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Optimal Operation of Multipurpose Reservoir for Irrigation Planning with Conjunctive Use of Surface and Groundwater

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Abstract

In the present study, a Linear Programming (LP) model is developed for the conjunctive use of surface water and ground water to obtain the optimal operating policy for a multipurpose single reservoir. The objective of the present study is to maximize the net benefit from the command area under consideration. The constraints imposed on the objective function are maximum and minimum irrigation demands, reservoir storages and canal capacity. The model takes into account the continuity constraint which includes inflows in to the reservoir, releases for irrigation, releases for hydro-power generation, evaporation losses, feeder canal releases, initial and final storages in the reservoir in each time period. The developed model is applied to the case study of Jayakwadi reservoir stage-I, built across river Godavari, Maharashtra, India. Initially the model is solved for the availability of surface water which results in net benefit of 3373.45 million rupees with irrigation intensity is 57.07%. Next the model solved by considering the availability of surface water and available potential of groundwater in the area, which results in net benefits of 3590.02 million rupees with an intensity of irrigation 58.48%. The present model takes in to account the socio-economic requirement of growing the essential crops to meet the requirement of the society. The model has also generated the canal wise optimal releases for irrigation and power, monthly utilization of groundwater, storages in the reservoir at the end of every month and corresponding head over the turbine.

Keywords

Reservoir Operation, Optimal Policy, Conjunctive Use, Groundwater, Irrigation Planning

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1. Introduction

The optimal operation of a reservoir system for efficient utilization of both surface and groundwater resources conjunctively requires knowledge of reservoir process and infield process. This knowledge facilitates to arrive at decisions on reservoir operation and cropping pattern by use of optimization models. These are characterized by a mathematical statement of objective function to give global optimum solutions.

Many researchers have worked on several aspects of the conjunctive use of surface and ground water such as 1) reservoir/stream and aquifer interaction for assessment of conjunctive use potential; 2) modeling of conjunctive use of surface and groundwater; 3) optimal planning using different techniques.

A comprehensive knowledge of surface-ground water interaction is essential to assess and plan of conjunctive use policies. Gupta and Paundyal [1] have studied the estimation of aquifer recharge and parameters from water level observations. Chiew *et al.* [2], Miles and Chamber [3], Barlo *et al.* [4], Nayak *et al.* [5] and Yang *et al.* [6] have developed integrated models to assess the interaction between the surface and groundwater processes. Use of water balance techniques for estimation of groundwater potential is used by Sodhi *et al.* [7], Chensheng He [8], Belaineh *et al.* [9], Jin-Fa-Chem *et al.* [10] and Manghi *et al.* [11]. For groundwater recharge estimation in India, a well established rainfall recharge estimation methodology of the Groundwater Estimation Committee (GEC-1997) [12] has been used to estimate groundwater recharge by Sethi, *et al.* [13], Sarojini Devi *et al.* [14] and Khare *et al.* [15] and [16]. Regulwar *et al.* [17] have estimated the groundwater resource by carrying out geoelectric field survey with vertical electrical sounding techniques (VES).

Varieties of conjunctive use optimization models are available in the literature as applicable to reservoir systems. Yeh [18] has reviewed reservoir management and operation models. According to him optimal coordination of many facets of reservoir system requires the assistance of computer modelling tools to provide information for rational management and operational decisions. Labadie [19] has reviewed state-of-the art in optimization of multi reservoir system. Out of the most favored optimization techniques for reservoir system models is the simplex method of LP and its variants because of its ability to solve large scale problems by converging to global optimal solution. Mohan and Jothiprakash [20] developed a LP model with an objective function of maximizing the net benefits accrued from the crops over a year. Then through fuzzy linear programming they considered the fuzziness involved in the objective function, inflow and the groundwater availability. The variation of magnitude of evaporation loss in the continuity equation due to varying water level or surface area is not considered by them.

A mathematical conjunctive use model to maximize the net benefits has been developed by Kashyap and Chandra [21] for arriving at an optimal conjunctive use policy incorporating spatially and temporally distributed groundwater withdrawals for predefined surface water availability for spatially distributed cropping pattern. Peralta *et al.* [22] have presented a mathematical optimization model (MODFLOW-finite-difference ground-water flow simulation model) for a case study with a management goal of maximizing the sum of sustainable groundwater pumping and surface water use. Modelling of conjunctive use is also carried out by [23]-[28]. A mathematical Linear Programming model for optimal conjunctive use planning in multi crop irrigation in a canal command area to maximize the sum of annual relative yields of crops in a normal year have developed by Vedula *et al.* [29]. They considered the three main components of the system as: the reservoir, irrigated area, and the underlying aquifer along with associated dynamic relationship. According to Khare *et al.* [15] [16] for real field problems many of the models are not appreciated by the field engineers because of the complex nature of the modeling techniques. Therefore, it is not always certain that the results obtained from less detailed models are less truthful than the results from complex model. Regulwar and Gurav [30] [31] have worked on the optimal cropping pattern for sustainable irrigation by maximizing different conflicting objectives simultaneously, however, without taking in to consideration the availability of groundwater in the command of the reservoir and the socio economic aspect of growing certain crops based on minimum requirement of the region, while optimizing the cropping pattern. They tackled the uncertainty in the different parameters under the fuzzy environment. Regulwar and and Pradhan [17] have presented irrigation planning with conjunctive use but they have not considered continuity equation of the reservoir while working out the availability of the surface water from the reservoir for irrigation. Present work deals with optimal operation of the multipurpose reservoir for multi crop irrigation, considering continuity equation, the availability of groundwater in the command and socio economic consideration of growing certain crops based on the minimum requirement of the region.

The objective of the study is to maximize net benefits by suggesting an optimum irrigation release policy and a cropping pattern by use of both surface water and groundwater conjunctively. A monthly model has been developed by considering various variables such as irrigation demand, land use restrictions, socio economic constraint, drinking water demand, industrial water demand, live storage restrictions, canal capacity restrictions and availability of groundwater. The uncertainty in the flow is tackled through its dependability.

In this direction an attempt is made to perform optimal reservoir operations using optimization tool. Present work deals with modeling for multi crop irrigation, considering continuity equation and the available groundwater potential.

2. Methodology

2.1. Objective Function

In the present study, the reservoir operation model is developed for Irrigation Planning with Conjunctive use of surface and groundwater. Model considers the objective of maximizing the net benefits from the available water resource from the command of a reservoir. It is expressed as:

$$\text{Max}Z = \sum_{z=1}^{nz}\sum_{c=1}^{nc} NB_{zc}A_{zc} - \sum_{z=1}^{nz}\sum_{t=1}^{12} CSW_{zt}\eta_s SWA_{zt} - \sum_{z=1}^{nz}\sum_{t=1}^{12} CGW_{zt}\eta_g GWA_{zt}$$

where,

Z = Total net benefit *i.e*. value of objective function in Rs.

NB_{zc} = It is net benefit estimated from irrigation of c^{th} crop from z^{th} canal zone.

A_{zc} = Area under the c^{th} crop in m^2 grown in z^{th} canal zone.

CSW_{zt} = Total cost of providing surface water during t^{th} month in z^{th} zone.

η_s is efficiency of surface water system.

SWA_{zt} = Surface water available at the head of the z^{th} canal at t^{th} time period.

CGW_{zt} = Total cost of providing groundwater during t^{th} month in z^{th} zone. It also includes the capital cost, pumping cost, operation and maintenance cost.

η_g is the efficiency of groundwater.

GWA_{zt} = Available groundwater in z^{th} zone during time period t^{th} without allowing mining.

2.2. Constraints

The objective function of maximization of net benefit is subjected to the following constraints such as:

2.2.1. Land Area Constraint

The total area allocated for different crops in a particular season should be less than or equal to the total culturable command area (TCCA) available during that season.

Season wise area constraints are given below:

1) Kharif Crops Area Constraint

$$\sum_{z=1}^{nz}\sum_{c=1}^{nkc} A_{zc} \le TCCA_{zk}$$

where,

$TCCA_{zc}$ = Total culturable command area during Kharif season in z^{th} canal zone.

c = 1 to nkc Crops in Kharif season,

2) Rabi Crops Area Constraint

$$\sum_{z=1}^{nz}\sum_{c=1}^{nrc} A_{zc} \le TCCA_{zr}$$

$TCCA_{zr}$ = Total culturable command area during rabi season in z^{th} canal zone.

c = 1 to nrc Crops in rabi season

3) Bi-seasonal Crops Area Constraint

$$\sum_{z=1}^{nz}\sum_{c=1}^{nbc} A_{zc} \le TCCA_{zb}$$

$TCCA_{zb}$ = Total culturable command area during bi season in z^{th} canal zone.
c = 1 to nbc crops in bi-season
4) Hot Weather Crops Area Constraint

$$\sum_{z=1}^{nz}\sum_{c=1}^{nhc} A_{zc} \le TCCA_{zh}$$

$TCCA_{zh}$ = Total culturable command area during hot weather season in z^{th} canal zone.
c = 1 to nhc crops in hot weather
5) Perennial Crops Area Constraint

$$\sum_{z=1}^{nz}\sum_{c=1}^{npc} A_{zc} \le TCCA_{zp}$$

$TCCA_{zp}$ = Total culturable command area during perennial season in z^{th} canal zone.
c = 1 to npc crops in perennial season.

2.2.2. Crop Area Constraint

Crop area constraint is also called as socio economic constraint. This constrain depends on the proposed cropping pattern considering socio-economic needs of the area. The land area constraint discussed in 2.2.1, restricts the maximum value of irrigated area under the crops in a particular season. Sometimes the benefit optimization model does not allow area for certain crops may be because of more water requirement and low benefit coefficient. However, crop area constraint restricts some minimum value for irrigated areas under such crops in a particular season to meet the local requirement of food.

$$A_c = P_c * TCCA$$

P_c = It is the percentage of C^{th} crop in Z^{th} canal zone with respect to $TCCA$.

2.2.3. Total Water Requirement of Crops Constraint

Net irrigation water requirement by all crops during time period t in each zone is to be satisfied from monthly available surface water and groundwater at the field.

$$\sum_{z=1}^{nz}\sum_{t=1}^{12}\sum_{c=1}^{nc} NIWR_{ztc} A_{ztc} \le \eta_s \left(\sum_{z=1}^{nz}\sum_{t=1}^{12} SWA_{zt} \right) + \eta_g \left(\sum_{z=1}^{nz}\sum_{t=1}^{12} GWA_{zt} \right)$$

A_{ztc} = Area of c^{th} crop under canal zone z during time period t.
η_s and η_g are efficiencies of surface water and groundwater systems respectively.

2.2.4. Canal Capacity Constraints

Releases from the reservoir in the canal during the time period t should be less than or equal to the canal capacity in each zone during the time period t.

$$SWA_{zt} = CC_{zt}$$

CC_{zt} = Capacity of z^{th} canal during time period t, (*i.e.* per month in m^3).

2.2.5. Reservoir Storage Constraint

The live storage in the reservoir in any time period t should be less than or equal to the maximum capacity and should be more than or equal to and the dead storage.

$$S_{\min} \le S_t \le S_{\max}$$

S_t = reservoir storage at the beginning of the month t (t = 1, 2, …, 12).

2.2.6. Continuity Constraint

The continuity constraint involves releases, overflows, storages, inflows and losses through the reservoir during the period "t" *i.e.* for period t expressed in unit of volume. The evaporation losses are expressed as function of storage. The storage continuity equation given by Loucks *et al.* [32] is adopted.

$$(1+a_t)S_{t+1} = (1-a_t)S_t + I_t - \sum_{z=1}^{nz}\sum_{t=1}^{12} SWA_{zt} - R_t - A_0E_t - O_t$$

where,

$a_t = 0.5A_a*Et$.

E_t = Average evaporation rate for each period.

A_a =Area corresponding to month wise average storage.

A_0 = Surface area corresponding to dead storage.

S_t =is reservoir storage at the beginning of the month *t*.

S_{t+1} = reservoir storage at the end of the month *t* and also at the beginning storage at the month $t+1$, *i.e*. storage in the next time stage.

R_t = Releases other than irrigation.

I_t = inflow in the reservoir during month *t*.

O_t = the overflow from the reservoir during month *t*, it should be greater than zero.

3. Description of the Study Area

The developed model is applied to the case study of Jayakwadi Reservoir Stage-I on the river Godavari in the State of Maharashatra, (India). The **Figure 1** shows the location of Jayakwadi Reservoir Stage-I.

It is a multipurpose project with gross and live storage capacities 2909 Mm^3 and 2170 Mm^3 respectively. The system of two canals *i.e*. Left Bank Canal 208 km in length and the Right Bank Canal 132 km in length serves an irrigable command area of 141,640 ha and 41,700 ha respectively. The reservoir has a pump storage power generation unit with 12 MW reversible pump turbine unit at the foot of the dam. The entire command area of the project lies within the Latitude 18˚46'N to 19˚30'N and Longitude 75˚20'E to 77˚45'E.

The total intensity of irrigation of Jayakwadi reservoir stage I is 102% distributed in 22% for kharif crops (Jowar 12% and Paddy 10%), 45% for rabi crops (Wheat 25%, Jowar 15% and Gram 5%), 28% for two seasonal crops (Cotton 25% and chilly 3%), 3% for hot heather ground nut and 4.5% for perennial crops (Sugarcane 3% and Banana 1.5%).

4. Major Considerations in Formulation of the Problem

1) The language for Interactive General Optimization (LINGO) has been used to solve the linear optimization problem.

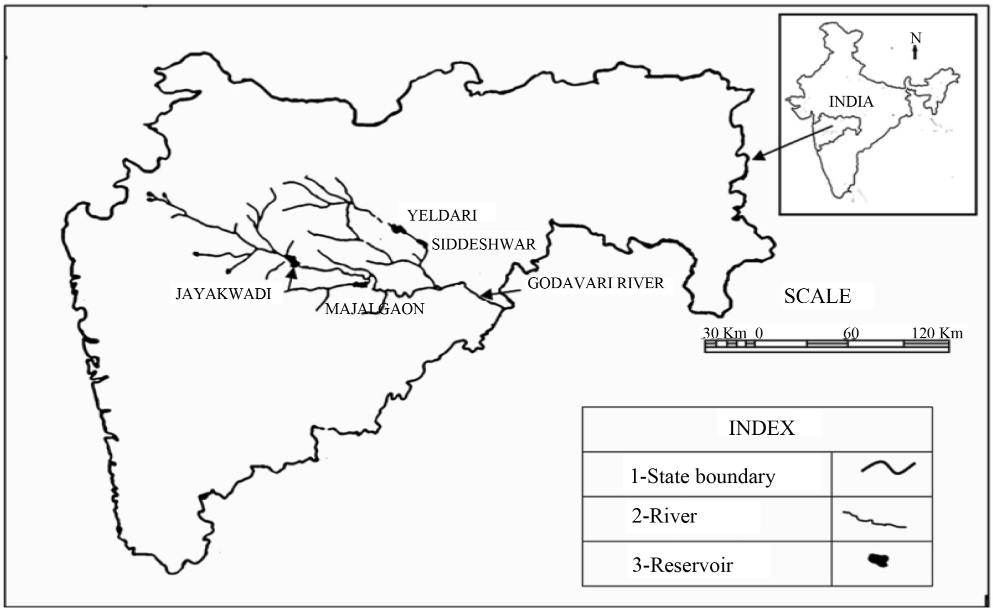

Figure 1. The location of jayakwadi reservoir stage-I.

2) The model considers the 75% dependable inflows in to the reservoir considering crops are grown throughout the year.

3) The inter-relationship between the variables and parameters involved in the model formulation is linear.

4) The soil in the command of the reservoir is considered to be homogeneous in nature.

5) Losses during conveyance in surface and groundwater system are considered as 40% and 20% respectively.

6) It is observed that the utilization of the groundwater is not uniform throughout the year. Farmers use more groundwater during the post monsoon period and before hot weather. It is, therefore, suitably assumed in absence of the data that about 60% of the total available groundwater would be utilized equally during October to March and rest during the remaining part of the year.

7) Releases for power generation in the pump storage power station are restricted between the monthly turbine capacity of 33.96 Mm^3 and release for firm power 22.67 Mm^3.

8) Month wise heads over the turbine are worked out from the storage-elevation curve of the reservoir.

9) Other uses of water considered in continuity equation are [33]:

a) Releases for water supply 31.63 Mm^3 per month.

b) Feeder canal releases for downstream storages during October to February as 50 Mm^3, 80 Mm^3, 70 Mm^3, 90 Mm^3, and 60 Mm^3 respectively.

10) 10% of the releases for the power generation in pump storage power station are considered as losses.

11) Evaporation losses which are worked out by considering the month wise variation of the surface area given by Loucks *et al.* [32].

5. Evaluation of Model Parameters

1) Net benefit *i.e.* the value of the objective function in Rs is calculated by considering the yield of the crop (*t/ha*), market price of the crop (*Rs/t*) and the cost of cultivation.

2) The cost of cultivation of crop is considered excluding the cost of water and including cost of labor, cultivation, planting, growing and harvesting. This is obtained from the Department of Statistics and Economics, Agricultural Department, Govt. of Maharashtra, India.

3) Available groundwater from recharge in the command without allowing mining is estimated using lumped empirical approach and guidelines of GEC-97 which is well established and practiced in India. The aquifer has been considered as a single reservoir of capacity equal to the specific yield. Groundwater utilization is restricted to the recharge to maintain the stable stream aquifer response. Recharge is mainly considered from the rainwater and return flow from the surface water irrigation from the reservoir.

4) Groundwater utilization is restricted to the recharge to avoid overdraft. Based on the joint work of the Central Ground Water Board, Government of India and Ground Water Survey and Development Agency (GSDA) of Government of Maharashtra [34] on the estimation of groundwater resource of Aurangabad district about 16% of the total precipitation joins to the groundwater corresponding to 55.20% of stage of groundwater development. Also part of the conveyance loss of surface water joins to it, which is approximately taken as 10% of the total conveyance loss of surface water in absence of the related data.

5) The cost of providing surface water is based on the local government norms and the cost of the groundwater is calculated by considering the capital cost, pumping cost, operation and maintenance cost.

6) Land area available for growing the crops is restricted to the cultivable command area under the respective canals. Socio economic constraint is imposed for minimum production of a particular crop by taking into consideration the need of the people.

7) Net irrigation water requirement by all crops during the monthly time period t in each zone is considered to be satisfied during all the seasons from available surface and groundwater. Irrigation water requirement is considered at the canal outlets and that of groundwater at source *i.e.* well by considering conveyance efficiencies as 60% and 80% respectively.

8) Net Water Requirement of crop during the time period t is estimated by modified Penman Method.

6. Results and Discussions

The model developed in the present study is applied to the case study of Jayakwadi reservoir stage-I by considering all considerations and the evaluated parameters as stated in earlier sections 4 and 5, to obtain the optimal cropping pattern and optimal release policies which maximize net benefits.

The model is solved by considering two cases as given below:

1) Case-I—by considering surface water only.

2) Case-II—by considering the conjunctive use of surface water and groundwater.

Being a multipurpose reservoir, after giving first priorities to the water supply for drinking and industrial use the optimal releases for the power generation and for irrigation are obtained from the model which are presented and discussed here.

6.1. The Optimal Cropping Patterns

The optimal cropping patterns for the case I and II obtained from the global optimal solution of the LP model are shown in the **Table 1**.

It is required to put socio economic constraints to the crops Rabi Wheat, Rabi Jowar, Rabi Gram and Hot Weather Ground Nuts in case-I and to Rabi Wheat, Rabi Jowar and Hot Weather Ground Nuts in case-II to take care of the requirement of the local population. The benefit optimization model has not allocated area to these crops during its first run. This is because of low benefit coefficients and more water requirement of these crops as compared to other crops. Putting socio economic constraint *i.e*. crop area constraint reduces the net benefits and increases the intensity of irrigation. However, it assures the production of certain essential crops to meet the need of the population in the command.

An intensity of irrigation of 57.07% and 58.48% is obtained for the Case-I and for Case-II. The intensity of irrigation as per the project report is 102.5%. The conjunctive use of surface and groundwater in the case-II has resulted in rise in the net benefits by 6.42%.

The model has allotted area to the crops kharif Jowar, bi-seasonal cotton, bi-seasonal chilly and perennial banana to the maximum extent for both the cases I and II as compared to the project cropping pattern given in Section 3. Even for sugarcane in case II, the allotted area is almost to its maximum extent due to conjunctive use of surface and groundwater.

Table 1. Optimal cropping pattern for Case-I and Case-II.

Crop Notation	Crop Name	Case-I—with only surface water Area under the crop in ha				Case-II—Conjunctive use Area under the crop in ha			
		Canal-I	Canal-II	Total	% over available total irrigable command area	Canal-I	Canal-II	Total	% over available total irrigable command area
A1	Kharif Jawar	16996.8	5004.00	22000.8	12	16996.80	5004.00	22000.8	12
A2	Kharif Paddy	00.00	00.00	00.00	00	1655.79	518.54	2174.34	1.18
A3	Rabi Wheat	10623.00	3127.5	13750.05	7.5	10623.0	3127.5	13750..05	7.5
A4	Rabi Jowar	6373.8	1876.5	8250.30	5.0	6373.80	1876.5	8250.30	5.0
A5	Rabi Gram	2124.8	625.5	2750.10	1.5	00.00	00.00	00.00	00
A6	Bi-Seasonal Cotton	35410.00	10425.00	45835.00	25	35410.0	10425.00	45835.00	25
A7	Bi-seasonal Chilly	4249.2	1251.00	5500.20	3.0	4249.2	1251.00	5500.20	3.0
A8	Hot Weather Groundnut	1274.76	375.30	1650.06	0.9	1274.76	375.3	1650.00	0.9
A9	Perennial Sugarcane	897.6428	1251.00	2148.64	1.17	4067.72	1251.00	5318.72	2.9
A10	Perennial Banana	2124.6	625.50	2750.10	1.5	2124.6	625.50	2750.10	1.5
Total		80074.40	24561.30	104635.70		82775.68	24454.35	107230.00	
Intensity of irrigation		56.53%	58.9%	57.07%	57.07%	58.44%	58.64%	58.48%	58.48%
Net benefits in Million Rs		3373.45				3590.02			

6.2. Optimal Monthly Canal Releases

The canal wise optimal monthly releases and the gross storage at the end of every month for both cases I and II obtained from the model are shown in Table 2.

The amount of surface water utilized for the optimal cropping pattern in case I is 1060.41 Mm^3 and for Case-II the corresponding value is 1053 Mm^3. However, in case II while using both the surface and groundwater conjunctively, the amount of groundwater utilized is 129.94 Mm^3 out of available 132.30 Mm^3.

The live storage values at the end of May in case-I and case-II are just 121.19 Mm^3 and 144.61 Mm^3 respectively. Its values are zero at the end of June in case-I and case-II respectively. The maximum gross storage of 2044.4 Mm^3 and 2054.43 Mm^3 is observed in the month of October in the both cases which is less than the maximum storage capacity of 2909 Mm^3 of the reservoir. Thus, there is no spill over the dam in any of the months.

There are maximum releases of 278.56 Mm^3 and 266.51 Mm^3 in the month of October in case-I and case-II respectively. No surface water releases are there in the months July and August in the case-II and minimum releases of 3.70 Mm^3 in the month of August in the case-I. It shows minimum use of surface water during the months July and August due to low irrigation demand due to precipitation.

Figure 2 shows the storages in the reservoir at the end of every month in Mm^3 for both cases.

Table 2. Monthly canal wise releases and storages in the reservoir at the end of every month for Case-I and Case-II.

Sr. No.	Month	Case-I				Case-II			
		Releases in Mm^3			Gross Storage in Mm^3	Releases in Mm^3			Gross Storage in Mm^3
		Canal-I	Canal-II	Total		Canal-I	Canal-II	Total	
01	June	9.74	7.01	16.75	738.00	14.02	4.26	18.28	738.00
02	July	4.41	1.69	6.10	776.44	00.00	00.00	00.00	774.92
03	August	2.77	0.93	3.70	1092.62	00.00	00.00	00.00	1097.17
04	September	49.08	15.40	64.48	1609.51	48.14	14.23	62.37	1617.63
05	October	212.48	66.07	278.56	2044.40	205.76	60.75	266.51	2054.43
06	November	164.19	52.75	216.94	1911.48	154.61	45.63	200.24	1933.26
07	December	85.18	28.89	114.08	1729.08	77.55	22.91	100.46	1767.07
08	January	93.93	31.85	125.79	1601.44	93.90	27.74	121.64	1652.49
09	February	39.98	17.39	57.37	1346.92	44.52	13.28	57.80	1401.27
10	March	36.62	17.91	54.53	1178.00	46.02	13.81	59.83	1231.07
11	April	45.06	23.49	68.55	1030.43	68.91	20.75	89.66	1076.50
12	May	32.97	20.51	53.48	859.19	58.65	17.77	76.42	882.61
	Total	776.46	283.95	1060.41	--	812.12	241.18	1053.3	--

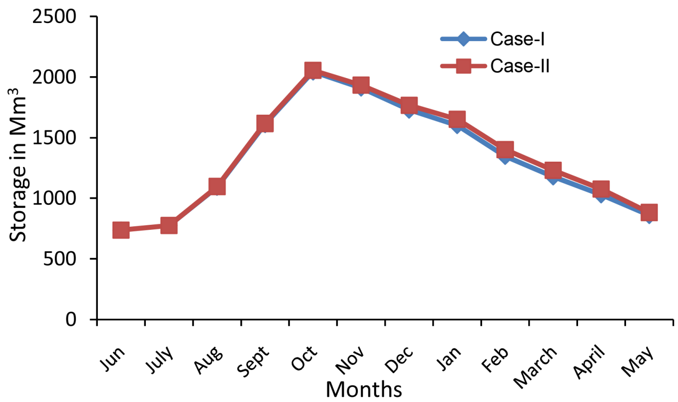

Figure 2. Month wise storages in both cases.

6.3. Releases for Power Generation, Head over the Turbine and Power Generated

The release of surface water from the reservoir for power generation is at its minimum requirement of 22.67 Mm^3 for firm power. The month wise varying values of the head over the turbine and the corresponding magnitude of power generated in MW during every month are shown in **Table 3**.

Depending upon the availability of the surface water and the head over the turbine the average power generated in the pump storage power generation unit is 1.66 MW per month.

The variation of the head over the turbine during the year is shown in the **Figure 3**.

It is observed that an average head of 27 m is available over the turbines in both the cases.

7. Conclusions

The optimal operation model of multipurpose reservoir for irrigation planning with conjunctive use of surface and groundwater is developed and applied to case study of Jayakwadi reservoir stage-I, Maharashatra State, India. Following conclusions are drawn from the study.

Table 3. Month wise releases for power, head over the turbine and power generated for Case-I and Case-II.

Sr. No.	Month	Case-I: Release for Power in Mm^3	Case-I: Head over the turbine in m	Case-I: Power generated in MW	Case-II: Release for Power in Mm^3	Case-II: Head over the turbine in m	Case-II: Power generated in MW
01	June	22.67	24.919	1.54	22.67	24.916	1.53
02	July	22.67	25.522	1.57	22.67	25.527	1.57
03	August	22.67	26.938	1.66	22.67	26.960	1.66
04	September	22.67	28.556	1.76	22.67	28.587	1.76
05	October	22.67	29.070	1.79	22.67	29.124	1.80
06	November	22.67	28.533	1.76	22.67	28.635	1.77
07	December	22.67	28.006	1.73	22.67	28.158	1.74
08	January	22.67	27.357	1.69	22.67	27.536	1.70
09	February	22.67	26.637	1.64	22.67	26.819	1.65
10	March	22.67	26.099	1.61	22.67	26.267	1.62
11	April	22.67	25.557	1.57	22.67	25.675	1.58
12	May	22.67	25.060	1.55	22.67	25.100	1.55

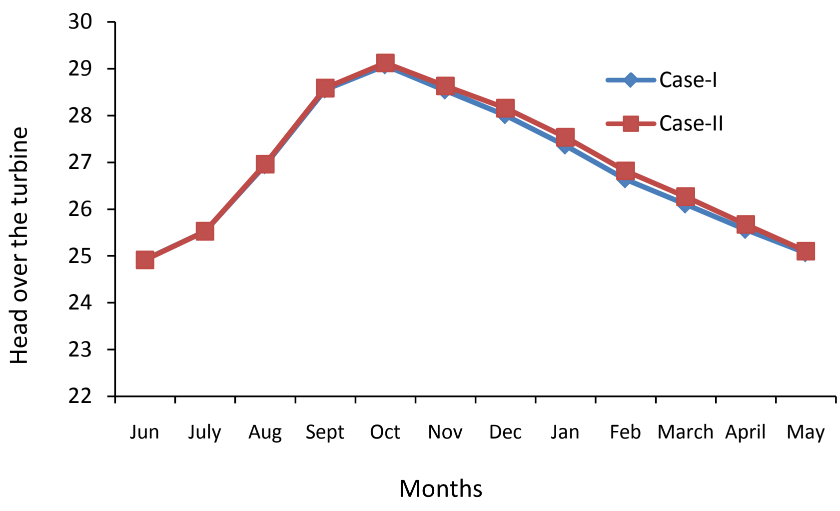

Figure 3. Month wise head over the turbine in both cases.

1) There is an increase of 2.47% in the intensity of irrigation in case-II as compared to the case-I. This may be due to conjunctive use planning. The benefits in case II is increased to 6.42% giving rise of 6.42% in the net benefits.

2) The socio-economic constraints have been considered to the crops of Rabi Wheat, Rabi Jowar, Rabi Gram and Hot Weather Ground Nuts in case-I and to Rabi Wheat, Rabi Jowar and Hot Weather Ground Nuts in case-II to take care of the minimum requirement of the local population. This also ensures crop rotation.

3) The storages available in hot weather have been allowed for growing perennial and the hot weather crops particularly the sugarcane which assured the running of sugar mills in the area by preventing the migration of labor to certain extent.

4) Being a multipurpose reservoir, after giving first priority to water supply the cropping patterns and the power generation are obtained as presented in the results.

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