DEMAND-SUPPLY ANALYSIS FOR IRRIGATION MANAGEMENT IN A COMMAND

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ABSTRACT

Water resource management is an important element of irrigation and crop production. Efficient irrigation systems and water management practices can help maintain farm profitability in an era of limited, higher-cost water supplies. The present study aimed to analyse scenarios based demand-supply assessment in Harsi command of Madhya Pradesh (India) under variable climatic, losses, cropping patterns and supplies conditions. The CROPWAT 8.0 software has been used to estimate crop water requirements using climatic data and cropping patterns. The gross water requirements and demand deficit/excess have been computed under variable climatic and field losses conditions for six different scenarios of design cropping pattern (DCP1 to DCP-6) and present cropping pattern (PCP-1 to PCP-6). The demand-supply analysis of Harsi system indicated that the present water supplies from reservoir are not able to fulfil the irrigation demands of design cropping system in different climatic conditions vary from 551.20 Mm^3 in wet rainfall years (DCP-1) to 617.86 Mm^3 in dry years (DCP-5) with 70% conveyance and 60% application efficiency of system with total availability of 427.19 Mm^3 water in the system. The irrigation demand of design cropping pattern can be reduced to 413.39 Mm^3 (DCP-2) in wet rainfall years to 463.39 Mm^3 (DCP-6) in dry rainfall years by improving conveyance and application efficiencies to 70% and 80% respectively. The gross water requirements for present cropping pattern with 70% conveyance efficiency and 60% application efficiencies may be 532.19 Mm^3 (PCP-1) that can be reduced to 399.14 Mm^3 (PCP-2) by improving the conveyance and application system. From the analysis, it may be concluded that there is a need of efficient reservoir operation and improvement of conveyance and application efficiencies to meet the crop water requirements under different climatic conditions.

INTRODUCTION

In India, agriculture is the major consumer of available water resources and therefore optimal use of water for irrigation is critical to social and economic sustainability of a country. The spatial and temporal distribution of water is extremely uneven and there is an urgent need to use available water resource management in efficient manners. The crop water requirements may be defined as the depth of water consumptively used by a crop plus unavoidable irrigation application losses. It also included other aspects of beneficially used water i.e. the water required for land preparation, leaching of salts, toxic substances and temperature control. The expected rainfall amount at various probability levels for different time periods, monthly, weekly etc. play an important role in estimating the water deficit/surplus on field at different periods of a crop. The estimation of water requirements of crop is essential for crop planning on a farm and also it is the basis on which an irrigation project is designed. The irrigation requirements depend on several factors like type of crop, soil, meteorological conditions, rainfall, land grading and leveling, water conveyance and distribution, timely supply of water in right quantities, method of water application, adequate inputs and agronomic technique, drainage etc. Therefore, the knowledge of spatial and temporal distribution of demands and supplies are important and an integrated approach is essential for economizing irrigation water use for optimum crop production.

A study in Mahendragarh distributary canal in Haryana State has been conducted to estimate net irrigation water requirement of crops under 17 minors for kharif and rabi seasons of 1992–93 period using IRS-1B satellite geocoded FCC images (Prasad et al. 1996). A prototype for spatial decision support system has been developed for the evaluation of water demand and supply management schemes (Manoli et al 2001). A water balance model supported with remote sensing data to estimate evapotranspiration was found suitable to provide accurate irrigation scheduling guidelines for individual fields (Manoli et al. 2001). Delavar et al. (2009) introduced a real time modelling approach for optimal water allocation during drought. The CROPWAT model of FAO with the help of agro-meteorological and remote sensing data (1986–1998 and 2008) was used to calculate irrigation water requirements of wheat and mustard crops grown in western Yamuna canal command (Raut et al. 2010) and found useful tool for irrigation management. Various operating models and decision support system (DSS) have been developed and applied by researchers to address the issues of water supply from reservoirs for irrigation planning, flood management, power generation, multi objectives operation, enhancement of efficiencies (Martin et al. 1984; Koch and Allen 1986; Arumugam et al. 1997; Majumdar and Ramesh 1997; Prajamwong et al. 1997; Panigrahi and Mujumdar 2000; Manoli et al. 2001; Cancelliere et al. 2002; Reddy and Nagesh 2006; Reddy and Nagesh 2007; El-Mesiry et al. 2007; Kim et al. 2008; Canon et al. 2009; Li et al. 2012; Hosseini et al. 2013; Nikoo et al. 2013; Wang and Liu 2013; Moghaddasi et al. 2013; Ahmadi et al. 2014 etc.).

CROPWAT 8.0

The CROPWAT 8.0 for Windows is a computer program for the computation of crop water requirements and irrigation requirements based on soil, climate and crop data (http://www.fao.org/nr/water/infores_databases_cropwat.html). CROPWAT 8.0 is a Window based program and apart from a completely redesigned user interface. CROPWAT 8.0 for Windows includes a host of updated and new features, including monthly, decade *and daily* input of climatic data, use of data from CLIMWAT database, possibility to estimate climatic data in the absence of measured values, decade *and daily* calculation of crop water requirements, calculation of crop water requirements and irrigation scheduling for paddy & upland rice, interactive user adjustable irrigation schedules, daily soil water balance output tables, graphical presentations data, crop water requirements and irrigation schedules, easy import/export of data, context-sensitive help system, multilingual interface and help system in English, Spanish, French and Russian, etc. The evapotranspiration (ET_0) in this software is computed using the Penman-Monteith equation can be expressed as:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad \text{....(1)}$$

where, ET_0 is reference evapotranspiration (mm/day), R_n is net radiation at the crop surface (MJ/sq. m/day), G is soil heat flux density (MJ/sq. m/day), T is mean daily air temperature at 2 m height (°C), u_2 wind speed at 2 m height (m/sec), e_s is saturation vapour pressure (kPa), e_a is actual vapour pressure (kPa), (es – ea) is saturation vapour pressure deficit (kPa), Δ is the slope vapour pressure curve (kPa/°C) and γ is psychrometric constant (kPa/°C). The rainfall is the basic inputs for determination of requirement of crop water requirement (CWR).

STUDY AREA

The study area for present study is Harsi command in M.P. The Harsi dam is situated on river Harsi at about 100 km from the Gwalior and 55 km from Dabra Town. The location map of Harsi irrigation project in Madhya Pradesh has been given in Figure 1. The present cropping pattern (PCP) of Harsi command consists of total irrigable area of 53518 ha which was further modified to 62675 ha as Design cropping pattern (DCP) after proposal of modification and construction of high level canals. Due to increasing demand of irrigation water in the command, shortage of water is experienced regularly and Sindh river water was diverted to Harsi dam through Mohini pick up weir in first phase and Madikheda dam in second stage for additional supplies. The irrigation supplies in Harsi command managed through 5 distributary committees namely Bhitarwar, Chinnor, Dabra, Harsi and Pichore those further divide into 26 water user associations (WUAs) for management point of view.

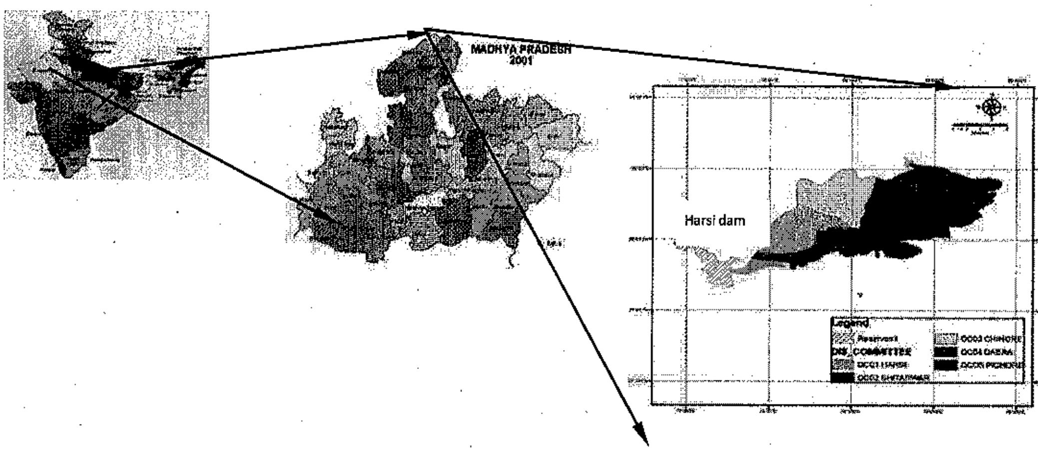


Figure 1. Location map of Harsi command

METHODOLOGY

The methodology for scenarios based demand supply analysis in a command consists of rainfall data processing for identification of dry, average and wet rainfall year, computation of crop water requirement, estimation of irrigation water requirement considering application/conveyance efficiencies and subsequently determination of excess/deficit based on availability of water in the system.

Rainfall Data Processing

For determination of rainfall distribution in dry, normal and wet years, probability analysis of yearly/seasonal rainfall data were conducted to estimate dependable yearly rainfall at 20%, 50% and 80% probability that can be designated as annual/seasonal rainfall for wet, normal and dry year respectively.

Computation of Crop/Irrigation Water Requirement

In the analysis, the crop water requirement for different 10 daily periods were estimated for design and present average cropping pattern in dry, average and wet rainfall years. The climate data, rainfall, crop coefficients and crop periods of different crops proposed in the design cropping pattern and present cropping pattern have been assigned and crop water requirement on 10-daily basis were determined with the help of CROPWAT 8.0 software. The data in the software can be given directly by typing or pasted from excel files (Figure 2). The crop water requirement may be converted to irrigation water requirement by applying application and conveyance efficiencies.

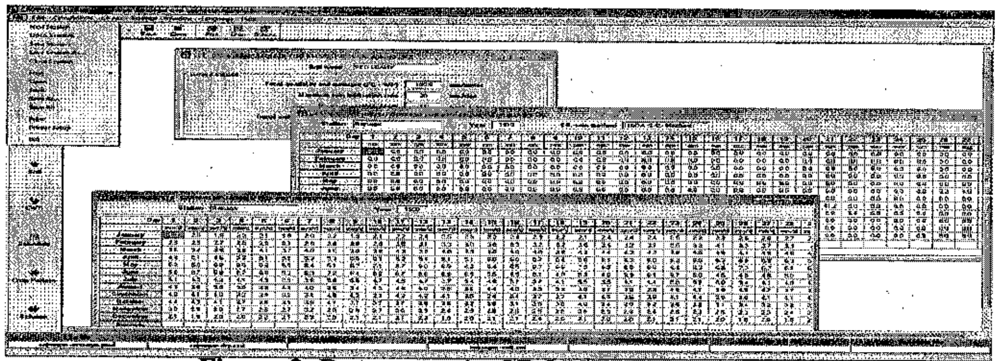


Figure 2. Data entry in CROPWAT 8.0 software

Demand Supply Analysis

The water balance approach has been used for computation of demand deficit or excess in the system. After computing the crop water requirement for different climatological conditions, the total water demand of the system was estimated using the application, conveyance and other losses. The storage capacity of Harsi reservoir was not sufficient to fulfil all irrigation demand of command; therefore this reservoir was connected from different sources through connected channels. The Harsi reservoir received water from Kaketo reservoir situated up-stream of Harsi reservoir on river Parvati. Water from Madikheda dam on river Sindh released water to Mohini Pick weir from where water is diverted to a tributary of Parvati which ultimately reached to Harsi reservoir. These sources supply water to Harsi reservoir during rabi crop season. The data related to supplies of water were analyzed to determine firm supplies of water from different sources to the system. The demand deficit or availability of excess water will be helpful to understand the current status of command, possibility of changes in cropping pattern and conveyance/application system.

ANALYSIS OF RESULTS

In the present study, scenarios based demand-supply assessment have been conducted to ascertain the competence of present water supply system in Harsi reservoir using popular and simple CROPWAT software under various scenarios given in the Table 1.

Rainfall Analysis

For estimation of seasonal rainfall for dry, average and wet years, probability analysis of seasonal rainfall has been carried out and a graph has been plotted on semi log paper with probability of exceedance on abscissa and seasonal rainfall on ordinate. The rainfall in wet, average and dry rainfall years have been computed as 878.08 mm, 674.90 mm and 570.68 mm respectively. The rainfall data of 2000, 2003 and 1992 have been used as representative data for dry rainfall, average and wet rainfall year respectively.

Table 1. Scenarios considered for computation of irrigation water requirement

S.N.	Scenario	Cropping Pattern	Rain and climate	Conveyance efficiency	Application efficiency
1.	DCP-1	Design	Wet rainfall year	70%	60%
2.	DCP-2	Design	Wet rainfall year	80%	70%
3.	DCP-3	Design	Average rainfall year	70%	60%
4.	DCP-4	Design	Average rainfall year	80%	70%
5.	DCP-5	Design	Dry rainfall year	70%	60%
6.	DCP-6	Design	Dry rainfall year	80%	70%
7.	PCP-1	Present	Wet rainfall year	70%	60%
8.	PCP-2	Present	Wet rainfall year	80%	70%
9.	PCP-3	Present	Average rainfall year	70%	60%
10.	PCP-4	Present	Average rainfall year	80%	70%
11.	PCP-5	Present	Dry rainfall year	70%	60%
12.	PCP-6	Present	Dry rainfall year	80%	70%

Computation of Demands on Harsi Reservoir

Irrigation water requirement for design cropping pattern

The designed cropping pattern in Harsi project consists of 15561 ha paddy, 648 ha urad, and 1081 ha soybean in kharif season and 15128 ha dwarf wheat, 2161 ha gram, 2161 ha mustard and 21612 ha HYV wheat in rabi season and yearly crops as sugarcane in 4322 ha. Sub-division wise crop water requirement (C.W.R.) and gross water requirement (G.W.R.) for designed cropping pattern in wet (DCP-1 and DCP-2), average (DCP-3 and DCP-4) and dry rainfall (DCP-5 and DCP-6) year have been presented in table 2. The gross water requirement with 70% conveyance efficiency and 60% field application efficiency may vary from 551.20 Mm^3 in wet rainfall years (DCP-1) to 617.86 Mm^3 in dry rainfall years (DCP-5). The gross water requirement can be reduced to 413.39 Mm^3 in wet rainfall years (DCP-2) and 463.39 Mm^3 in dry rainfall years (DCP-6) by improving conveyance efficiency to 80% and application efficiency to 70%. The results of analysis indicated that 8% and 12% more water is required during average and dry rainfall years respectively corresponding to wet rainfall years.

Irrigation water requirement for present cropping pattern

The present cropping pattern in Harsi command consists of 23482 ha paddy, 25223 ha wheat (HYV) and 4453 ha sugarcane. The sub-division wise crop water and gross water requirements for variable climatic and efficiencies conditions (PCP-1 to PCP-6) have been depicted in Table 3. The gross water requirements for present cropping pattern with 70% conveyance efficiency and 60% application efficiencies may be 532.19 Mm^3 (PCP-1), 595.07 Mm^3 (PCP-3) and 619.95 Mm^3 (PCP-5) for wet, average and dry rainfall years. By improving conveyance efficiency and application efficiency to 80% and 70% respectively, the gross water requirements for present cropping pattern may be reduced to 399.14 Mm^3 (PCP-2), 446.30 Mm^3 (PCP-4) and 464.96 Mm^3 (PCP-6) which indicate about 25% saving of water. The scenarios based assessment of gross water requirements for different WUAs will be helpful for water resource managers to plan releases of water from Harsi reservoir.

Table 2. Sub-division wise Crop water requirement (CWR) and gross water requirement (GWR) for design cropping pattern (All values in Mm^3)

Sub-division	CWR	GWR		CWR	GWR		CWR	GWR	
		DCP-1	DCP-2		DCP-3	DCP-4		DCP-5	DCP-6
Harsi	41.90	99.76	74.82	45.38	108.05	81.04	46.97	111.83	83.88
Bhitawar	45.63	108.64	81.48	49.42	117.67	88.25	51.15	121.79	91.34
Chinore	48.77	116.12	87.09	52.82	125.76	94.32	54.67	130.17	97.63
Sank SwarnRekha SD No 1	46.92	111.71	83.79	50.81	120.98	90.73	52.59	125.21	93.91
Dabra	48.28	114.95	86.21	52.28	124.48	93.36	54.12	128.86	96.64
Total	231.50	551.20	413.39	250.71	596.93	447.70	259.51	617.86	463.39

Table 3. Sub-division wise Crop water requirement (C.W.R.) and gross water requirement (G.W.R.) for present cropping pattern (All values in Mm^3)

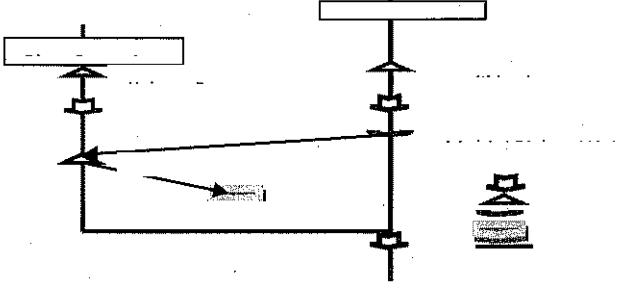
Sub-division	C.W.R.	G.W.R.		C.W.R.	G.W.R.		C.W.R.	G.W.R.	
		PCP-1	PCP-2		PCP-3	PCP-4		PCP-5	PCP-6
Harsi	40.46	96.33	72.25	45.24	107.71	80.79	47.13	112.21	84.16
Bhitawar	44.06	104.90	78.68	49.27	117.31	87.98	51.32	122.19	91.64
Chinore	47.09	112.12	84.09	52.65	125.36	94.02	54.86	130.62	97.96
Sank SwarnRekha SD No 1	45.3	107.86	80.89	50.65	120.60	90.45	52.77	125.64	94.23
Dabra	46.61	110.98	83.23	52.12	124.10	93.07	54.3	129.29	96.96
Total	223.51	532.19	399.14	249.93	595.07	446.30	260.38	619.95	464.96

Supply Assessment in Harsi Project

The Harsi project is a major irrigation project situated in Dabra Tehsil of Gwalior district of Madhya Pradesh. The Harsi command area is situated in a natural drainage system of river Parvati in the initial stage followed by Sindh River a Tributary of the Yamuna. The tail command is on the boundary of Chhachhond, a small tributary of river Sindh, whereas the river Noon passes across the command to drain excess water from most of the command area. The system also receives water from Kaketo dam, Madikheda dam and Mohini pickup weir. The water transfer system for Harsi reservoir is presented in Figure 3. The 75% dependable rainfall of study area is 659 mm and the corresponding yield as per actual observation is 250.43 Mm^3 and thus the live storage of 192.66 Mm^3 may generally be filled most of the year. The distribution of annual replenishment in Harsi reservoir from various sources can be seen in Table 4. The total available water in Harsi system may be about 427.2 Mm^3.

Demand Supply Analysis

The gross water requirement for design cropping pattern may vary from 413.39 Mm3 to 617.86 Mm^3 under variable conditions of climate, rainfall and field efficiencies. Similarly, gross water requirement for present cropping pattern may fluctuate between 399.14 and 619.95 Mm^3. From the analysis, it has been observed that the gross water requirement for design cropping in Harsi command in average rainfall years may be 596.93 Mm^3 at 70% conveyance and 60% application efficiency, which is nearly thrice the live storage capacity of reservoir and hence replenishment of water from other sources is done through transfer of water from Kaketo reservoir and Madikheda reservoir through Mohini pickup weir. The gross water requirement from present cropping pattern during dry rainfall year may reached to 619.95 Mm^3 at 70% conveyance at 60% application efficiency which can be reduced to 464.96 Mm^3 by improving the efficiencies.



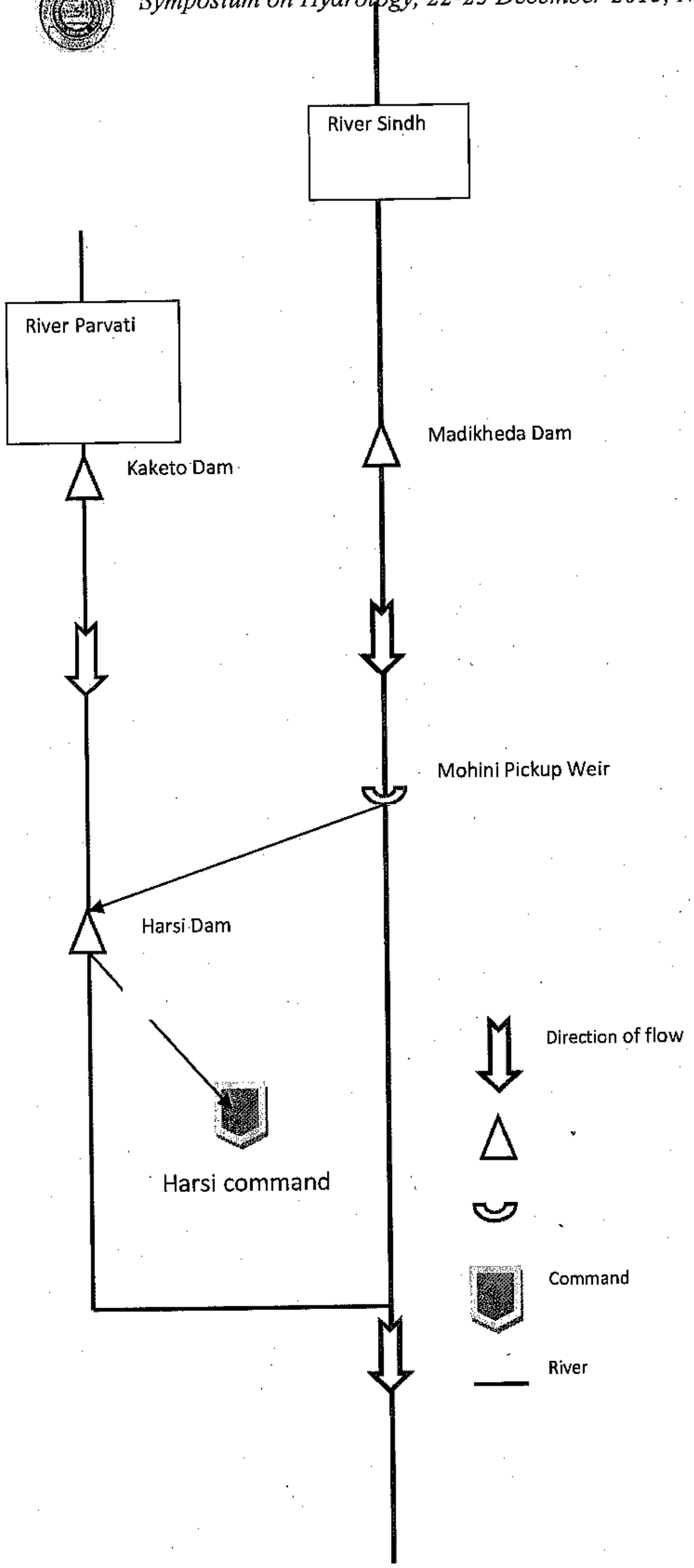


Figure 3. The water transfer system for Harsi reservoir

Table 4. Annual replenishment of water in Harsi reservoir

S.N.	Source of water to the system	Quantity
1.	**75% Dependable yield of Harsi Reservoir (Live storage)**	**192.66 Mm^3**
2.	**Deduction for seepage and evaporation (15% approx)**	**28.66 Mm^3**
3.	**Remaining usable water**	**164.00 Mm^3**
4.	From Kaketo feeder reservoir during summer	36.79 Mm^3
5.	From Mohini pick-up weir through feeder channel during Monsoon	107.07 Mm^3
6.	From Madikheda dam	199.33 Mm^3
7.	**Replenished water (Approximately 75% of sum of 4, 5 and 6)**	**263.19 Mm^3**
8.	**Total water available for irrigation (8=3+7)**	**427.19 Mm^3**

The crop water requirement for present and design cropping pattern by improving the efficiencies (80% conveyance and 70% application efficiency) is less than the available water in wet and average rainfall years and some areas can be brought under irrigation. The total demand and deficit under different scenarios are given in Table 5.

CONCLUSIONS

The scenarios based assessment of demand and supplies may be considered as an efficient tool for planning and management of irrigation in a command and operate reservoir in judicious manner and CROPWAT can play an important role. The seasonal rainfall at 20%, 50% and 80% dependability were computed as 878.08 mm, 674.90 mm and 570.68 mm and considered as wet, average and dry year rainfall respectively for Harsi command. The gross water requirement for crops grown as per design cropping pattern with 70% conveyance efficiency and 60% application efficiency may vary from 551.20 Mm3 in wet rainfall years (DCP-1) to 617.86 Mm^3 in dry rainfall years (DCP-5) respectively which can be brought to 413.39Mm^3 to 463.39 Mm^3 that can be managed through efficient reservoir operation and consumptive use. The gross water requirement for present cropping pattern under average conditions with 70% conveyance and 60% application efficiency may be about 595.07 Mm^3 (PCP-3) that can be reduced to about 446.3 Mm^3 (PCP-4) by improving efficiencies. It may be concluded that 12% and 16% more water required during dry or drought years for designed and present cropping pattern respectively that led demand deficit to 31% of total demand. Therefore, efficient planning for reservoir operation, selection of crops and consumptive use of surface and ground water should be used considering the frequent drought situation in the region. The scenarios based assessment of crop and gross water requirement for different WUAs may be helpful for management authority to plan efficient releases from Harsi reservoir under variable climate and field conditions.

Table 5. The demand-supply analysis for Harsi command (All values in Mm^3)

Cropping Pattern	Wet rainfall year		Average rainfall year		Dry rainfall year	
	70-60	80-70	70-60	80-70	70-60	80-70
Designed cropping pattern	(DCP-1)	(DCP-2)	(DCP-3)	(DCP-4)	(DCP-5)	(DCP-6)
Demand	551.20	413.39	596.93	447.7	617.86	463.39

Deficit (-)/Excess	-124.01	13.8	-169.74	-20.51	-190.67	-36.2
Present cropping pattern	(PCP-1)	(PCP-2)	(PCP-3)	(PCP-4)	(PCP-5)	(PCP-6)
Demand	532.19	399.14	595.07	446.3	619.95	464.96
Deficit (-)/Excess	-105	28.05	-167.88	-19.11	-192.76	-37.77

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