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Development of Rotational Water Allocation Plan for a Command Area of Som-Kagdar Irrigation Project

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A B S T R A C T

In the present study, diagnostic analysis of the irrigation system was done and a rotational water allocation plan on the basis of ET requirement of crops was developed for a command area. The crop water requirements for the major Rabi crops viz. wheat, gram and barley were computed by Penman-Monteith method using computer program 'CROPWAT' and these were used in the development of rotational water allocation plan. This system leads to increased credibility and reliability, enhanced equity in water distribution, proper utilization of water resources and increased water use efficiency.

Introduction

Irrigation water use is by far the largest use of water by mankind worldwide. More than 28 Billion ha of land is irrigated all over the world in various irrigation projects. Most of irrigation projects, however, have poor efficiency (30-50 %); thus, they are unable to achieve their design target. Efforts have been devoted to improve efficiency of complex hydraulic systems at different levels (physical/structural and operational /management).

George *et al.,* (2000) developed an irrigation scheduling model for performing irrigation scheduling under various management options for both single and multiple fields. Komakech *et al.,* (2011) reported that spate irrigation systems pose institutional and technical challenges: collective action is challenged by complex upstream–downstream interactions between users within the system, and the high labour demands for regular reconstruction of temporary diversion weirs and intake structures. Das *et al.,* (2015) developed a decision support system for the land and water resources allocation. Conjunctive use of 87% surface and 13% groundwater was found the most feasible. Ajai (2015) developed two management models for optimal land and water resources allocation. The models were applied in a canal command in semi-arid area of India.

Net return from the command area was increased by about 22% under optimal planning. Ajai and Sudhindra (2012) reported that poor quality groundwater can be used conjunctively with good quality canal water to fulfil crop water demand and maximize net annual returns particularly, in the arid and semi-arid regions where good quality soil and water resources are limited.

Mishra *et al.*, (2000) estimated the actual crop evapotranspiraton (ET_a) using continuous crop coefficient (K_C) function. Bhakar and Singh (2001) compared estimated ET with measured ET of wheat and green gram crops and found higher values of measured ET than estimated ET for both the crops. Jang Lin *et al.*, (2001) estimated crop water requirement by using CROPWAT model for different crops as paddy, spring and autumn corns, sorghum and soybean. Mishra *et al.*, (2002) presented the alternative delivery scheduling approaches intended to overcome the problem of low efficiency in Indian irrigation projects. Bhakar and Singh (2003) estimated reference evapotranspiration under sub-humid climatic conditions of Rajasthan. Hargreaves and Allen (2003) described a brief history of development of the 1985 Hargreaves equation and its comparison to evapotranspiration predicted by FAO Penman- Monteith method. Dobaria (2005) studied that rotational water supply system leads to increased credibility and reliability, enhanced equity in water distribution, proper utilization of water resources and increased water use efficiency.

Materials and Methods

Study area

The Som-Kagdar irrigation project is operational since 1983 on Som River, which is a tributary of Mahi River. The Som River originates from the village Som of tehsil kherwara in Udaipur district of Southern Rajasthan, India. Most of the command area consists of hilly track. Ground water is available at an average depth of 15 m from the land surface. The area receives annual rainfall of 599 mm. The soil in the command area is clay loam and is suitable for cultivation of most of the crops. The distribution system of Som-Kagdar irrigation project consists of two main canals: Right main canal and left main canal, both covers a length of 12.31 km and 29.96 km respectively. The Gross command area, culturable command area and irrigated command area under the project was 9125 ha, 5731 ha and 4550 ha respectively.

Method of calculation of crop water requirements

Crop water requirement for seasonal crops grown in study area were determined by using 'CROPWAT' software based on Penman-Monteith equation. For this purpose, the mean monthly values of climatological parameters were collected from nearest meteorological observatory, CTAE, Udaipur, (Raj.).

Crop stage wise crop-coefficients were selected with the help of FAO-56. Net water requirement was determined for wheat and gram crops by using decade wise (10 days) values of ET_0.

The average daily crop evapotranspiration (ET_{crop}) was determined by:

$$ET_{crop} = K_c . ET_0 \quad \text{.........................(1)}$$

Irrigation requirement is determined by

$$IR_{Req} = ET_{crop} - P_{eff} \quad \text{.........................(2)}$$

Where,

ET_{crop} = Crop evapotranspiration,
K_c = Crop coefficient,

ET_0 = Reference evapotranspiration,
IR_{Req} = Irrigation requirement,
P_{eff} = Effective rainfall

The seasonal irrigation requirement of the crop was then multiplied with the cropped area in order to obtain the total demand for commands. The rotational water supply is thus designed to ensure timely, adequate and equitable distribution of water. It will eliminate all drawbacks of traditional irrigation system. It would facilitate application of water to an individual farm which is efficient and can be well managed by farmers.

Development of a rotational water allocation plan

Preparation of Rotational Water Allocation was made on the basis of ET requirements for one rotation on selected outlet on the minor.

Roster of turns

When water is delivered in the watercourse, it requires some time to reach up to each delivery point (called Nakka). This time of filling is called Bharai. Similarly it requires some time to empty through each delivery point, this time of emptying is called Jharai.

Total time of each farmer (hours)

= Calculate time to satisfy FIR with fixed supply of water + his Bharai - his Jharai...(3)

(Bharai is zero for all farmers except the last).

ET demand in each rotation varies as per the growth of the crop. Hence in each rotation ET requirement will be different. To satisfy the ET requirement in each rotation with fixed supply, time of supply will vary from rotation to rotation. Time to satisfy Field Irrigation Requirement with fixed supply of water and then correction factor to time was worked out to compensate for losses in the field channel.

Results and Discussion

Reference evapotranspiration

The output of the software was the monthly ET_0 values which are presented in table 1. It can be seen from the table that values of ET_0 were higher during the months of May and June (7.4 and 6.8 respectively) which is justified by the higher maximum and minimum temperatures, relative humidity, more windy conditions and more number of sun shine hours during the day.

Net irrigation requirement

Effective rainfall was calculated by USDA Soil Conservation Service method using CROPWAT software. As the effective rainfall was less than 2.0 mm in the months of January, February and November, the values were not considered for the calculation purpose.

$P_{eff} = P_{tot} (125 - 0.2 P_{tot}) / 125$
for $P_{tot} < 250$ mm and
$P_{eff} = 125 + 0.1 P_{tot}$
for $P_{tot} > 250$ mm

The output of the software was irrigation requirements in mm/day as well as in mm/dec. during whole crop season.

Tables 2, 3 and 4 presents the calculation of crop evapotranspiration and irrigation requirement for wheat, Gram and barley respectively. The total irrigation requirement for wheat, Gram and barley crop is found to be 333.9 mm, 218.5 mm and 299.9 mm respectively.

The limitation of this model is that it gives irrigation requirement in mm/dec only. Therefore, fortnightly (14 days) crop water requirement is calculated for Rabi crops by using extrapolation method and given in table 5 and shown in figures 1, 2 and 3 respectively.

Total growing period for wheat, gram and barley is 130, 100 and 120 days respectively in the command area. Therefore, the last fortnight for wheat, gram and barley crops includes only 4, 2 and 8 days respectively.

Amarpura minor was selected for developing the rotational water allocation plan. Out of 15 outlets on Amarpura minor, rotational plan was developed for outlet No. 4 of 20 cm width and 20 cm flow depth for which discharge on head was 0.009 cumec. Conveyance efficiency of this water course was calculated as 73 percent per km. Wheat and gram crops were grown in the command of selected outlet. Rotation is done from tail to head of this outlet. On the basis of water distribution system, whole cropped area is divided in 11 groups for rotation and group numbering is done from tail to head.

Calculations were done for 2nd, 5th and 8th fortnight irrigations representing starting, middle and end of growing period to develop rotational water allocation plan for the area. It becomes clear from tables 6, 7 and 8 that this outlet will be run for 5th –8th December during 2nd fortnight, 17th – 28th January during 5th fortnight and 1st – 14th March during 8th fortnight. In this way all farmers even on tail end are getting their fair share in proportional to land holding.

Table.1 Reference evapotranspiration ET0 according to Penman-Monteith method

Month	Max. Temp. ^{0}C	Min. Temp. ^{0}C	RH %	Wind km/day	Sunshine hours	Solar Radiation MJ/m^2/day	ET$_0$-Penman mm/day
January	23.6	5.6	59	74	9.1	16.3	2.4
February	25.9	7.3	52	86	9.6	19.2	3.2
March	31.4	12.8	39	112	9.8	22.2	4.6
April	35.8	18.9	31	147	10.2	24.6	6.3
May	37.8	24.1	35	183	10.3	25.5	7.4
June	35.8	25.4	54	214	8.3	22.5	6.8
July	30.7	24	75	181	4.6	16.9	4.4
August	29.5	22.9	79	126	4.5	16.2	3.8
September	30.7	20.9	69	102	7.7	19.7	4.3
October	32.4	15.5	53	78	9.3	19.6	4
November	28.7	10.4	54	78	9.1	16.8	3.1
December	25	6.5	58	67	8.9	15.4	2.4
Year	**30.6**	**16.2**	**55**	**121**	**8.5**	**19.6**	**1605**

Table.2 Crop evapotranspiration and irrigation requirements for wheat
(Planting date: 20 November)

Month	**Dec**	**Stage**	**Coeff K_c**	**ETcrop mm/dec**	**IR Req. mm/day**	**IR Req. mm/dec**
November	3	Init.	0.3	8.6	0.85	8.5
December	1	Init.	0.3	7.9	0.79	7.9
December	2	Deve.	0.41	9.8	0.98	9.8
December	3	Deve.	0.62	14.9	1.49	14.9
January	1	Deve.	0.83	20.1	2	20
January	2	Deve.	1.04	25.3	2.52	25.2
January	3	Mid.	1.15	30.8	3.06	30.6
February	1	Mid.	1.15	33.8	3.35	33.5
February	2	Mid.	1.15	36.8	3.64	36.4
February	3	Mid.	1.15	42.2	4.2	42
March	1	Late	1.03	42.5	4.24	42.4
March	2	Late	0.78	35.8	3.58	35.8
March	3	Late	0.53	27.1	2.69	26.9
TOTAL	**13**			**335.8**		**333.9**

Table.3 Crop evapotranspiration and irrigation requirements for gram
(Planting date: 25 November)

Month	**Dec**	**Stage**	**Kc**	**ETcrop mm/dec**	**IR Req. mm/day**	**IR Req. mm/dec**
November	3	Init.	0.4	5.8	1.14	5.7
December	1	Init.	0.4	10.6	1.05	10.5
December	2	Init./Deve	0.45	10.9	1.09	10.9
December	3	Deve.	0.62	14.9	1.49	14.9
January	1	Deve.	0.83	20.1	2.01	20.1
January	2	Deve/Mid	1	24.1	2.4	24
January	3	Mid	1.05	28.1	2.8	28
February	1	Mid	1.05	30.9	3.06	30.6
February	2	Mid/Late	0.99	31.8	3.14	31.4
February	3	Late	0.83	30.3	3	30
March	1	Late	0.6	12.4	2.47	12.4
TOTAL	**11**			**219.9**		**218.5**

Table.4 Crop evapotranspiration and irrigation requirements for barley
(Planting date: 23 November)

Month	Dec	Stage	Kc	ETcrop	IR Req.	IR Req.
November	3	Init	0.3	6	0.85	5.9
December	1	In/Dev	0.33	8.8	0.88	8.8
December	2	Deve	0.54	13	1.3	13
December	3	Deve	0.88	21.2	2.12	21.2
January	1	Dev/mid	1.1	26.6	2.65	26.5
January	2	Mid	1.15	27.8	2.78	27.8
January	3	Mid	1.15	30.8	3.06	30.6
February	1	Mid	1.15	33.8	3.35	33.5
February	2	Mid	1.15	36.8	3.64	36.4
February	3	Mid/Late	1.05	38.4	3.81	38.1
March	1	Late	0.79	32.8	3.26	32.6
March	2	Late	0.49	22.6	2.26	22.6
March	3	Late	0.19	2.9	0.96	2.9
TOTA L	**13**			**301.6**		**299.9**

Table.5 Fortnightly irrigation requirements of Rabi crops (mm)

S. No.	Fortnight	Wheat	Gram	Barley
1	1st	11.66	15.15	12.11
2	2nd	12.54	16.42	17.76
3	3rd	20.85	24.50	32.33
4	4th	31.12	32.83	38.72
5	5th	40.68	40.55	46.78
6	6th	48.06	43.56	48.72
7	7th	55.44	40.55	51.90
8	8th	57.95	4.94	39.64
9	9th	44.78	-	11.94
10	10th	10.76	-	-
Total		333.9	218.5	299.9

Table.6 Rotational water allocation plan for 2nd fortnight irrigation

Sr. No.	Survey No.	Group No.	Distance from Outlet (m)	Demand		NIR for 14 days (mm/ha)	Total NIR (ha-mm)	FIR (ha-mm)	Time (min)	Bharai (min)	Jharai (min)	C.F.	Corrected time (hr-min)	Supply (hr-min)	
				Crop	Area (ha)									From	To
1	1933	1	1600	Wheat Gram	0.84 0.12	13 16	13	19	356	120	-	1.67	13:10	Mon 10:00	Mon 23:10
2	1950	2	1550	Wheat	0.72	13	9	13	248	-	4	1.63	6:35	Mon 23:10	Tue 5:45
3	1966	3	1300	Wheat	0.96	13	12	18	330	-	11	1.48	7:50	Tue 5:45	Tue 13:35
4	2035	4	1250	Wheat	0.85	13	11	16	293	-	4	1.45	6:55	Tue 13:35	Tue 20:30
5	2004	5	1000	Wheat	0.82	13	11	15	282	-	19	1.33	5:50	Tue 20:30	Wed 2:20
6	1980	6	8000	Wheat Gram	1.34 0.12	13 16	19	28	509	-	15	1.25	10:10	Wed 2:20	Wed 12:30
7	1991	7	650	Wheat Gram	0.78 0.24	13 16	14	20	370	-	11	1.19	17:10	Wed 12:30	Thu 5:40
8	1985	8	300	Wheat Gram	1.21 0.32	13 16	21	30	555	-	26	1.08	9:35	Thu 5:40	Thu 15:15
9	2000	9	250	Wheat	1.34	13	17	24	450	-	4	1.06	7:50	Thu 15:15	Thu 23:05
10	1955	10	200	Wheat	0.48	13	6	9	159	-	4	1.05	2:45	Thu 23:05	Fri 1:50
11	1114	11	50	Wheat Gram	1.77 0.24	13 16	27	38	713	-	11	1.01	11:50	Fri 1:50	Fri 13:40

Table.7 Rotational water allocation plan 5th fortnight irrigation

Sr. No.	Survey No.	Group No.	Distance from Outlet (m)	Demand		NIR for 14 days (mm/ha)	Total NIR (ha-mm)	FIR (ha-mm)	Time (min)	Bharai (min)	Jharai (min)	C.F.	Corrected time (hr-min)	Supply (hr-min)	
				Crop	Area (ha)									From	To
1	1933	1	1600	Wheat Gram	0.84 0.12	41 40	42	56	1000	120	-	1.67	31:10	Mon 10:00	Tue 17:10
2	1950	2	1550	Wheat	0.72	41	19	41	759	-	4	1.63	20:30	Tue 17:10	Wed 13:40
3	1966	3	1300	Wheat	0.96	41	38	55	1018	-	11	1.48	24:50	Wed 13:40	Thu 14:30
4	2035	4	1250	Wheat	0.85	41	34	49	907	-	4	1.45	21:50	Thu 14:30	Fri 12:20
5	2004	5	1000	Wheat	0.82	41	34	50	926	-	19	1.33	20:50	Fri 12:20	Sat 9:10
6	1980	6	8000	Wheat Gram	1.34 0.12	41 40	55	73	1352	-	15	1.25	27:50	Sat 9:10	Sun 13:00
7	1991	7	650	Wheat Gram	0.78 0.24	41 40	39	58	1074	-	11	1.19	21:00	Sun 13:00	Man 9:00
8	1985	8	300	Wheat Gram	1.21 0.32	41 40	62	88	1611	-	26	1.08	28:30	Man 9:00	Tue 13:30
9	2000	9	250	Wheat	1.34	41	51	73	1352	-	4	1.06	23:50	Tue 13:30	Wed 13:20
10	1955	10	200	Wheat	0.48	41	70	28	518	-	4	1.05	8:55	Wed 13:20	Wed 22:15
11	1114	11	50	Wheat Gram	1.77 0.24	41 40	89	56	1518	-	11	1.01	25:20	Wed 22:15	Fri 1:35

Table.8 Rotational water allocation plan 8th fortnight irrigation

Sr. No.	Survey No.	Group No.	Distance from Outlet (m)	Demand		NIR for 14 days (mm/ha)	Total NIR (ha-mm)	FIR (ha-mm)	Time (min)	Bharai (min)	Jharai (min)	C.F.	Corrected time (hr-min)	Supply (hr-min)	
				Crop	Area (ha)									From	To
1	1933	1	1600	Wheat Gram	0.84 0.12	58	48	68	1260	120	-	1.67	38:25	Mon 10:00	Wed 00:25
2	1950	2	1550	Wheat	0.72	58	41	59	1093	-	4	1.63	29:35	Wed 00:25	Thu 6:00
3	1966	3	1300	Wheat	0.96	58	55	71	1315	-	11	1.48	32:10	Thu 6:00	Fri 14:10
4	2035	4	1250	Wheat	0.85	58	49	70	1296	-	4	1.45	31:15	Fri 14:10	Sat 21:25
5	2004	5	1000	Wheat	0.82	58	49	70	1296	-	19	1.33	28:20	Sat 21:25	Mon 00:45
6	1980	6	8000	Wheat Gram	1.34 0.12	58	72	103	1907	-	15	1.25	39:35	Mon 00:45	Tue 16:20
7	1991	7	650	Wheat Gram	0.78 0.24	58	45	64	1185	-	11	1.19	23:15	Tue 16:20	Wed 15:35
8	1985	8	300	Wheat Gram	1.21 0.32	58	70	101	1870	-	26	1.08	33:10	Wed 15:35	Fri 00:45
9	2000	9	250	Wheat	1.34	58	72	103	1907	-	4	1.06	33:35	Fri 00:45	Sat 10:20
10	1955	10	200	Wheat	0.48	58	24	35	648	-	4	1.05	11:15	Sat 10:20	Sat 21:35
11	1114	11	50	Wheat Gram	1.77 0.24	58	68	97	1796	-	11	1.01	30:00	Sat 21:35	Mon 3:35

In conclusion, the limited supplies of canal water and scanty rainfall have forced reservoir managers and farmers to decide on an irrigation schedule and optimum for each crop soil condition so as to maximize profit. This particular study is aimed at helping both reservoir managers and farmers in decision-making. Existing irrigation status of this outlet was very low. Tail enders were facing with the problem of unavailability of sufficient irrigation water. A comparison of this schedule was done with the existing irrigation schedule of Amarpura minor during current year and concluded that there is necessity to improve irrigation scheduling of Amarpura minor according to given plan. The methods for water distribution, as applied under the former large-scale collective farming system, have become irrelevant, leading to much chaos, inequity and unreliability in water supply to farmers.

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