International Journal for Research in Engineering Application & Management (IJREAM)
ISSN : 2454-9150 Vol-09, Issue-02, May 2023

Assessment of Irrigation Potential of Kulsi River Basin using System Analysis Techniques

Dr. Krishna Kamal Das

Lecturer (SG) in Civil Engineering, Bongaigaon Polytechnic, Assam, India. ***kkdhji@gmail.com***

Abstract: Agriculture is the predominant user of most of the water resources. Efficient use of water for irrigation can help in sustainable development of the region. A typical reservoir operation model should be incorporated for reservoir release for efficient irrigation system. Under a multi-crop environment, the various crops compete for the available water whenever the water available is less than the irrigation demands. In water-scarce conditions, the deficit allocation among the competing crops has significant influence on irrigation system performance. In this paper an attempt has been made to study the irrigation potential of Kulsi river basin using system analysis techniques. The Kulsi river basin is located on the southern part of the river Brahmaputra. The basin is in between 25032/ N & 260 07/ N and 900 45/ E & 910 48/ E. In this study, Non Linear Programming model have been developed to study the irrigation potential of the basin. Three irrigation management plans have been developed for the study. The model is run for the target of irrigation reliability ≥ 75 % and hydropower reliability ≥ 90 %. Three irrigation management plans are proposed for the study. From the study it is found that at optimal reservoir capacity 522.722 Mcm, the irrigation potentials of the Kulsi basin are 146.502 Mcm, 152.449 Mcm and 166.201 Mcm for irrigation management plan-1, plan-2 and plan-3 respectively.

Keywords: Irrigation potential, Non-Linear Programming, Simulation, Reliability, CROPWAT, Linear programming.

I. INTRODUCTION

For sustainable use of water resources, an efficient reservoir operation policy is very important in planning and management of water resources. The reservoir operation policy includes amount of water to be released to meet various demands in a systematic way. The water resources problems are very complex. It is not easy to formulate them into mathematical equations and have a solution. Simulation and optimization techniques are the tools to solve these complicated problems. In this paper the potential of irrigation from Kulsi basin is studied using system analysis techniques. The Kulsi multipurpose project was undertaken jointly by the Brahmaputra Board, Central Water Commission and Government of Assam jointly for hydropower generation, irrigation and flood moderation. It is proposed to construct concrete dam across the river Kulsi. The proposed site for the dam is about 1.5 km downstream of Ukium village in Assam. The basin occupies the area in Kamrup and Goalpara district of Assam, also West Khasi hills and East Garo hills district of Meghalaya. Figure-1 shows the location map of Kulsi basin. The basin is surrounded by Bharalu, Kallong and Kopili sub basin in the east side, Krishnai- Dudhnoi sub-basin in the west side, West Khasi hills in the south side and the mighty river Brahmaputra on the north side. Kulsiriver is a tributary of the Brahmaputra river system. The total catchment area of Kulsi river basin is 3770 Km^2. The catchment area upto dam site is 1628 km^2. The culturable commanded area is taken as 32800 Ha.

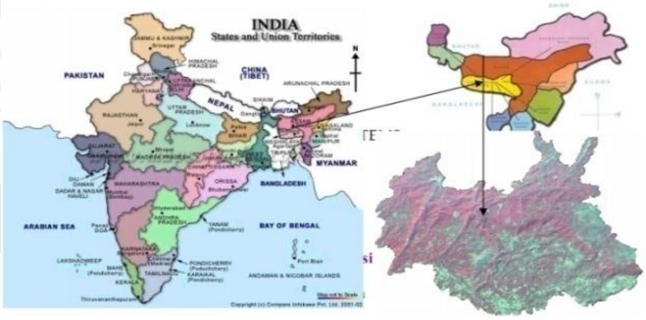

Fig-1: Location Map of Kulsi Basin

II. LITERATURE REVIEW

Water resources system analysis has now been generally accepted to provide an efficient way of answering the numerous questions regarding planning of a large-scale real life water resources system for which the conventional methods of analysis will be inadequate. The approach and appropriate technique varies from problem to problem depending up on state of development of the system and range of decision-making [15].[16]Developed a monthly time series simulation model for evaluating the performance of Ukai reservoir in Gujarat, India serving municipal, industrial, irrigation water demands, hydropower generation and flood moderation. They used

 DOI : 10.35291/2454-9150.2023.0120

simulation models for performance assessment under four different conditions and investigated the reliability, resilience, vulnerability and sustainability indices.[6]Enumerated that mathematical modelling provides a way, perhaps the principal way of predicting the future behaviour of existing or proposed water resources system. A mathematical model is a set of equations that describes and represents the real life water resources system. Application of models to real life system have improved the understanding of such systems, and hence contributed to improved system design, management, and operation. A simulation model for planning water resources developments in the Chi River basin and to evaluate the alternatives under different scenarios for planning of reservoir and irrigation projects was developed by[5]. They explained the principal characters of the model and enumerated the input data required for development of the model. [18] Developed an extensive simulation model to appraise the ongoing practical approaches for integrated operations of a multi-reservoir system on Kukadi Irrigation Project. They mentioned that in a multi-reservoir system all the reservoirs are interdependent on each other. Due to scantly rainfall the availability of water in the reservoir made the operational system of multi-reservoir system more complex. [9]Revealed that when optimization and simulation models are combined together the approach gives the best results. They reviewed various literatures on simulation, optimization and combined simulation–optimization modelling approach and reported an overview of their applications.[2]Reviewed the different optimization methodologies developed for solving problems related to water resources. A real-time operational model was developed by [19] for multipurpose reservoir operation for irrigation and hydropower generation on Bhadra reservoir of Karnataka, India. The optimal monthly real-time operation demonstrated the relevance, applicability and the relative advantages for reservoir operation. [17] Presented a multi-reservoir reliability-based simulation (RBS) model considering the integrated operation of the systems. The model employed the general algorithm of the single-reservoir RBS model. [7]A SWAT model was developed to assess the available water resources of the Dhidhessa River Basin (DRB) for the potential application of surface water irrigation and improvement of agricultural crop productivity. The study also estimated the irrigation water requirement of six selected crops (cabbage, maize, tomato, pepper, groundnut and sugarcane) and successfully identified their irrigation command areas. [20] Reviewed the simulation–optimization modelling techniques used to solve the critical issues relating to reservoir system. They noted that for a reliable optimization models an accurate simulation model is very essential. The combination of simulation-optimization models gives best results in reservoir managements. [21] Estimated the crop water requirements in an agro-ecological unit of Kerala. They used CROPWAT 8.0 for estimation of crop water requirements [10] with the available climatic data. They estimated the net irrigation demands, gross irrigation demands and irrigation scheduling for different crops grown in the area. [14]Outlined that for management and planning of irrigation system CROPWAT derived a composite interrelationship among meteorological, crops and soil characteristics. To evaluate the evapotranspiration, irrigation scheduling and crop water requirements under various cropping pattern, CROPWAT is an essential tool. Linear programming model was formulated by [13] and solved using LINGO solver to allocate areas for maximizing crop production and optimal use of limited irrigation water. From the results they concluded that to solve real world problems for maximizing crop yield LP model is promising. [11] Developed an LP model to evaluate maximum profit from the traditional cropping pattern considering market demands, irrigation water requirements, cropping area constraints at Kalihati, Bangladesh. The model allocated the crop area and depth of irrigation water requirements for maximizing the objective function.An extensive review on various programming models used for irrigation planning and management were done by [1]. He outlined that in the models mainly considered to maximize net income, minimize water logging and minimizing and ground water depletion using linear programming, non-linear programming, dynamic programming, and genetic algorithm. Depending on the review he provided a basis to select an appropriate model for irrigation planning and management. Application of the simulation techniques to real life problems related to rivers in India was reported in doctoral works carried out in India, e.g.[8], [4], [3], [12].

III. METHODOLOGY

Hydrological data are collected for the study of Kulsi multipurpose project from various sources. Monthly inflow data have been collected from the Central Water Commission, Brahmaputra & Barak Basin Organization, Shillong. The monthly data series collected are classified data and permission for publication could not be obtained. Evaporation data available at the Lokapriya GopinathBordoloi International Airport, Borjhar, Assam, have been considered for the project. The area- capacity-elevation values estimated by Survey of India from reservoir area map have been collected from the project authority and used for the present study. Gross command area of Kulsi project is 37908 Ha. An area of 32800 Ha (net irrigable area) is to be irrigated using the water of Kulsi reservoir.

For formulation of linear programming model for optimal cropping pattern, the data such as the area of crop field, crop yield, market price and cost of production have been collected from the project authority. Assessment of crop water requirement is done using FAO – Penman-Monteithmethod. The analysis is done in CROPWAT 8.0

 DOI : 10.35291/2454-9150.2023.0120

software. To calculate the crop water requirements, thirty nine varieties of crops suitable for the basin are considered.The crop water requirements are calculated for entire crops at different time periods depending on the cropping season and finally water requirements on 10-day basis for all the crops are calculated. The analysis showed the total crop water requirement (delta) for the basin to be 3593.2 mm.The monthly crop water requirements and effective rainfall in various months are shown in figure-2.

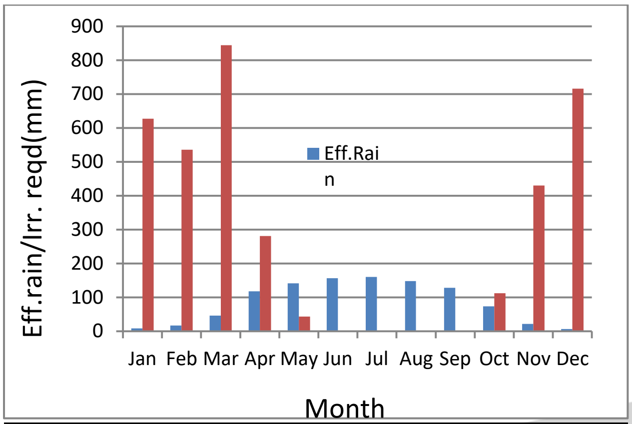

Fig- 2: Monthly crop water requirements and effective rainfall

Linear programming model is formulated to suggest the optimal cropping pattern giving the maximum net benefit. The objective function of the model is subject to the constraints: water availability, crop land requirement, protein and calorie requirements and minimum and maximum crop area. While calculating net benefits, the yield, market price and cost of cultivation are considered. The linear programming model consisting of three major components: an objective function for maximization of production, a set of linear constraints and a set of non-negativity constraints. The model is formulated to allocate land among the different crops, in order to maximize the production from the command area. The LP model developed is solved using LINGO package. The water supply available at inlet is considered as the only source of available water in the command area. The monthly 75% dependable available water for irrigation is calculated by deducting the ecological release from total reservoir release. Monthly dependable water available for irrigation is shown in the table-1.The copping pattern is a dynamic decision to be made depending on population growth and corresponding protein and calorie requirements. The outcome of the model gives three optimal cropping patterns for the year 2030 (plan-1), 2040 (plan-2) and 2050 (plan-3) respectively. The areas under different crops are suggested by the model for optimal benefits. Accordingly the total irrigation requirements for all the plans are estimated.

Table-1: Monthly dependable available water for irrigation

Months	75% dependable water (Ham)	Months	75% dependable water (Ham)
Jan	4366.76	Jul	4852.019
Feb	4447.223	Aug	4331.665
Mar	4546.257	Sep	4331.665
Apr	4692.331	Oct	4331.665
May	4805.358	Nov	4331.665
Jun	4956.605	Dec	4331.665

It is good practice to change the cropping pattern after some period rather than a long term cropping pattern. So, considering minimum area constraints as 5% of the area for each crop proposed by the project authority and CCA 32800 Ha, three irrigation management plans have been suggested for the projected year 2030 as paln-1, for projected year 2040 as plan-2 and for projected year 2050 as plan-3. The total irrigation requirements for plan-1, plan-2 and plan-3 are 93.282 Mcm, 97.069 Mcm and 105.825 Mcm respectively.

For each plan, it has been observed that the irrigation requirement is the maximum in the month of March. Generally the agricultural land is to be prepared for sowing crops in this period; hence maximum water is required for preparation of agricultural land. From June to September no irrigation water is required to be supplied, as this is the monsoon period and sufficient rainfall occurs in this period in the study area. From October to March there is scantly rainfall in the study area and hence irrigation water is needed to be supplied for growing crops. The monthly irrigation requirements for the cropping pattern as per plan-1, plan-2 and plan-3 are shown in figure-3

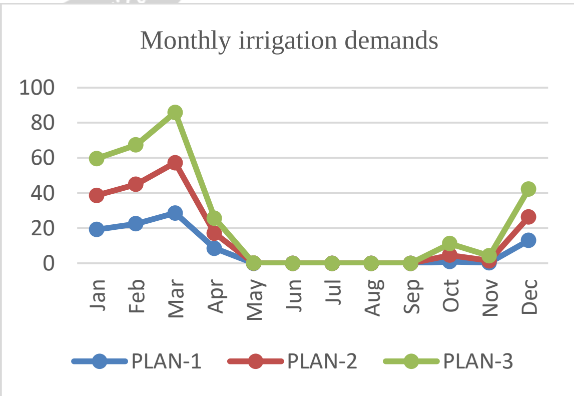

Fig- 3: Monthly irrigation demands

Finally, a simulation and optimization model has been developed to study optimal irrigation that can be done with the help of available mentioned data. In simulation, it is assumed that in any time period if water is available, then demand has to be met. Ecological, irrigation and hydropower demands are considered in this model. As per the guidelines provided by National Water Development

 DOI : 10.35291/2454-9150.2023.0120

Agency, Govt. of India, 10% of the average non-monsoon flow is to be considered as ecological demand; and this amount should be available in the downstream of river at any time. As per the National Water Policy in India, the ecological and irrigation demand are given higher priority than the hydropower demand. In Kulsi project, irrigation and power generation are compatible, i.e., irrigation yields are also available for power generation.

The application of the model is started with the assumption that the initial storage in the reservoir is 300 Mcm. It is a theoretical approach considering the worst condition. Here 39 years of monthly inflow data is used and the month of "May" is considered as the start of each water year. The best fitted equations obtained from 'storage v/s elevation' and 'storage v/s area' curves from elevation – storage – area relationships have been used in the simulation model. The model is run for the irrigation management plan-1, plan-2 and plan-3. From these data, by utilizing simulation model, irrigation reliability and average annual irrigation along with the hydropower potential are obtained under different scenarios without compromising the target of irrigation reliability ≥ 75 % and power reliability ≥ 90 %.

IV. RESULTS AND DISCUSSIONS

The simulation model is developed for determining the irrigation and hydropower potential from the basin. Deterministic inflow, flow continuity, storage bounds, storage-area-elevation relationships, demand requirements, evaporation losses, spills, plant capacity constraints /relationships are incorporated in to the model. The simulation model is run for the target of irrigation reliability ≥ 75 % and power reliability ≥ 90 %.

Simulation model is run to see the behaviour of the reservoir under different scenarios and results are summarized below.

In the first case, the Plant capacity 55 MW, reservoir capacity 525.64 Mcm (FRL) and tail water level 51.0 m are kept constant and firm power is varied. The annual irrigation requirement for plan-1 is 93.282 Mcm. Initially firm power is assumed 6.00 MW to run the simulation model. After that the firm power is successively increases to see the changes in power and irrigation reliabilities under successive simulation run. The results of the iterations are presented in table-2. It is oberved that the firm power 10.70 MW fulfills the target reliabilities. Beyond firm power 10.70 MW the power reliability becomes less than 90% though the irrigation reliability is satisfied. Hence, the firm power 10.70 MW is best suited for reliability of hydropower and irrigation.

The simulation model is also run for the plan-2 and plan-3 by changing the irrigation demands. The irrigation demands for plan-2 and plan-3 are 97.069 Mcm, 105.825 Mcm respectively. From the iterations it is observed that the firm power 10.70 MW satisfisfied the target reliabilty of irrigation and hyrdropwer for all the plans. Beyond the firm power 10.70 MW power reliabilty becomes less than 90% though the irrigation reliability is satisfied.

Table -2: Firm power vsirr. rel/pow.rel/av.ann.irr/av.ann.pow. (plan-1)

Firm power (MW)	Irrigation reliability (%)	Power reliability (%)	Average annual irrigation (Mcm)	Average annual power (MW)
6.00	96.1	96.10	93.28	166.28
10.50	95.28	91.79	92.29	157.40
10.65	94.87	91.37	91.73	156.85
10.70	**94.87**	**90.14**	**91.71**	**156.28**
10.75	94.87	89.94	91.71	155.99
11.00	94.87	88.50	91.71	154.40

In the second step, firm power of 10.70 MW, plant capacity 55 MW and tail water level 51.0 m have been kept constant and the reservoir capacity is varied. For running the model initially reservoir capacity in considered 400.0 Mcm and the simulation model is run under different reservoir capacities. From the iterations it is seen that for reservoir capacity 525.64 Mcm, the target reliabilities are satisfied shown in table-3. The corresponding elevation for the reservoir capacity 525.64 Mcm is 115 m (FRL).

Similarly, the model is also run for the plan-2 and plan-3 by changing the corresponding irrigation demands. From the iterations it is observed that the reservoir capacity 525.64 Mcm satisfied the target reliabilities for all plans.

Table-3: Reservoir capacity vs irr. rel/pow.rel/av.ann.irr/av.ann.pow. (plan-1)

Reservoir capacity (Mcm)	Irrigation reliability (%)	Power reliability (%)	Average annual irrigation (Mcm)	Average annual power (MW)
400.00	91.37	74.95	86.57	136.04
500.00	94.87	88.29	91.71	152.14
522.00	94.87	89.94	91.71	155.73
522.50	94.87	89.94	91.71	155.81
522.722	**94.87**	**90.14**	**91.71**	**155.84**
525.00	94.87	90.14	91.71	156.18
525.50	94.87	90.14	91.71	156.26
525.64	**94.87**	**90.14**	**91.71**	**156.28**
530.00	94.87	90.96	91.71	156.93

To obtained the optimal reservoir capacity, optimization is done and found that the reservoir capacity 522.722 Mcm satisfied the target reliabilities. Table- 3 shows the results of the iterations for plan-1.

Table 4: Summury of results of plan-1, plan-2 and plan-3

Particulars	Plan-1	Plan-2	Plan-3
Optimal reservoir capacity (Mcm)	522.722	522.722	522.722
Maximum drawdown level (M)	90	90	90
Irrigation demands (Mcm)	93.282	97.069	105.825
Average annual irrigation (Mcm)	91.71	95.50	104.24
Overall irrigation reliability (%)	94.87	94.87	94.66
Optimal irrigation (Mcm)	146.502	152.449	166.201

 DOI : 10.35291/2454-9150.2023.0120

V. CONCLUSION

From the model output under different scenarios without compromising the target of irrigation reliability ≥ 75 % and power reliability ≥ 90 %, the results obtained are summarized (Table-4). The model results include the optimal reservoir capacity, firm power, maximum annual power, average annual power without compromising the target reliabilities.The optimal reservoir capacity required is 522.722 Mcm. Average annual irrigation 91.71 Mcm, 95.50 Mcm and 104.24 Mcm with overall irrigation reliabilities 94.87 %, 94.87 % and 94.66% respectively can be done from plan-1,plan-2 and plan-3. It is observed that the overall irrigation reliabilities are far more than the target reliabilty, which suggest that the irrigation release can be increased above the given demands. The extent upto which the irrigation release can be increases is also calculated for future use. For optimal irrigation demands the model is optimised. It is found that irrigation demands can be increased to 146.502 Mcm, 152.449 Mcm and 166.201 Mcm respectively from plan-1, plan-2 and plan-3.

REFERENCES

[1] Ajay Singh, (2014), "Irrigation Planning and Management Through Optimization Modelling," European Water Resources Association (EWRA), vol. 28(1), pages 1-14, January.

[2] Asmadi Ahmad, Ahmed El-Shafie, SitiFatinMohdRazali and Zawawi Samba Mohamad, "Reservoir Optimization in Water Resources: a Review", Water Resour Manage (2014) 28:3391–3405 DOI 10.1007/s11269-014-0700-5.

[3] B. Sarma (2005), "Planning for Optimal Inter Basin Water Transfer", Ph.D. Thesis, Department of Hydrology, IIT Roorkee, India.

[4] B. Talukdar (1999), "Operation of a multipurpose reservoir using stochastic dynamic programming", Ph.D. Thesis, Department of Hydrology, University of Roorkee, Roorkee, India.

[5] B. S. Piper, Chaiyuth Sukhsri, Suwit Thanopanuwat and D. G. Knott, "A simulation model for planning water resource developments in the Chi River Basin", Water Resources Management, June 1989, Volume 3, Issue 2, pp 141–153.

[6] Christopher J. Barrow, "River basin development planning and management: A critical review" World Development, Volume 26, Issue 1, January 1998, Pages 171-186

[7] Dawit M, Olika BD, Muluneh FB, Leta OT, Dinka MO. Assessment of Surface Irrigation Potential of the Dhidhessa River Basin, Ethiopia. *Hydrology*. 2020; 7(3):68. https://doi.org/10.3390/hydrology7030068

[8] D. K. Srivastava (1976). "Optimization of Complex Water Resources Systems by Screening Simulation Model". Ph.D. Dissertation, Indian Institute of Technology. New Delhi, India.

[9] Deepti Rani, Maria Madalena Moreira (2010), "Simulation–Optimization Modelling: A Survey and Potential Application in Reservoir Systems Operation". Management, April 2010, Volume 24, Issue 6, pp 1107-1138.

[10] FAO Irrigation and Drainage Paper-24, "crop water requirements", Food and Agriculture Organization of the United Nations

[11] HasanSymum and Mohammad F Ahmed, "Linear Programming Model to Optimize Water Supply and Cropping Area for Irrigation: A Case Study for Kalihati", Global Journal of Researches in Engineering: G Industrial Engineering, Volume 15 Issue 2 Version1.0 Year 2015

[12] Julius H. Kotir, Carl Smith, Greg Brown and Ron Johnstone , A system dynamics simulation model for sustainable water resources management and agricultural development in the Volta River Basin, Ghana", Science of The Total Environment, Volume 573, 15 December 2016, Pages 444-457.

[13] M.A Chowdhury and DibakarChakrabarty, " Optimal Crop Yield under Limited Water Availability –A Linear Programming Approach", Journal of Basic and Applied Engineering Research; Volume 2, Number 10; April-June, 2015 pp. 892-895.

[14] Muhammad Nazeer, "Simulation of maize crop under irrigated and rainfed conditions with cropwat model", Journal of Agricultural and Biological Science, 2009 Vol.4 No.2 pp.68-73 ref.13.

[15] P.D. Dahe (2001), "Planning for optimal development of a river basin", Ph. D. Thesis, Department of hydrology, University of Roorkee, India.

[16] Priyank J. Sharma, P. L. Patel and V. Jothiprakas, "A Simulation – Optimization Approach in Development of Operation Policy for a Multipurpose Reservoir", E-proceedings of the 36th IAHR World Congress 28 June – 3 July, 2015, The Hague, the Netherlands.

[17] R. Afzali, S. Mousavi, and A. Ghaheri (2008). "Reliability-Based Simulation-Optimization Model for Multireservoir Hydropower Systems Operations: Khersan Experience." J. Water Resour. Plann. Manage., 134(1), 24–33.doi: 10.1061/ (ASCE) 0733-9496 (2008)134:1(24)

[18] R. Arunkumar and V. Jothiprakash, "Evaluating a multi-reservoir system for sustainable integrated operation using a simulation model", Sustainable Water Resources Management, pp 1–10,6 October 2017.

[19] S. Vedula& S. Mohan (1990), "Real-time multipurpose reservoir operation: a case study", Hydrological Sciences - Journal - des Sciences hydrologiques, 35, 4, 8/1990.

[20] Sabah S. Fayaed, Ahmed El-Shafie and Othman Jaafar, "Reservoir-system simulation and optimization techniques", Stochastic Environmental Research and Risk Assessment, October 2013, Volume 27, Issue 7, pp 1751–1772.

[21] U. Surendran, C. M. Sushanth, George Mammen, and E. J. Joseph, "Modelling the crop water requirement using FAO-CROPWAT and assessment of water resources for sustainable water resource management: A case study in Palakkad district of humid tropical Kerala, India", International Conference on Water Resources, Coastal and Ocean Engineering (ICWRCOE 2015), Science Direct, Aquatic Procedia 4 (2015) 1211 – 1219

 DOI : 10.35291/2454-9150.2023.0120