

Optimization Based Approach for Land, Water and Human Resources Management: A Comparative Study

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ABSTRACT: The study area Nuh region, Haryana state, India, lies between 27° 59' 30.4" to 28° 13' 40.3" North Latitude and 76° 57' 20.5" to 77° 10' 58.38" East longitude. It has predominant rural demography with agriculture and agro-based dairy & poultry business as back bone to its economy. Analysis of the existing scenario of the study area in terms of water, land and human resources was carried out to identify key parameters. These were used as input to MATLAB based optimization model to obtain optimal cropping policy and corresponding water and human labour requirements with emphasis on food and nutritional security, employability, environmental concerns and agro-based business of the region. A comparative study among the policies, which were obtained from different objectives viz.: 1. Maximization of net benefits; 2. Minimization of water use; 3. Minimization of emissions; and 4. Maximization of human labour employment, have been carried out.

KEYWORDS: MATLAB, Optimization, Maximization, Minimization, Food Security, Objectives, Net Benefits.

I. INTRODUCTION

The importance of agriculture sector in sustaining economic growth in developing countries, with limited cultivable land & growing population pressure, has been recognized way back in 1970's during Green Revolution. During this period continuous expansion of farmland and dual cropping policy on existing farmland took place in Haryana and Punjab [1, 2]. In India, the scope for horizontal expansion of land was virtually exhausted and the entire rainfall is uncertain and occurs within a short span of few days (within about 300 hours). Therefore, expansion of irrigation facilities, multiple sequences of crops, optimal cropping and water use policies are becoming critical requirements in agricultural sustainability [3, 4]. Food and Agriculture Organization (FAO) [5] has enunciated that the agriculture is an important engine of growth of rural economy and poverty reduction, yet this sector is underperforming in many countries. Department of Agriculture and Cooperation (DoAC) of Ministry of Agriculture, GOI in its report on State of Indian Agriculture [6] reiterated that agriculture is a critical sector of the Indian economy & forms the resource base for a number of agro-based industries and agro-services. FAO [7] advocated that integration of approaches according to local conditions, optimal utilization of natural resources and maximizing benefits & minimizing trade-offs should be given higher priority to achieve the goals of reducing poverty and malnutrition as well as sustainable inclusive growth. Attempts have been made by various researchers (list exhaustive) [8, 9, 10, 11, 12, 13] to study the optimal allocations of land, water, and other resources, multiple crop models in irrigated agriculture and are of the opinion that linear programming is one of the best tools for optimal allocation of resources where various crops are competing for a limited quantity of land and water resources. Rao [14] has reviewed that at least four Nobel prizes were awarded for contributions related to linear programming.

The present work focused on optimal utilization land, water and human resources to evolve a policy by comparing various policies which were obtained for different objectives. In the first stage of research work, identification of

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problems and requirements of the study area were studied. In the second stage, the data pertaining to land resources, water resources, human resources and other aspects were collected and procured and analysed to compute the key parameters. In the third stage, optimization model, comprises of objective function(s) and constraints conforming to the needs of the study area, was developed. Analysis was carried out using MATLAB.

II. RELATED WORK

IDENTIFICATION OF STUDY AREA

Mewat is one of the 21 districts of Haryana state of India. It was carved out as the 20th district from erstwhile Gurgaon and Faridabad districts on 4th April 2005 with its head quarter at Nuh. Nuh region falls under the Sub-Tropical, Semi-arid climatic zone with hot temperature mainly characterized by extreme dryness of air in summer. It is the land of a community locally called as “Meos” and is predominantly rural in demography. The main occupation of the people of this region is agriculture and agro-based dairy business. Domestic, agricultural and agro-based industrial needs including livestock demands are major demands of the region. As there is no river in Nuh region its agriculture is based on rain fed, canal water & groundwater. Potable drinking water is a problem in the region. Water supply was augmented by Rajiv Gandhi Rannay Well Drinking Water Supply Augmentation Project (known as rannay well project) scheme [13, 15, 16, 17]. The groundwater levels of the Mewat district from the year 1974 to 2006 showed a negligible (0.03 m/year) declining trend of water level (Arya 2011). There are 22 observation wells in Nuh region that are identified. In Nuh regions sand layers are few and the whole lithology is made up of clay and kankar and whereas electric conductance varied between 358 to 9210 micromhos/cm at 25^o C in the study area. The shallow groundwater up to a depth of 20 m was by and large fresh and fit for irrigation. Some parts were affected by water logging condition near Nuh, Malab and Akaira villages. It is also observed that water logging conditions are more in post-monsoon season resulted in salinity and thus declining agricultural production. Quality of groundwater varies widely within a small area and CGWB recommended micro level survey by taking every village as a unit. Also observed that salinity in the area has led to formation of silty-clay (Sand: 0-20; silt: 40-60; clay: 40-60) soil and its salt affected variety is called solonchak [17, 18, 19].

The annual rainfall of the region varies considerably from year to year. The maximum rainfall is experienced during the monsoon season, which reaches its peak in the month of July. The principal precipitation occurs during monsoon period from June to September when about 80% of the rainfall is received. The average annual rainfall (44 years average) in the district is 549 mm and increases towards east. On an average, there are 28 rainy days in the district [18, 19]. Two principal crop seasons, *Kharif* (monsoon, June-July to October) and *Rabi* (winter, November-March) are practiced in a year. Major crops during kharif season are paddy, pearl millet, sorghum, sorghum fodder and dhaincha and other crops are arhar (pigeon pea), mung (green gram), gwar (cluster bean), til (sesamum) and vegetables. During the Rabi season major crops are wheat, barley and mustard and other crops are gram, oilseed, pulses, Rabi fodder (berseem), and vegetables [19, 16, 13]. It was observed that the population of the study area increased from 212855 in 2001 to 287101 in 2011 (1.35 times). During same time interval, total number of households increased from 30879 to 42213, rural household increased from 29146 to 38714 and urban households from 1733 to 3499. It may be noted that growth rate of children population was less than the growth rate of total population of the study area. It was observed that the total population of the workers decreased from 85122 to 73700 (i.e. 13.42%) and whereas urban population of workers was increased from 3121 to 5437 (i.e. 74%). This may be due to migration of workers to adjacent cities [13].

The Most of the Villages of Nuh region are situated nearby the State Highway No13 & Major District Road No: 132. Nuh town is located at Delhi-Alwar state highway and is well connected by road network with all major towns in the region and is nearly 75 km from Delhi, 32 km from Palwal and 51 km from industrial complex of Faridabad and still remained as a region of socioeconomically backwardness and is identified as one of the most backward region by planning commission in 10th Five Year Plan. Thus Nuh region has been identified for the research work.

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DATA ACQUISITION & ANALYSIS

Assessment of Water Resources & Requirements

This consists of assessing total water resources available for the study area and computing total water demands for all sectors excluding irrigation. For the study area, available water resources are divided into four categories: (i) Canal water resources, (ii) Net groundwater available, (iii) Run-off water and (iv) Ranney well water. Similarly, Water demands excluding irrigation are evaluated into four categories: (i) Basic water requirement, (ii) Livestock and poultry requirement, (iii) Industrial requirement and (iv) Water for future allocations. The difference between total water available and total demands excluding irrigation is computed and used as total water available for irrigation in the model. The water input contains both surface water and groundwater and used as surface water input and groundwater input. Further water requirements of each crop are computed and used as input to the model.

Assessment of canal water resources

Net canal water availability for irrigation have been computed by deducting seepage losses (during conveyance) & other losses from gross water supply at the head of canal. Water supply at the head of the canal is obtained by multiplying discharge, in cumecs, and operating time in seconds. Seepage losses were calculated according to the case of Ghaggar basin canal systems seepage losses computed by Tyagi [21], Yangchan [22], Maitry [19] and Rao [13]. Other losses assumed as 20% [19], [13]. All the computations related to estimation of total canal water availability in monsoon and non-monsoon seasons of all canals and computations have been done using MATLAB.

Assessment of groundwater resources

The groundwater balance equation used by Khare [8], Rao [9, 13] and Maitry [19] was used. Net groundwater availability obtained from CGWB reports on groundwater resource and development potential of the study area Maitry [19] and up to 60% development of net groundwater availability considered as safe category is adopted in the study.

Assessment of runoff-water

Assessment of runoff water of the study area is estimated by using the empirical equations already developed by Uttar Pradesh Irrigation Research Institute (UPIRI) [23].

Ranney well water

At present Rajiv Gandhi drinking water supply augmentation project supplying about 55 lpcd of water to 28 villages of Nuh region. Ranney Well Water available for these identified villages of the region is computed for the prospective population of the year 2011.

Basic Water requirements

Different organizations, agencies and individuals have given different norms of water requirements and 100 lpcd (including UFW) is assumed for computing basic water requirements of the study area [13].

Livestock & poultry water requirement

Actual values of water requirements of livestock and poultry depends on many variable such as climate and cultural practices and different agencies recommended different quantities and 30 lpcd is used for assessing livestock (cattle) and 20 lpcd per 100 for poultry water requirement of the study area [13]

Industrial and future allocations

Growth rate demand of 7% [13] for future allocations of water for industrial needs was assumed.

Assessment of water requirements of crops

Food and Agriculture Organization (FAO- 56) methodology was used to compute the amount of water needed by the various crops to grow optimally.

Land Resources

The area under different crops during present study duration for both kharif and rabi seasons, irrigated and non-irrigated areas, socio economic characteristics of the farmers and crop production activities in terms of inputs, outputs and their prices, other related information constituted the bulk of the data collected and obtained from Office of Deputy Director of Agriculture and Office of Chief executive officer (CEO), Nuh, Mewat.

Human Resources

The human labour resource requirements and their restrictions have to be assessed considering available family labour and permanent labour on the farms. The labour was converted into adult man hours. An adult labour was assumed to work eight hours a day and twenty-five days a month. One female labour unit was assumed to be equivalent to 0.75 times of male labour unit Kaur [24], Rao [13]

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Environmental aspects

Emissions as N₂O & CO₂ and CO₂ Equivalents (CO_{2e})

Intergovernmental Panel on Climate Change (IPCC) and Inter International Food Policy Research Institute (IFPRI) guidelines were used to compute N₂O and CO₂ emissions. The international standard practice is to express greenhouse gases in carbon dioxide (CO₂) equivalents or CO_{2e} [25,13]

Minimum area required

Indian Council of Medical Research's (ICMR) & National Food Security Act (NFSA) guide lines were used compute the minimum cropping area required for different crops [26, 27].

III. DEVELOPMENT OF MODEL FOR DIFFERENT OBJECTIVES

OBJECTIVE 1

Maximization of Net Benefits

$$MAX(Z) = \sum_{j=1}^{nd} \sum_{i=1}^{nc} NR_{j,i} \times A_{j,i} \quad \dots(1)$$

nc = number of crops

nd = number of divisions (villages) of the study area (=119)

NB_{j,i} = net benefits from *i*th crop of *j*th division (village)

A_{j,i} = area of *i*th crop of *j*th division (village)

OBJECTIVE 2

Minimization of Water Use

$$Z = \sum_{j=1}^{nd} \sum_{i=1}^{nc} NIR_{j,i} \times A_{j,i} \quad \dots(2)$$

NIR_{j,i} = Net Irrigation Requirement of *i*th crop of *j*th village

OBJECTIVE 3

Minimization of Emissions

$$Z = \sum_{j=1}^{nd} \sum_{i=1}^{nc} FU_{j,i} \times A_{j,i} \quad \dots(3)$$

FU_{j,i} = Fertilizer Use of *i*th crop of *j*th village

OBJECTIVE 4

Maximization of Human Labour Employment

$$Z = \sum_{j=1}^{nd} \sum_{i=1}^{nc} HLR_{j,i} \times A_{j,i} \quad \dots(4)$$

HLR_{j,i} = Human Labour Requirement (in man-days) of *i*th crop of *j*th village

CONSTRAINTS

1. Total water required by all crops shall be less than or equal to total available water in that year.
2. Groundwater draft is always less than or equal to net groundwater available
3. Total irrigated area in Kharif season shall be less than or equal to cultivable area in kharif season
4. Total irrigated area in Rabi season shall be less than or equal to cultivable area in Rabi season
5. Total emissions (as CO₂ from groundwater pumping) from optimal cropping pattern shall be less than or equal to total emissions from existing cropping pattern
6. Total human labour required shall be less than or equal to total human labour available.

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7. Minimum area under each crop should be such that it shall satisfy food and nutritional requirements of study area
8. Maximum area under each crop should be such that it shall satisfy storage and marketing requirements of the area
9. Total domestic water required (*DWR*) for the population of the region should be less than or equal to total water allocated for domestic water use consumption
10. Total water required for livestock water use should be less than or equal to total water allotted for livestock water use consumption
11. Total water required for Industrial water use should be less than or equal to total water allotted for Industrial water use consumption
12. Total net benefits from the proposal shall be greater than or equal to the total benefits from existing condition.
13. Total human labour employment generated by the policy shall be greater than or equal to the human labour employment generated by the existing condition.

IV. ANALYSIS OF THE MODEL & DISCUSSIONS

MATLAB Based Optimization Model

Linprog(linprog.m) module of MATLAB was used for analysing the developed optimization LP model for various objectives. The particulars of 'linprog' are briefly described in following sections and syntax is tabulated in Table 1.

linprog: It solves linear programming problems specified by

$$\min_x f^T \cdot x \quad \text{such that} \begin{cases} A \cdot x \leq b \\ Aeq \cdot x = beq \\ lb \leq x \leq ub \end{cases} \quad \dots (5)$$

Table 1: Syntax of "linprog"

<i>A</i>	The matrix of coefficients of linear inequality constraints: $A \cdot x \leq b$
<i>b</i>	Vector of coefficients of corresponding right-side vector: $A \cdot x \leq b$
<i>Aeq</i>	The matrix of coefficients of linear equality constraints: $Aeq \cdot x = beq$
<i>Beq</i>	Vector of coefficients of corresponding right-side vector: $Aeq \cdot x = beq$
<i>f</i>	The vector of coefficients for the linear term in the linear equation $f^T \cdot x$
<i>x</i>	Vector of design variables
<i>lb, ub</i>	Lower and upper bound vectors (or matrices).

Objectives 1 & 4 are of maximization (coefficients of objective function are "-") and objectives 2 & 3 are of minimization (coefficients of objective function are "+"). These objectives were subjected different constraints as discussed above (inequality constraints- " \geq " & " \leq "). These are further subjected to four conditions- A, B, C and D based on cropping areas as given below.

Condition A:

- i. $lb \geq$ area based on food requirements
- ii. $ub \leq$ area based on storage requirements

Condition B:

- i. $lb \geq 0$
- ii. ub - no bounds

Condition C:

- i. $lb \geq 0$
- ii. ub - no bounds (except tomato ≤ 100)

Condition D:

- i. $lb \geq$ area based on food requirements
- ii. ub - no bounds (except tomato ≤ 100)

Where

lb : lower bound ub : upper bound

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While analyzing the model solutions were obtained in such a way that all constraints including conditions (A, B, C and D) and sub-conditions were satisfied and exitflag remained '1' (exitflag=1 means solution optimal). The results are presented in Table no's 2, 3, 4 and 5. Area in ha, Water Use in ha.m, Net benefits in Million \square , labour in man-days and N_2O in kg per year.

Table 2- Proposal based on Maximization of Net Benefits

Crop Name	Area	Water Use	Net Benefits	Labour	N_2O
Paddy	1996.00	2385.22	54.591	381236	719
Pearl Millet	12583.00	3661.65	94.624	1509960	15729
Sorghum	16808.00	857.21	103.873	2134616	16808
Fodder	2584.00	279.07	11.085	328168	2584
Dhaincha	100.00	22.00	0.298	8200	20
Kharif Pulses	1856.00	974.40	37.120	152192	371
Barley	15296.88	6103.46	334.543	2921704	15297
Mustard	1980.00	845.46	30.710	237600	1980
Tomato	100.00	69.00	8.608	12700	300
Wheat	14631.12	8778.67	418.889	1858152	21947
Berseem	2349.00	845.64	10.805	192618	2349
Rabi Pulses	1570.00	832.10	34.540	128740	314
Total	71854.0	25653.88	1139.686	9865886	78417

Table 2 depicts the details of optimal cropping areas of different proposed crops that can be irrigated and corresponding water use details, net benefits, labour employment and emission details for the proposal based on maximization of net benefits.

Table 3- Proposal based on Minimization of Water Use

Crop Name	Area	Water Use	Net Benefits	Labour	N_2O
Crop Name	Area (ha)	Water Use (ha.m)	Net Benefits (Million \square)	Labour (man-days)	N_2O (kg/year)
Paddy	1996.0	2385.22	54.591	381236	718.56
Pearl Millet	12583.0	3661.65	94.624	1509960	15728.75
Sorghum	16808.0	857.21	103.873	2134616	16808.00
Fodder	2584.0	279.07	11.085	328168	2584.00
Dhaincha	100.0	22.00	0.298	8200	20.00
Kharif Pulses	1856.0	974.40	37.120	152192	371.20
Barley	9454.1	3772.19	206.762	1389756	9454.12
Mustard	1980.0	845.46	30.710	211860	1980.00
Tomato	100.0	69.00	8.608	22800	300.00
Wheat	14163.0	8497.80	405.487	1770375	21244.50
Berseem	2349.0	845.64	10.805	298323	2349.00
Rabi Pulses	1570.0	832.10	34.540	113040	314.00
Total	65543.12	23041.75	998.503	8320526	71872.13

In comparison with the proposal based on maximization of net benefits, proposal based on minimization of water use is suggested to be irrigating less area, providing less net benefits and human labour employment but at the same time it is utilizing less water with less N_2O emissions.

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Table 4- Proposal based on Minimization of Emissions (i.e. Fertilizer Use)

Crop Name	Area (ha)	Net Benefits (Million ₹)	Water Use (ha.m)	Labour (man-days)	N ₂ O (kg/year)
Paddy	1996.0	54.590	2385.22	381236	718.56
Pearl Millet	12583.0	94.624	3661.65	1509960	15728.75
Sorghum	5966.1	36.870	304.27	757689	5966.06
Fodder	2584.0	11.085	279.07	328168	2584.00
Dhaincha	100.0	0.297	22.00	8200	20.00
Pulses	10602.7	212.053	5566.40	869418	2120.53
Barley	279.0	6.101	111.32	41013	279.00
Mustard	1980.0	30.709	845.46	211860	1980.00
Tomato	100.0	8.608	69.00	22800	300.00
Wheat	14163.0	405.486	8497.80	1770375	21244.50
Berseem	2349.0	10.805	845.64	298323	2349.00
Rabi Pulses	5785.0	127.269	3066.05	416520	1157.00
Total	58487.71	998.503	25653.88	6615562	54447.40
Labour Male/Day 17352		Labour Female/day 5784			

Tables 4 and 5 depicts details of optimal cropping areas, net benefits, water use, human labour employment and emissions as N₂O for the proposals based on minimization of emissions and maximization of human labour employment respectively.

Table 5- Proposal based on Maximization of Human Labour Employment

Crop Name	Area (ha)	Net Benefits (Million ₹)	Water Use (ha.m)	Labour (man-days)	N ₂ O (kg/year)
Paddy	2078.2	56.840	2483.51	396945	748.17
Pearl Millet	12583.0	94.624	3661.65	1509960	15728.75
Sorghum	16725.8	103.365	853.01	2124170	16725.75
Fodder	2584.0	11.085	279.07	328168	2584.00
Dhaincha	100.0	0.297	22.00	8200	20.00
Pulses	1856.0	37.120	974.40	152192	371.20
Barley	15765.0	344.780	6290.23	2317455	15765.00
Mustard	1980.0	30.709	845.46	211860	1980.00
Tomato	100.0	8.608	69.00	22800	300.00
Wheat	14163.0	405.486	8497.80	1770375	21244.50
Berseem	2349.0	10.805	845.64	298323	2349.00
Rabi Pulses	1570.0	34.540	832.10	113040	314.00
Total	71854	1138.263	25653.88	9253489	78130.37
Labour Male/Day 24271		Labour Female/day 8090			

The proposals based on different objectives were compared in Table 6 and it was observed that all the proposals were performing better than the existing scenario. The proposal based on maximization of net benefits projected to irrigate 41.45, 0, 9.63 and 22.85 percent more than existing, objective 2, 3 and 4 respectively. It was also observed that proposal based on objective 1 expected to provide 49.13, 6.62, 18.57 and 49.13 percent more employment opportunities than existing, objectives 2, 3 and 4 respectively to the available population of the study area. In respect of emissions as CO_{2e} (tonne/ ha) proposal based on objective-1 anticipated to emit 50, 0, 5.2 and 14.3 percent less emissions than existing, objectives 2, 3 and 4 respectively. Whereas in terms of net benefits policy based on objective 1 estimated to return 14.13, 0.12, 14.13 and 14.13 percent more returns in Million ₹ than existing, objectives 2, 3 and 4 respectively. With respect to water use, 25653.88 ha.m quantity of water has been allocated (after fulfilling demands of the study area), for

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all objectives, which was 2.46 percent less than that of existing condition. It was assessed that objective 3 utilized 10.18 percent less water than allocated.

Table 6- Model output of all objectives

Category	Crop Area (ha)	Human Labour (per day)			Emissions (t/year)				Net Benefits (Million ₹)		Water Use (ha.m)
		M	F	Total	CO ₂	N ₂ O	CO _{2e}	CO _{2e} t/ha	Total	P (₹)	
Existing	50795	17352	5784	23136	163742.4	59.9	181602.1	3.6	998.5	3478	26302.59
Objective 1	71854	25878	8626	34504	107750.2	78.4	131118.5	1.8	1139.6	3970	25653.88
Objective 2	71854	24271	8090	32361	107750.2	78.1	131033.3	1.8	1138.2	3964	25653.88
Objective 3	65543	21824	7275	29099	107750.2	71.8	129168.1	1.9	998.5	3478	23041.75
Objective 4	58487	17352	5784	23136	107750.2	54.4	123975.5	2.1	998.5	3478	25653.88

Note:- M: Male F: Female P: per capita per annum t: tonne

V. CONCLUSION

Out of all the policies evolved based on different objectives, as discussed earlier, the policy based on maximization of net benefits (i.e. objective 1) performed better in optimal utilization of land, water and human resources. Thus evolved policy suggests optimal utilization of land resources by providing maximum cropping area to suitable required crops, optimal utilization of water resources, fulfilment of food security requirements of the region with increased cropping areas of required crops, fulfilment of nutritional security of the region to help poverty alleviation and eliminating malnutrition, consideration of demands of livestock requirements and hence thrust on agro-based business, consideration of human labour employment and social development, consideration of Environmental concerns to reduce emissions of greenhouse gases to reduce global warming phenomena and more net benefits infers increased per capita and enhancement of financial status of the people of the region

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