1. **Multi Objective Decision Making In Sustainable Irrigation Planning**
2. **Fuzzy Mathematical Programming for Optimal Multipurpose Multi-reservoir Operation**
3. **Multi objective Irrigation Planning with Conjunctive use of Surface and Groundwater under Fuzzy Environment**
4. **Calibration and influence of uncertainty analysis of hydrological responses in watershed management practices**
5. **Effect of Climate Change on Runoff Generation**

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1.0 INTRODUCTION

Water resources systems planning, development and management is the area in which irrigation planning problem involves with multiple possible and valuable planning objectives. Some of them, one can represent in terms of monetary returns and a few which one cannot, are social upliftment, environmental status, ecological balance, conservation of natural resources etc.

Irrigation planning problem becomes more complicated, if uncertainty is included in the form of drought and floods, fluctuations in the market price of crops and its yields, non availability of right type of labour at right time and inflow variation from season to season. To tackle such kind of vagueness in planning with multiple objectives and the imprecision involved in the parameter values, the fuzzy set theory is considered as an alternative approach.

1.2 Necessity and Motivation

The irrigation planning is dependent on many factors such as weather, climate, temperature, rainfall, marketing, and resource availability, which are not easily quantified and often are not fully controllable. These factors are the common sources of uncertainty.

Since uncertainty plays an important role in any irrigation planning, a model with multiple objectives that takes into account uncertainty should be used. Conventional mathematical programming schemes lucidly cannot handle all these issues.

It is expected that a fuzzy mathematical programming approach should yield in more realistic and flexible optimal solutions for the water resources systems planning, specifically for sustainable development and management of water resources. One of the greatest advantages of using the fuzzy logic to deal with uncertainty is that one may tackle it more clearly than conventional mathematical programming models available till today.

1.3 Objectives

The main objective of this study is to develop and apply Multi Objective Fuzzy linear Programming (MOFLP) model for sustainable irrigation planning for Jayakwadi project stage-I, Maharashtra State, India.

The developed MOFLP sustainable irrigation planning model (MOSIPFUZZY) is used to find out an optimal cropping pattern that maximizes conflicting objectives simultaneously such as Net Benefits (NB), Crop Production (CP), Employment Generation (EG) and Manure Utilization (MU).

All four objectives to be maximized and the last three are related to sustainability .

In addition, the other objective is to develop and apply the Single Objective Fuzzy Linear Programming (SOFLP) model for sustainable irrigation planning to find out an optimal cropping pattern that minimizes the Cost of Cultivation (CC)

Case-I Optimal Cropping Pattern Planning with Fuzzy Objective Functions

Case-II Optimal Cropping Pattern Planning with Fuzzy Resources

Case-II Optimal Cropping Pattern Planning with Fuzzy Technological Coefficients

Case-IV Optimal Cropping Pattern Planning with Fuzzy Technological Coefficients and Resources

Case-V Optimal Cropping Pattern Planning with Fuzzy Objective Function Coefficients, Technological Coefficients and Resources Using Exponential Membership Function

Case-VI Optimal Cropping Pattern Planning with Fuzzy Objective Function Coefficients, Technological Coefficients and Resources Using Linear Membership Function

Case-VII Optimal Cropping Pattern Planning with Fuzzy Decision Variables and Resources

Case-VIII Optimal Cropping Pattern Planning with Fuzzy Decision Variables and Decision Parameters

Case-IX Optimal Cropping Pattern Planning which Minimizes the Cost of Cultivation with:

a) fuzzy objective function coefficients, technological coefficients and resources using interactive method

b) fuzzy decision variables and resources

c) fuzzy decision variables and decision parameters

1.4 Theme

Two aspects addressed in this study, which are namely Sustainability and Uncertainty involved in irrigation planning.

Sustainability incorporated in the model, with a view for the proper utilization of the various resources such as water, land etc.

Uncertainty is one of the prime concerns related to deal with irrigation planning, which makes irrigation planning problem more complex.

These aspects can be probably addressed to sufficient satisfaction using fuzzy sets.

2.0 LITERATURE REVIEW

Raju and Nagesh Kumar [14], Raju and Nagesh Kumar [15]

Sahoo *et al*. [18]

Regulwar and Anand Raj [53]

Gasimov and Yenilmez [147]

Jimenez *et al*. [163]

Arikan and Gungor [170]

Nasseri [172]

Allahviranloo [173]

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From the above literature, it is found that to tackle the uncertainty involved in irrigation planning problem the fuzzy logic have been applied with either objectives fuzzy in nature or fuzzy objectives along with fuzzy resources.

But no formulation and application of MOFLP model has been reported for irrigation planning in which fuzzy objective function coefficients, fuzzy technological coefficients and fuzzy resources and fuzzy decision variables.

The present study considers all fuzzy decision parameters and fuzzy decision variables in a mathematical model as it is the case in real life.

2.4 Justification for Research Gap

Generally the irrigation planning is dependent on many factors such as weather, climate, temperature, rainfall, marketing and resource availability, which are not easily quantified and often are not fully controllable.

These factors are the common sources of uncertainty. In actual planning practice/exercise, the input data and other parameters such as demand, resources, cost and objective functions are also imprecise (fuzzy) because some information are incomplete or unobtainable.

One of the greatest advantages of using the fuzzy to deal with uncertainty is that one may tackle it more clearly than conventional mathematical programming models available till today.

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The uncertainty is associated with different terms such as

a) hydrology,
b) hydrogeology,
c) soil and its characteristics,
d) climatic variables, hydro meteorological parameters (rainfall, evaporation and deep percolation losses, infiltration loss from rainfall, discharge rate from tube wells, reference evapotranspiration which is a function of humidity, radiation, daily sunshine hours, wind velocity, and crop resistances),

e) management practice data (irrigation system efficiency, field water application efficiency, fertilizer and labour availability, and current market price of the crop produce),

f) crop data (cropping pattern, planning date, crop base period, crop coefficients at different growth stages and nutrient requirement by each crop),

g) basin data (cultivable area, gross command area, soil type, and topography).

The irrigation planning is dependent on many factors such as weather, climate, temperature, rainfall, marketing, and resource availability, which are not easily quantified and often are not fully controllable. These factors are the common sources of uncertainty.

In actual planning practice/exercise, the input data and other parameters such as demand, resources, cost and objective functions are also imprecise (fuzzy) because some information are incomplete or unobtainable.

Since uncertainty plays an important role in any irrigation planning, a model with multiple objectives that takes into account uncertainty should be used.

Table 4.1: Solution for the Net Benefits, Crop Production, Employment Generation and Manure Utilization for Crop Areas by LPP Model and MOFLP

S. N.	Crop and Season	Solution for Maximization of				Compromised Solution for four Conflicting Objectives under Fuzzy Environment (λ=0.580)
		Net Benefits (Z_1) (Area of Crop) (ha)	Crop Production (Z_2) (Area of Crop) (ha)	Employment Generation (Z_3) (Area of Crop) (ha)	Manure Utilization (Z_4) (Area of Crop) (ha)	Area of Crop (ha)
1	Sugarcane (P)	4249.20	4249.20	0.00	4247.75	2166.18
2	Banana (P)	2124.60	2124.60	0.00	2124.60	2124.60
3	Chilies (TS)	4249.20	4249.20	4249.20	4249.20	4249.20
4	L S Cotton (TS)	0.00	0.00	35410.00	35410.00	28567.80
5	Sorghum (K)	16996.80	16996.80	16996.80	16996.80	16996.80
6	Paddy (K)	6445.75	0.00	14164.00	14164.00	14164.00
7	Sorghum (R)	0.00	14683.76	0.00	20277.26	0.00
8	Wheat (R)	35410.00	35410.00	35410.00	0.00	23832.78
9	Gram (R)	7082.00	0.00	6437.72	0.00	7082.00
10	Groundnut (HW)	0.00	0.00	0.00	4249.02	0.00
	Net Cropped Area	76557.55	77713.56	112667.72	101718.63	99183.36

For Maximization of Net Benefits: Z_1=1683.04 ($\mathbf{Z_1^+}$) (Million `); Z_2=472166.50 (Tons); Z_3=24.72 (Million Man Days); Z_4=76554.09 (Tons); Irrigation Intensity (%) = 54.05
Crop Production: Z_1=1654.75 (Million `); Z_2=473464.40 ($\mathbf{Z_2^+}$) (Tons); Z_3=23.25 ($\mathbf{Z_3^-}$) (Million Man Days); Z_4=70516.11 ($\mathbf{Z_4^-}$) (Tons); Irrigation Intensity (%) = 54.86
Employment Generation: Z_1=1255.69 ($\mathbf{Z_1^-}$) (Million `); Z_2=106674.40 ($\mathbf{Z_2^-}$) (Tons); Z_3=34.44 ($\mathbf{Z_3^+}$) (Million Man Days); Z_4=159485 (Tons); Irrigation Intensity (%) = 79.54
Manure Utilization: Z_1=1459.84 (Million `); Z_2=446120.20 (Tons); Z_3=26.17 (Million Man Days); Z_4=182542.50 ($\mathbf{Z_4^+}$) (Tons); Irrigation Intensity (%) = 71.81

For Compromised Solution: Z_1=1503.73 (Million `); Z_2=319563.50 (Tons); Z_3=29.74 (Million Man Days); Z_4=154506.50 (Tons); Irrigation Intensity (%) = 70.02

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