Proposed optimized cropping pattern for different water availability scenarios in Markonahalli reservoir for Upper ShimshaIrrigation Project, Karnataka, India

ABSTRACT

The optimization model has been developed using linear programming by considering the stochastic nature of the inflows to the reservoir and solved for different storage water availability levels in reservoir viz., 60 per cent, 70per cent, 80per cent, 90per cent and 100 per cent to obtain various cropping patterns under canal command area. Linear programming is used either to maximize or minimize a given objective function. The total command area for cultivation is likely divided between the *Kharif* and *Rabi* seasons, with different crops being prioritized in each season based on their growing conditions and water availability. The existing area of 2639.38 ha for paddy is significantly reduced to a constant 1000 ha in the optimized scenarios, regardless of water availability. Sugarcane, with present area of 296.54 ha, the area is increased to 1722.13 ha under 100 per cent water availability but is reduced progressively to just 410.13 ha at 60per cent water availability. Optimization trend highlights finger millet's resilience and suitability under lower water conditions, making it a preferred crop when water is scarce.

Keywords: {*optimization, stochastic, crops, water and programming*}

1. INTRODUCTION

Cropping pattern in command areas follow uniform pattern in most part of the country, as most of the farmers prefer to grow water demanding crops like paddy and sugarcane. Consequently water shortage during *kharif* cropping season is a common phenomenon and even water may not reach the tail end of command area and farmers would eventually end up with no crop [1]. This trend is most common during scanty rainfall years. To overcome such problems various studies were conducted for optimized cropping pattern based on the water availability in reservoirs, selection of crop and command area to be irrigated with the available water based on crop water requirement. Linear programming, Non-linear programming models and Dynamic models were developed to get the optimized water availability for entire command area. However, it is imperative to note that the relationship between optimal water resources allocation and water availability is nonlinear, [2]. Besides the optimization strategy, there is an alternative method that ensures an equitable reduction of water usage among different crops. This approach is more standard and user-friendly for water managers and is implemented in Iran and other nations [3].Shimsha river, tributary of Cauvery basin, taking its origin at the foothills of the Devarayanadurga hills of Tumkur district, Karnataka. Upper Shimsha Irrigation Project(USIP) is an irrigation scheme of the reservoir, located at Markonahalli operating by *CauveryNiravari Nigam*, near Yediyur of Kunigal taluk comes under minor irrigation project of

Karnataka. The reservoir has live storage capacity of 64 M m^3 and serves a cultural command area of 5942 ha out of 7203 ha of gross command area. The total catchment area for Markonahalli reservoir is 4103 km^2[4]. The present study uses may help to understand the hydrological parameters and their interactions with spatial and temporal variability for present and future assessment of water resource availability in this command area. The present study is aimed to get the optimal allocation of irrigation water depending upon the availability of water from the source. The net revenue from agricultural production will be maximized with the set of constraints like crop area, cropping pattern, minimum and maximum storage, canal capacity, water requirement of crops, etc.

2. MATERIAL AND METHODS

Optimizing water allocation through reservoirs can be a complex task, often involving multiple objectives and constraints. Python provides powerful libraries, such as SciPy and Pyomo, which can help implement these optimization problems effectively. Below is a basic procedure for setting up and solving an optimization problem for water allocation through reservoirs.To optimize the water release from a reservoir for maximizing the water supply for irrigation besides, ensuring that the reservoir does not dry up and meets environmental flow requirements. Python library was used to define and solve the optimization problem by framing objective function and constraints as follows:

Linear Programming (LP) deals with that class of programming problems for which the constraints as well as the function to be optimized are linear relations among the variables. When the resources are scarce, there is a need for allocation of limited resources to priorities or activities. This technique is used either to maximize or minimize a given objective function. The solution to the linear programming (LP) model was obtained using simplex method. In a more convenient matrix notation, a typical LP problem [5] can be written as;

$$Max/(Min) Z = CT_x \quad ...(1)$$

Subject to the constraints

$$Ax > B$$

$$and \ x. > 0$$

Where, C is a (n×1) vector known constant; x is a (n ×1) vector of decision variables; A is a (m ×n) matrix of known constant and B is a (m×n) vector of constants. The problem is to find asset of x, the decision variables, that maximize (or minimize) the objective function Z .

Crop yield considered is same throughout the command area in spite of variation in management practices. The model has been developed considering the stochastic nature of the inflows to the reservoir and solved for different storage water availability levels of inflows viz., 60 per cent, 70per cent, 80per cent, 90per cent and 100 per cent to obtain various cropping patterns under canal command area.

2.1 Objective function

The objective function has been formulated to allocate land resource for the existing crops, so as to maximize the net benefit and is given by

$$MaxZ = \sum_{j=1}^{12} Bj \times Aj \qquad ...(2)$$

Where, Z is the net benefits from the command area (Rs.); B_j is the net benefits from j^{th} crop (Rs. /ha) and A_j is the area under j^{th} crop in the command (ha)

2.1.2 Constraints

The objective function is subjected to the following constraints:

2.1.3 Capacity constraints

The storage of the reservoir at any month should not exceed the maximum storage capacity of reservoir, S_{max} and storage should be greater than dead storage, S_{min} for all months.

$$S_t \le S_{\max}, t = 1,2,.............. 12 \qquad ...(3)$$

$$S_t \ge S_{\min}, t = 1,2,..............12 \qquad ...(4)$$

2.1.4 Water requirement constraints

The water release for irrigation in each month should be greater than or equal to the amount of water needed for irrigation to the crops cultivated under canal command of USIP in that month.

$$R_t - \sum_{i=1}^{m}\sum_{j=1}^{n} C_W R_{jt} \times A_{ij} \ge 0, t = 1,2.......12 \qquad ...(5)$$

Where, R_t represents the water release for irrigation from the reservoir during month t (ha-cm) and $C_W R_{jt}$ represents the crop water requirement for irrigating the crop j during the month t.

2.1.5 Continuity constraints

The continuity equation can be written as follows:

$$S_{t+1} = S_t + I_t - R_t - E_t - PL_t; t = 1,2.........12 \qquad ...(6)$$

Where, S_t is the water storage in the reservoir at time t; S_{t+1} is the water storage in the reservoir at time t +1; It is the inflow into the reservoir at time interval Δt; R_t = Water release from the reservoir at time interval Δt; E_t is the evaporation from the reservoir at time interval Δt and PL_t is the percolation losses from the reservoir at time interval Δt.

In the above equation the combined evaporation and percolation losses were assumed to be 15 per cent of the average water storage in reservoir for the period Δ_t as suggested by [6].The time period Δt was taken as a month in this model

$$E_t + PL_t = 0.15 \times \left[\frac{(St + S_{t+1}}{2} \right] \qquad ...(7)$$

2.1.6 Land availability constraints

The sum of area irrigated under each crop should not exceed the total available land under canal command of USIP. This can be represented by the following equations.

$$\sum_{j=1}^{n} A_{ij} \le A_i \text{ ; } \quad i=1......m \qquad ...(8)$$

Where, A_{ij} represents total available land in the canal command of i[th] canal (ha)

3. RESULTS AND DISCUSSION

The study estimates the irrigation water demand for the existing cropping pattern and employs an optimization technique to recommend suitable crops and the necessary canal water release, guided by canal performance indicators. The findings so far reveal that the actual cultivated area being prioritized in each season based on their growing conditions and water availability [2]. Therefore, it is proposed to maximize net profit and water use efficiency by proposing different scenarios based on water and land as the major inputs.

The 30 m resolution LULC map of the USIP command area for the target year 2023 and NDVI was selected in different period of the same year to identify different crops available in command area and same was depicted in Fig.1. This map provides extent and distribution of different LULC types using object-based classification and the RF algorithm on the GEE platform, unlike the majority of previous studies that adopted a pixel-based approach for LULC mapping within the GEE environment [7], the current study used an object-based approach. The data shows that the canal command area farmers grow paddy, sugarcane, plantation crop, finger millet and pulses in *Kharif* season and pulses are extensively cultivated during *Rabi*. It was observed that paddy during *Kharif* season (2639.38 ha) ranked first followed by pulses (1040 ha), plantation crop (901.53 ha), finger millet (790.96 ha) and sugarcane (296.54 ha).

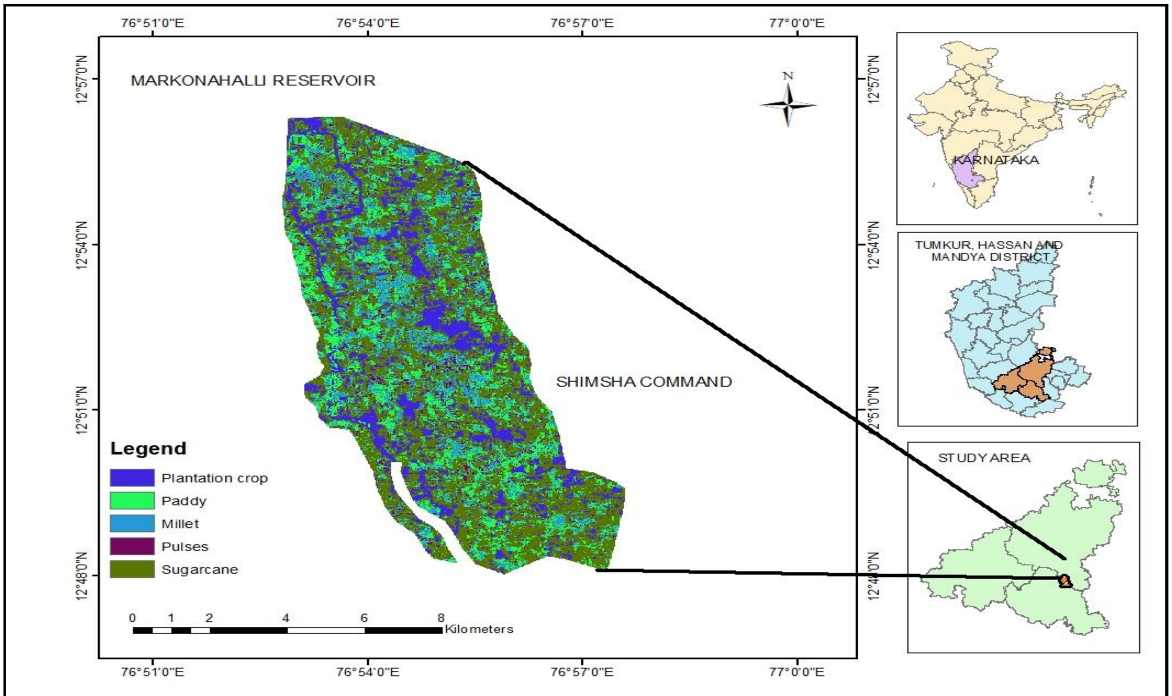

Fig. 1. Land use land cover classification showing different crops in command area of USIP during 2023

The data in table 1 provides insights into the seasonal cropping patterns, crop diversity and relative importance of different crops in terms of area allocation within the command area. Paddy is the dominant crop during the *Kharif* (monsoon) season, occupying 54.54 per cent (Table 1) of the total command area, suggesting it is the primary crop grown in this region during the rainy season. During the *Rabi* (winter) season, there is no paddy cultivation, indicating that paddy is primarily a *Kharif* crop in this area. Finger millet is cultivated in both *Kharif* and *Rabi* seasons, with a higher area allocated during the *Kharif* season (12.47% of the command area) compared to the *Rabi* season (9.09%).Pulses like green gram and black gram are grown in both seasons, with a significantly higher area allocated during the *Rabi* season (18.18% and 23.03%, respectively) compared to the *Kharif* season (0.54% each). Sugarcane and plantation crops (likely perennial crops) occupy a consistent area of 13.7 per centand 18.18per cent, respectively, in both *Kharif* and *Rabi* seasons, indicating their year-round cultivation.Bengal gram is cultivated only during the *Rabi* season, occupying 9.09per cent of the command area, suggesting it is a *Rabi* crop in this region. The total command area for cultivation is likely divided between the *Kharif* and *Rabi* seasons, with different crops being prioritized in each season based on their growing conditions and water availability.The cropping pattern appears to be well-diversified, with a mix of cereals (paddy, finger millet), pulses (green gram, black gram, Bengal gram), cash crops (sugarcane), and plantation crops, potentially contributing to better risk management and resource utilization.

Table 1: Area occupied by different crops under existing cropping patternscenario in USIP

Sl.No.	Crop	Area (ha)			Area (%)		
		Kharif	*Rabi*	*Summer*	*Kharif*	*Rabi*	*Summer*

1	Paddy	2639	-	-	44.41	-	-
2	Finger millet	791	500	-	13.31	10.08	-
3	Green gram	30	-	500	0.50	-	18.54
4	Black gram	30	-	500	0.50	-	18.54
5	Sugarcane	296	296	296	4.98	5.97	10.98
6	Plantation crop	901	901	901	15.16	18.16	33.41
7	Bengal gram	-	-	500	-	-	18.54
8	Uncultivated and other crops	1255	3265	2265	21.12	65.80	83.98

Crop area allocation has been optimized, likely to maximize productivity, water efficiency, profitability, or a combination of these factors. Python programme's extensive library and syntax make it an excellent choice for solving linear programming problems, allowing for efficient and effective optimization. Table 2 shows a strategic approach to managing crop areas under five different water availability scenarios: 100per cent, 90per cent, 80per cent, 70per cent, and 60per cent. The key crops considered for optimization are Paddy, Pulses, Finger Millet, Plantation Crops, and Sugarcane.The existing area of 2639.38 ha for paddy is significantly reduced to a constant 1000 ha in the optimized scenarios, regardless of water availability. This indicates a critical threshold for paddy cultivation, balancing its high water demand with the need to maintain constant production, as paddy is the staple food grain in the study area. Similarly area for plantation crops remains constant at 901.53 ha across all scenarios. This is due to plantation crops are maintained of such economic importance, that their area cannot be reduced without significant impact. Land with left uncultivated and minor crops also kept constant in all the scenarios (273.59 ha).

Table 2. Proposed Optimized cropped area under different water availabilityscenarios for USIP

Sl. No.	Crops	Existing crop area (ha)	Proposed optimized crops	Proposed optimized cropping area	
	Scenario 1: 100 per cent water availability			**(ha)**	**(%)**
1	Paddy	2639.38	Paddy	1000.00	16.83
2	Pulses	1040.00	Pulses	300.00	5.05
3	Finger millet	790.96	Finger millet	1743.86	29.35
4	Plantation crop	901.53	Plantation crop	901.53	15.17
5	Sugarcane	296.54	Sugarcane	1722.13	28.98
6	Uncultivated land and other crops	273.59	Uncultivated land and other crops	274.47	4.62
	Scenario 2: 90 per cent water availability			**(ha)**	**(%)**
1	Paddy	2639.38	Paddy	1000.00	16.83
2	Pulses	1040.00	Pulses	300.00	5.05
3	Finger millet	790.96	Finger millet	2071.87	34.87
4	Plantation crop	901.53	Plantation crop	901.53	15.17
5	Sugarcane	296.54	Sugarcane	1394.13	23.46

6	Uncultivated land and other crops	273.59	Uncultivated land and other crops	274.47	4.62
	Scenario 3: 80 per cent water availability			**(ha)**	**(%)**
1	Paddy	2639.38	Paddy	1000.00	16.83
2	Pulses	1040.00	Pulses	300.00	5.05
3	Finger millet	790.96	Finger millet	2399.87	40.39
4	Plantation crop	901.53	Plantation crop	901.53	15.17
5	Sugarcane	296.54	Sugarcane	1066.13	17.94
6	Uncultivated land and other crops	273.59	Uncultivated land and other crops	274.47	4.62
	Scenario 4: 70 per cent water availability			**(ha)**	**(%)**
1	Paddy	2639.38	Paddy	1000.00	16.83
2	Pulses	1040.00	Pulses	300.00	5.05
3	Finger millet	790.96	Finger millet	2727.87	45.91
4	Plantation crop	901.53	Plantation crop	901.53	15.17
5	Sugarcane	296.54	Sugarcane	738.13	12.42
6	Uncultivated land and other crops	273.59	Uncultivated land and other crops	274.47	4.62
	Scenario 5: 60 per cent water availability			**(ha)**	**(%)**
1	Paddy	2639.38	Paddy	1000.00	16.83
2	Pulses	1040.00	Pulses	300.00	5.05
3	Finger millet	790.96	Finger millet	3055.87	51.43
4	Plantation crop	901.53	Plantation crop	901.53	15.17
5	Sugarcane	296.54	Sugarcane	410.13	6.90
6	Uncultivated land and other crops	273.59	Uncultivated land and other crops	274.47	4.62

4. CONCLUSION

Sugarcane, a water-intensive crop, sees a significant reduction in optimized area as water availability decreases. From an initial 296.54 ha, the area is increased to 1722.13 ha under 100 per cent water availability but is reduced progressively to just 410.13 ha at 60per cent water availability. This substantial decrease underscores the need to cut down on water-intensive crops under water-scarce conditions**.** Finger millet shows a substantial increase in the optimized crop area as water availability decreases. Starting from 1743.86 ha at 100 per cent water availability, it increases progressively to 3055.87 ha at 60 per cent water availability. This trend highlights finger millet's resilience and suitability under lower water conditions, making it a preferred crop when water is scarce. Similarly, the area for pulses is reduced from 1040 ha to a constant 300 ha across all scenarios. This optimization analysis demonstrates a strategic approach to managing crop areas under varying water availability scenarios. By reducing water-intensive crops and increasing areas for more resilient crops, the strategy aims to ensure sustainable agricultural practices, maximize water use efficiency, and maintain overall productivity. This holistic approach is crucial for adapting to changing water resources and ensuring the long-term viability of agriculture in the region. [8] mentioned scope for optimization of crop plan, objectives and constraints, approaches, seasonality issues, sensitivity analysis and various computer software packages used in computing the optimum models. In devising various land and water allocation scenarios for the proposed cropping pattern, we factored in both the area and total water depth needed for major crops. Hence, our study focused on cropping intensity to create different cropping scenarios. By integrating cropping intensity with water availability, we identified cropping patterns that promise maximum net returns and optimal utilization of the available water resources.

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