Deriving Operation Policy for Multiple Reservoir System under Irrigation using LPM Model

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Abstract: The specified multiple reservoir system is located in the Rajkot district part of Gujarat. As it witnesses fewer, severe, moderate or normal drought, drought mitigation measures and proper reservoir operation policy should help to reduced acute shortage of water for irrigation as well as water supply. It is also observed that improper water resources management has resulted in reduced yield of crop and hence net income of farmers. The linear programming (LP) as optimization technique practical and practicable optimizes water resources system. Because of its simplicity and easily solved by using computer software LINGO. Therefore, it has vital significance to implement in day to day practice of reservoir operation by water resources planning and management sector. The linear programming monthly (LPM) models developed for different nine dependability levels of inflow for multiple as well as individual reservoir operations to derive maximum net benefit (NB) over year from command area. Most of reservoir operated at 75% dependability level in normal year. The NB and total optimal crop area increased by 4.2% and 8.0 % respectively in multiple reservoir operation as compared to individual reservoir operation at 75% dependability level of inflow. The irrigation intensity is increased in command area of Nyari-2, Aji-3 reservoir in multiple reservoir operation as compared to individual reservoir operation due to augmentation of low cost, low water requiring crops (Rajko, Juvar/Bajray/ Maize, Wheat, and Onion) which will reduce impact of drought in locality. Based on the results, it is concluded that reservoirs are operated in multiple reservoir systems at 75% dependability level of inflow and derived optimum operation policy for optimum utilization of limited freshwater of the reservoir in a drought-prone area.

Keywords: Maximum NB, Optimum cropping pattern, LPM, Multiple Reservoir System, LINGO 17.

1. INTRODUCTION

The Gujarat state falls under a high drought-prone area [3]. The existing situations like uneven rainfall distribution, below-average rainfall, deforestation, over-irrigation, and lack of sense of traditional rainwater harvesting system have resulted drought in state of Gujarat. Inadequate water resources pose a big threat to economy, human activities, and live hood in the Saurashtra region of Gujarat [18]. About 10 to 15 percentage taluka of Gujarat are declared drought affected in normal year [21]. There were two major droughts during early 1970s. But 1980s was worst decade to witness four major droughts of which the worst drought declared was in the year 1987-88 that affected more than 87% area of the state [24]. The drought indices are the key indicator of the onset of the drought [11]. Standard precipitation index (SPI) is main indices to forecast the drought [7], [23]. Conclusion based on SPI value, Rajkot district has witnessed severe drought in year 1982,1985,1986,1987,1999,2000,2002 and 2012. The normal droughts were 1990, 1991, 1993, 2001 and 2004. The fewer droughts were felt by Rajkot district in year 1987. The Rajkot district has experienced severe drought in year 2012 in current decade. On average, the Rajkot district has drought conditions once every 2 to 3 years [22]. Moderate drought was declared for Padadhari and Vichiyala taluka of Rajkot district, Dhrol and Jodiya Taluka of Jamnagar district in year 2018.[8] Therefore, utilization of this limited freshwater is one of most important and essential to managing the drought-prone areas.

Therefore, the first objective of this study to carry out research in this selected study area is to optimum utilization of limited available freshwater of the reservoir by using optimization theory in reservoir operation. Optimization theory will help in optimum water allocation of available limited freshwater of the reservoir for different purposes such as water supply and irrigation throughout the year to satisfy water demand. Optimum water allocation points out employment of optimization techniques i.e. Linear Programming (LP), Chance Constraint Linear Programming (CCLP), etc. in individual as well as multiple reservoir operations to derive optimum cropping pattern and maximum net benefits over year from command area to increase yield of crop and hence income of farmer.

The LP as optimization technique practical and practicable optimizes the water resources system. Because of its simplicity and applicability, it has special status. The LP model can be easily solved by using computer software like GAMS, LINDO, LINGO, MPL, and Win QSB [12] which is easily available through internet search engine. The LP as most popular optimization technique is utilized for sustainable irrigation planning of Jayakwadi irrigation project, Maharashtra [27]. The LP technique is used to optimize cropping patterns in Shringonda Tahsir which is part of semi arid region and rain shadow and Barmer district of Rajasthan [20], [34]. The LP model used to derive maximizes net benefit from markandeya command area of Ghataprabha River [29].
The chance constraint linear programme (CCLP) developed for annual and monthly models to optimize the cropping pattern and derive maximize net benefit from command area in individual reservoir operation [14]. The LP model developed to derive maximum revenue from optimum water supply release for municipal and Industrial purposes [1].

I look at the global population continuously rising, it is expected to reach the 9.7 billion mark in 2050 from the current level of 7.4 billion [31]. This is increase in population requires 60% additional food in next 35 years [10]. The provision of irrigation is vital for achieving food security [09]. This is particularly important in arid and semi-arid regions where precipitation is not reliable and highly erratic; both in quality and in distribution [30]. However second objective of this selected study area is to increase irrigation potential with proper planning and management of water resources system result in increase in yield of crop which leads to increasing prosperity of farmers. A new water resources system planning approached that the practical and environmental constraints with time have required the individual reservoir operation to be transformed to multi reservoir over a reservoir [5], [25]. The developed plan operation model which is used to analyze water resources evaluation law, assess impacts of multi-reservoir operation and determine the optimal operation policy of multiple reservoir system [13]. The benefits derived from joint operation of system of reservoirs exceed the benefits from independent operation of each reservoir [32].

II. STUDY AREA

Fig.1 Schematic Diagram of Multiple Reservoir System

The multiple reservoir system considered in this study area is situated between the global coordinates of 21° 23’ 52” N and 22° 34’00” N latitudes, 70° 34’00” E and 70° 44’ 36”E longitudes, and located at Aji river basin, Rajkot district, Gujarat. Aji river basin includes the main Aji river, Nyari-Dondi as left bank tributary, Demi-Khodapipar, bangawadi as right bank tributary and total thirteen medium/minor reservoirs which are constructed on main Aji river and on its tributary. Aji-2, Nyari-2, and Aji-3 reservoirs are selected in multiple reservoir systems as a study area; other reservoirs are not included due to the nonavailability of data. Schematic diagram of multiple reservoir system is shown in Fig.1. In this study area, Nyari-2 and Aji-2 reservoirs are operated in parallel, while Aji-2 and Aji-3 reservoirs are operated in series in multiple reservoir systems. The principle crops in Aji-2, Nyari-2, and Aji-3 reservoir command area are observed to be ground nut, fodder, maize, spike millet (Juvar), millet (Bajra), wheat, gram, vegetable, cotton, and castor. There are two seasons namely Kharif season (July to October) and Rabi season (November to February). Crops are observed during these seasons in the command area. Castor and Cotton are cultivated as biannual crops (observed in two seasons). Release for irrigation, storage, evaporation losses, overflow, inflow and observed cropping pattern data were collected for Aji-2, Nyari-2 and Aji-3 reservoir for the year 2005-06 to 2016-17 from Rajkot Irrigation Division. Nyari-2 reservoir has a gross storage capacity (GSC) of 12.25 MCM and 0.75MCM as dead storage capacity (DSC). It has only left bank canal (LBMC) having gross command area (GCA) and cultivated command area (CCA) 2070ha, 1695 ha respectively. Its discharge capacity is 3.06 m³/s. Aji-2 reservoir has GSC 22.09MCM with 1.33 MCM as DSC. The LBMC has GCA of 2529 ha and CCA of 2384 ha. and its discharge capacity is 2.92 m³/s. Aji-3 has a GSC of 61.95 MCM with 4.25MCM as DSC. The Aji-3 reservoir has Left and Right bank main canal system is compositely provided irrigation facilities to cultivable command area 6635 ha. Left and Right bank main canal discharge capacity is 4.5 m³/s and 2.27 m³/s respectively [19].

III. FORMULATION OF MATHEMATICAL MODEL

The LPM models formulation consists of objective functions with sets of constraints.

A. Objective Function: Maximization of NB (Multiple Reservoir Operation)

The objective function of the present study is to derive maximum the net benefit (NB) accrued in the multi-reservoir system by optimization of cropping pattern over a year and mathematically represented as

Objective Function (Z1): Max NB = Σj ∑i(Cij akij + Cij ai j + Cij atij) (1)

Where NB= Net benefits derived from irrigation in the system in MRs; j = index of reservoir = 1, 2, 3; i= index of Crop = 1, 2, 3……n; akij= allocated area during Kharif season at site j under crop i in ha. , ai j= allocated area during Rabi season at site j under crop i in ha. , atij= allocated area during two seasons at site j under crop i in ha. ni = total number of crops considered at site j; Cij = Coefficient of net benefits at site j per unit area of allocated crop in Rs/ha. The net benefit coefficient calculated per hectare after deducting all expenditure of cultivation, seed, fertilizer, pesticides and watering etc. It is assumed that the farmers and the members of his family are doing labour work on their own. The crop yield selling rate of marketing yard, Rajkot is considered as per the year 2015-2016. Others necessary information for computation of the net benefits coefficient is collected from authorities of agronomists, Rajkot. The objective function depends on a set of constrains which are discussed step by step as below:

1) Constraints: Land Allocation Constraints

The same land should be made available for a given crop throughout the growing season. For all the growing months m of crop i at site j,
\[ \sum_{i=m}^{n} A_{ijm} \leq CCA \quad j=1,2,3; \quad m=1,2,\ldots,12; \quad i=1,2,3\ldots.n \]

Where \( A_{ijm} \) is the total irrigated area in ha at site j under crops in period m; CCA is the cultrual command area at site j in ha.

2) Crop Area Constraints

The total crop area in each month is less than the possible maximum at each site.

\[ (a_{ijm})_{\min} \leq a_{ijm} \leq (a_{ijm})_{\max} \]

Where \( (a_{ijm})_{\max} \) max= Maximum observed area in ha under crop i in period m at site j; \( (a_{ijm})_{\min} \) min= Minimum observed area in ha under crop i in period m at site j.

3) Storage Continuity Constraints

The surface water continuity constraint specifies the relationship of the month to month reservoir storage. There is no downstream release from each reservoir, therefore it is considered as zero. It is mathematically given by

\[ S_{m+1}^{1} = S_{m}^{1} + I_{m} - \sum_{i=1}^{3} RI_{im} \leq E_{m} - Ov_{m} \quad (4) \]

\[ S_{m+1}^{2} = S_{m}^{2} + I_{m} - \sum_{i=1}^{3} RI_{im} \leq E_{m} - Ov_{m} \quad (5) \]

\[ S_{m+1}^{3} = S_{m}^{3} + I_{m} - \sum_{i=1}^{3} RI_{im} + Ov_{m}^{1} + Ov_{m}^{2} - E_{m} + Ov_{m}^{2} - 2R_{W_{m}} \quad (6) \]

date: j=1 For Aji-2, j=2 For Nyari-2 and j=3 For Aji-3 reservoir. Where \( m= \) Index of month 1,2,...,12; \( S_{m}^{1} \) = Storage at site j at the beginning of month ‘m’ in MCM; \( RI_{im} \) = Water diversion requirement of crop i at j during its growing month m and equal to zero for the non-growing months, \( I_{m} \) = Dependable Inflow in MCM in to reservoir during month m; \( Ov_{m}^{1} \) = Overflow in MCM from j reservoir during month m; \( RW_{m} \) = Release for drinking water supply from j reservoir during month m; Reservoir; \( E_{m} \) = Reservoir evaporation in MCM at site j during the month m.

4) Water Diversion Requirement

Crop growth water requirement in the canal has to be met from the reservoir release by considering the efficiencies of the surface water system. The constraint which is mathematically expressed as:

\[ \sum_{i=1}^{3} N_{IR_{im}A_{ijm}} \leq \eta_{i} RI_{jm} \]

Where \( N_{IR_{im}} \) = Net irrigation requirement of crop i at j during its growing month m; and collected from the office of the Agronomist-Nasari, District: Valsad. \( \eta_{i} \) = Efficiency of the surface water system; and has been taken to be 62.5% of Aji-2, Nyari-2 and 65% of Aji-3 for Left Bank Main Canal (LBMC) (unlined canal) [2]. \( RI_{jm} \) = Water diversion requirement of crop i at j during its growing month ‘m’.

Dependable Inflow

The dependable inflow for Aji-2, Nyari-2, and Aji-3 is calculated for each month. First the Weibull method [6] is used to calculate the probability of inflow exceeded

\[ P = \frac{m+n}{n} \]

Where P = event probability, n= Number of years of data available, m= Ranke of event occurrence. Then projected monthly inflow at 50, 55, 60, 65, 70, 75, 80, 85 and 90 % dependable levels are calculated based on interpolation method, and are utilized to develop LPM model and accordingly models are named as LPM50, LPM55, LPM60, LPM65, LPM70, LPM75, LPM80, LPM85, and LPM90.

5) Canal Carrying Capacity Constraints

At any month “m”, Water diversion requirement must be less than or equal to the carrying capacity of the main canals and is explained as,

\[ RI_{jm} \leq CCC_{m} \]

Where \( CCC_{jm} \) = Canal carrying capacity of the jth reservoir for month ‘m’.

The LPM model is conceptualized for Aji-3 reservoir in individual as well as multiple reservoir system for all dependability level of inflow that water release through a individual irrigation canal from the reservoir to a composite command comprising the left and right bank command area to address the limitation of the model in its inability to deal with different random releases into left and right bank canals which have the same source of supply [26]. Therefore canal carrying capacity constraint for Aji-3 reservoir was given in LPM model as per the following:

\[ R_{3m} \leq CCC_{3m}, CCC_{3m} = \sum_{i=1}^{9} LPM_{i} \]

Water supply Release Constraints

The water supply release from the reservoir at the j site of the reservoir should be greater than the minimum water supply release and should be less than the maximum water supply release which is arrived at on the basis of the observed release of water supply under the reservoir. Then it is expressed as:

\[ (R_{jm})_{\min} \leq R_{jm} \leq (R_{jm})_{\max} \]

Where \( R_{jm} \) = Release of water supply from the reservoir at j site for the month ‘m’ in MCM.

7) Reservoir Storage Capacity Constraints

The reservoir storage in any time period should not be more than the maximum capacity of the reservoir and should not less than the dead storage of reservoir.

\[ (S_{jm})_{\min} \leq S_{jm} \leq (S_{jm})_{\max} \]

Where \( S_{jm} \) = Storage at month ‘m’ of the reservoir at site j in MCM.

8) Evaporation Constraints

A linear relationship has to be established between the volume of evaporation loss in the reservoir and average storage for month ‘m’.

\[ E_{jm} = a_{jm} + b_{jm} (S_{jm} + S_{jm+1})/2 \]

Where \( E_{jm} \) = evaporation loss from the reservoir in MCM during the month ‘m’ at j site; \( S_{jm} \) = Initial storage of reservoir during month ‘m’ at j site in MCM; \( S_{jm+1} \) = final storage of reservoir during month ‘m’ at j site in MCM; \( a_{jm} \) and \( b_{jm} \) = regression coefficient during month ‘m’ at j site. Monthly linear regression models for each month are developed using 9 years actual data of evaporation and average storage with Microsoft Excel. The summary of monthly linear regression model is presented in Table I with value of statistical parameter ‘r’. From Table I, it has been observed that r value yielded in rage 0.6 to 0.99 except 0.15 in June month of Nyari-2 for three reservoirs which means strong linear relation exists between average storage and evaporation. In June month of Nyari -2, less r value yielded due to very less average storage available in the reservoir.
9) **Overflow Constraints**

The overflow constraint is provided in the LPM model; otherwise, the model will spill over even when the reservoir storage is less than its capacity. The overflow constraint is mathematically expressed as:

\[ \text{Ovf}_{jm} = S_{jm} + I_{jm} - R_{jm} - E_{jm} - K \]  

(14)

Where \( K \) = Gross Storage Capacity of the reservoir in MCM at \( j \) site.

**B. Objective Function: Maximization of NB**  
(Individual Reservoir Operation)

The objective function of the present study is to maximize the net benefit (NB) accrued in the individual reservoir operation by optimization of cropping pattern over a year and mathematically represented as

\[ \text{Objective Function (Z)} \text{Maximize NB}= \sum_{i=1}^{N}(C_{i}a_{ki} + C_{\text{short}+\text{long}}) \]  

(15)

Where NB = Net benefits occurred in catchment in million rupees(MRs); \( i = \) index of crop = 1, 2, 3,……..n. \( C_{i} = \) Coefficient of net benefits per unit area of allocated crop in Rs/ha, \( a_{ki} = \) area allocated to crop during the Kharif season in ha in LBMC command area, \( a_{ri} = \) area allocated to crop during the Rabi season in hectare (ha) in LBMC command area, \( a_{ti} = \) area allocated to crop during the two seasons in ha in LBMC command area. The net benefit coefficient calculated per hectare after deducting all expenditures of cultivation, seed, fertilizer, pesticides, and watering, etc. It is assumed that the farmers and the members of his family are doing labor work on their own. The crop yield selling rate of marketing yard, Rajkot is considered as per the year 2015-2016. Other necessary information for computation of the net benefits coefficient is collected from authorities of agronomists, Rajkot.

1) **Constraints**

The objective function of individual reservoir operation also depends on the same set of constraints which are discussed step by step under section 3. A. Moreover, in only one constraint i.e. Storage Continuity Constraint makes distinction which is described in the next subheading.

2) **Storage Continuity Constraint**

The storage continuity constraint expresses the link of the month to month storage of individual reservoir and it is mathematically expressed as:

\[ S_{t+1} = S_{t} + I_{t} - R_{t} - E_{t} - \text{Ovf}_{t} \]  

(16)

Where \( I_{t} = \) Dependable Inflow in MCM into the reservoir during month \( t \), \( \text{Ovf}_{t} = \) Overflow in MCM from the reservoir in the month \( t \).

### IV. RESULTS AND DISCUSSION

There were thirty six different LPM models developed in individual input files and solved by using LINGO 14.0 [15] and LINGO 17.0 unlimited constraint version which is provided by LINDO System Private Limited, Chicago[16]. But LPM85 and LPM90 provided an infeasible solution while other models resulted maximum NB, total optimum crop area, optimal cropping pattern and optimum storage, optimum release for irrigation which are discussed under this section.

A. **Comparative Analysis of NB and Total Optimum Crop Area**

The comparative results of net benefit and total optimum crop area are provided from different models when reservoirs operated in individual as well as multiple reservoir systems that are presented in Table II. From Table II, it can be seen that maximum NB and total optimum crop area increased from 80% to 50% dependability level of inflow when reservoir is operated in individual as well as multiple reservoir systems. Also from Table II, it can be seen that the NB and total optimum crop area increased by 4.2% and 8% respectively in multiple reservoir operation as compared to individual reservoir operation at 75% dependability level of inflow while it also increased by 5.90 % and 1.93 % respectively at 80% dependability level of inflow. An increase in crop area was made possible due to more availability of water in the reservoir while the reservoir is operating in multiple reservoir system. The maximum NB and total optimum crop area increased 3.42 % and 4.56 % respectively in multiple reservoir operation as compared to individual reservoir operation at 50% dependability level of inflow because of maximum crop area constraints are satisfied, therefore reduction in increase in percentage is observed even though increase in inflow. Therefore the maximum NB and total optimum crop area gradually reduced from 50% dependability level to 80% dependability level that means linear relationships exist between the maximum NB as well as total optimum crop area and dependability level of inflow.

Taking reference to existing literature, it has been noticed that the reservoir is operated at 75 % dependability level of inflow [4]. However, the maximum NB is derived million Rs 1067.64 at 75% dependability level of inflow when three reservoirs operated in multiple reservoir system. But the summation of maximum NB is reduced to Rs 4911.
Table II: Comparative Analysis of NB and Total Optimum Crop Area

| LPM | Reservoirs are operated in Multiple Reservoir System | Reservoirs are operated in Individual | Derived NB Increase (MRcs.) | Total Crop Area Increase (ha) | % of Total Optimum Crop Area Increase (ha) | % of NB Increase (ha) |
|-----|----------------------------------------------------|-----------------------------------|----------------------------|----------------------------|----------------------------------------|-----------------------|
| 50  | 11192.84                                          | 1282.56                           | 10682.65                  | 1238.71                    | 43.85                                  | 510.19                | 4.56                  | 3.42 |
| 55  | 11152.62                                          | 1280.78                           | 10646.76                  | 1236.83                    | 42.95                                  | 488.05                | 4.38                  | 3.35 |
| 60  | 11110.80                                          | 1278.77                           | 10622.75                  | 1235.81                    | 42.96                                  | 488.05                | 4.39                  | 3.36 |
| 65  | 11086.14                                          | 1277.45                           | 10597.57                  | 1234.60                    | 42.85                                  | 488.36                | 4.41                  | 3.35 |
| 70  | 10130.16                                          | 1201.93                           | 8800.01                   | 1116.20                    | 85.73                                  | 1330.15               | 13.13                 | 7.13 |
| 75  | 8264.29                                           | 1067.64                           | 7603.27                   | 1022.85                    | 44.79                                  | 661.02                | 8.00                  | 4.20 |
| 80  | 6246.78                                           | 835.84                            | 6126.35                   | 786.53                     | 49.31                                  | 120.43                | 1.93                  | 5.90 |

B. Seasonal Optimum Crop Area and NB

Seasonal optimum crop area and Maximum NB derived from Aji-2, Nyari-2 and Aji-3 command area in individual reservoir operation are presented in Table III(a). From Table III(a), it has been seen that maximum NB in individual reservoir operation is derived million Rs 417.27, 140.87, 464.71 respectively in Aji-2, Nyari-2 and Aji-3 command area, when these three reservoirs are operated individually at 75% dependability level of inflow. There are mostly observed crop in Kharif and Rabi season. The biannual crop is observed during both seasons which is seeded in Kharif season and harvested in Rabi season. And Optimum crop area in Rabi season is more as compared to Kharif season. By vigilantly observation of inflow value, it was found that if there is large inflow from July to Sept month then there is the chance of a more irrigation area irrespective of the value of inflow during another month which is happened at all dependability level of inflow in individual reservoir operation. Moreover, Kharif, Rabi, and Biannual crop area increase from 75% to 50% dependability level inflow.

Seasonal optimum crop area resulted from different LPM in multiple reservoir operation are presented in Table III(b). From Table III(b), it can be seen that Kharif, Rabi, and Biannual crop area increased from 75% to 50% dependability level inflow, but Kharif area of Aji-2 is more resulted by LPM at 80% dependability level, it means that model has chosen crop area such a way that its required less water for grown during kharif season.

C. Optimum Crop Area and Irrigation Intensity

The total optimum crop area and calculated irrigation intensity at different dependable inflow level in multiple reservoir operation and individual reservoir operation is presented in Table IV. From Table IV, it can be seen that total optimum crop area and irrigation intensity gradually increased with step by step reducing the dependability level of inflow in individual as well as multiple reservoir operation. The irrigation intensity is the ratio of crop area shown in particular season to cultivated command area. The total irrigation intensity is the sum of irrigation intensity of Kharif season, Rabi and biannual season. It can be also seen that even with a 50% dependability level, it is not possible to irrigate the entire command area because water available in scare during dry period (Dec-March) of reservoir operation, and the maximum irrigation intensity is computed 159.34%, 94.30%, 87.35% in Aji-2, Nyari-2 and Aji-3 reservoir command area respectively in multiple reservoir operation while it is computed 144.09%, 85.64%, 87.62% in Aji-2, Nyari-2 and Aji-3 reservoir command area respectively in individual reservoir operation. At 75% dependability level, total irrigation intensity is found 139.81%, 67.07%, 57.95% in Aji-2, Nyari-2, Aji-3 reservoir respectively in multiple reservoir operation, while it is found 144.09%, 63.20%, 46.82% in Aji-2, Nyari-2, Aji-3 reservoir respectively in individual reservoir operation. However multiple reservoir operation at 75% dependability level will prove more efficient due to increasing overall total irrigation intensity in multiple command areas. It can be also seen that irrigation intensity increase in command area of Nyari-2 and Aji-3 which falls under Padadhari taluka. The Padadhari taluka is one of the highly drought-prone areas of, Rajkot district. So it is advisable to operate reservoir in multiple reservoir systems at 75% dependability level of inflow to mitigate drought impact in the study area.

1) Comparative Optimum Cropping Pattern

The resulted in optimum cropping pattern from proposed model LPM75 of the multiple as well as individual reservoir operation is presented in Table V. From Table-V, it has been seen that crop area of caster(at1) 99.24 %, others crop (Rajko/Methi) (ar2) 99.77% are augmented in LBMC of Aji-2, Crop area of Juvat/bajri/Maize(ak2) 96.15% is augmented in LBMC of Nyari-2 and crop area of Dodder(ar3) 80.10%, Wheat(at1) 22.51%, Onion/Garlic 62.69% are augmented in composite canal command area of Aji-3 in multiple reservoir operation as compared to individual reservoir operation. Hence the cropping area increased and the net benefits directly enhanced in multiple reservoir operations. Low cost crop (Juvat/Bajri/Maize, Onion, Wheat, Rajko, Dodder) are augmented in higher percentage which is food grains. So it is beneficial in study area to mitigate drought impact.
V. MODEL VALIDATION

The model is formulated and validated using 80%, 20% data of total year of collected respectively. The model of multiple reservoir operation is validated by comparing optimum cropping pattern resulted from LPM75 with the actually observed cropping pattern of the year 2014-15 and the year 2015-16 in LBMC of Aji-2, Nyari-2, and Aji-3 reservoir. In Fig. 2 (a) LBMC of Aji-2, it can be seen that cotton, castor, other crops (Fodder), groundnut area were augmented by 45.35%, 95.83%, 93.30%, 83.80 respectively while it is compared with the year 2014-15. Similarly trend observed when it is compared with the year 2015-16. In Fig. 2(b) LBMC of Nyari-2, it was observed that wheat, Juvar/bajri/maize areas were augmented by 76.1%, 92.75% respectively while it is compared with the year 2014-15. But only Juvar/bajri/maize augmented when it is compared with the year 2015-16. And From Fig. 2(c), it was observed that castor, other crops (Fodder), wheat, garlic/onion, Vegetable, ground nut area were augmented by 77.73%, 82.73%, 22.51%, 99.92%, 97.93%, 39.87% respectively in composite canal command area while it is compared with the year 2014-15. Similarly trend observed when it is compared with year 2015-16. But cotton was grown as dominate crop in Aji-3 command area in the year 2015-16. It shows, people are more concentrated on cotton which will increase risk in failure of crops in less rainfall year. There should be necessary to increase awareness among the people of Aji-3 command area regarding this risk of failure.
Table V: Comparative Optimum Cropping Pattern Resulted from LPM75

| LBMC/CC  | Season       | Crop Notation | Crop     | Unit | Multiple reservoir System operation | Individual reservoir operation | % area increase in multiple reservoir operation |
|----------|--------------|---------------|----------|------|-------------------------------------|-------------------------------|-----------------------------------------------|
| Aji-2 Reservoir | Two Season   | at₁ | Cotton    | ha   | 913.60                              | 913.6                          | 99.24                                         |
|           |              | at₂ | Castor    | ha   | 78.87                               | 0.6                            |                                               |
|           | Rabi Season  | ar₁ | Other Crop(Rajko/Methi) | ha   | 449.20                              | 1.03                           | 99.77                                         |
|           |              | ar₂ | Juvar/Bajri/Maize | ha   | 0.58                                | 0.58                           |                                               |
|           |              | ar₃ | Cumin     | ha   | 181.83                              | 181.83                         |                                               |
|           |              | ar₄ | Wheat     | ha   | 138.17                              | 975.28                         |                                               |
|           |              | ar₅ | Vegetables | ha   | 0.40                                | 0.4                            |                                               |
|           | Kharif Season| ak₁ | Groundnut | ha   | 1389.92                             | 1181.25                        | 15.01                                         |
|           |              | ak₂ | Juvar/Bajri | ha   | 0.48                                | 0.48                           |                                               |
|           |              | ak₃ | Others Crops | ha   | 1.13                                | 1.13                           |                                               |
| Nyari-2 Reservoir | Two Season   | at₁ | Cotton    | ha   | 436.65                              | 48.29                          |                                               |
|           |              | at₂ | Castor    | ha   | 1.62                                | 35.94                          |                                               |
|           | Rabi Season  | ar₁ | Other Crop(Fodder) | ha   | 1.57                                | 34.84                          |                                               |
|           |              | ar₂ | Juvar/Bajri/Maize | ha   | 0.19                                | 0.19                           |                                               |
|           |              | ar₃ | Cumin     | ha   | 4.91                                | 4.91                           |                                               |
|           |              | ar₄ | Wheat     | ha   | 326.45                              | 326.45                         |                                               |
|           |              | ar₅ | Garlic/Onion | ha   | 1.89                                | 2.95                           |                                               |
|           |              | ar₆ | Vegetables | ha   | 1.00                                | 1                              |                                               |
|           | Kharif Season| ak₁ | Groundnut | ha   | 221.32                              | 221.32                         |                                               |
|           |              | ak₂ | Juvar/Bajri | ha   | 141.30                              | 5.44                           | 96.15%                                        |
|           |              | ak₃ | Others Crops | ha   | 1.16                                | 1.16                           |                                               |
| Aji-3 Reservoir | Two Season   | at₁ | Cotton    | ha   | 1557.85                             | 1557.85                        |                                               |
|           |              | at₂ | Castor    | ha   | 62.57                               | 62.57                          |                                               |
|           | Rabi Season  | ar₁ | Other Crop(Fodder) | ha   | 497.67                              | 99.01                          | 80.10                                         |
|           |              | ar₂ | Juvar/Bajri/Maize | ha   | 1.16                                | 1.16                           |                                               |
|           |              | ar₃ | Cumin     | ha   | 151.68                              | 151.68                         |                                               |
|           |              | ar₄ | Wheat     | ha   | 224.68                              | 174.1                          | 22.51                                         |
|           |              | ar₅ | Garlic/Onion | ha   | 395.88                              | 137.67                         |                                               |
|           |              | ar₆ | Pulses    | ha   | 361.57                              | 361.57                         |                                               |
|           | Kharif Season| ar₇ | Vegetable | ha   | 1.19                                | 1.19                           |                                               |
|           |              | ak₁ | Groundnut | ha   | 530.53                              | 530.53                         |                                               |
|           |              | ak₂ | Juvar/Bajri | ha   | 9.59                                | 9.59                           |                                               |

Note: Optimal results of respective crops are indicated with a bold value

Fig. 2(a) Optimum cropping pattern compared with actual crop pattern of the year 2014-15 and the year 2015-16 in Aji-2 LBMC command area.

Fig. 2(b) Optimum cropping pattern compared with actual crop pattern of the year 2014-15 and the year 2015-16 in Nyari-2 LBMC command area.
VI. THE HEDGING RULE CURVE IN PRIORITY OF IRRIGATION

Reservoirs are operated according to sets of rules for releasing and storing depending upon the purpose to be served. The reservoir operation rule should be prepared in accordance with the principle of conservational use of in case single purpose, or multiple purposes. Individual or Multiple reservoir operation regulation schedules are required to develop with considering sets of constraints involved in the system. A rule is based on detailed sequential analysis of various critical combinations of hydrological conditions and water demand. Extreme climate condition like droughts is a normal part of climate which occurrences are unavoidable. Therefore, it is necessary to pay more attention to drought including water shortage. Drought related impacts can be mitigated by hedging rules for reservoir management [33]. The hedging parameters used to construct the hedging rule and evaluated [28]. Parametric rule Proposed for different goals of operation in the planning and management of multiple reservoir systems [17]. The storage operation policy (hedging rule curve) of Aji-2, Nyari-2 and Aji-3 reservoir is derived based on priority of irrigation at 75% dependability level of inflow which is presented in Fig 3(a), (b) and (c) respectively. The optimal solution of the model consists of 2D reservoir rule curve with variable water allocation for irrigation purposes at each operating period. Reservoir operating period Jun to May, the reservoir operation rule curves presented some interesting variation. From Fig.3 (a), (b), (c), it can be seen that resulted optimum initial storage from individual reservoir and multiple reservoir operation are almost equal. Hedging rule curve storage is higher than minimum observed storage and lower than maximum actual observed storage during operating period. It is suggested to maintain hedging rule curve storage in Aji-2, Nyari-2, and Aji-3 reservoir during the operation period in multiple reservoir operations to derive maximum NB. The highest optimum initial storage is observed during October month and it gradually reduces till the month of May. From Fig.3 (c), it can be seen that actually observed maximum storage in month of August is higher than existing rule curve storage; therefore it is advisable to change it.

VII. OPTIMAL RELEASE POLICY WHEN IRRIGATION IS PRIORITY

The optimal release policy derived for left bank main canal release in three reservoirs Aji-2, Nyari-2 and Aji-3 as the irrigation priority in individual and multiple reservoir operation at 75 % dependability level of inflow is presented in Fig. 4(a), (b) and (C). Here it may be noticed that water releases made to left bank canal to meet the demand of irrigation while at the same time minimum water supply demand too.

The optimal release policy obtained for the Aji-2 reservoir is shown in Fig 4 (a). From Fig. 4(a), It can be seen that irrigation releases are observed high in kharif season in multiple reservoir operations as compared to individual...
reservoir operation due to augmentation of cotton and castor crop in kharif season, therefore net irrigation benefits are derived more in multiple reservoir operations.

Fig. 4(a) Optimal Release Policy for Aji-2 Reservoir at 75% dependable inflow

The optimal release policy obtained for Nyari-2 reservoir is shown in Fig.4 (b). From Fig. 4(b), it can be seen that irrigation releases are observed more during entire operation time in individual reservoir operation as compared to multiple reservoir operation, but irrigation intensity is derived high in multiple reservoir operation. It means model has chosen crop which is demanding more water in individual reservoir operation as compared to chosen crop by model in multiple reservoir operation.

Fig. 4(b) Optimal Release Policy for Nyari-2 Reservoir at 75% dependable inflow

Fig. 4(c) Optimal Release Policy for Aji-3 Reservoir at 75% dependable inflow

The optimal release policy obtained for Aji-3 reservoir is shown in Fig.4(c). From Fig. 4(c), it can be seen that irrigation releases are observed high in multiple reservoir operation as compared to individual reservoir operation due to augmentation of crop area i.e. castor, other crops (Fodder), wheat, garlic/onion, Vegetable, groundnut, therefore net irrigation benefits are derived high in multiple reservoir operation. It shows surplus water release from Nyari-2 and Aji-2 during operation period

VIII. CONCLUSION

In this study, The LPM models have been developed to derive maximum NB and optimum cropping pattern by operating reservoir as individual as well as in multiple reservoir system. The results of different LPM were compared for individual and multiple reservoir operations. In multiple reservoir operation at 75% dependability level, the irrigation intensity increased in command area of Nyari-2 and Aji-3 which are fall under the drought-prone area. The crop area of caster (at2) of 99.24 %, others crop (Rajko/Methi) (ar) of 99.77% are augmented in LBMC of Aji-2. The Crop area of Juvar/ bajir/Maize (ak)of 96.15% is augmented in LBMC command area of Nyari-2 and crop area of Fodder (ar)of 80.10%, Wheat(at)of 22.51%, and onion/Garlic (ar)of 62.69% is augmented in composite canal command area of Aji-3 in multiple reservoir operation as compared to individual reservoir operation. Hence the optimum cropping area increased and the net benefits directly enhanced in multiple reservoir operations. The NB derived in multiple reservoir operation was 4.2% better than individual reservoir operation. However it is concluded to operate reservoir in multiple reservoir systems at 75% dependability level of inflow instead of individual reservoir operation and derived optimum storage and release policy for multiple reservoir operation. Multiple reservoir operation policies guide to maintain required storage and irrigation release during operation period to derive maximum net benefit of 1067.64million Rupees. In future study of risk assessment of multiple reservoir operation policy can be carried out using reliability, resilience and vulnerability parameter of operation measure.

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