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Interactive Fuzzy Multi-objective Programming in Land Re-organisational Planning for Sustainable Rural Development

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***Abstract*—**Sustainability in rural production system can only be achieved if it can suitably satisfy the local requirement as well as the outside demand with the changing time. With the increased pressure from the food sector in a globalised world, the agrarian economy needs to re-organise its cultivable land system to be compatible with new management practices as well as the multiple needs of various stakeholders and the changing resource scenario. An attempt has been made to transform this problem into a multi-objective decision-making problem considering various objectives, resource constraints and conditional constraints. An interactive fuzzy multi-objective programming approach has been used for such a purpose taking a case study in Indian context to demonstrate the validity of the method.

***Keywords*—**Land re-organisation, Crop planning, Multi-objective Decision-Making, Fuzzy Goal Programming.

I. Introduction

IN today's globalised world, every sector of the economy needs to re-orient itself to meet the changing demand. This is very much necessary as the need patterns of the individuals are getting transformed by the intensity of the local and global forces. The rural sectors of the developing economies are not exceptions in this regard. The sudden boom in food retail sectors has also changed the orientation and status of farming from purely individualistic to group oriented activities in India. This is due to the growing demand of marketable and exportable food products through efficient supply chain management by retail chains which enabled farmers a better price for their products. However, for a sustainable development, this sector need to satisfy the requirements of the local people not only in terms of increased per capita income, but also the type and quantity of food they get from the locality due to their cultural inertia. As per the guidelines of UNESCO's "World Decade for Cultural Development", a development strategy would be endogenous, when it would be in the framework of its societal culture. But, the effect of globalization would also make it sustainable when it would be in equilibrium due to cultural and global forces.

The challenges ahead for a country like India is to produce more food and agricultural commodities under conditions of diminishing per capita arable land and water resources and expanding biotic and non-biotic stresses. The dimensions of challenges faced for developing scientific strategies and public policies for sustainable food security prevailing in the country can be estimated from the expanding scenario of the population growth of the country, which will reach between 1.5 billion and 1.8 billion by the year 2050 as per the estimate of International Water Resources Society in 1999. The United Nation agencies have put the figure at 1.64 billion. In terms of food requirement, the country needs 450 million tonnes of food grain to meet the requirement by 2050 AD as against the present food production of 200 million tonnes. To produce the food requirement of 450 million tonnes is a gigantic task with the limited resources. The country to day with respect to global term has 16% of human population, 15% of farm population, 2% of geographical area, 1%of rainfall, 0.5 % of forest and 0.5% of grazing land. At present juncture it is inevitable for India to improve its agriculture production technology not only to satisfy the food requirement of the growing population but also to improve the economic conditions of the majority population who live in rural areas and whose livelihood is from agriculture sector. Thus agriculture is the backbone of the Indian economy. It accounts for 27% of GDP, contributes 21% of total exports, and raw materials to several industries. In the present juncture there is increase in demand for water resources between agricultural and non-agricultural sectors as a result, the developed systems warrant efficient use of resources in the irrigated agricultural sector as it utilises major share of water resources i.e, nearly 80% of the total water resources. More over in spite of steady development of irrigation potential there is not appreciable increase in agricultural production. The factors contributing to this are under utilisation of irrigation potential created during different plan periods and improper water management as a result there is wastage of water and waterlogging in some fields and water inadequacy in other. Moreover, the absence of proper crop plan and irrigation scheduling based on different parameters

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like soil, land type; cultural practices and priority of farmers; and increasing market demand for selected crops has forced the planners for a suitable land re-organisation and common resource management for effective delivery from this sector meeting the needs of the local people as well as the outside markets.

The study emphasizes primarily to optimise the economic and social returns for the water users especially in the farming sector by efficient use of water resources. In the present scenario inadequate attention is currently being given for satisfying simultaneously the goals of the individual farmers, group of farmers or association of farmers and the Government. Since, water is not reaching the tail areas of the command area in the dry season, there is discrepancy between the actual water demand and delivery at different time periods. Unreliability in water supply attributed to the absence of predetermined irrigation schedule, canal operation plan and an optimal crop plan. The canal systems are unable to achieve their potential irrigation intensities, which concern to the irrigation engineers as well as to the researchers. The strategies that can be adopted in the project area with available resources can be viewed from various angles of management considerations, which are multi-dimensional in nature. The criteria that can be perceived are narrated below:

Criteria which are of more concern to the farmers viz., more benefit and less investment cost;

Criteria, which are more concern to the Government and planners viz., more area to be brought under irrigation, more production of foodstuffs and generation of more employment.

Considering these into account as well as various resource constraints and conditional constraints, a suitable cropping pattern is very much essential over the existing one for a possible re-allocation of land to a new system of crops satisfying the local requirements. This is due to the current forces arising out of globalization and changing lifestyles all around. Due to the tremendous pressure in food sector traditional agriculture need a fresh look for an agrarian economy like India for a possible re-organization of its cultivable land system through optimum utilization of water and other available resources.

II. Planning for Sustainable Rural Development

The command area of Satasankha distributary in Orissa state of India covering an area of 1817.45 ha. has been selected for this study. Satasankha distributary takes off from Sakhigopal branch canal at R.D 23.844 km. The Sakhigopal branch canal serves to command area of 28,831 ha. between the Bhargavi river and the central drains of the Bhargavi and Daya doab. This is the doab VII of Mahanadi delta. The higher lands in the command, is located adjacent to the river and drain transversely to the interior. Soils of the study area are mostly alluvial, sandy near the rivers and become heavier in lower areas. The data collection was made according to the requirement of the present study area from relevant Departments and by field survey. A few assumptions have been considered in the development of the allocation models. They are as follows:

All the relationships within the model are linear.

There are two types of land so as topography is concerned but the soil of the project area is homogeneous.

Each unit of land under consideration receives same management practices for a particular crop activity. Hence, the yield and benefit under a particular crop activity are constant.

The unit area of all the paddy crops considered in this study are divided in to two equal area and are staggered by one week from each other but will receive same management treatment and will give same yield.

All activity levels for different crops are considered independent of each other and within their finite limit and non-negative in nature.

Timing and period of cropping are constant and do not vary over years.

Resources are divisible and transportable.

The irrigation cost per unit area for a particular crop is same irrespective of location within the command.

Though a year is distinctly divided into three seasons namely kharif, rabi and summer so far as cropping activity is concerned, there is certain overlapping situations exists in few crop activities and care is taken by providing suitable constraints during weekly analysis by dividing the entire year in to fifty two weeks.

It is planned that the dates (standard weeks) for commencement of kharif, rabi and summer seasons are 11th June (24th), 22nd October (43rd) and 29th January (5th) respectively. After a careful consideration of the climatic conditions, topography, drainage problem, land and soil type, existing practices and the affinity of farmers as explained in foregoing sections, a crop calendar has been planned and presented in Table I, basing on which the proposed study has been proceeded. The notations assigned to the crops are also described in this table. Here after, where ever required crops will be designated as the notations assigned.

TABLE I
GROWING PERIOD OF DIFFERENT CROPS AND ASSIGNED NOTATIONS

Crops	Notations as Variables Assigned	Sowing date	Harvesting Date	Standard Week
Kharif (Rainy Season)				
1. Paddy –I	X_1	11th Jun	14th Oct	24-41
2. Paddy-II	X_2	11th Jun	28th Oct	24-43
3. Brinjal	X_3	11th Jun	21st Oct	24-42
4.Ridge-Gourd	X_4	11th Jun	30th Sep	24-39
Rabi (Winter)				
5.Paddy-II	X_5	12th Nov	18th Mar	46-11
6. Pulse	X_6	19th Nov	18th Feb	47-7
7. Groundnut	X_7	5th Nov	18th Feb	45-7
8. Fodder	X_8	5th Nov	15th Apr	45-15
9. Potato	X_9	5th Nov	25th Feb	50-8
10.Tomato	X_{10}	22nd Oct	28th Jan	45-4
11.Cabbage	X_{11}	22nd Oct	21st Jan	46-3
12. Brinjal	X_{12}	22nd Oct	21st Jan	46-3
Summer				
13.Porovol	X_{13}	19th Feb	6th May	5-18
14. Groundnut	X_{14}	19th Feb	13th May	5-19
15. Green gram	X_{15}	12th Feb	13th May	8-19
16. Vegetable	X_{16}	18th Mar	13th May	11-19
Annual				
17. Rice-Fish	X_{17}	4th Jun	13th May	23-19
18. Banana	X_{18}	28th May	6th May	22-18

Kharif (126 days) 11th Jun to 21st Oct (24th - 42st week)
Rabi (98 days) 22nd Oct to 18th Feb (45th - 7th week)
Summer (98 days) 19th Feb to 13th May (5th - 19th week)

For the formulation of a land re-organisatioal model based on the above crops resource utilization as well as availability data over a period of 11 years has been considered for a consistent and reliable plan. Some of the basic assumptions for such time-series data are as:

i. The crop water requirement for the crops actually grown and proposed in the problem is estimated on the basis of 30 years historical meteorological parameters. The procedure used here for a water balance equation in which rainfall, irrigation water availability and evapo-transpiration are considered as stochastic variables

ii. The irrigation requirement for the crops grown in the past and presumed to have been grown in the past have been calculated on the basis of crop water requirement and effective rainfall.

iii. The period of consideration is 11 years from 1996 to 2006. The average value of population is 14,647 and standard deviation is 1085.

iv. The average productivity was determined from the farmers for the crop actually they had grown in the past and has been reconciled with the productivity reported by different agencies. The average productivity of the crops which were not grown in the command and assumed as grown in the study period were taken from the nearby command in the same agro-climatic zone.

As the labour force available and bullock data for the period 1996-2006 were not available, the labour force available during 2007 has been considered for the purpose based on the assumption that the availability of agricultural labour force were more during previous years in that area and presently it is in a decreasing trend as there is migration of people to other profession and use of farm machinery are increasing.

The cost of cultivation and benefit were calculated from the data collected from the farmers and reconciling with price index for those years.

The population growth for the study area calculated based on the data given in the District statistical hand book of Puri District.

In multi-criteria decision-making process for Water Resource Management Problem, ideal resource criteria play important role for crop planning and irrigation scheduling for exploring the potentiality of the project area. In this process there is sufficient scope for analytic decision making. Various analytical tools have found their way in this area, but multi-objective programming is more appropriate and realistic as it takes into account the multi-dimensionality of the field reality. Generally, there does not exist a single solution which can maximise (minimise) all the objectives. There exists a set of alternatives out of which a “good alternative” also termed as “compromise solution” has to be singled out. To accomplish this, the various available methods are, utility theory, goal programming, vector-maximum methods etc. which may have interactive approaches also.

The present paper highlights the multi-objective decision making approach to crop planning and irrigation scheduling. The problem for such a system can be presented as:

$$Max \sum_j c_{ij} x_{ij} \quad : \ i = 1,2 \ldots m$$
$$\sum \sum (a_{ij}, \sigma'_{ij}) x_{ij} \le (b_{ij}, \sigma''_{ij}) \qquad (1)$$
$$x_{ij} \ge 0 \ \text{for all} \ i \ and \ j$$

where, c_{ij}, x_{ij} represents the various conflicting objectives in the decision environment and the resource constraints are based on time-series data. The nature of these constraints reduces the problem to a stochastic-multi-objective decision-making form for which a solution procedure is essential.

Mohan and Srinivas, developed a chance-constrained model to derive the optimal cropping pattern and optimal water utilisation for two different drought conditions (75% and 80% of the mean flows) in Vaippar basin of Tamilnadu [14]. It was seen that as the drought intensity increased, the quantum of assured water decreased. The optimal situations suggested, during droughts the dry crops like groundnut and cotton could be grown fully and ragi, sunflower and rice can be grown only in part of the total area available.

Johnson used chance constrained linear programming (CCLP) to determine the optimum service area for a rehabilitated surface irrigation scheme so that the expenditure on farm development works for intensive irrigation is not wasted [13]. Due to the uncertain nature of monsoon rainfall, the service area dependent on the reservoir storage is a stochastic value. In the light of extreme variability in inflows average annual runoff may be an incorrect statistic to be used for design purpose. Under the situation, CCLP with a given reliability level allows for an examination of the impact of not always being able to meet the target of serving all of the irrigated area.

Azahar presented a procedure to estimate probabilistic irrigation requirement for low land rice cultivation. The procedure was used for a water balance equation in which rainfall and evapo-transpiration were considered as stochastic variables [7]. The Leaky law, total probability theorem and SMEMAX (smallest, median and maximum) and power transformations were tried to estimate weekly rainfall and normal distribution for estimating weekly evapo-transpiration. The objective was to maximise the net returns from all the crops, subject to the land, the reservoir water, the crop water demand, the ground water and the capacity of each water resource constraints.

III. Land Re-Organisation Decision System

The notations, symbols, variables and constants used for the model can be explained as:

A_{ij} = Total area available for i-th crop in j-th land (ha.)
B_{ij} = Average benefit from `i'th crop on `j'th land(Rs./ha)

B_k = Average benefit from animal of type `k' per year(Rs.)

σ_{Bij} = Standard deviation of benefits from `i'th crop on `j'th land over the period(Rs./ha)

σ_{Bk} = Standard deviation of benefits from `k'th animal/bird over the period(Rs./ha)

C_{ij} = Average cost of cultivation of `i' th crop in `j' th land(Rs. /ha)

C_k = Average cost of rearing of animal of type `k'(Rs.)

σ_{Cij} = Standard deviation of investment for `i'th crop on `j'th land over the period(Rs./ha)

σ_{Ck} = Standard deviation of investment for `k'th animal/bird over the period(Rs./ha)

L_{ij} = Labour engagement in `i' th crop`j' th land(Man-days)

L_k = Labour engagement in `k' th animal/bird (Man-days)

P_{ij} = Average production from `i' th crop in `j' th land (kg. /ha.)

P_k = Average production from `k' th animal (kg /animal)

σ_{Pij} = Standard deviation of production from `i' th crop in`j' th land (kg. /ha.)

σ_{Pk} = Standard deviation of production from `k' th animal (kg. /ha.)

W_{ij}^{w} = Average depth of water required for `i' th crop on ` j' th land for `w' th week (ha-mm.)

W_k^{w} = Depth of water required for `k' th Animal for `w' th week (ha-mm.)

W^{w} = Average quantity of total availability of water in `w' th week (ha-mm.)

σ_{Wij} = Standard deviation of water requirement for `i'th crop on `j'th land in `w' th week over the period (ha-mm)

σ_{Wk} = Standard deviation of water requirement for `k'th animal in `w' th week over the period for which stochastic analysis is made, ha-mm

σ_{Ww} = Standard deviation of total available Water in `w' th week over the period for which stochastic analysis is made, ha-mm

E_{ij}, E_k and E_N = Average quantity of energy from `i'th crop in `j'th land /hector; energy from animal of type `k' per year and total energy requirement of the population per year respectively(Kcal.)

$\sigma_{Eij}, \sigma_{Ek} and \sigma_{EN}$ = Standard deviations of energy from `i'th crop in `j'th land /hector; energy from animal of type `k' per year and total energy requirement of the population per year respectively over the period (Kcal.)

T_{ij}, T_k and T_N = Average quantity of protein from `i' th crop on `j' th land / hector; protein from animal of type `k' per year and total protein requirement of the population per year respectively (kg.).

$\sigma_{Tij}, \sigma_{Tk} and \sigma_{TN}$ = Standard deviations of protein from `i' th crop on `j' th land / hector; protein from animal of type `k' per year and total protein requirement of the population per year respectively over the period (kg.)

I_{ij}, I_k and I_N = Average quantity of iron from `i' th crop on `j' th land / hactor; iron from animal of type `k' per year and total iron requirement of the population per year(kg)

$\sigma_{Iij}, \sigma_{Ik} and \sigma_{IN}$ = Standard deviations of iron from `i' th crop on `j' th land / hactor, iron from animal of type `k' per year and total iron requirement of the population per year over the period(kg.)

Ca_{ij}, Ca_k and Ca_N = Average quantity of calcium from `i' th crop on `j' th land / hector; calcium from animal of type `k' per year and total calcium requirement of the population per year respectively (kg.)

$\sigma_{Caij}, \sigma_{Cak} and \sigma_{CaN}$ = Standard deviations of calcium from `i' th crop on `j' th land /hector, calcium from animal of type `k' per year and total calcium requirement of the population per year respectively over the period (kg.)

Ce_{ij} and C_E = Average quantity of cereal from `i' th crop on `j' th land / hector and cereal requirement of the population per year (kg.)

$\sigma_{Ceij} and \sigma_{CE}$ = Standard deviations of cereal from `i' th crop on `j' th land / hector and cereal requirement of the population per year over the period (kg.)

Pe_{ij} and P_E = Average quantity of pulse from `i' th crop on `j' th land /hector and pulse requirement of the population per year respectively (kg.)

$\sigma_{Peij} and \sigma_{PE}$ = Standard deviations of pulse from `i' th crop on `j' th land per hector and pulse requirement of the population per year respectively (kg.)

Pp_{ij} and Pp = Average quantity of potato from `i' th crop on `j' th land /hector and potato requirement of the population per year respectively (kg.)

$\sigma_{Ppij} and \sigma_{PP}$ = Standard deviations of potato from `i' th crop on `j' th land per hector and potato requirement of the population per year respectively over the period (kg.p

Vg_{ij} and V_G = Average quantity of vegetable from `i' th crop on `j' th land /hector and vegetable requirement of population respectively(kg)

$\sigma_{Vgij} and \sigma_{VG}$ = Standard deviations of vegetable from `i' th crop on `j' th land /hector and vegetable requirement of population respectively over the period (kg)

Oe_{ij} and O_E = Average quantity of oil seeds from `i' th crop on `j' th land / hector and total oil seed requirement of population per year respectively (kg)

$\sigma_{Oeij} and \sigma_{OE}$ = Standard deviations of oil seeds from `i' th crop on `j' th land / hector and total oil seed requirement of population per year respectively over the period (kg)

Objective functions

An optimization model has been designed to satisfy both the farmer's interest as well as the national interest. While the farmer's interest is to maximize the net profit and minimize the investment, the national objective is to maximise the irrigated area, to maximize the production as well as the labour employment. Keeping this in view, a multi-objective optimization model has been formulated to achieve the stated objectives which are presented as:

(i) Maximization of Area

The area irrigating different crops, in the command area should be maximized. Mathematically, it can be expressed as:

$$\text{Maximize } Z_A(X) = \sum_{i=1}^{18}\sum_{j=1}^{2}(A_{ij})X_{ij} \qquad (2)$$

(ii) Maximization of Benefit

The benefit from each crop, dairy, poultry and rice-fish should be maximized. Mathematically, it can be expressed as:

$$\text{Maximize } Z_B(X) = \sum_{i=1}^{18}\sum_{j=1}^{2}(B_{ij})X_{ij} + \sum_{k=1}^{3}(B_k)Y_k \qquad (3)$$

(iii) Minimization of Investment

In developing countries, capital availability to undertake agricultural farming practices is a limiting factor. Hence for any implementable plan, the allocation of crops and animal should be such that the investment is minimum. Mathematically it can be expressed as:

$$\text{Minimize } Z_I(X) = \sum_{i=1}^{18}\sum_{j=1}^{2}C_{ij}X_{ij} + \sum_{k=1}^{3}C_kY_k \qquad (4)$$

(iv) Maximization of Labour

In a populous country like India, it is inevitable to have always a higher potential of labour forces. Therefore utilizing the entire labour force effectively has always been a problem on the part of the Government. In fact one of the economic policies of every country is to maximize the use of available labour resources in the best of its forms to generate higher production. Therefore, mathematically, it can be expressed as:

$$\text{Maximize } Z_L(X) = \sum_{i=1}^{18}\sum_{j=1}^{2}L_{ij}X_{ij} + \sum_{k=1}^{3}L_kY_k \qquad (5)$$

(v) Maximization of Production

Keeping the usual planning practice of maximizing the production of agricultural productions to become self sufficient in food production to meet the ever-increasing population as well as the growing market demand, attempts have been taken to maximize production. Mathematically, it can be expressed as:

$$\text{Maximize } Z_P(X) = \sum_{i=1}^{18}\sum_{j=1}^{2}(P_{ij})X_{ij} + \sum_{k=1}^{3}(P_k)Y_k \qquad (6)$$

Constraints

The constraints that play a key role in optimizing the desired objectives under consideration are described below. Some of the resource constraints are based on historical data and hence, stochastic in nature.

Area Constraint

The total of area allocated to different crops/rice-fish farming in any particular week should be less than or equal to the total available cultivable area. Mathematically, this type of constraint is given by:

i. Area Suitability Constraints

It is planned that out of the total command area of 1817.45 ha, in the low land areas(j=1,Total 760.25 ha) crops denoting variables X_2,X_5,X_6, X_8 andX_{17} can be grown and in the medium land areas(j=2,Total 1057.20) crops denoting variables X_1, X_3, X_4, X_7, X_9, X_{10}, X_{11}, X_{12} and X_{18} are suitable and the crops assigned with variables X_{13}, X_{14}, X_{15} and X_{16} are suitable for both the land types. Mathematically, these constraints are given by:

$$\sum_i (A_{i1})X_{i1}^{cw1} \le \sum_j A \text{ during the year} \qquad (7)$$

for i = 1 to 18; j = 1

$$\sum_i (A_{i2})X_{i2}^{cw2} \le \sum_j A \text{ during the year} \qquad (8)$$

for i = 1 to 18; j = 2

$$\sum_i (A_{ij})X_{ij}^{cw3} \le \sum_j A \text{ during the year} \qquad (9)$$

for i = 1 to 18; j = 1,2

cwm: m=1,2,3 crtical weeks of the year for low land, high land and low & medium land taken together respectively.

ii. Existing Crop Area Constraint

Besides paddy that covers most of the areas during *kharif* season, farmers also used to grow a variety of crops during *rabi* season. In fact, during the field survey, the existing crops and the extent of area practised in the command area are found and the same area will not be reduced as per the local practice practice. Accordingly, the minimum area to be devoted to different crops are estimated and this also takes care of minimum bare seasonal requirement and presented in form of equations as:

$$X_i \ge A_i^{\min} \text{ :for(5)} \qquad (10)$$

i	3	4	10	11	12	13	16	17	18
$A_i^{\min}$, ha	5	10	5	10	5	15	5	5	10

iii. Lack of Facility Crop Area Constraint

Depending on market demand, storing facility like cold storage and related factors it has been planned to limit the area of some vegetable and rice-fish farming for which the area allocated should not exceed the allowable limit. Mathematically this can be shown as

$$X_i \leq A_{\max} \quad (11)$$

for i=17,18; $A_{\max}$ = 25 ha,30 ha respectively

iv. Labour Constraint

Total requirement of the labour in a week should not exceed the labour available in that week to avoid uncertainty of getting migrated labour force in time during the week. Mathematically, it can be expressed as

$$\sum_i \sum_j L_{ij}^w X_{ij}^w + \sum_k L_k^w Y_k \leq L^W \quad (12)$$

for i = 1 to 18; j=1,2; w = 1 to 52; k = 1 to 3;

v. Bullock Power Constraint

The requirement of bullock days in a week for all the crops taken should not be more than the available bullock days for which critical weeks(cwd) are considered. Mathematically,

$$\sum_i \sum_j D_{ij}^{cwd} X_{ij}^{cwd} \leq D^{cwd} \quad (13)$$

for i = 1 to 18; j = 1 to 2; where

vi. Water Requirement Constraint

Water requirement for different irrigated crops in the field for a particular week must be less than or equal to the water available from all the existing water sources in that particular week. The water requirement of animal is met from either surface or groundwater sources. Both water availability and requirement based on historical data and hence, stochastic in nature. This can be represented as:

$$\sum_i \sum_j (W_{ij}^w, \sigma_{Wij}) X_{ij}^w + \sum_k (W_k^w, \sigma_{Wk}) Y_k \leq (W^w, \sigma_{Ww}) \quad (14)$$

for i = 1 to 18; ; j = 1 to 2;w = 1 to 52; k = 1to 3;

vii. Nutritional Constraint

From the historical record(1996-2006), the produce from the farming system ought to meet the nutrient requirements such as calorie, protein, calcium, iron and carbohydrate for the human population of the project for the period considered. These constituents are stochastic in nature and can be mathematically expressed as follows:

viii. Energy (Calories) Constraint

$$\sum_i \sum_j (E_{ij}, \sigma_{Eij}) X_{ij} + \sum_k (E_k, \sigma_{Ek}) Y_k \geq (E_N, \sigma_{EN}) \quad (15)$$

for i = 1 to 7 and 9 to 18 ; j = 1 to 2; k = 1 to 3;

ix.Protein Constraints

$$\sum_i \sum_j (T_{ij}, \sigma_{Tij}) X_{ij} + \sum_k (T_k, \sigma_{Tk}) Y_k \geq (T_N, \sigma_{TN}) \quad (16)$$

for i = 1 to 7 and 9 to 18 ; j = 1 to 2; k = 1 to 3;

x. Calcium Constraint

$$\sum_i \sum_j (Ca_{ij}, \sigma_{Caij}) X_{ij} + \sum_k (Ca_k, \sigma_{Cak}) Y_k \geq (Ca_N, \sigma_{CaN}) \quad (17)$$

for i = 1 to 7 and 9 to 18 ; j = 1 to 2; k = 1 to 3;

xi. Iron Constraint

$$\sum_i \sum_j (I_{ij}, \sigma_{Iij}) X_{ij} + \sum_k (I_k, \sigma_{Ik}) Y_k \geq (I_N, \sigma_{IN}) \quad (18)$$

for i = 1 to 7 and 9 to 18 ; j = 1 to 2; k = 1 to 3;

xii. Food Constraint

The production of food stuff i.e, cereal, pulses, potato, vegetables and oilseeds are generally considered under food requirement constraint. Based on historical records (1996-2000), total production of cereals (rice), pulses, potato, and vegetables should meet the actual requirement of the project population for the period. The requirements are based on minimum per capita requirement as recommended by Indian Council of Medical Research. In this problem both are stochastic in nature and can be expressed as:

Cereal constraint

$$\sum_i \sum_j (Ce_{ij}, \sigma_{Ceij}) X_{ij} \geq (C_E, \sigma_{CE}) \quad (19)$$

for i = 1,2,5,17; j = 1 to 2;

Pulse constraint

$$\sum_i \sum_j (Pe_{ij}, \sigma_{Peij} X_{ij}) \geq (P_E, \sigma_{PE}) \quad (20)$$

for i = 6,15,17; j = 1 to 2;

Potato constraint

$$\sum_i \sum_j (Pp_{ij}, \sigma_{Ppij}) X_{ij} \geq (P_P, \sigma_{PP}) \quad (21)$$

for i = 16; j = 2;

kiii. Vegetable Constraint

The constraint for vegetable was formulated based on historical data with restriction of area but should able to meet requirement as vegetable of one season can not be stored for other season due to lack of cold storage. Mathematically,

$$\sum_i \sum_j (Vg_{ij}, \sigma_{Vgij}) X_{ij} \quad \geq \quad (V_G, \sigma_{VG}) \tag{22}$$

for i = 3,5,10 to13,16 and 17; j = 1 to 2;

xiv. Oilseed Constraint

$$\sum_i \sum_j (O_{ij}, \sigma_{Oij}) X_{ij} \quad \geq \quad (O_E, \sigma_{OE}) \tag{23}$$

for i = 7 and 14; j = 1 to 2;

xv. Affinity Constraint

Due to strong affinity of the local people for rice, it is expected that at least 1550 ha (nearly 85 % of the total area) area in kharif and 185 ha (nearly 10 % of the total area) of area in rabi season would be devoted to paddy cultivation. Mathematically, these constraints can be written as

$$\sum_i \sum_j X_{ij} \quad \geq \quad 1550 \quad \textit{ha (kharif)} \tag{24}$$

for i = 1, 2; j = 1, 2;

$$\sum_i \sum_j X_{ij} \quad \geq \quad 185 \quad \textit{ha (rabi)} \tag{25}$$

for i = 5; j = 1;

xvi. Animal Feed Constraint

In the present integrated resource planning, dairy and poultry are associated with crop planning. The requirement for animal in terms of green fodder, dry straw, protein and carbohydrate are estimated. Total availability of green fodder should be at least equal to the requirements of the animal population, while the availability of dry fodder should be more than the requirement. Mathematically,

1. *Green fodder constraint*

$$G_{8,1} X_{8,1} - \sum_k G_k Y_k = 0.0 \tag{26}$$

for k = 1 and 2;

2. *Dry straw constraint*

$$\sum_i \sum_j S_{ij} X_{ij} - \sum_k S_k Y_k \quad \geq \quad 0.0 \tag{27}$$

for i = 1 ,2, 5, 7 to 15, 17; j = 1 to 2; k = 1 and 2 ;

xviii Dairy and Poultry Constraint

In the present planning consideration the dairy and poultry population are restricted to a minimum and maximum number except the buffalo population has been kept constant at the existing level.

$$N_l \leq Y_i \leq N_m \tag{28}$$

Milch Cows: i=1, $N_l = 160, N_m = 1000$

Milch Buffaloes: i=2, $N_l = 21, N_m = 21$

Poultry: i=3, $N_l = 2500, N_m = 50000$

IV. Methodology

This paper deals with application of stochastic multi-criteria decision making to crop planning problem for irrigation scheduling. In this problem resource constraints with stochastic nature have been taken into account. This is due to the fact that time series data for resources availability as well as requirement for the last ten years have been considered for the optimal allocation of land to various crops and number of diary and poultry units in an integrated manner. Normally data for such purpose are considered taking the mean value only. But with the consideration of time series data the inclusion of the standard deviation along with the mean has been considered. Out of several techniques for stochastic linear programming problem with randomised constraint, the most important is chance constrained technique. This is because constraints having finite probability of being violated as suggested by Charnes and Cooper [2]. The stochastic linear Programming problem of such type may be stated as:

Maximise $f(x) = \sum_{j=1}^{n} G_j X_j$

s.t. $\text{Prob}\left[\sum_{j=1}^{n} a_{ij} X_j \leq b_i\right] \geq p_i, i = 1,2,...m$

$$X_j \geq 0, \qquad j = 1,2\ldots n \tag{29}$$

where a_{ij}, and b_i are random variables and pi are the specified probability with $0 \leq p_i \leq 1$. This chance constrained technique permits the constraints to be violated by a specified (small) probability P_l (not necessarily equal to 1), then the chance constraint reduces to,

$$\text{Prob} \left[\hat{A}_l(\overline{X}) \leq \hat{b}_l\right] \geq P_l, \qquad l = 1,2,\ldots\ldots\ldots\ldots m^1 \tag{30}$$

From, relation (30) one can get

$\hat{Y}_l(\overline{X}) = \hat{A}_l(\overline{X}) - b_i$, *for all l*,

which are mutually independent random variables distributed normally as

$\hat{Y}_l(\overline{X}) \approx N(\mu_l(Y), \sigma_l(Y))$ *for all l*, where

$\mu_l(Y) = \left(\mu_l^A(\overline{X}) - \mu_l^b\right)$ and

$\sigma_l(Y) = \left[\sigma_l^A(X) + \left(\sigma_l^b\right)^2\right]^{1/2}$.

Now, the constraint (30) is equivalent to

$$\text{Prob} \left[Y_l(\overline{X}) \leq 0\right] \geq P_l, \quad \textit{for all } l$$

$$\Rightarrow \text{Prob}\left[\frac{Y_l(\overline{X})-\mu_l(Y)}{\sigma_l(Y)} \le \frac{-\mu_l(Y)}{\sigma_l(Y)}\right] \ge P_l$$

$$\Rightarrow \phi\left[\frac{-\mu(Y)}{\sigma_l(Y)}\right] \ge P_l$$

, where φ is the standard normal variate N (0,1)

$$\Rightarrow \mu_l(Y)+\phi^{-1}(P_l)\sigma_l(Y) \le 0$$

$$\Rightarrow \mu_l^A(X)-\mu_l^b+\phi^{-1}(P_l)\left[\left\{\sigma_l^A(\overline{X})\right\}^2+\left(\sigma_l^b\right)^2\right]^{1/2} \le 0 \quad ,for \ all \ l \qquad (31)$$

which is the precise form of the chance constraint (30).

For example, when we say that the investment required for a particular crop say paddy is Rs.12000/-, this amount signifies the mean value of investment to be Rs. 12000/- for the time series data without considering the variance factor of the investment over the period. In this model the said factor has been considered for the resources matrix. The stochastic constraints has been considered as follows

$$\sum_i\sum_j \hat{a}_{ij}x_{ij} \le \hat{b}_{ij}$$

, which can be expressed as (32)

$$\sum_i\sum_j (a_{ij},\sigma'_{ij})x_{ij} \le (b_{ij},\sigma''_{ij})$$

Hence, a multi objective problem incorporating this type of constraint can be formulated as

$$Max\sum_j c_{ij}x_{ij} \quad : \ i = 1,2\ldots.m$$

$$\sum\sum(a_{ij},\sigma'_{ij})x_{ij} \le (b_{ij},\sigma''_{ij}) \qquad (33)$$

$$x_{ij} \ge 0 \ \text{for all} \ i \ and \ j$$

A fuzzy logic based algorithm to tackle the problem has been presented where; the stochastic constraints can be converted to their respective deterministic forms. The application of such an algorithm to the said problem has resulted in a land allocation system which has to be re-organized based on the resource constraints as well as demand and cultural conditions. An interactive approach based on the implicit trade-off concept in terms of satisfaction of the decision-maker (DM) similar to the concepts of Zeleny [6], Benayoun et. al. [10] has been implemented for the purpose.

The algorithm implemented for this study is an interactive algorithm where the computation stage involves a compensatory operator for aggregating the fuzzy sets resulting from the various objectives in the decision system. Fuzzy multi-objective programming approach converts each objective to a corresponding fuzzy set which then can be aggregated by an appropriate operator to result in a decision set. This involves the application of fuzzy logic as proposed by Zadeh [7] to multi-objective decision systems (Bellman and Zadeh [11]. Some of the applications of fuzzy programming to such agricultural decision systems are due to, Slowinski [9], Sinha et al [12],[13], Das and Mangaraj[4], Biswas and Pal [3], Sharma [5]etc. .

Step 1: Solve the MCDM (31) problem as a single objective linear programming problem using only one objective at a time and ignoring the others. These solutions are termed as ideal solutions.

Step 2: From the result of step-1, determine the corresponding values for every objective at each solution derived with the values of all objectives at each ideal solution, pay-off matrix can be formulated as follows:

$$\begin{array}{c} \\ x_1 \\ x_2 \\ . \\ . \\ x_m \end{array}\begin{array}{c} \begin{array}{cccccc} G_1(x) & . & G_2(x) & . \ . \ . \ . & . & G_m(x) \end{array} \\ \begin{bmatrix} G_1^*(x^1) & G_2(x^1) & . & . & . & G_m(x^1) \\ G_1(x^2) & G_2^+(x^2) & . & . & . & G_m(x^2) \\ . & . & & & & . \\ . & . & & & & . \\ G_1(x^m) & G_2(x^m) & . & . & . & G_m(x^m) \end{bmatrix}\end{array}$$

Here x_1, x_2, …… x_m are the ideal solution of the objectives $G_1(x)$, $G_2(x)$….$G_m(x)$ respectively.

Step 3: Convert the objective $G_i(x)$ to its equivalent fuzzy goal. Combine all the fuzzy goals using "Add" operator and solve the models as:

$$\text{Max} \sum_{i=1}^{m}\mu_{Gi}(x)$$

$$\text{St.} \ \mu_{Gi}(x) \le \frac{G_i(x)-G_i(x)^{Min}}{G_i^*(x)-G_i(x)^{Min}} \quad : \ i = 1,2\ldots m \qquad (34)$$

$$A_j(x) \le b_j \quad : \ j = 1,2\ldots1$$

$$\mu_{Gi}(x), \ x \ge 0$$

Determine the output of $x = x^1$ which yields $\mu_{Gi}(x) = \mu_i$. If the decision yields satisfactorily for all membership values, then go to Step 6.

Step 4: The decision-maker (DM) is asked as to whether he can make some concession in the levels of any membership functions, whose attainment in his opinion is more satisfactory to improve those that are less satisfactory. Suppose the DM is not satisfied with the solution $x = x^1$ and he can concede an amount $\Delta\mu_h$ from μ_h . Then transform

$$G_i(x)^{Min} \longrightarrow G_i(x^1) \quad \text{and}$$

$$G_i^*(x) \longrightarrow G_i^*(x) \quad \text{for all} \ i \ne h$$

Step 5: Solve the equivalent model as:

$$\text{Max} \sum_{i=1}^{m} \mu_{Gi}(x) \quad : \quad i \neq h$$

$$\text{s.t. } \mu_{Gi}(x) \leq \frac{G_i(x) - G_i(x^1)}{G_i^*(x) - G_i(x^1)} \quad : \quad i \neq h$$

$$G_h(x) \geq G_h(x^1) - \Delta\lambda_h (G_h^*(x) - G_h) \tag{35}$$

$$A_j(x) \leq b_j \quad : \quad j = 1,2\ldots.l$$

$$\mu_{Gi}(x), \; x \geq 0$$

Determine the output of $x = x^{11}$ which gives $\mu_{G_I}(x) = \theta_i$

Step 6: If the solution is satisfactory to the DM, then the associated solution is the final solution; otherwise go to step 4 and repeat the procedure until the DM becomes satisfied with the attainment levels of all the membership functions of the objectives.

V. Results and Discussions

The multi-objective model which has been tackled by fuzzy goal programming approach uses linear promming model for its solution. The advantage of this approach is that, the model can be reduced to a set of LPPs depending upon the number of objective functions in the system. The land re-organisational model which used the methodology stated in section-IV has been solved using LINDO software. The compromise decision on the basis of the stochastic criteria, with single and multi objective problem for crop planning obtained are given in Table II. This table also provides an analysis of the optimal results of different objectives i.e optimal crop plan for area coverage (ha), benefit (Rs.), investment (Rs.), labour generation (Man days) and production (Kg).Also a comparison of achievement levels of other objectives with these optimal values has also been presented in Table II. In this table, figures within the parenthesis indicate the percentage of attainment to its max./ min. value as of the case of objective. The information on intensity of cropping is also available for each of the optimal crop plan in Table III. A modified result is also available through an interactive procedure, where the attainment levels of various objectives in percentage are given. For instance, these are area (98.67), benefit (95.92), investment (167.34), labour force (99.34) and production (97.05). Hence, one can observe that with this interactive procedure the cropping intensity achieved in study area is 238.915 percent, which is very close to the maximum cropping intensity and at the same time takes care of simultaneous satisfaction of all other objectives.

TABLE II
Area Allocation under Different Strategies

	Max. Area	Max. Benefit	Min. Cost	Max. Labour	Max. Production	Compromise Strategy	Modified Compromise Strategy
X_1	828.406	828.584	827.1	828.585	828.118	828.584	828.584
X_2	745.375	721.416	722.9	721.415	721.882	721.416	721.416
X_3	208.794	208.616	5	208.615	190.71	208.616	208.616
X_4	10	10	19.894	10	12.195	10	10
X_5	185	185	185	185	185	185	185
X_6	77.301	0	0	0	0	18.446	33.241
X_7	1005.858	983.826	1005.858	979.249	989.681	990.264	994.883
X_8	3.416	18.133	3.416	4.517	18.133	18.133	16.515
X_9	21.342	21.342	21.342	21.342	21.342	21.342	21.342
X_{10}	5	5	5	5	5	5	5
X_{11}	10	10	10	10	10	10	10
X_{12}	5	5	5	5	5	5	5
X_{13}	15	15	15	15	15	15	15
X_{14}	368.346	393.636	368.346	398.889	386.915	386.246	380.943
X_{15}	379.603	358.497	354.325	349.372	342.062	365.887	370.729
X_{16}	436.449	430.201	15	435.982	429.988	430.201	430.888
X_{17}	14.875	5	5	25	25	25	25
X_{18}	10	10	10	10	26.177	10	10
Y_1	160	1000	160	222.824	1000	1000	907.611
Y_2	21	21	21	21	21	21	21
Y_3	2500	15298	2500	50000	2500	2500	2500

X_i: Area allocated (ha.); Y_i: Population Number

Thus the reorganized land planning based on the result achieved with the help of fuzzy goal programming will lead towards a development strategy in the rural sector through agriculture. In a country like India whose rural economy is mostly agrarian based, a sustainable development in the context of globalization is only possible by way of improved land and water management by reorganizing land allocation system for various agricultural activities keeping in view of the local and market requirements.

TABLE III
Level of Achievement and Cropping Intensity Under Different Objectives I.(Figures Within the Parenthesis Indicates the Percentage of Attainment to its Max. or Min. Value as of the Case of Objective)

Criteria → Objective ↓	Area (ha)	Benefit (Rs.)	Investment (Rs.)	Labour (Man Days)	Prod (Kg)	Crop Intensity (%)
Max. Area	4329.765 (100.00)	24199882 (76.92)	22568702 (139.63)	821563.3 (96.64)	14571057 (84.68)	240.970
Max. Benefit	4209.251 (97.22)	31459905 (100.00)	28076388 (173.71)	846042.6 (99.51)	16904818 (98.25)	233.253
Min. Investment	3578.181 (82.64)	15994733 (50.84)	16163145 (100.00)	657522 (77.34)	7609452 (44.22)	198.523
Max. Labour	4212.966 (97.30)	28756762 (91.41)	26478510 (163.82)	850166.1 (100.00)	15025187 (87.32)	235.658
Max. Production	4212.203 (97.28)	31021114 (98.61)	27771350 (171.82)	844518.6 (99.34)	17206553 (100.00)	237.396

Additive operator	4254.135 (98.25)	30843709 (98.04)	27545998 (170.42)	846622.3 (99.58)	16952263 (98.52)	237.920
Interactive	4272.157 (98.67)	30176202 (95.92)	27046630 (167.34)	844575 (99.34)	16698883 (97.05)	238.915

VI. Conclusion

The solution obtained in this model is due to the stochastic nature of resource constraints in the decision environment. This is due to time series data for resource constraints. However, the constraints have been reduced to deterministic form and with a multiple number of objectives in the decision environment, the model takes the shape of a typical multi-objective decision making problem. The concept of graded satisfaction associated with each of the objective makes it more suitable to be formulated in terms of fuzzy logic. Hence, the approach of fuzzy goal programming becomes more meaningful for it which necessitates a fuzzy aggregation operator for aggregating several fuzzy criteria in the decision environment. A compensatory operator has been used for the purpose in an interactive mode. A satisfactory solution can be obtained through a series of interaction making a trade-off analysis amongst the objectives. This model is based on maximum satisfaction obtained for each of the objectives with respect to resource and conditional constraints. By using this model the irrigated land can be reorganized to get maximum satisfaction of the multiple stakeholder of the rural area and hence lead to sustainable development.

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