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

Bhavana K. Ajudiya, P. K. Majumdar, S. M. Yadav

Abstract*: The specified multiple reservoir system is located in 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 into reduced yield of crop and hence net income of farmers. The linear programming monthly (LPM) models developed for different nine dependability level of inflow for multiple as well as individual reservoir operation 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 reservoirs 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/Bajry/Maize, Wheat, and Onion) which will reduce impact of drought in locality. However it can conclude that reservoirs are operated in multiple reservoir system at 75% dependability level of inflow as per derived optimum operation policy instead of individual reservoir operation to optimum utilization of limited fresh water of reservoir in drought prone area.

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

I. INTRODUCTION

The Gujarat state falls under highly 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 Saurastra 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 an average, Rajkot district has drought condition once in every 2 to 3 year [22]. Moderate drought was declared for Padadhari and Vichiya taluka of Rajkot district, Dhrol and Jodiya Taluka of Jamnagar district in year 2018.[8] Therefore, utilization of this limited fresh water is one of most important and essential to manage the drought prone areas.

Therefore, first objective of this study to carry out research in this selected study area is to optimum utilization of limited available fresh water of reservoir by using optimization theory in reservoir operation. Optimization theory will help in optimum water allocation of available limited fresh water of 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 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 pattern 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].

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The chance constraint linear programme (CCLP) developed for annual and monthly model 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 purpose [1].

If look at global population continuously rising and 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 the 60% additional food in next 35 year [10]. The provision of irrigation is vital for achieving food security [09]. This is particularly important in arid and semi arid region 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 in irrigation potential with proper planning and management of water resources system would result in increase in yield of crop which leads to increasing prosperity of farmer. A new water resources system planning approached that the practical and environmental constraints with time, has 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

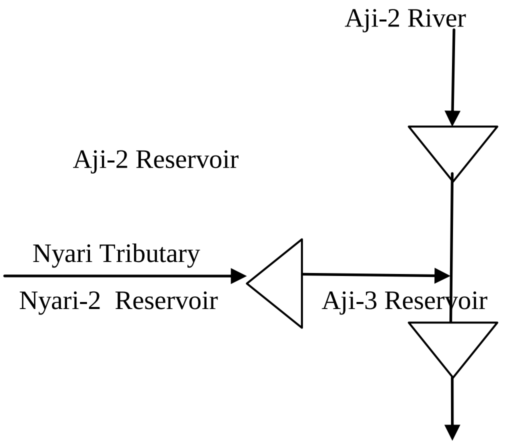

Fig.1 Schematic Diagram of Multiple Reservoir System

The multiple reservoir system considered in this study area is situated between the global coordinates of 21º 23′ 52" N and 22º 34′00" N latitudes, 70º 34′ 00" E and 70º 44′ 36"E longitudes, and located at Aji river basin, Rajkot district, Gujarat. Aji river basin includes 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 system as a study area, other reservoirs are not included due to non availability 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 m^3/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 m^3/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 culturable command area 6635 ha. Left and Right bank main canal discharge capacity is 4.5 m^3/s and 2.27 m^3/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=

$$\Sigma_j^3 \sum_i^{nj} (C_{ij}ak_{ij} + C_{ij}ar_{ij} + C_{ij}at_{ij}) \qquad (1)$$

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; ak_{ij}= allocated area during Kharif season at site j under crop i in ha. , ar_{ij}= allocated area during Rabi season at site j under crop i in ha. , at_{ij}= allocated area during two seasons at site j under crop i in ha. n_j = total number of crops considered at site j; C_{ij} = 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,

$$\sum_{i=1}^{jn} A_{ijm} \leq CCA \quad , j=1,2,3 ; \quad m= 1,2,\ldots\ldots 12; \ i= 1,2,3\ldots n. \tag{2}$$

Where A_{ijm} is the total irrigated area in ha at site j under crops i in period m ; CCA is the culturable 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.

$$(a_{ijm})\min \leq a_{ijm} \leq (a_{ijm})\max , \tag{3}$$

Where (a_{ijm}) max= Maximum observed area in ha under crop i in period m at site j; (a_{ijm}) 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 month to month reservoir storage. There is no downstream release from each reservoir, therefore it is considered as zero. It is mathematically given by

$$S^{j=1}{}_{m+1} = S^1{}_m + I^1{}_m - \sum_{i=1}^{1n} RI_{im} - E^1{}_m - Ovf^1{}_m , \tag{4}$$

$$S^{j=2}{}_{m+1} = S^2{}_m + I^2{}_m - \sum_{i=1}^{2n} RI_{im} - E^2{}_m - Ovf^2{}_m - RW^2{}_m, \tag{5}$$

$$S^{j=3}{}_{m+1} = S^3{}_m + I^3{}_m - \sum_{i=1}^{3n} RI_{im} + Ovf^1{}_m + Ovf^2{}_m - E^3{}_m - Ovf^3{}_m - RW^3{}_m \tag{6}$$

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; $S^j{}_m$ = Storage at site j at the beginning of month 'm' in MCM; RI_{jim}= Water diversion requirement of crop i at j during its growing month m and equal to zero for the non-growing months, I_{jm} = Dependable Inflow in MCM in to reservoir during month m; $Ovf^j{}_m$ = Over flow in MCM from j reservoir during month m; $RW^j m$ = Release for drinking water supply from j reservoir during month m; Reservoir; E_{jm} = 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:

$$\sum_{i=1}^{jn} NIR_{im} A_{im} \leq \eta_s RI_{jim} \tag{7}$$

Where NIR_{im}= Net irrigation requirement of crop i at j during its growing month m; and collected from the office of the Agronomist-Navsari, District: Valsad. η_s = 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_{jim} = Water diversion requirement of crop i at j during its growing month 'm'.

5) 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 calculated the probability of inflow exceeded

$$P = m/n+1 \tag{8}$$

where P = An 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.

6) 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,

$$RI_{jm} \leq CCC_m \tag{9}$$

Where CCC_{jm} = Canal carrying capacity of j^th 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 two 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 following:

$$RI_{3m} \leq CCC_{3m} \text{ of LBMC} + CCC_{3m} \text{ of RBMC} = \text{Composite Canal carrying capacity} \tag{10}$$

Where CCC_{3m} = Canal carrying capacity of Aji-3 reservoir for month'm'. However RI_{3m} = Irrigation Release from Composite Canal of Aji-3 Reservoir

7) 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 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:

$$(R_{jm})\min \leq R_{jm} \leq (R_{jm})\max \tag{11}$$

Where R_{jm} = Release of water supply from the reservoir at j site for the month 'm' in MCM.

8) 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 dead storage of reservoir.

$$(S_{jm})\min \leq S_{jm} \leq (S_{jm})\max \tag{12}$$

Where S_{jm} = Storage at month 'm' of the reservoir at site j in MCM.

9) Evaporation Constraints

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

$$E_{jm} = a_{jm} + b_{jm}[-(S_{jm} + S_{j(m+1)})/2 \tag{13}$$

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 reservoir 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.

Table I: Summary of Monthly Regression Model with Statistical Parameter

Month	Aji-2 Reservoir			Aji-3 Reservoir			Nyari-2 Reservoir		
	a	b	r	b	a	r	b	a	r
Jan	0.086	0.028	0.8373	0.050	-0.310	0.8874	0.035	0.078	0.9971
Feb	0.060	0.028	0.8173	0.057	-0.302	0.8626	0.036	0.064	0.9961
March	0.053	0.048	0.8337	0.060	0.039	0.9949	0.060	0.094	0.9931
April	0.052	0.057	0.9000	0.065	0.112	0.9992	0.075	0.076	0.9904
May	0.042	0.066	0.9198	0.065	0.177	0.9963	0.091	0.058	0.9814
June	0.122	0.046	0.7036	0.025	0.354	0.6489	0.006	0.192	0.1591
July	0.172	0.042	0.7218	0.042	0.243	0.7587	0.062	0.062	0.8654
Aug	0.099	0.051	0.9910	0.048	0.234	0.9870	0.059	0.887	0.9841
Sep	0.147	0.047	0.9970	0.052	-0.111	0.9373	0.056	0.012	0.9998
Oct	0.059	0.045	0.9995	0.043	0.120	0.9254	0.048	0.111	0.9998
Nov	0.098	0.036	0.9859	0.042	-0.0142	0.8615	0.041	0.974	0.9990
Dec	0.097	0.029	0.9132	0.046	-0.280	0.8444	0.032	0.096	0.9973

10) 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:

$$Ovf_{jm} >= S_{jm} + I_{jm} - R_{jm} - E_{jm} - K \quad (14)$$

Where K = Gross Storage Capacity of 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

Objective Function (Z) Maximize NB=

$$\sum_{i=1}^{n}(C_i ak_i + C_i ar_i + C_i at_i) \quad (15)$$

Where NB = Net benefits occurred in catchment in million rupees(MRs); i= index of crop = 1, 2, 3…….n. C_{ij} = Coefficient of net benefits per unit area of allocated crop in Rs/ha, ak_i = area allocated to crop during the Kharif season in ha in LBMC command area, ar_i = area allocated to crop during the Rabi season in hectare (ha) in LBMC command area, at_i = area allocated to crop during the two seasons in ha in LBMC command area. 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.

1) Constraints

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

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:

$$S_{t+1} = S_t + I_t - R_t - E_t - ovf_t \quad (16)$$

Where It = Dependable Inflow in MCM into the reservoir during month t. Ovft = Overflow in MCM from the reservoir in the month

IV. RESULTS AND DISCUSSION

There were thirty six different LPM models developed in individual input file and solved by using LINGO 14.0 [15] and LINGO 17.0 unlimited constrain 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 system 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 system. 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. 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 are 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 mean linear relation exist between the maximum NB as well as total optimum crop area and dependability level of inflow.

Taking reference of 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 1022.85 x10^6 when three reservoirs operated in individual at 75% dependability level of inflow which is reduced by 4.2%.

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 (MRs.)	Total Crop Area Increase (ha)	% of Total Optimum Crop Area Increase (ha)	% of NB Increase (ha)
	Total Optimum Crop Area in ha	Derived NB in MRs.	Total Optimum Crop Area in ha	Sum of derived NB in MRs.				
50	11192.84	1282.56	10682.65	1238.71	43.85	510.19	4.56	3.42
55	11152.62	1280.78	10664.57	1237.83	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	10597.78	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 is derived million Rs 417.27, 140.87, 464.71 respectively in Aji-2, Nyari-2 and Aji-3 command area, when this three reservoirs are operated individually at 75% dependability level of inflow There are mostly observes crop in Kharif and Rabi Season. Biannual crop are observed during both season 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 during July to Sept month then there is the chance of a more irrigation area irrespective of the value of inflow during other 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 increase from 75% to 50% dependability level inflow, but kharif area of Aji-2 is more resulted by LPM at 80% dependability level, it mean 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 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 area. It can be also seen that irrigation intensity increase in command area of Nyari-2 and Aji-3 which are fall under Padadhari taluka. The Padadhari taluka is one of highly drought prone area of , Rajkot district. So it is advisable to operate reservoir in multiple reservoir system at 75% dependability level of inflow to mitigate drought impact in the study area.

1) Comparative Optimum Cropping Pattern

The resulted 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(at_2) 99.24 %, others crop (Rajko/Methi) (ar_2) 99.77% are augmented in LBMC of Aji-2, Crop area of Juvar/ bajri/Maize(ak_2) 96.15% is augmented in LBMC of Nyari-2 and crop area of Fodder(ar_1)80.10%, Wheat(at_2) 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 operation. Low cost crop (Juvar/Bajri/Maize, Onion, Wheat, Rajko, Fodder) are augmented in higher percentage which are food grains. So it is beneficial in study area to mitigate drought impact.

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Table III(a): Seasonal Optimum Crop Area and NB Resulted from Different LPM in Individual Reservoir Operation

LPM	Optimum crop area and Max. NB derived from Aji-2 command area				Optimum crop area and Max. NB derived from Nyari-2 command area				Optimum crop area and Max. NB derived from Aji-3 command area			
	Kharif (ha)	Rabi (ha)	Biannual (ha)	NB (MRs.)	Kharif (ha)	Rabi (ha)	Biannual (ha)	NB (MRs.)	Kharif (ha)	Rabi (ha)	Biannual (ha)	NB (MRs.)
50	1182.86	1337.96	914.20	417.27	226.76	750.73	474.23	166.35	540.12	3635.37	1620.42	655.09
55	1182.86	1337.96	914.20	417.27	226.76	732.65	474.23	165.47	540.12	3635.37	1620.42	655.09
60	1182.86	1337.96	914.20	417.27	226.76	690.83	474.23	163.45	540.12	3635.37	1620.42	655.09
65	1182.86	1337.96	914.20	417.27	226.76	665.90	474.23	162.24	540.12	3635.33	1620.42	655.09
70	1182.86	1337.96	914.20	417.27	226.76	540.83	474.23	160.58	540.12	1962.63	1620.42	538.35
75	1182.86	1337.96	914.20	417.27	359.80	370.34	474.23	140.87	540.12	936.38	1620.42	464.71
80	1104.59	1150.69	992.47	398.88	359.80	332.07	6.12	53.14	540.12	439.98	1200.51	334.51

Table III(b) : Seasonal Optimum Crop Area Resulted From Different LPM in Multiple Reservoir Operation

LPM	Optimum crop area in Aji-2 command area			Optimum crop area in Nyari-2 command area			Optimum crop area in Aji-3 command area		
	Kharif (ha)	*Rabi (ha)*	*Biannual (ha)*	*Kharif (ha)*	*Rabi (ha)*	*Biannual (ha)*	*Kharif (ha)*	*Rabi (ha)*	*Biannual (ha)*
50	1414.62	1414.62	969.38	362.62	761.46	474.23	540.12	3635.37	1620.42
55	1414.62	1414.62	969.38	362.62	721.24	474.23	540.12	3635.37	1620.42
60	1414.62	1414.62	969.38	362.62	679.42	474.23	540.12	3635.37	1620.42
65	1414.61	1414.62	969.38	362.62	654.77	474.23	540.12	3635.37	1620.42
70	1391.53	949.02	992.47	362.62	405.45	474.23	540.12	3394.30	1620.42
75	1391.53	949.02	992.47	362.62	336.01	438.27	540.12	1633.83	1620.42
80	1469.80	334.78	914.20	269.69	332.07	6.12	540.12	669.47	1620.42

Table IV: Total Irrigation Intensity and Optimum Total Crop Area Resulted from Different LPM

LPM	Total optimum crop area irrigation intensity under LBMC Command area in multiple reservoir system operation						Total optimum crop area irrigation intensity under LBMC Command area in individual reservoir operation					
	Aji-2 Reservoir		*Nyari-2 Reservoir*		*Aji-3 Reservoir*		*Aji-2 Reservoir*		*Nyari-2 Reservoir*		*Aji-3 Reservoir*	
	Total Crop Area (ha)	*Total Irrigation Intensity (%)*	*Total Crop Area (ha)*	*Total Irrigation Intensity (%)*	*Total Crop Area (ha)*	*Total Irrigation Intensity (%)*	*Total Crop Area (ha)*	*Total Irrigation Intensity (%)*	*Total Crop Area (ha)*	*Total Irrigation Intensity (%)*	*Total Crop Area (ha)*	*Total Irrigation Intensity (%)*
50	3798.62	159.34	1598.31	94.30	5795.91	87.35	3435.02	144.09	1451.72	85.64	5795.91	87.62
55	3798.62	159.34	1558.09	91.92	5795.91	87.35	3435.02	144.09	1433.64	84.58	5795.91	87.62
60	3798.62	159.34	1516.27	89.46	5795.91	87.35	3435.02	144.09	1391.82	82.11	5795.91	87.62
65	3798.61	159.34	1491.62	88.00	5795.91	87.35	3435.02	144.09	1366.89	80.64	5795.87	87.62
70	3333.02	139.81	1242.3	72.70	5554.84	83.72	3435.02	144.09	1241.82	73.26	4123.17	62.33
75	**3333.02**	**139.81**	**1136.9**	**67.07**	**3794.37**	**57.19**	**3435.02**	**144.09**	**1071.33**	**63.20**	**3096.92**	**46.82**
80	2718.78	114.04	697.88	41.18	2830.01	42.65	3247.75	136.23	697.99	41.17	2180.61	32.96

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 Patten resulted from LPM75 with the actual 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 crop (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 crop (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 crop 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	Season	Crop Notation	Crop	Unit	Multiple reservoir System operation	Individual reservoir operation	% area increase in multiple reservoir operation
Aji-2 Reservoir	Two Season	at_1	Cotton	ha	**913.60**	**913.6**	
		at_2	Castor	ha	**78.87**	0.6	99.24
	Rabi Season	ar_1	Other Crop(Rajko/Methi)	ha	**449.20**	1.03	99.77
		ar_2	Juvar/Bajri/Maize	ha	**0.58**	**0.58**	
		ar_3	Cumin	ha	**181.83**	**181.83**	
		ar_4	Wheat	ha	138.17	**975.28**	
		ar_5	Garlic/Onion	ha	**178.84**	178.84	
		ar_6	Vegetables	ha	**0.40**	0.4	
	Kharif Season	ak_1	Ground nut	ha	**1389.92**	1181.25	15.01
		ak_2	Juvar/Bajri	ha	**0.48**	**0.48**	
		ak_3	Others Crops	ha	**1.13**	**1.13**	
Nyari-2 Reservoir	Two Season	at_1	Cotton	ha	436.65	**438.29**	
		at_2	Castor	ha	1.62	**35.94**	
	Rabi Season	ar_1	Other Crop(Fodder)	ha	1.57	**34.84**	
		ar_2	Juvar/Bajri/Maize	ha	**0.19**	**0.19**	
		ar_3	Cumin	ha	**4.91**	**4.91**	
		ar_4	Wheat	ha	**326.45**	**326.45**	
		ar_5	Garlic/Onion	ha	1.89	**2.95**	
		ar_6	Vegetables	ha	**1.00**	**1**	
	Kharif Season	ak_1	Ground nut	ha	**221.32**	**221.32**	
		ak_2	Juvar/Bajri	ha	**141.30**	5.44	96.15%
Aji-3 Reservoir	Two Season	at_1	Cotton	ha	**1557.85**	**1557.85**	
		at_2	Castor	ha	**62.57**	**62.57**	
	Rabi Season	ar_1	Other Crop(Fodder)	ha	**497.67**	99.01	80.10
		ar_2	Juvar/Bajri/Maize	ha	**1.16**	**1.16**	
		ar_3	Cumin	ha	**151.68**	**151.68**	
		ar_4	Wheat	ha	**224.68**	174.1	22.51
		ar_5	Garlic/Onion	ha	**395.88**	147.67	62.69
		ar_6	Pulses	ha	**361.57**	**361.57**	
		ar_7	Vegetable	ha	**1.19**	**1.19**	
	Kharif Season	ak_1	Ground nut	ha	**530.53**	**530.53**	
		ak_2	Juvar/Bajri	ha	**9.59**	**9.59**	

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

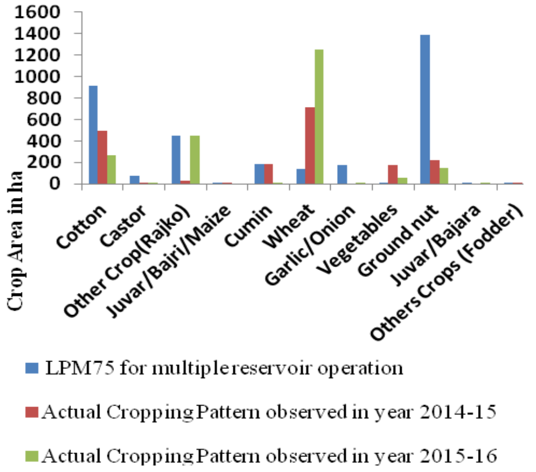

Fig. 2(a) Optimum cropping pattern compared with actual crop pattern of year 2014-15 and the year 2015-16 in Aji-2 LBMC command area.

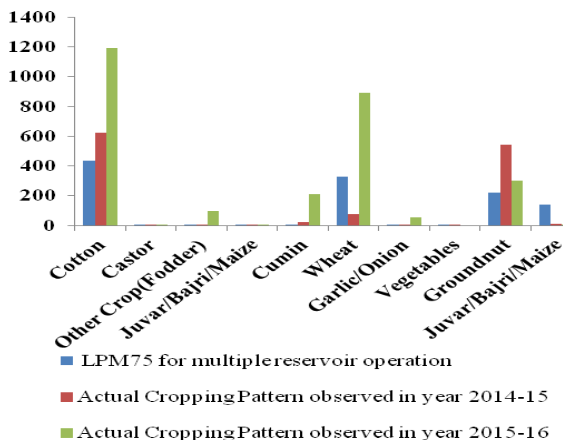

Fig. 2(b) Optimum cropping pattern compared with actual crop pattern of year 2014-15 and the year 2015-16 in Nyari-2 LBMC command area.

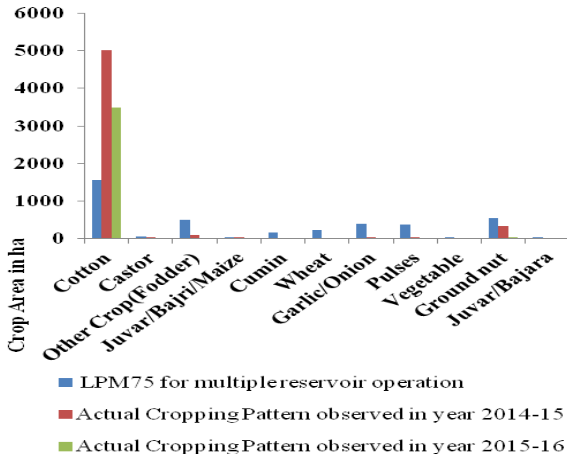

Fig.2(c) Optimum cropping pattern compared with actual crop pattern of year 2014-15 and the year 2015-16 in Aji-3 composite canal command area.

VI. THE HEDGING RULE CURVE IN PRIORITY OF IRRIGATION

Reservoirs are operated according sets of rules for releasing and storing depending upon the purpose to be served .The reservoir operation rule should be prepared in accordance of principle of conservational use of in case single purpose, or multiple purpose. 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 condition and water demand. Extreme climate condition like droughts is a normal part of climate which occurrences are unavoidable. Therefore, it is necessary for pay more attention on drought including water shortage. Drought related impacts can be mitigated by hedging rule for reservoir management [33]. The hedging parameters used to construct the hedging rule and evaluated [28]. Parametric rule Proposed for different goal of operation in planning and management of multiple reservoir system [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 are 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 purpose 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 operation period in multiple reservoir operation to derive maximum NB. 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 actual observed maximum storage in month of August is higher than existing rule curve storage; therefore it is advisable to change it.

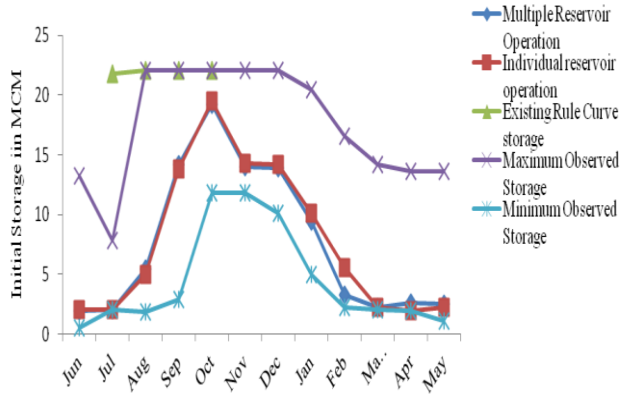

Fig. 3(a), Hedging rule curve of Aji-2 reservoir at 75% dependable inflow.

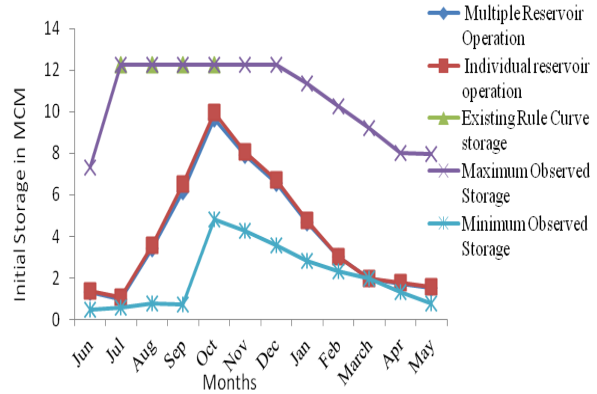

Fig. 3(b), Hedging rule curve of Nyari-2 Reservoir at 75% dependable inflow

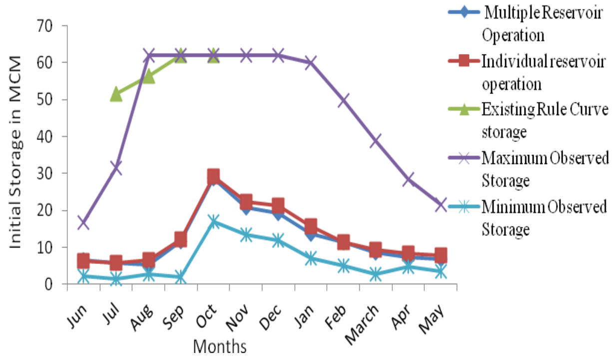

Fig. 3(c), Hedging rule curves of Aji-3 Reservoir at 75% dependable inflow

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 demand of irrigation while at the same time minimum water supply demand too.

The optimal release policy obtained for 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.

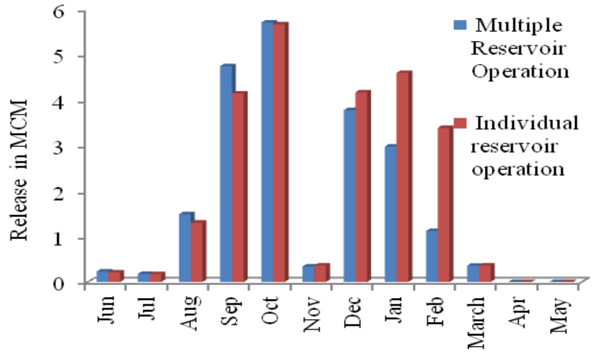

Fig. 4(a) Optimal Release Policy for Aji-2 Reservoir at 75% dependable inflow

The optimal release polices 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 are demanding more water in individual reservoir operation as compared to chosen crop by model in multiple reservoir operation.

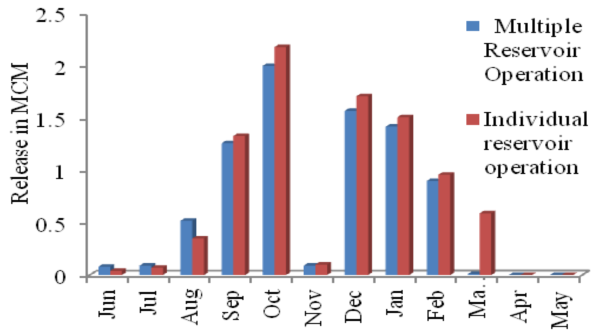

Fig. 4(b) Optimal Release Policy for Nyari-2 Reservoir at 75% dependable inflow

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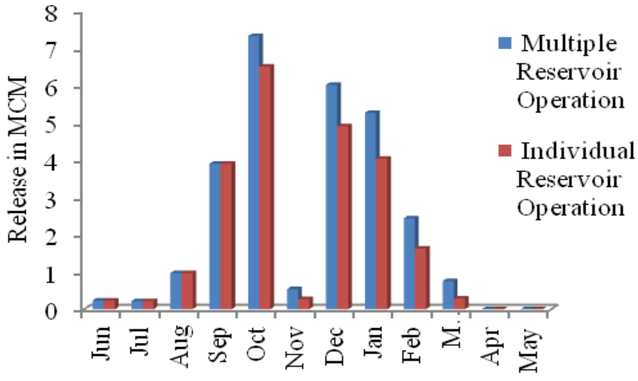

Fig. 4(c) Optimal Release Policy for Aji-3 Reservoir at 75% dependable inflow

The optimal release polices 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 crop (Fodder), wheat, garlic/onion, Vegetable, ground nut, 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 operation. 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 drought prone area. The Crop area of Juvar/ bajri/Maize (ak_2) is augmented in LBMC command area of Nyari-2 and crop area of Fodder (ar_1), Wheat (at_2), and onion/Garlic are 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 operation. Augmentation of low cost, low water requiring crops are beneficial in drought prone area to mitigate drought impact. However it is concluded to operate reservoir in multiple reservoir system at 75% dependability level of inflow instead of individual reservoir operation and derived optimum multiple reservoir operation policy. Multiple reservoir operation policy can help to maintain required water for irrigation purpose during operation period by transferring water from upstream reservoir to downstream reservoir to derive maximum net benefit; therefore it is advisable to maintain minimum initial storage as per hedging rule. Moreover, the 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. In future study risk assessment of multiple reservoir operation can be carried out using reliability, resilience and vulnerability parameter of operation measure.

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REFERENCES

1. Ajudiya, B. K; and Yadav, S.M. (2017) "Optimization of Water Supply Using Linear programming Monthly Model" presented in Hydro-2017 conference on Hydraulics, Water Resources & Coastal Engineering, L. D. College of Engineering, Ahmadabad, 21-23 December, 2017.
2. Anonymous (1987), Project Report On Aji-III irrigation Scheme, Rajkot Irrigation Division, Narmada, Water Resources, Water Supply and Kalpasar Department, Gujarat.

3. Anonymous (2009), Manual for "Drought Management department of Agricultural and cooperation, Ministry of agricultural, Government of India, New Delhi.
4. Anonymous (2005) "Manual on "The Real Time Integrated Reservoir Operation" Reservoir Operation Directorate, Government of India, pp 46, New Delhi.
5. Chang, L.C; & Chang, F. J.(2009) " Multi-objective evolutionary algorithm for operating parallel reservoir system, Journal of Hydrology , 377(12), 12-20.
6. Chow, V.T., Maidment, D.R., and Mays, L.W.(1988). Applied Hydrology, McGraw-Hill, New York.
7. Cancelliere, A; Di Mauro, G; Bonaccorso, B; and Rossi, G;(2007). "Drought forecasting u sing the standardized precipitation Index", Water Resources Management 21, pp 801-809.
8. Drought Declaration Circular, SCY-102018-791-S.1, Annexure 3, Government of Gujarat, Revenue Department, Sachivalay, Gandhinagar.
9. Das B., Singh A., Panda S. N; Yasuda H.(2015) Optimal land and water resources allocation polices for sustainable irrigated agriculture, Elsevier, J of Land use policy, 42:527-537.
10. FAO(2013), FAO Statistical year book 2013, World food and agriculture. Food and agriculture organization of the United Nation, Rome, P.P. 289.
11. Gupta, A. K; Tyagi, P; and Shegal, V. K. (2011) "Drought Disaster challenges and mitigation in India: strategic appraisal" Current Science, 25 June 2011, Vol.100, No12, pp 1795-1806.
12. Heydari M; Othman F; Qdari K; Noori M and Shahiriparsa A, (2015) " Introduction to Linear Programming as a Popular Tool in Optimal Reservoir Operation, a Review" Advances in Environmental Biology, Vol 9, issue 3, pp 906 -917.
13. Jothiprakash, V., Ganeshanshanthi, J., and Arunkumar, R.(2011b). "Development of Operational Policy for a multiple reservoir systems in India using genetic algorithm". Water Resource Management, 25(10), pp. 2405-2423.
14. Jothiprakash, Arunkumar, R., and Ashok Rajan,(2011a) A. "Optimal crop planning using a chance constrained linear programming model" IWA, Water Policy 13, pp. 734–749, 2011.
15. LINGO version 14.0, LINDO System Ltd, Chicago.
16. LINGO version 18.0, unlimited constraints, LINDO System Ltd, Chicago.
17. Nalbantis, I; & Koutsoyiannis, D.(1977) " A parametric rule for planning and management of multiple reservoir system, Water Resources Research, 33(9), 2165-2177.
18. Nathan, K. K. (2001) "Poor Water Resources and Drought in the Gujarat/Saurastra Region of India. Drought Network News (1994-2001). 58, National Drought Mitigation Centre, University of Nebraska- Lincoln.
19. Narmada, Water Resources, Water Supply and Kalpasar Department [Online]https://guj-nwrws.gujarat.gov.in , Access on 23th March, 2014
20. Pandit, A.P., Aher, A.B., and Kulkarni, S.D.,(2012) "Impact of Water Resources Utilization and Cropping Pattern in Shrigonda Tahsil, Ahmednagar, Maharashtra: A case study" Proceeding of International Conference SWRDM-2012.
21. Rachchh, R. and Bhatt, N. (2014a) "Monitoring of Drought Event by standard precipitation Index (SPI) in Rajkot District, Gujarat, India" International Journal of Engineering Development and Research, Vol 2, Issue 1, pp 917-921, 2014.
22. Rachchha, R and Bhatt, N. (2014b) "Monitoring and Forecasting of Drought Events for Saurashtra Region". ME Thesis, L. E. College, Morbi, GTU, Gujrat.
23. Ramkar, P. and Yadav, S.M.(2018) " Spatiotemporal Drought Assessment of a Semi –arid Part of Middle Tapi River Basin, India". International Journal of Disaster Risk Reduction, 28, PP- 414-426.
24. Roy, A. K. and Hirway, I. (2007), Project Report for "Multiple Impacts of Droughts and Assessment of Drought Policy in major Drought Prone State in India", submitted to the planning commission, Government of India, New Delhi.
25. Robert, M.H; Jared, L. C; and Charles, S.R. (1977) " Gains from joint operation of multiple reservoir system" Water Resources Research, 13(2), 239-245
26. Sreenivasa, K. & Vedula S. (1996). "Reservoir operation for hydropower optimization: a chance-constrained approach", Sadhana, Springer, 21(4), pp. 503–510.
27. Srinivasa Raju, k; Nageshkumar; D; and Lucien Duckstein, (2006). "Artificial Neural Network and Multicriterion Analysis for Sustainable Irrigation Planning" Computers & Operation Research, 33(2006), pp.1138-1153.
28. Srinivasan, K. and Philipose, M. C. (1996) " Evaluation and selection of hedging policies using stochastic reservoir simulation, Water Resources Management, 10(3), 163-188.
29. Shreedhar, R; Hiremath, C.G; and Shetty G.G(2015) " Optimization of Cropping Pattern using Linear Programming Model for Markandeya command area" International Journal of Scientific & Engineering Research, 9(6), pp. 1311-1325.
30. Singh A(2011) estimating long term regional ground water recharge for the evaluation of potential solution alternatives to water logging and salinisation. J Hydrol 406(3-4): 245-255.
31. United Nations (2015) World population prospects: 2015 revision population data base online http://www.un.org/esa/population/unpop.htm. Accessed 30 May 2019.
32. Wang, L.K; Yang; C.T; and M-H-S Wang (eds)(2016), Advances in Water Resources Management, Hand book of Environmental Engineering, Vol.16, PP. 1-110, 2016.
33. Wilhite, D.A.(1993) "The enigma of drought, In D.S. Wilhite (Ed.). Drought assessment, management and planning: theory and case studies (pp 3-15) Kluwer Academic.
34. Zavery, P. and Parmar, A. (2013) 'Change in cropping utilizing Narmada main canal water: a case study of Barmar district', IJRET, Vol.2, Isuue 10, pp. 99-105.

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