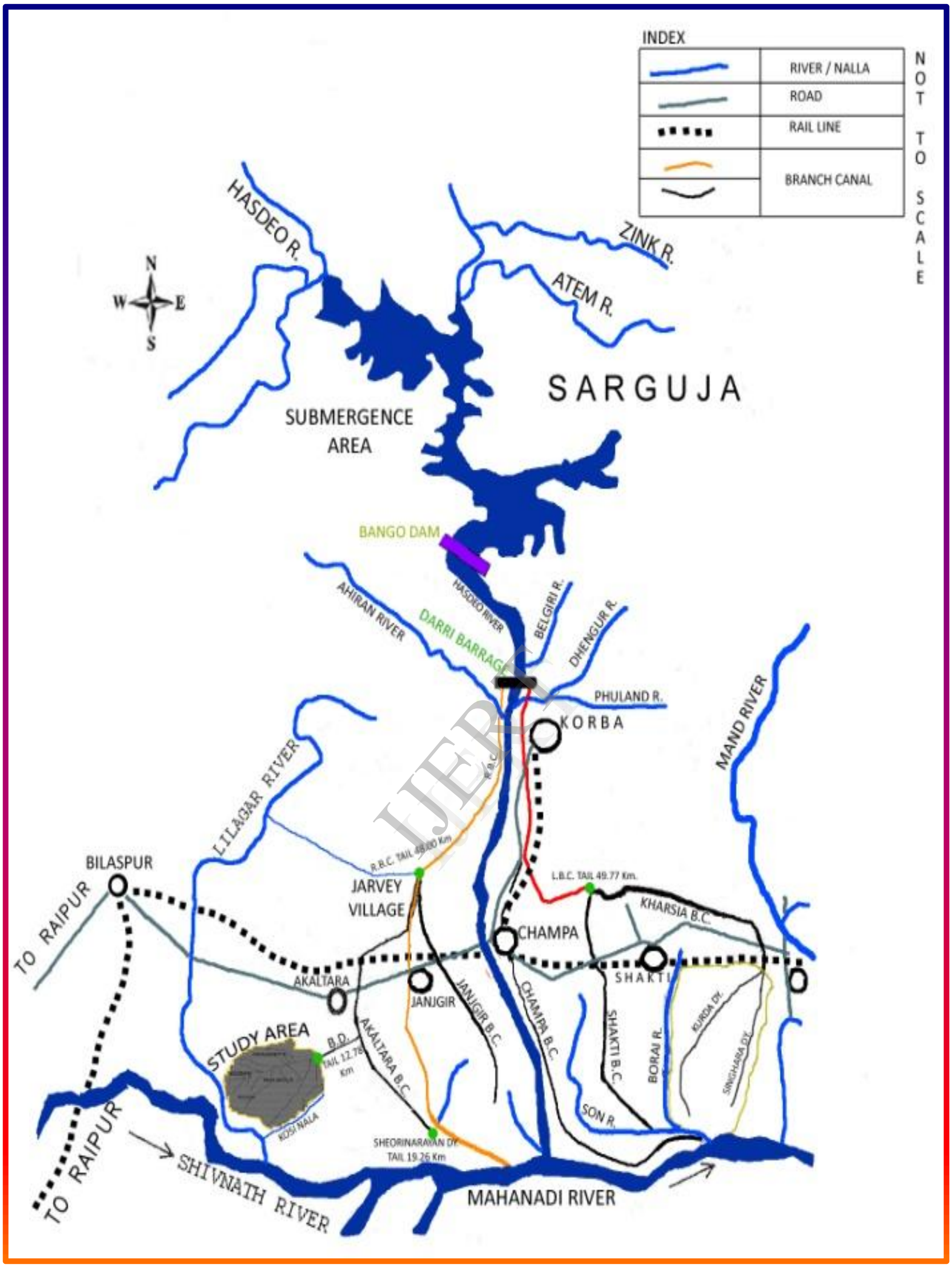

Fig. 1 Index map of Hasdeo Bango Irrigation Project

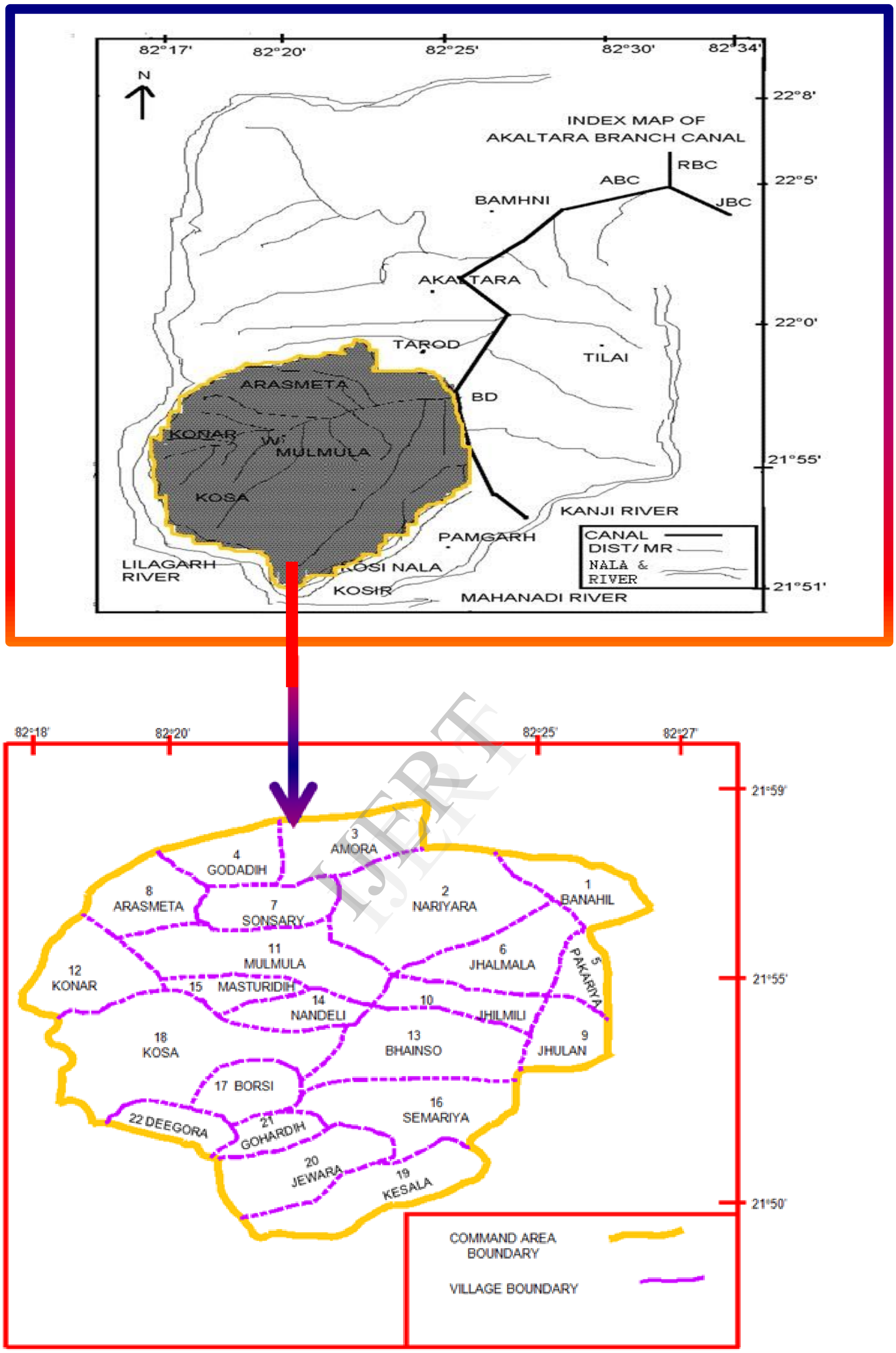

Fig. 2 Banahil distributary and its benefited village boundary

OBJECTIVE FUNCTION :-

$$\text{Max Z} = \sum_{j=1}^{3}\sum_{i=1}^{5}\left[P_i Y_{ij} - C_{ij}\right]A_{ij} - \sum_{j=1}^{3}\sum_{i=1}^{5} C_i^{w} A_{ij}$$

Equation can be represented as second order polynomial (Hexem & Heady, 1978)

$$Y_{ij} = f(DW) = a_{0,ij} + a_{1,ij}\,DW_{ij} + a_{2,ij}\,DW_{ij}^{2}$$

where, Z is the net return in Rupees (Rs);

P_i is the sale prices of crop i in Rs/kg;

Y_{ij} is the yield of crop i in soil j in Kg/ha;

C_{ij} is the cost of cultivation for crop i in soil j including the canal water cost in Rs/ha;

A_{ij} is the cultivated area of crop i in soil j are decision variable in ha;

C_i^{w} is the cost of canal water for crop i in Rs/ha;

DW_{ij} is the depth of water applied to the crop i in soil j are decision variable in cm; and $a_{0,ij}$, $a_{1,ij}$, and $a_{2,ij}$ are the regression coefficients.

For specific crop I and soil j, the equations can be written as

$$Y_{ij} = f(DW) = a_{0,ij} + a_{1,ij}\,DW_{ij} + a_{2,ij}\,DW^{2}_{ij} \qquad (1)$$

Where, Y_{ij} is the yield of the crop I in soil j, kg/ha and DW_{ij} is the depth of water applied to the crop I in soil j, cm.

The objective function of the optimization model can be, mathematically, expressed as

$$MaxZ = \sum_{j=1}^{3}\sum_{i=1}^{5}\left[P_i\{f(DW_{ij})\} - C_{ij}\right]A_{ij} - \sum_{j=1}^{3}\sum_{i=1}^{5} C_i^{w})A_{ij} \qquad (2)$$

Substituting Eq. (1) in Eq. (2) it yields a non-linear system

$$MaxZ = \sum_{j=1}^{3}\sum_{i=1}^{5}\left[P_i(a_{0,ij} + a_{i,ij}DW_{ij} + a_{2,ij}DW_{ij}^{2}) - C_{ij}\right]A_{ij} - \sum_{j=1}^{3}\sum_{i=1}^{5} C_i^{w})A_{ij} \qquad (3)$$

Where $Y_{ij} = f(DW) = a_{0,ij} + a_{1,ij}\,DW_{ij} + a_{2,ij}\,DW^{2}_{ij}$ (4)

Constraints

The objective functions in subject to the following constraints based on the availability of the resources, soil characteristics, and market considerations as follows:

Land availability

$$\sum_{i=1}^{5} A_{ij} \le TA_j, \forall j$$

(5)

$$\sum_{j=1}^{3} TA_j \le TC \quad (6)$$

Where, TA_j is the total area of soil j, ha; and TC is the total command area, ha.

Water allocation

$$\sum_{j=1}^{3} \sum_{i=1}^{5} (DW_{ij} - GIR_{ijij}) \ge 0 \quad (7)$$

Where, GIR_{ij} is the gross irrigation requirement of crop I in soil j, cm.

Water supply

The cumulative water demand of crop I in soil j should be less than or equal to the minimum available water supply. It can be expressed as

$$100 \sum_{j=1}^{3} \sum_{i=1}^{5} DW_{ij} A_{ij} \ge ACW \quad (8)$$

Where, ACW is the minimum available canal water, m^3.

Canal capacity constraint

The cumulative water demand of crop I in soil j should be less than or equal to the canal capacity. It can be expressed as

$$100 \sum_{j=1}^{3} \sum_{i=1}^{5} DW_{ij} A_{ij} \le 24x3600\,(CCxDC) \quad (9)$$

Where, CC is the design capacity of canal, m^3/s and DC is the duration of canal operation, days.

Crop area constraint

$$A_{ij} \ge \mu_{ij} TA_{ij} \forall i, j \quad (10)$$

Where, μ_{ij} is the restriction area constant (fraction)

Water bound

$$L_{ij} \le DW_{ij} \le U_{ij} \quad (11)$$

Where, L_{ij} is the lower limit, cm; and U_{ij} is the upper limit, cm.

Non-negativity constraint

The area and water applied depth values should always be positive

$$A_{ij} \ge 0; \forall i, j \quad (12)$$

$$DW_{ij} \ge 0; \forall i, j$$

(13)

Methodology

To obtain the optimal cropping pattern, the five selected crops i.e. wheat, sunflower, mustard, gram and safflower in the CCA 11106.43 hectare of Banhil Distributary. The solution to the above formulated nonlinear optimization model using Lingo 11 to maximize net return (Z) can be obtained by solving equitation 2 as the objective function and equitation 5-13 as constraints. The success of an optimization model based on the facts that, one is the selection of suitable model to a particular problem and second is efficient formulation of objective function and constraints in a systematic manner.

Many studies have used these models are optimization model for optimizing land and water resources system for specific condition and can't be used directly in all irrigation system, because of the fact that each of water resources system has different characteristic and different requirement are objectives (Yeh 1985).

The research aim of the present study is based on to obtain optimal cropping pattern and develop optimization modelling strategy to assess canal supply and demand scenario for existing and alternative cropping pattern. The general relationship between applied water and crop yield per unit area can be represented in two ways:

(i) Applied water VS yield
(ii) Consumptive use of water ET VS yield is shown in fig. 3.

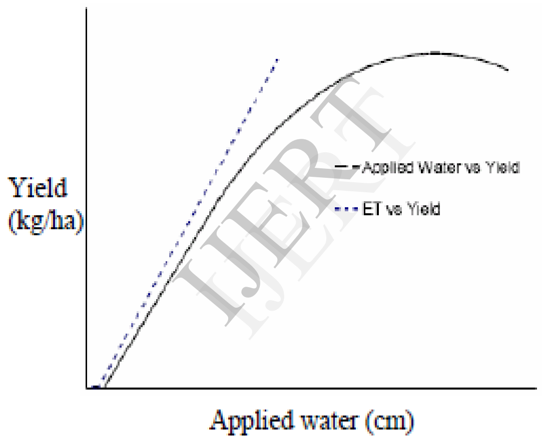

Fig. 3 General relationship between applied water and crop yield

The factors influencing the optimization model are water production function (crop yield Vs depth of water applied) is the experimental data of different crops in different soils, were collected from the annual progress reports, Indian Council of Agricultural Research, All India Coordinated Project for research on Water Management, Indira Gandhi Agricultural University, College of Agricultural & Research Station, Bilaspur, Chhattisgarh in India.

Procedure has been shown in the form of flow chart in Fig. 4.

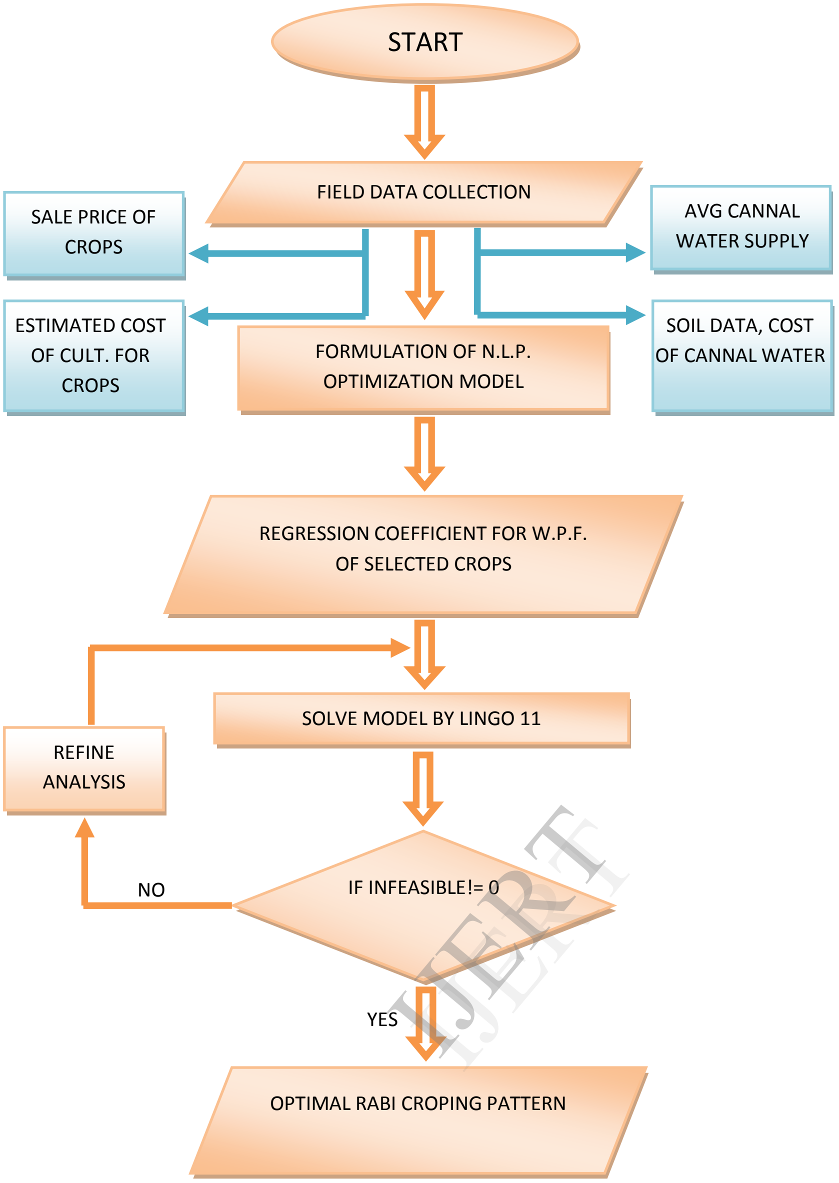

Fig. 4 Flow chart of methodology used for optimal Rabi cropping pattern

Sale price of crop (P_i), cost of cultivation including canal water cost (C_{ij}) and the cost of canal water (C_i^w). The regression constants and graphical views of water production function of different crops in different soils are given in Table 1 and Figure 5, 6 & 7 respectively.

The total land has been sub divided in to a no. of sub areas on the basis of soils and land availability constraints. The minimum available canal water during the study period has been taken as 35.34Mm^3. The land area constraints for certain crops have fixed as minimum so that the most profitable crops should not be dominant over the entire command area, which will also fulfil the basic food requirement of local people. The limitation of minimum area for each crop has been fixed as per the present cropping pattern (wheat 30%, sunflower 4%, mustard 16%, gram 8%, and safflower 4%) as specified in the respective constraints. These minimum areas given based on the existing Rabi cropping pattern of the command, has been fixed by personal contact from the farmers and agricultural officers.

Table 1 Regression coefficient of water production function of selected crops under different soils

Sl.	Crop	Soil	Production functions coefficients ($Y = a_0 + a_1 x + a_2 x^2$)			
			a_0	a_1	a_2	R^2
1	Wheat	Clay	-1218.44	307.54	-5.07	0.92
		Clay Loam	-1964.79	309.27	-4.18	0.89
		Sandy Clay Loam	-5934.41	414.96	-4.76	0.93
2	Sunflower	Clay	-694.89	222.11	-4.22	0.97
		Clay Loam	-694.89	222.11	-4.22	0.97
		Sandy Clay Loam	-694.89	222.11	-4.22	0.97
3	Mustard	Clay	-1044.10	284.37	-8.01	0.96
		Clay Loam	-1044.10	284.37	-8.01	0.96
		Sandy Clay Loam	-1044.10	284.37	-8.01	0.96
4	Gram	Clay	-296.47	242.07	-7.98	0.94
		Clay Loam	-296.47	242.07	-7.98	0.94
		Sandy Clay Loam	-296.47	242.07	-7.98	0.94
5	Safflower	Clay	-1427.30	334.47	-9.81	0.93
		Clay Loam	-1427.30	334.47	-9.81	0.93
		Sandy Clay Loam	-1427.30	334.47	-9.81	0.93
6	Summer rice	Clay	-10931.00	254.98	-0.91	0.93
		Clay Loam	-20982.00	337.72	-1.04	0.84
		Sandy Clay Loam	-2958.20	81.69	-0.22	0.89

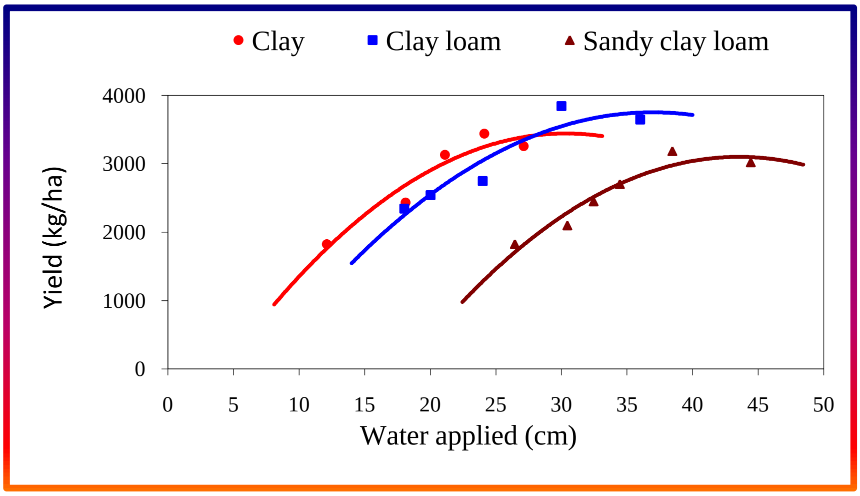

Fig. 5 Water production function of wheat in different soils

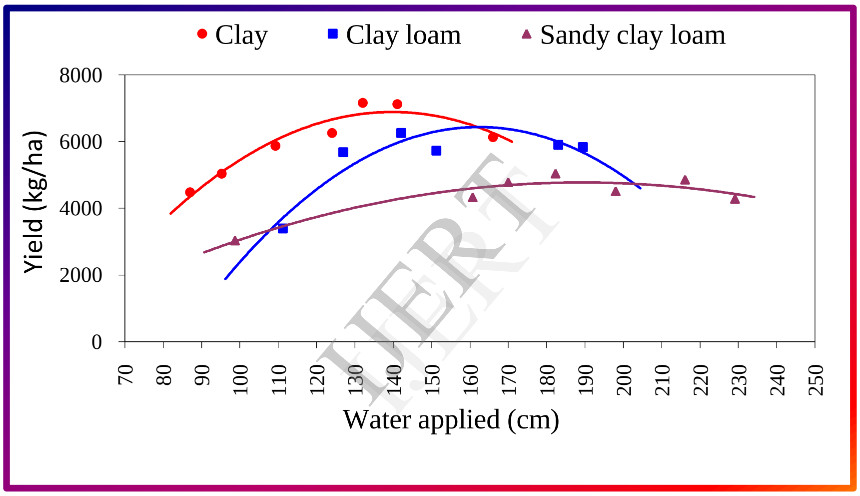

Fig. 6 Water production function of summer rice in different soils

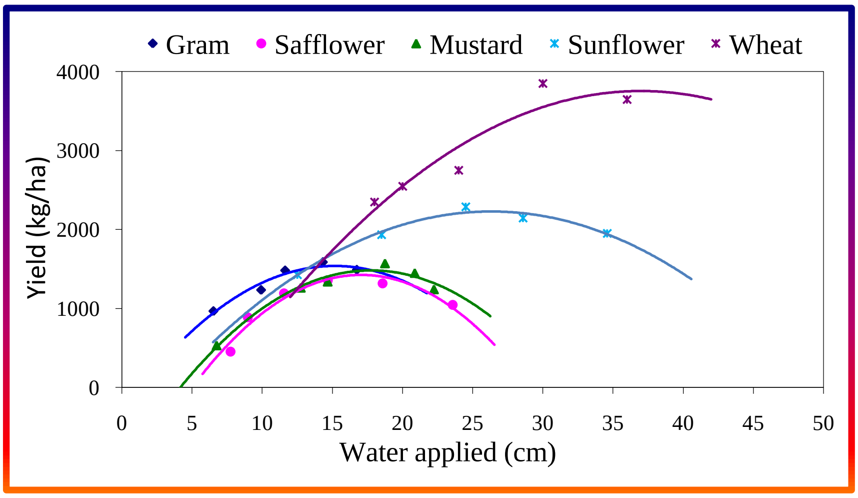

Fig. 7 Water production function of Rabi crops in clay loam soil

The average daily canal flow (CF) data of Banahil Distributary has been collected during the study period from the water resources; Government of Chhattisgarh is illustrated in Fig. 8.

- ❖ The discharge of canal varies from **5.20 to 0.31 m^3/s**
- ❖ Average discharge of **4.31 m^3/s** and standard deviation of **0.931 m^3/s.**
- ❖ Duration of canal operation during study in summer season varies from **114** to **133** days with an average of **121** days.

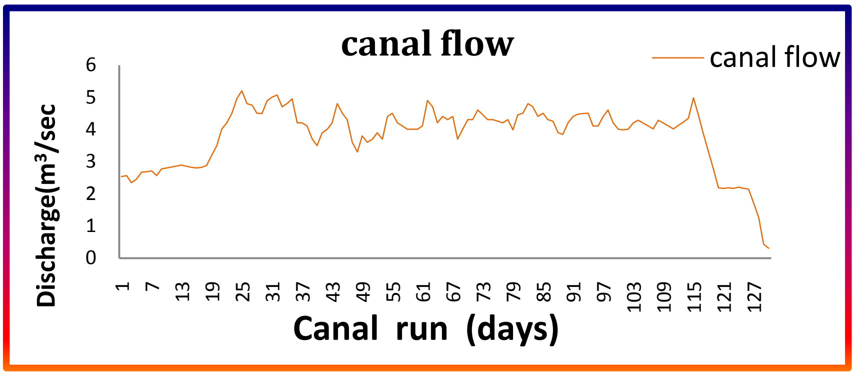

Fig. 8 Average daily canal flow of Banahil Distributary

Results and Discussion

The present study focussed on development of NLP optimization model has been solved by the application of Lingo 11 to derive the optimal cropping pattern.

COMPARISION OF OPTIMAL RABI CROPPING PATTERN WITH THE SUMMER RICE:-

Net return (Z)

- ❖ Summer rice, Rs 6, 30, 11,784 with the average crop grown area from 20% CCA (2101 ha.) Rs 29,991/ha.
- ❖ Optimal cropping pattern, Rs 30, 70, 99,700 from 100% CCA Rs 27,650/ha.
- ❖ Optimal cropping pattern 4.87 times higher than summer rice with saving of 8% of canal water.
- ❖ Total net return Rs 30, 70, 99,700 (Rs.27.650/ha).
- ❖ Most profitable crops
- ❖ Wheat (55.83%) as shown in Fig. 9
- ❖ Sunflower (16.16%)
- ❖ Minimum available irrigation water (35.334 Mm^3)

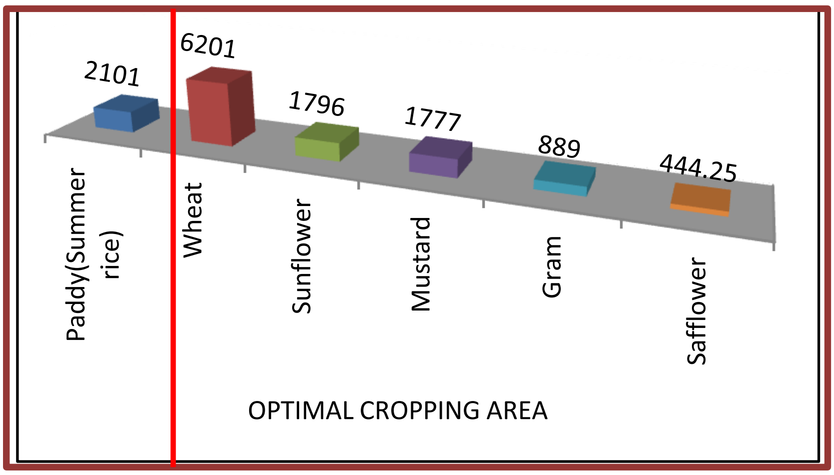

Fig. 9 shows the optimal cropping area for different crops

Sensitivity Analysis

Sensitivity analysis has been perform to test the effectiveness of optimization model among all the variable input parameters i.e. sale price of crops P_i in Rs. /kg, cost of cultivation C_{ij} in Rs. /kg and the cost of canal water C_i^w in Rs. /ha to find out the most sensitive input parameter that changes the result of model (optimal solution) related to the objective function parameters varied from -20 to20% of their respective value.

Most sensitive parameter has been always kept in priority while using the NLP for the optimal cropping pattern the net return are affected by sensitivity analysis so, take care for which variable is most sensitive, in present study sale price of crop is most sensitive parameter among C_{ij}, C_i^w although the minimum sale price of wheat is Rs.12.85/kg according to the crop year as on 25.10.2011 (Ref. www.pib.nic.in) than other corps instead of higher sale price.

Sensitivity of optimization parameters on net return (Z)

The effect of change in all selected input parameters (P_i, C_{ij} & C_i^w) on Z of the optimal solution revealed that the Pi is the most sensitive input parameters followed by C_{ij}. The C_i^w is found to be the least sensitive parameter since in the range of -20 to 20% had negligible effect below 1% as shown in Fig. 10.

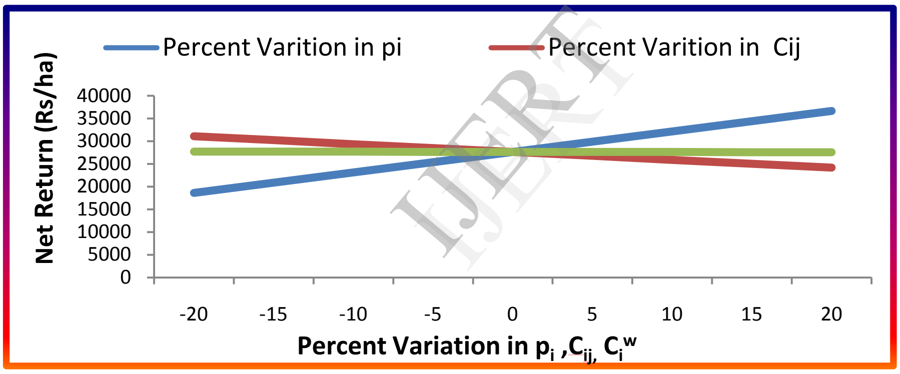

Fig.12 Sensitivity of optimization parameters on net return

Conclusion

The following conclusions have been drawn from the study:

- Kharif (Rice) occupied 100% of the CCA while in Rabi season, crop area varies according to the availability of the water in reservoir.
- Summer Rice (Paddy) occupied an average of about 20% of CCA of the study area.
- 47% excess water was supplied to the command for summer rice as compared to the actual seasonal water demand (149.52 cm)
- The excess (surplus) irrigation water can be utilized :
  (a) in downstream command for crop cultivation.
  (b) In any other purposes like domestic-industrial and municipal uses.
- The developed NLP model gave total net profit of Rs 30, 70, 99,700 (Rs. 27,650/ha) with the optimal area under wheat, sunflower, mustard, gram and safflower as 6200.92, 1795.71, 1777.03, 888.52 and 444.26 ha, respectively.
- The wheat is the most profitable crop followed by sunflower and their allocation is 55.83% and 16.16% of the CCA, respectively.

- Thus the optimal cropping pattern not only gives higher net return but also covered 100% CCA with 8% saving in seasonal supply (2.83 Mm^3) by proper utilization.

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