PERFORMANCE EVALUATION OF SRI RAM SAGAR IRRIGATION PROJECT

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ABSTRACT

In this study, the performance evaluation of Sri Ram Sagar Project (SRSP) has been carried out through the formulation of a tri-seasonal (kharif, rabi and summer seasons) linear programming model developed using 396 decision variables and 528 constraint equations using 44 years (1950-1993) of historical data. Based on the long term historical data, a suitable operating policy has been developed for the better performance of SRSP reservoir. The results reveal that the release combination (3, 6), i.e., three irrigation releases for kharif season and six irrigation releases for rabi season gives 33 years of satisfaction with 11 deficit years out of the 44 years, which is said to be well within the 75% dependability condition. Hence, it is a practicable case of optimal release combination. Further, no irrigation releases during summer season can be assured. Subsequently, the verification of water use efficiency of the reservoir has also been carried out using the selected performance indicators.

Key words: Irrigation, Reservoir operation, Optimization, Performance indicators

INTRODUCTION

In recent years, the utilization and management of water resources are of top priority, which makes it imperative to go for new projects and to improve the performance of the existing projects for the economic growth of the region. It is a well known fact that water quantity is a limited resource to undertake new irrigation projects in most of the regions in India. Nevertheless, improving the performance of the existing irrigation projects is more preferable to develop new irrigation projects which are sustainable and attractive for the region (Sener et al., 2007). Being faced with ill-timed and insufficient rainfall, agriculture in India is heavily dependent on irrigation. In India, irrigation sector uses nearly 85% of its available water resources (Oza, 2007). The water supply for irrigation is mostly drawn from the surface water reservoirs. The performance of irrigation systems supplying water from the reservoirs are characterized by water scarcity, heterogeneity in soils, crops, climate, and water distribution network and large number of users. Therefore, it is very difficult to meet the growing irrigation water demands when the water resources are limited. To overcome this difficulty, efficient management and operating policies has to be developed for the better performance of the irrigation systems.

The efficient management and operation of the reservoir system calls for complex engineering and mathematical techniques coupled with excellent managerial judgment. Linear Programming (LP) is one of the most popular optimization technique used in water resources systems planning to optimize a set of objectives (Vedula and Kumar, 1996; Vedula and Mujumdar, 2005; Long, 2006). The Linear Programming technique has advantages over other optimization models as it is easy to understand and does not require any initial solution.

Many researchers used the linear programming technique for water resources planning and operation of reservoir systems. Loucks et al. (1981) proposed conceptual procedures of LP technique on reservoir operation, and, subsequently, Chaturvedi (1987) reinstated the conceptual procedures of LP technique on reservoir problems. Yeh (1985) provided a state-of-the-art review of LP technique for reservoir management and operations. Tandaveswara et al. (1992) illustrated a LP model for overdeveloped irrigation system in South India. Pillai et al. (1992) also developed a multi-objective optimization procedure for water resources systems. Mohan and Diwakar (1992) developed a linear multi objective programming model using constraint technique to derive the optimal releases from large-scale multi reservoir system. Lakshminarayana and Rajagopalan (1997) used linear Programming model for maximizing the irrigation benefits for the Bari Doab Basin in North India. Mujumdar and Teegavarapu (1998) developed a deterministic LP model for short-term annual operation of an irrigation reservoir. Duranyildiz et al. (1999) developed a chance-constrained LP model, which accounts for the random nature of inflows to optimize the monthly operation of a real reservoir. Raju and Kumar (1999) developed a multi-criterion decision making based optimization model in irrigation planning. Further, Raju and Kumar (2000) proposed the optimum cropping pattern for Sri Ram Sagar Project (SRSP) using linear programming approach. Raju and Kumar (2004) developed a model for irrigation planning and irrigation scheduling and found that the Genetic Algorithm (GA) and linear programming solution having reasonably same performance. Furthermore, Kumar et al. (2006) presented a GA model for obtaining an optimal operating policy and optimal crop water allocations for the Malaprabha single-purpose irrigation reservoir in Karnataka State of India and again concluded that the optimal operating policy obtained using GA is similar to that of the linear programming. Sener et al. (2007) evaluated the performance of the Hayrabolu irrigation scheme of the Thrace district in Turkey using different comparative indicators. Recently, Pant et al. (2010) developed an optimization model based on linear programming for determining the optimal crop plan for the command area of Pamba-Achankovil-Vaippar (PAV) link project in Kerala state of India.

Comprehensive studies of the earlier research works emphasize on the improvement of the existing projects for the economic growth of the region. The new projects are not encouraged due to limited resource constraint. Therefore, in order to improve the performance of the existing system, the
The present study has been carried out for the Sri Ram Sagar Project (SRSP) to evaluate its performance through the linear programming approach using 44 years of historical data (1950-1993) as this project is facing water scarcity during non-monsoon period. The water use efficiency of the reservoir is also tested using the selected performance indicators. Although, some of the past research work mostly emphasizes the irrigation planning of the SRSP integrating the reservoir operation and canal scheduling, the present study differs from them in terms of the use of comparative indicators while assessing the performance of the system.

THE STUDY AREA

The Sri Ram Sagar Project (SRSP), formerly known as the Pochampadu irrigation project has been built on Godavari River is one of the major peninsular rivers in southern India. This irrigation project is located at Pochampadu village (18°58’N latitude and 70°20’ E longitudes) in Nizamabad district of Andhra Pradesh (AP) state of southern India. This project has been built to utilize Godavari river water for irrigation and drinking purposes in Telangana regions of Andhra Pradesh state. The regions such as Nizamabad, Adilabad, Khammam, and Warangal districts of Andhra Pradesh state are covered under this project. The SRSP dam comprises of concrete spillway sections with 42 gates with flanked non-overflow masonry and earthen embankment structures on either sides. The reservoir has a water spread area of about 133 Million square meters (Msqm) at the Full Reservoir Level (FRL) equal to 332.54 m. The gross storage capacity of the reservoir is about 3172 Million cubic meters (Mcm). As a result of sedimentation, the live storage capacity reduced to 2166.10 Mcum. The Minimum Draw Down Level (MDDL) storage capacity of the reservoir is about 10.10 Mcum. A flood flow canal has been built to utilize flood water and this water is stored in the Lower Manair Reservoir (LMR) which is situated at a chainage of 146 km from the SRSP. The LMR has a net storage capacity of about 310.00 Mcum at the FRL equal to 318.00 m.

Figure 1 demonstrates the schematic diagram of SRSP. This project has three canals viz., Saraswathi, Lakshmi and Kakatiya canals (see, Figure 1). The first, Saraswathi canal takes off from the left flank of SRSP reservoir and run up to a chainage of 141 km, and in between at a chainage of 47 km, the Kadam reservoir is situated. This canal irrigates an area of about 752.88 km² which covers the command area before and after the Kadam reservoir (i.e., Stage-I and Stage-II of the project). The second, Lakshmi canal takes off from the right flank of SRSP having a length of 3.5 km with a command area of about 66.77 km². The third, Kakatiya canal, a major canal running up to a chainage of 347 km has three reaches, such as Reach-I (upper reach), Reach-II (middle reach) and Reach III (tail reach). The Reach-I and Reach-II comes under Stage-I, and the Reach III alone comes under stage-II of the project. The upper reach takes off from the right flank of the SRSP and terminates in LMR at a chainage of 146 km. The middle reach runs below LMR up to a chainage of 284 km where the stage-I of the project ends. The tail reach runs up to the end of the stage-II of the project and gets terminated at a chainage of 347 km. The total command area of the Kakatiya canal alone (considering the area under all the three reaches) becomes about 5887.81 km². Further, when all the three canals are considered, the total command area of the whole project becomes about 6707.46 km² (which covers the area under Stage I and II of the project).

The climatic condition of the command area is subtropical and semi-arid. The average annual rainfall in the command area is around 1000 mm. Because of the influence of the South-West monsoon, kharif season (June-September) receives about 80-85% annual rainfall. Deep sandy loam and deep clay loam soils are pre-dominant in the command area. The depth of the sandy loam soil is about 450-900 mm with a volumetric water holding capacity of 7-8%, whereas, the depth of deep clay loam soil is about 1000-1800 mm with a volumetric water holding capacity of 14-20%. Further, there are a large number of small farmers in the command area. About 60% of farmers hold less than 0.01 km² of land, about 20% hold 0.01-0.02 km² and 10% hold 0.02-0.04 km². The main crops grown in command area preferred by the farmers are paddy (rice), sugarcane, maize and groundnut almost in equal proportion followed by pulses, cotton and other crops.

Figure 2 reveals the mean monthly rainfall and evaporation details of the SRSP reservoir for a period of 44 years (1950-1993).
Figure 3 shows the annual inflows into the SRSP reservoir for a period of 44 years (1950-1993), while Figure 4 reflects the mean monthly inflows into the SRSP reservoir for the same period. It is seen from Figure 2 that, the *kharif* (June-September) season receives more rainfall than *rabi* (October-January) season due to the influence of monsoon. It is also evident from Figure 4 that, *kharif* season receives very high inflows due to the influence of South-West monsoon, whereas the *rabi* season receives less inflows due to the lean season. The inflow into the SRSP reservoir with 75% dependability is about 4473.53 Mcum which is observed in the year 1968. The minimum (1985.30 Mcum) and the maximum (30047.17 Mcum)
inflows were also observed in the years 1972 and 1990, respectively. Further, in many places of the southern parts of India, *kharif* season (June-September) crops are supplemented by rainfall over *rabi* season (October-January) crops. The *rabi* crops are frequently affected by droughts and monsoon failures in this region. Therefore, it is imperative to assure *rabi* irrigation over *kharif* irrigation. Considering the importance of *rabi* irrigation, a suitable methodology has been proposed herein for assessing the performance of the SRSP reservoir.

In the present methodology, the water year starts from 1st June and ends on 31st May of the ensuing year. A tri-seasonal time step is followed to formulate the model. The water year is divided into three seasons namely *kharif* (June-September), *rabi* (October-January) and summer (February-May). A Linear programming (LP) model is formulated to estimate the number of optimal irrigation releases from the SRSP that can be supplied for both the *kharif* and *rabi* seasons. However, for the summer season, it is assumed zero release for irrigation. The command area under all the three canals of the SRSP reservoir is lumped together; consequently, the total command area of the project becomes about 6707.46 km² (see, Figure 1). The net irrigation demand has been calculated using CROPWAT software by considering the major cropping practices in the command area and this net irrigation demand is about 402.08 Mcum per week. The National Thermal Power Corporation (NTPC) power demand is about 6.58 Mcum per week. The SRSP system is also expected to meet the drinking water needs on a priority basis over irrigation, and its drinking water demand is about 155.74 Mcum per year. The releases for drinking water and power supply are made concurrently with the irrigation releases from SRSP reservoir. Further, the conveyance efficiency is assumed as 85%. Since the model is developed for seasonal time step, all the monthly data of inflows, irrigation demands, drinking water demands, and evaporation losses are converted to a seasonal data and supplied as an input to the model. The developed model primarily computes the season wise optimal releases from the reservoir. The model also estimates the end storages of the reservoir. The releases are to be planned according to the water availability status in the reservoir at the beginning of each season. Further, the number of farm holders being very large and more than 4 or 5 crops sown in each season, it is not quite possible to plan delivery of water to farmers on the basis of crop water demand. Even in each Water Users Association (WUA), there would be about 250-500 farmers growing different crops. The water demand therefore has necessarily to be averaged out and water deliveries have to be planned on the basis of water availability status. Thus farmers are not eligible to demand water on the basis of crop water requirement. On the basis of equity, the quantity of water to be released for irrigation will be fixed. No partial release will be made. This assumption should be used as a guideline in scheduling the irrigation releases from the reservoir. Therefore, in this context, an attempt has been made to maximize the irrigation releases from the SRSP reservoir through optimality procedure by fixing the six releases for *rabi* season, which are assumed sufficient to meet the *rabi* season demands. Further, the number of releases required for the *kharif* season is estimated by increasing its release count until the system gains the optimality status without affecting the fixed *rabi* season release.

**Formulation**

The performance evaluation of the SRSP is done through the formulation of a tri-seasonal (*kharif*, *rabi* and summer seasons). Linear programming model with 396 decision variables and 528 constraint equations using 44 years (1950-1993) of historical data. It is assumed that all the relations among the decision variables are linear and certain both, in constraints as well as in objective function. The objective function is to maximize the irrigation releases for both the *kharif* and *rabi* seasons. Note that, the irrigation releases for summer season are assumed to be zero. The following equations (1) to (13) are formulated to optimize the SRSP reservoir system.

**Objective function:**

\[ Z = \sum_{t=1}^{N} IR_t \]  

where, \( IR_t \) = irrigation release for the season \( t \); and \( N = \) number of time periods in a water year \((N = 3 \text{ seasons})\)

**Constraints:**

(i) **Continuity constraints**

\[ S_{k+1} - S_k + I_k - IR_k - SP_k - E_k - DW_k \]  

(ii) **Irrigation release constraints**

\[ IR_k \leq \eta ID_k \]  

\[ IR_r \leq \eta ID_r \]  

\[ IR_s = 0 \]  

(iii) **Storage capacity constraints**

\[ S_{k+1} \geq S_{\min} \]  

\[ S_{r+1} \geq S_{\min} \]  

\[ S_{s+1} \geq S_{\min} \]  

\[ S_{k+1} \leq S_{\max} \]  

\[ S_{r+1} \leq S_{\max} \]  

\[ S_{s+1} \leq S_{\max} \]  

Where, the suffixes \( k, r, \) and \( s \) in all the above equations indicate *kharif*, *rabi* and summer seasons. The notations such as \( S, I, IR, SP, E, ID \) and \( DW \) indicate storage, inflow, irrigation release, spill, evaporation, irrigation demand, and drinking water releases, respectively, corresponding to their seasons. \( S_i \) is the beginning storage and \( S_{t+1} \) is the end storage of the season \( t \). \( S_{\min} \) and \( S_{\max} \) are the minimum and maximum storage capacity limitations of the reservoir.
symbol \( \eta \) indicates the conveyance losses considered for analysis. The developed model is solved using simplex algorithm. The model effectively computes the optimal irrigation release combinations from the reservoir for both the kharif and rabi seasons. Further, water balance study is also carried out for the computed optimal irrigation release combination from which the end storages of the reservoir can be computed.

**WATER USE PERFORMANCE INDICATORS**

Many researchers (Bos and Nugteren, 1974; Levine, 1982; Pery, C.J., 1996; Molden et al., 1998; Sener et al., 2007) have used various performance indicators such as economic performance, water use performance, agricultural performance and environmental performance on diversified schemes like irrigation and drainage management, agricultural production, economic management, water-use management, physical and environmental management etc. In the present study, the two types of performance indicators such as relative irrigation supply (RIS) and water self-sufficiency (WSS) are used to assess the water use efficiency of the SRSP reservoir. Relative irrigation supply (RIS) is the ratio of total irrigation supply to the total irrigation demand, whereas the water self-sufficiency (WSS) is the ratio between the total input into the reservoir and total output from the reservoir. For this purpose, the LP model result (i.e., the suggested optimal release combination only) is used to get the water balance estimates for 44 years of historical inflows. Then the cumulative values of water balance estimates are used for the application of performance indicators. Earlier, no such investigation has been made on this particular study area. Therefore, this kind of study certainly develops a new strategy and new adjustment for long-term goals under determined system performance.

**RESULTS AND DISCUSSION**

In order to assess the performance of the SRSP reservoir, six types of trial release combinations such as (1, 6), (2, 6), (3, 6), (4, 6), (5, 6) and (6, 6) are attempted to fix the number of optimal releases to be supplied from the reservoir for both kharif and rabi seasons. Note that, from the parenthesis, the first number corresponds to the number of irrigation releases to be made for the kharif season, and the second number corresponds to the number of irrigation releases to be made for the rabi season. In all the above proposed trial release combinations, the rabi season irrigation releases are fixed (i.e., six number of irrigation releases) and they are assumed to be adequate to meet rabi irrigation demands. Further, the kharif season irrigation releases are incremented without affecting the rabi release, viz., (1, 6), (2, 6), (3, 6), (4, 6), (5, 6) and (6, 6) from which one best optimal release combination is to be computed. Furthermore, the obtained LP results are analyzed...
Fig. 6. Release combination-wise total number of deficit years observed during 1950-1993

and presented herein. Figure 5 shows the number of deficit years with reference to the season-wise release combination for a period of 44 years (1950-1993). Figure 6 demonstrates the release combination-wise total number of deficit years observed for a period of 44 years (1950-1993). Figure 7 reveals the total number of years of satisfaction and deficit obtained for the release combination (3, 6). Figure 8 illustrates the yearwise beginning storages in the reservoir for a given period of 44 years (1950-1993). Figure 9 demonstrates the annual evaporation losses from the SRSP reservoir for a period of 44 years (1950-1993). Further, Table 1 shows the summary of season-wise pertinent characteristics of various release combinations attempted for optimizing the SRSP reservoir. Table 2 demonstrates the estimated water balance of the SRSP reservoir for a period of 44 years (1950-1993). The failure of the release combination is determined based on the number of deficit years and the cumulative spill calculated for a period of 44 years.

For the release combination (1, 6), rabi releases failed in 10 years out of 44 years, however, the kharif releases remain unaffected (see Figure 5). It can also be inferred from Table 1 that the water is excessively spilling from the reservoir, viz., cumulative spill is estimated about 276735.04 Mcum and the total deficit is about 5958.30 Mcum for the total duration of 44 years. Optimality cannot be gained when the reservoir is surplus and spilling excessively. Hence, the trial releases combination (1, 6) is not a feasible solution for optimality condition.

For the release combination (2, 6), rabi season gets affected by 11 years out of 44 years and kharif season remain unaffected. It shows that, rabi irrigation releases are well within the 75% dependable limits (i.e., 33 satisfactions out of 44 years). It is again realized from Table 1 that, the estimated total deficit and cumulative spill for this trial release combination (2, 6) was 7929.65 Mcum and 259987.63 Mcum, respectively. When compared with the release combination (1, 6), the release combination (2, 6) shows a considerable reduction in the cumulative spill to an amount of 16747.41 Mcum. However, still, the attainment of optimality cannot be attributed to the release combination (2, 6) until its next release combination (3, 6) is verified. Note that, for this (2, 6) release combination, the deficit value is about 7929.65 Mcum (see Table 1).

For the (3, 6) release combination (i.e., 3 irrigation releases for kharif season and 6 irrigation releases for rabi season), rabi season shows 11 deficit years and kharif season shows 33 years of satisfaction out of 44 years (See Figures 5 and 6). Similar to the (2, 6) release combination, the (3, 6) release combination has also been observed well within the 75% dependable limit (i.e., 33 satisfactions out of 44 years), but gains one extra release for kharif season compared to that of
Fig. 7. Total number of years of satisfaction and deficit obtained for (3, 6) release combination

Fig. 8. Year-wise beginning storages in the SRSP reservoir
Fig. 9. Annual evaporation losses from the SRSP reservoir

Table 1. Summary of season-wise pertinent characteristics of various release combinations
(All values are in Mcum)

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Release combination</th>
<th>Deficit</th>
<th>No. of years of deficit</th>
<th>Total deficit</th>
<th>Cumulative spill for all the years</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Maximum</td>
<td>Minimum</td>
<td>Average</td>
<td>Kharif</td>
</tr>
<tr>
<td>1</td>
<td>(1,6)</td>
<td>1287.12</td>
<td>22.87</td>
<td>595.83</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>(2,6)</td>
<td>1661.41</td>
<td>22.87</td>
<td>720.87</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>(3,6)</td>
<td>2035.65</td>
<td>22.87</td>
<td>852.28</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>(4,6)</td>
<td>2159.75</td>
<td>22.87</td>
<td>895.29</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>(5,6)</td>
<td>2412.50</td>
<td>5.49</td>
<td>1069.91</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>(6,6)</td>
<td>2412.50</td>
<td>22.87</td>
<td>986.39</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 2. Estimated cumulative water balance of the SRSP reservoir during 1950-1993
(All values are in Mcum)

<table>
<thead>
<tr>
<th>Water Balance for 44 years</th>
<th>Beginning Storage</th>
<th>Inflow</th>
<th>Evaporation Loss</th>
<th>Release for Irrigation Kharif</th>
<th>Release for Irrigation Rabi</th>
<th>Drinkingwater Release</th>
<th>Deficit</th>
<th>Spill</th>
<th>End Storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cumulative</td>
<td>41246.22</td>
<td>426286.69</td>
<td>26049.61</td>
<td>53072.80</td>
<td>96775.17</td>
<td>6852.56</td>
<td>9374.87</td>
<td>245692.15</td>
<td>39090.62</td>
</tr>
<tr>
<td>Mean</td>
<td>937.41</td>
<td>9688.33</td>
<td>592.04</td>
<td>1206.20</td>
<td>2199.44</td>
<td>155.74</td>
<td>213.07</td>
<td>5583.91</td>
<td>888.42</td>
</tr>
</tbody>
</table>
the earlier (2, 6) release combination. The cumulative spill reduces further to an amount of 24295.32 Mcum with slight increase in deficit value of 9375.11Mcum (see Table1). The drinking water demand is about 155.74 Mcum which is met in full for all the 44 years. Further, a total maximum deficit of 2035.65 Mcum and a minimum deficit of 22.87 Mcum were also observed (see Table 1) from this trial run. Therefore, in order to gain the efficient performance of the SRSP reservoir, the computed (3, 6) release combination may be the practical optimal solution. However, the subsequent release combinations such as (4, 6), (5, 6) and (6, 6) failed to give irrigation releases within the 75% dependable limits (see Table 1). Further, it is again evident from Figure 5 and 6 revealing the release combinations (4, 6), (5, 6) and (6, 6) that the kharif season is affected by 3, 4 and 5 years, and the rabi season is affected by 11, 12 and 13 years, respectively. Hence, all these three release combinations such as (4, 6), (5, 6) and (6, 6), can be treated as infeasible solutions.

After computing the optimal release combination from the LP model developed for SRSP, the annual water balance study has also been carried out for the same (3, 6) optimal release combination and the estimated season beginning storages are shown in Figure 8. The estimated cumulative and mean values of all the pertinent characteristics assessed for the water balance study for a period of 44 years (1950-1993) is summarized and shown in Table 2.

For the release combination (3, 6), the net irrigation demand for kharif season comes about 1206.24 Mcum when calculated using per week demand equal to 402.08 Mcum and its cumulative demand for total period of 44 years becomes to be 53072.80 Mcum. Similarly, when analyzed for rabi season the net demand is estimated as 2412.50 Mcum and its cumulative demand for the same 44 years is estimated as 106150.00 Mcum. From Table 2, it is realized that, the cumulative kharif season demands are met full for the total period of 44 years as there were no failure of kharif releases. However, the cumulative rabi season demands met only at a quantity of 96775.17 Mcum with a cumulative deficit of 9374.87 Mcum as there were 11 failures noticed. From Table 2, it can be found that the mean evaporation losses, spill and the deficit are 592.04 Mcum, 5583.91 Mcum and 213.07 Mcum, respectively. The annul evaporation losses from the SRSP reservoir for the (3, 6) release combination is also illustrated in Figure 9.

**Water Use Performance**

The selected comparative indicators are used to assess the water use performance of the SRSP. For this purpose, the LP model result (i.e., (3, 6) optimal release combination) has been used to estimate the annual water balances for the total period considered for analysis. Two types of selected indicators, relative irrigation supply (RIS) and water self-sufficiency (WSS) were used to assess the performance of the SRSP. The RIS value indicates whether there is an adequate supply done or not to meet the demand of water. A RIS values of one or higher indicates adequate while the values smaller than one indicate inadequate supply of irrigation.

Using the cumulative values from Table 2, it is calculated that, for kharif season, RIS = 1.0 value which shows the adequate supply of water; whereas, for the rabi season, RIS = 0.91 value comes to 0.91 which shows slightly inadequate supply of water from the reservoir. Further, the RIS value obtained for the rabi season is allowed well within the 75% dependable release limit (i.e., 33 years of satisfaction and 11 deficit years out of 44 years). Therefore, slight inadequacy does not affect the performance of the SRSP reservoir much in a long-term. However, the RIS value of the rabi season can be improved by reducing the deficiency of supply by minimizing the spill. The minimization of spill is not included in the objective function for the present study as it is beyond the scope of this work.

Further, the value of WSS is calculated by taking the ratio between all the cumulative inputs to the reservoir (i.e., inflows, beginning and end storages), to the cumulative outflows (i.e., evaporation losses, kharif releases, rabi releases, drinking water and spill) to the reservoir. The water self-sufficiency WSS for all the 44 years is estimated as 118.25%, indicating that the SRSP reservoir is self-sufficient, and not in need of any other alternate water sources when the release combination (3, 6) is adapted. Hence, the suggested optimal release combination (3, 6) is a practicable case of optimal release combination for achieving the efficient performance of the SRSP reservoir. Any variation in the RIS and WSS values will affect the optimal release combination (3, 6) and may not generate the same performance.

**CONCLUSION**

In light of the above study carried out to evaluate the performance of the SRSP reservoir by formulating a tri-seasonal optimization model using 44 years (1950-1993) of historical data, the following conclusions can be drawn:

- The drinking water supply demands have been met in all the 44 years.
- The release combination (3, 6), i.e., three irrigation releases for the kharif season and six irrigation releases for the rabi season gives 33 years of satisfaction with 11 deficit years out of the 44 years, which is said to be well within the 75% dependability condition. Hence, it is a practicable case of optimal release combination. No irrigation release is assured during the summer season.
- As the developed optimization model accounts for the whole command area of 6707.46 km² for simulation, further extension of area is not recommended.
- Rabi crop is planned depending on the water availability status at each end of the kharif season.
- The National Thermal Power Corporation (NTPC) power demands are also met simultaneously with the irrigation releases.

The computed optimal release combination (3, 6) obtained from the LP model is again verified by the selected comparative indicators. For this purpose, the annual water balance study is also performed and their cumulative values are estimated for a period of 44 years. The relative irrigation supply with $RIS = 1.00$ for the kharif season indicates adequate supply of water and a value of $RIS = 0.91$ for the rabi season indicating slightly inadequate supply of water from the reservoir. Further, the water self-sufficiency value with $WSS =$
118.25% indicates that the SRSP reservoir is self-sufficient which does not need any other source of supply when (3, 6) release pattern is adopted.

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