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Development of Crop Water Demand Based Water Delivery Schedule for a Canal Command

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ABSTRACT

Crop water demand-based canal water delivery schedule was developed using geospatial tools and CROPWAT model for the *Jhajjar* distributary of Western Yamuna Canal Command in Haryana, India. The geospatial database of different soil, water and crop parameters in the command area were developed and analyzed using the Geographic Information System (GIS) tool. Further, the geospatial data were used to work out the irrigation schedule of different crops using CROPWAT model. It was observed from the analysis that the gross irrigation water requirement of wheat was 363.4 mm and that of rice was 1386 mm with effective rainfall depths of 55.8 and 461.8 mm during the wheat (*rabi*) and rice (*kharif*) growing seasons, respectively. The crop water demand driven protocol developed in this study estimated that about 25.5% of area under the Jhajjar distributary could be supplied with adequate irrigation, considering the operational canal release roster of the distributary. Nontheless, it could be recommended to modify the existing roster as per the crop water demand estimates, or use of ground water resource in area of deficit canal supply to match the crop water demand in the entire canal command.

Canal irrigation is the second largest source of irrigation in India, which covers about 26% (16.7 Mha) of 63.3 Mha net irrigated area, followed by tubewell irrigated area of 39Mha (Anon., 2010). Considering the rapid decline of groundwater due to over exploitation, canal irrigation will play a major role in enhancing agricultural production in the command area. However, surface water development through reservoirs and canals will not reduce the demand for ground water unless it can meet the requirement for "*just-in-time*" water supply without discriminating against tail-end users (Ackermann, 2012).

Most of the major irrigation commands in India suffer from the problems of inadequate and unreliable water supply, often causing wide gaps between irrigation potential created and utilized (Rao and Rajput, 2009). Singh *et al.* (2010) reported that improper irrigation water management would make the rice–wheat cropping system of Haryana unsustainable with dwindling quantity and deteriorating quality of the ground water resources in the region. Currently, water allocation to the irrigated farms in the Northern India is based on *warabandi* system, in which every farmer is supposed to get equal number of rotational water supplies during a given period of time per unit of land. Water distribution is based on the size of the land holding and not on the type of crop grown in the area (Shah, 2003). It was observed that the *warabandi* system designed to minimize the inequity in the water available at the head and at the tail reaches of the canal command could not fulfill this objective (Jurriens *et al.,* 1996). Santhi and Punderikanthan (2000) developed a multi-criteria approach for scheduling the rotational distribution (LBMC) of the *Sathanur* Irrigation Project in the State of Tamil Nadu in India. The results indicated that the performance of the water distribution system was better with the present model as compared to the conventional rostering procedure adopted in the region. The concept can be extended to any level of rotational distribution, starting from main canal down to farm outlets.

Geographical information system (GIS) has a great potential as a tool for developing efficient irrigation schedule and improve the irrigation water management, besides its many other applications. Salmah *et al.* (1994) had highlighted the advantages of data acquisition, synthesis and analysis of soil, plant and water related information of canal command within the GIS environment for efficient water management. Ray and Dhawal (2001) used satellite-based remote sensing (RS) data and GIS tools to estimate the seasonal crop evapotranspiration in *Mahi* Right Bank Canal (MRBC) command area of Gujarat, India. Crop coefficients (K_c) for various crops grown in MRBC region were estimated from the RS derived soil-adjusted vegetation index (SAVI) values. A reference crop evapotranspiration (ET_0) map was generated using the point meteorological observations. Further, the K_c and ET_0 maps were combined to generate seasonal crop evapotranspiration (ET_{crop}) map for scheduling of irrigation. Rowshon *et al*. (2003) developed an interface in MapBasic programming language using GIS for the spatial and temporal distribution of irrigation supply for a large scale rice irrigation project in Malaysia.The developed GIS-user interface enabled visualization of discharge in a rice irrigation scheme taking into account the spatial and temporal variability. Fortes *et al.*(2005) developed a GIS-based conceptual non-distributed water balance model to support improved irrigation scheduling in the *Syr Darya* basin, Uzbekistan. The irrigation requirements were optimized, and the comparative analysis of irrigation scheduling scenarios showed the capabilities of the model to support the selection of water saving alternatives.Yarahamdi (2003) estimated water balance in irrigated area in *Salmas* and *Tasoj* region of Iran by using remote sensing analysis of satellite images, GIS and CROPWAT model. It was observed that the water balance in *Tasoj* region had a negative trend with increased difference of water demand and water availability in the region. Rao *et al.* (2004) used GIS to dynamically link a Decision Support System (DSS) with irrigation water requirement model for real time estimation of water demands for *Guvvalagudem* major distributary of the *Nagarjunasagar* Left Canal, Andhra Pradesh, India. The system allowed interactive selection of distributaries and the real time estimation of water demands in each distributary over the entire canal network. For real time estimates, the model used the real time weather data, weather forecasts and distributary level information of different crops and soil of the region. George *et al*. (2004) developed a GIS integrated irrigation scheduling model for rice using a daily water balance approach. The model was tested by comparing daily simulated and measured water depths for *kharif* (monsoon) 1999 and *rabi* (dry) 2000 seasons for the outlet No.5l (commanding 12.2 ha) of the *Tarafeni* South main canal in the *Kangsabati* irrigation project, West Bengal, India. Model prediction results showed that there was a mismatch between demand and supply, and the water deficiency arose during *rabi* season. Kuo *et al.* (2006) carried out field experiments at the Hsuehchia experimental station, Taiwan from 1993 to 2001 to calculate the reference and actual crop evapotranspiration, derived the crop coefficient and collected required input data for the CROPWAT model. They estimated irrigation water requirements of paddy and upland crops at the *Chianan* irrigation command, Taiwan. Raidu and Giridhar (2011) created a geospatial database of canal command area of *Wazirabad* canal command area of Hyderabad, India, to compute water demands for consolidated land parcel units under each distributary and up to the minor canal. Al-Nazer (2011) used CROPWAT model to estimate the crop water requirements of different crops in the Gaza strip, Israel. Further, the spatio-temporal variability map of crop water requirement were generated in GIS and disseminated to farmers for determination of irrigation needs based on crop type and the geographical location.

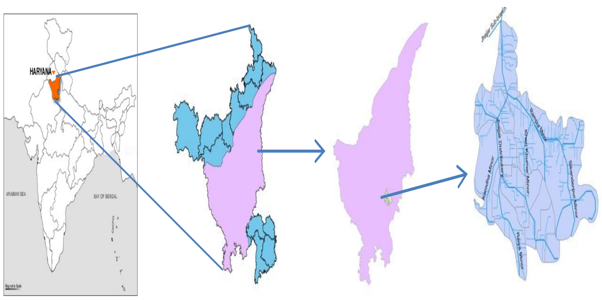
Keeping the above information in view, a study was undertaken to develop water supply schedule of *Jhajjar* distributary of Western Yamuna Canal Command (WYCC) based on the crop water requirement using geospatial tools and CROPWAT model. Geospatial tools *viz.* remote sensing, GIS and GPS were used to acquire and analyze the information about land use, soil type and canal network with quantity of water released by different off-take points in the command area and develop the crop water demand-based water delivery schedule to the farmers' fields through different off-take points. The basic objective of this study was to develop the crop water demand-based canal water roster for prevention of the problems of waterlogging and soil salinization, besides enhancing the water productivity in the command area. Thus, the surplus water supplied by the canal exceeding the crop water requirement could be made available to the tail end farmers of the command area, which generally receive less amount of canal water.

MATERIALS AND METHODS

Description of Study Area

The present study was undertaken in the *Jhajjar* distributary of the Western Yamuna Canal Command (WYCC). The location map of the study area with canal network is shown in Fig.1. The selected *Jhajjar* distributary is located at the tail end segment of the

WYCC, which lies between 28^0 33’ 37.6” to 28^0 43’ 24.4” North latitudes and 76^0 32’ 44.5” to 76^0 43’ 43.6” East longitudes. The gross area commanded by the distributary is about 7766 ha. The general topology of the area is flat with undulating terrain having maximum and minimum elevation of 222 m and 212 m above mean sea level (msl), respectively. The head segment of the distributary has a saucer-shaped depression, which causes the problem of waterlogging and subsequent soil salinization. The region falls under semi-arid climate with an average annual rainfall of 750 mm. The soils are mainly sandy and sandy loam in texture. The temperature varies from a minimum of 7 ^{0}C during the month of January, to a maximum of 39 ^{0}C during the month of May.



India Haryana WYCC Jhajjar Distributary

Fig.1: Location map of the study area

Relevant climatic data of the study area for a period of 25 years (from 1987 to 2011) were used for irrigation scheduling of rice and wheat using CROPWAT. The WYCC was designed for supply of water to canals from barrage system; and often suffers from inflexibility, shortage and uncertainty of canal water supply depending on the flow of the river Yamuna. The tail end of the Jhajjar canal command area commanded by the WYCC faces problems of gap in demand and supply, soil salinization and waterlogging, deterioration of groundwater quality, poor maintenance of irrigation and drainage infrastructure, diversion of irrigation water to other sectors as well as poor socio-economic conditions of farmers.

Data Acquisition

The data required to undertake the analyses was acquired from different sources. The canal roster was acquired from Jhajjar Water Service Division, Jhajjar, Haryana. Geopstial data base of soil texture was prepared using the soil map of NBSS&LUP in the scale of 1:500,000. Survey of India (SOI) toposheetes were used to delineate the canal network in the selected the *Jhajjar* distribitray of WYCC. Land use and land cover map was generated using remote sensing image in the scale of 1:250,000 acquired from the National Remote Sensing Agency (NRSA), Hyderabad. Climatic data was extracted from the FAO CLIMWAT software, and used in CROPWAT for irrigation scheduling of rice and wheat crops.

Generation of geo-spatial database of *Jhajjar* distributary

The acquired data were converted to geospatial data base format using the GIS software ArcGIS 10.0 version (ESRI, 2011) and remote sensing image analysis software ERDAS Imagine 10.0 version software (Erdas imagine, 2010).

CROPWAT model was used for estimation of irrigation requirement for rice and wheat. The generated point, line and polygon feature classes of the command area provided the information pertaining to the area and perimeter of different cropped fields in the command, length of different canals and location of off-take points in the distributary. Further, the remote sensing images of LISS III and LISS IV sensors of IRS satellite were used to generate the land use and land cover map of the study area.

The soil map in GIS format was prepared using the analog map sheet of National Bureau of Soil Survey and Land Use Planning (NBSS&LUP). The digitized data were analyzed to identify the spatial distribution of the soil types of the region. The soil textural classes in the region provided the information on the soil moisture characteristics of the study area. The GPS was used to collect the location information of different feature classes besides ground truthing to corroborate the real field information acquired using the GIS and RS software analyzed data.

The information of canal network, crop type, soil type along with meteorological and irrigation water release schedule were used in CROPWAT to estimate the crop evapotranspiration and the irrigation requirement of rice and wheat crops grown in the region. Subsequently, considering the conveyance efficiency in the water courses, the water demand at different off-take points in the canal network were estimated and the water release schedule was prepared using CROPWAT model. This developed crop-based water release schedule was then compared with the operational canal roster in the study area for demand-supply analysis. Besides this, the rice-wheat cropped regions of the canal command receiving canal irrigation less than the estimated crop water demand was delineated, and the quantity of ground water required to fill the gap was also estimated. The methodology for computation of crop water demand-based canal water release schedule is presented in form of a flow chart (Fig. 2).

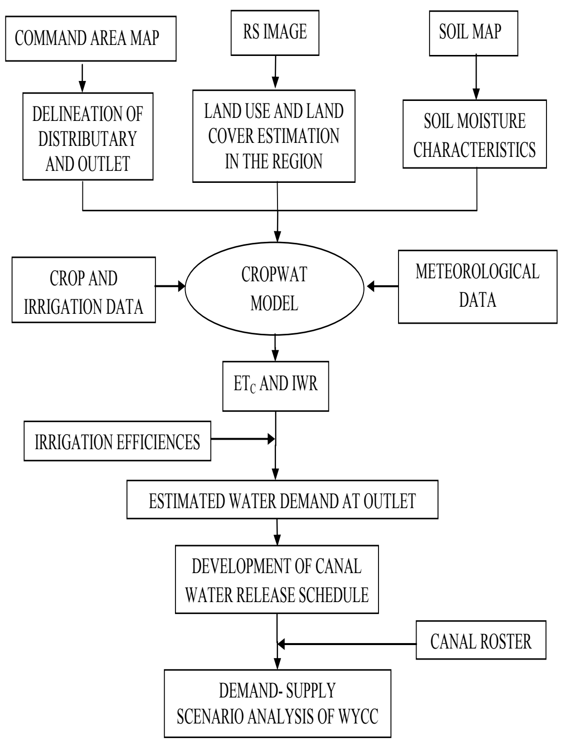


Fig. 2: Flow chart for development of crop water demand based water delivery schedule

Irrigation Scheduling and Total Water Requirement of Rice and Wheat Crops

The crop water requirement varies according to the climatic parameters, crop type and its variety, stages of crop growth and soil type in the command. Moreover, there exists a large spatial variation of these parameters in the canal command. Therefore, all these parameters need to be considered to generate a roster of canal water release schedule based on the crop water requirement of different crops grown, including the conveyance losses. The meteorological data of the region and the crop types were used in the CROPWAT ver. 8.0 (Smith, 2006) to estimate the crop evapotranspiration and subsequent irrigation requirement of crops and the total number of irrigations during the crop growth period.

Calculations of the crop water demand and irrigation requirements in CROPWAT were carried out using the climatic, crop and soil data. Reference crop evapotranspiration (ET_0) values were estimated using the FAO Penman-Monteith equation based on daily climatic data (*viz.* minimum and maximum air temperature, relative humidity, sunshine hours, solar radiation and wind speed, etc.), rainfall data and crop growth parameters (*viz.* planting date, crop coefficients, growth stages, root depth, critical depletion fraction, etc.). Irrigation water requirement was estimated from the daily water balance in the crop root zone and the effective rainfall depth using CROPWAT 8.0 model.

Calculation of the total irrigation requirement of puddled rice is different from that of other field crops due to requirement of irrigation water to meet evaporation losses and also to compensate for the percolation losses in the puddled fields under conventional method of rice cultivation. Moreover, prior to transplanting, substantial irrigation water is required for the land preparation and raising the nursery. Therefore, the input data requirement for irrigation water requirement of rice crop in CROPWAT was different than other crops. Moroever, for irrigation scheduling the soil texture, total available soil moisture, initial soil moisture depletion and percentage of total available moisture were considered.

For wheat cultivation, the criterion used for irrigation scheduling was that the irrigation starts when moisture level in the soil reduces to 50% of available moisture and continues until soil moisture attains the field capacity. In case of rice, irrigation scheduling criteria was that the irrigation starts when standing water dissappers and continues till it reaches 50 mm. After entering all input data in appropriate file format of CROPWAT model, the irrigation schedule and the crop water requirement for rice and wheat were estimated.

Development of crop water demand-based water delivery schedule

In order to prepare the water delivery schedule of the distributary, a reverse estimation procedure was adopted. In this method, the estimation of irrigation water supply was carried out based on the crop water demand at field level and accounted upto the canal off-take point. Total volume of water to be released was estimated by using the irrigation scheduling depths estimated by CROPWAT for rice and wheat, the cropped area and conveyance losses. Computation of total volume of irrigation water and its depth was carried out for rice and wheat crops besides the conveyance losses encountered during distribution of water to farmers fields. The conveyance loss was estimated based on the wetted area of the channels, which was obtained by multiplication of the length and wetted perimeter of channels. Further, a standard value of 0.00526 $m^3.s^{-1}$ per million square metre of wetted area was used to estimate the conveyance loss in the distributary (Anon., 2011). Further, the data of canal discharge was entered in the attribute table pertaining to different off-take points of the distributary. Generated data base in GIS format was used for acquiring information about the crop grown in the command area, the irrigation water requirement, the losses in the field channels and the estimated crop based water supply at different off-take points using the irrigation scheduling information obtained from CROPWAT.

Comparison of existing schedule with crop water demand-based schedule

The crop water demand-based rostering for release of water at different off-take points of the distributary was obtained using the canal irrigation network, crops grown, and soil and climatic parameters. Also, the area commanded by each off-take point was delineated. Different off-take points as identified by the *Jhajjar* water services Division consisted of a number of outlets, Table 1. The developed roster based on crop water demand-based analysis was compared with the operational roster of *Jhajjar* water service Division. The difference in the demand and supply as per the estimate was also prepared, and linked with the point attribute feature class data base of GIS pertaining to different off-take points of the distributary. Further, using the attribute quarry module of the ArcGIS, the areas for which the water supply was less than the demand were identified. Moreover, to overcome the deficit of irrigation water in these identified regions in the canal command, the quantity of ground water and its contribution in percentage of the total water requirement for rice and wheat crops on monthly basis were estimated for different off-take points of the distributary.

RESULTS AND DISCUSSION

Generation of Geospatial Database of the Distributary

The canal network map of *Jhajjar* distributary, consisting of six minor canals *viz. Baghpur*, *Rampur*, *Karodha, Raiya, Kheri Khumar* and *Sikanderpur*are is presented in Fig. 3. The geospatial data base of the canal network provided the information about the location in latitude and longitude of the off-take points, the length of the water courses commanded by each off-take point, total length of the canal network and the area commanded by the entire distributary. Soil texture map of the study region is shown in Fig. 4, and the network of the distributary with minor canals having delineated

Table 1. Different off-take points in the canal network and number of outlets under these points

Sl. No.	Off-take point	Number of outlets
1	Point A	4
2	Point B	5
3	Point C	10
4	Point D	13
5	Point E	19
6	Point F	12
7	Point G	15
8	Point H	7
9	Point I	3
10	Point J	4
11	Point K	3
12	Point L	4

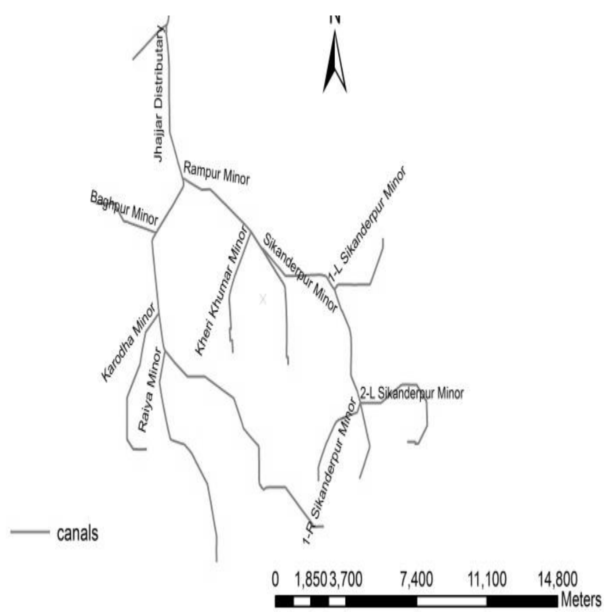


Fig. 3: Selected *Jhajjar* distributary along with its minors

area is presented in Fig. 5. It was observed from the Fig. 5 that the total length of the minor canals was 60.8 km. It was observed from the Fig. 4 that there was a predominance of sandy and sandy loam soil covering 5,943 ha and 1,823 ha area of the canal command, respectively. Similarly, the land use and land cover map generated using RS image analysis revealed coverage of about 5,600 ha area under rice-wheat cropping system. The command area comprising of 12 off-take points from A to L in the distributary is shown in Fig. 6.

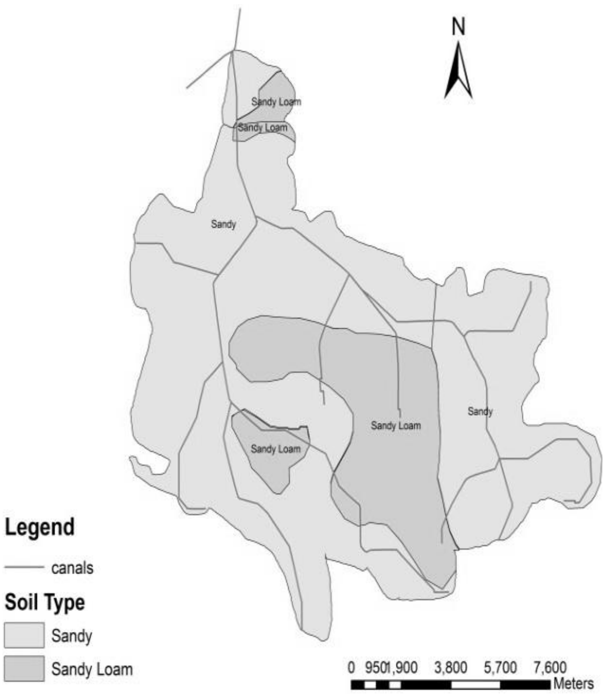


Fig. 4: Soil texture map of the command area

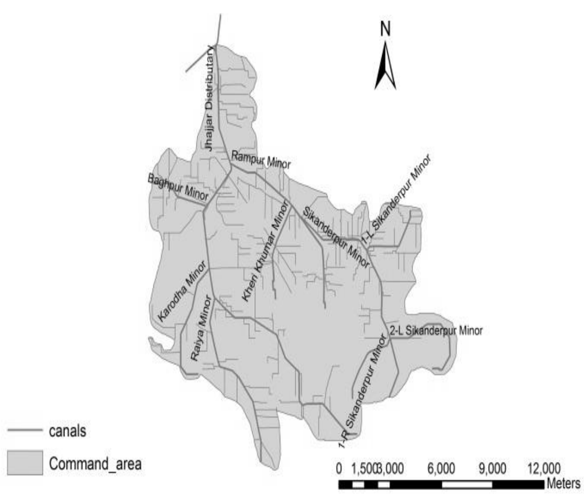


Fig. 5: Area commanded by the distributary with different minor canals

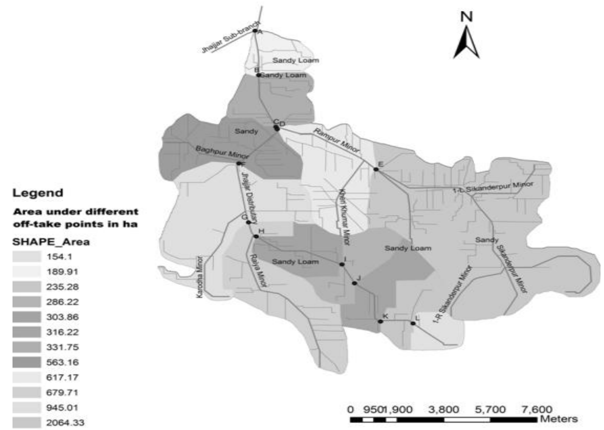


Fig. 6: Delineated area commanded by different off-take points

Irrigation Water Requirement and Scheduling of Rice and Wheat

The depth of irrigation and its date of application, crop evapotranspiration and effective rainfall for rice and wheat is shown in Table 2 and 3, respectively. The effective rainfall for rice and wheat were 461.8 and 55.8 mm, respectively. The net irrigation water requirement for rice was 969.6 mm, and for wheat it was 254.6 mm. The gross irrigation water was estimated by considering the application efficiency of 70% in the command area (Pakhale *et al.*, 2010). The gross irrigation requirement of rice and wheat for different growth stages and days after sowing (DAS) was estimated and presented in Table 4 and Table 5, respectively. It was observed that 17 irrigations were scheduled for rice and 4 for wheat, with gross irrigation water requirement of 1386 mm and 363.4 mm, respectively.

Development of Crop Water Demand-based Water Delivery Schedule

The operational schedule of the distributary and the discharge rate of 12 off-take points (from A to L) for different months are presented in Table 6. Rice crop was grown for a period from last week of June to last week of October during *kharif* season every year because of the fixed rostering of canal supply in the distributary. Similarly, wheat crop is grown each year between 3rd week of November and last week of March in next year during the *rabi* season. During the estimation of crop water demand, the dates of sowing adopted by farmers of the region were considered, which were based on the canal roster of that region.

It was observed from Table 6 that the discharge rate

Table 2. Irrigation requirement of rice crop at *Jhajjar*

Month	Ten-day period	Kc value#	ETc, mm.day^{-1}	ETc, mm.ten-day^{-1}	Effective rain, mm.ten-day^{-1}	Irrigation requirement, mm.ten-day^{-1}
June	1	1.2	0.94	4.7	7.3	0.00
June	2	1.06	7.97	79.7	18.1	161.61
June	3	1.06	7.08	70.8	28.0	189.05
July	1	1.05	5.92	59.2	41.2	71.03
July	2	1.05	5.01	50.1	51.6	71.03
July	3	1.07	5.01	55.1	51.1	29.00
August	1	1.11	5.07	50.7	51.1	43.5
August	2	1.15	5.01	50.1	52.7	41.5
August	3	1.16	5.32	58.5	46.3	42.2
September	1	1.16	5.61	56.1	40.0	56.1
September	2	1.16	5.82	58.2	34.9	43.2
September	3	1.39	6.81	68.1	25.0	53.1
October	1	1.49	7.23	72.3	12.2	60.58
October	2	1.49	7.12	71.2	1.7	69.5
Total				823.8	461.8	969.6

#Source – Tyagi et al. (2010)

Table 3. Irrigation requirement of wheat crop at *Jhajjar*

Month	Ten-day period	Kc value#	ETc mm.day^{-1}	ETc, mm.ten-day^{-1}	Effective rain, mm.ten-day^{-1}	Irrigation requirement, mm.ten-day^{-1}
November	2	0.28	0.92	5.5	0.8	4.8
November	3	0.28	0.85	8.5	2.1	6.4
December	1	0.51	1.34	13.4	3.1	10.3
December	2	0.86	1.98	19.8	3.6	16.2
December	3	1.15	2.71	29.8	4.2	25.5
January	1	1.17	2.79	27.9	5	22.9
January	2	1.17	2.79	27.9	5.7	22.3
January	3	1.17	3.24	35.6	5.8	29.8
February	1	1.17	3.64	36.4	6.1	30.3
February	2	1.08	3.7	37	6.4	30.6
February	3	0.85	3.53	28.2	5.9	22.3
March	1	0.63	3.06	30.6	5.2	25.3
March	2	0.46	2.51	10.1	1.9	7.7
Total				310.7	55.8	254.6

 # Source – Dash (2011)

Table 4. Irrigation scheduling for rice cultivation

Date	DAS	Stage	Net irrigation requirement, mm	Gross irrigation requirement, mm
11-Jun	-19	Pre-puddling	69.53	99.33
16-Jun	-14	Pre-puddling	46.04	65.77
20-Jun	-10	Pre-puddling	46.04	65.77
25-Jun	-5	Pre-puddling	51.04	72.91
26-Jun	-4	Puddling	67.27	96.10
27-Jun	-3	Puddling	33.74	48.20
29-Jun	-1	Puddling	37.00	52.86
6-Jul	6	Initial	71.03	101.47
20-Jul	20	Initial	101.03	144.33
1-Aug	32	Development	43.5	62.14
19-Aug	44	Development	83.7	119.57
1-Sep	63	Mid season	56.1	80.14
16-Sep	78	Mid season	43.2	61.71
26-Sep	88	Mid season	53.1	75.86
5-Oct	97	Late season	60.58	86.54
14-Oct	106	Late season	69.5	99.29
22-Oct	114	Maturity	38.2	54.57

Table 5. Irrigation scheduling for wheat cultivation

Date	DAS	Stage	Net irrigation requirement, mm	Gross irrigation requirement, mm
15-Nov	1	Initial	21.5	30.71
12-Dec	28	Development	64.6	92.29
10-Jan	57	Mid season	113	161.43
9-Feb	87	Late season	55.3	79.00

of all the 12 off-take points were higher during the month of June as compared to other months of crop growing season, due to preparation of puddled field for transplanting of rice. It was also observed from Table 6 that in the developed crop water demand-based schedule, the release for off-take point E was highest with 11.93 $m^3.s^{-1}$ irrigating an area of 2064 ha as compared to the off-take point L (0.89 $m^3.s^{-1}$) commanding a lesser area of 154 ha**.** The developed schedule showed a variable discharge rate of all off-take points for different months in a year. Contrastingly, the canal rosters adopted by *Jhajjar* Water Services Division of Haryana indicted a fixed supply for different off-take points for all months during a year (Table 7). Comparison of Table 6 pertaining to crop water demand-based irrigation schedule developed in this study and Table 7 revealed a picture of deficit and surplus irrigation during different months, and for different off-take points of the distributary. It was observed that the release of water at off-take points C as per the existing roster was at higher discharge rate (1.85 $m^3.s^{-1}$) in comparison to the crop water demand-based estimates of 1.74, 1.55, 1.55, 1.71, 0.36, 0.88, 0.88, 1.09, 1.14 $m^3.s^{-1}$ for a duration of seven days for the months of July, August, September, October, November, December, January, February and March, respectively. Therefore, the excess water scheduled in the canal roster for off-take point C in these months can be supplied to off-take points D and E, where the water demand was high and supply was less. Also, provision of a fixed discharge rate for an off-take point for all months in a year might not be a rational approach. Therefore, a time variant water release schedule may be prepared to ensure judicious utilization of irrigation water in canal commands keeping in view of the change in water requirement of crops grown in the region at different growth stages to meet the evapotranspirative demand. The crop water demand-based schedule developed in this study may thus be recommended for the region to enhance the productivity of the canal command and save canal water. This can prevent the problems of waterlogging and salinity in the region.

Demand Supply Analysis for Different off-take Points in Selected Distributary

The developed crop water demand-based canal water delivery schedule (Table 6) and the prevailing canal roster (Table 7) of the study area were converted to depth units of irrigation water, and were compared for different off-take points and months for the rice-wheat growing period. The demand and supply for each of the twelve off-take points on monthly basis are presented in Fig. 7. It was observed from the figure that off-take points A, B and C located in the head end of the distributary were releasing more water, which generally exceeded the crop water demand for four months out of the nine-month period of canal water supply. Therefore, the operational water release schedule adopted by the Water Service Division since its inception might be attributable to the problem of waterlogging and salinity in the head end of the distributary, which was corroborated by field investigations. Further, the quarry building module of ArcGIS was used to identify the regions of water deficit. It was observed from the geospatial analysis that the water deficit regions were more (70%) in the tail reach of the command with minimal (4.5%) in the lower middle reach, amounting to a total of 74.5% of

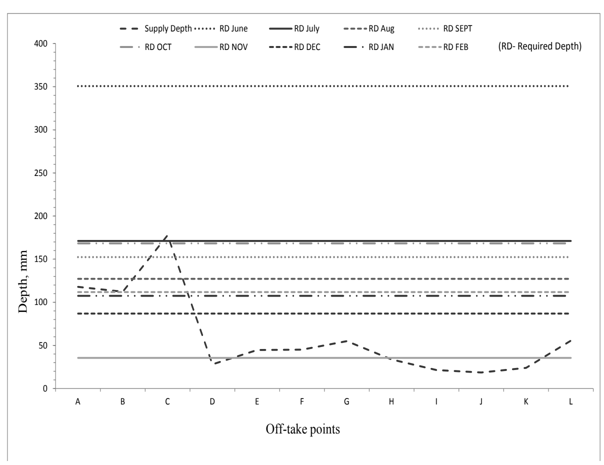


Fig. 7: Demand-supply gap at different off-take points of the *Jhajjar* distributary from June to February

Table 6. Crop water demand-based canal water delivery schedule of different off-take points of *Jhajjar* distributary

Sl. No.	Month	Week	Discharge ($m^3.s^{-1}$)											
			A	B	C	D	E	F	G	H	I	J	K	L
1.	June	8 to 15	1.10	1.92	3.57	3.25	11.93	5.46	3.93	1.76	1.65	1.83	1.36	0.89
2.	July	18 to 25	0.54	0.94	1.74	1.59	5.82	2.66	1.92	0.86	0.81	0.89	0.66	0.43
3.	August- September	27 to 3	0.48	0.83	1.55	1.41	5.18	2.37	1.71	0.76	0.72	0.79	0.59	0.39
4.	October	6 to 13	0.53	0.92	1.71	1.56	5.73	2.62	1.89	0.84	0.79	0.88	0.65	0.43
5.	November	15 to 22	0.11	0.19	0.36	0.33	1.20	0.55	0.40	0.18	0.17	0.18	0.14	0.09
6.	December-January	25 to 1	0.27	0.48	0.88	0.81	2.96	1.35	0.97	0.44	0.41	0.45	0.34	0.22
7.	February	3 to 10	0.34	0.59	1.09	1.00	3.66	1.67	1.20	0.54	0.51	0.56	0.42	0.27
8.	March	14 to 21	0.35	0.61	1.14	1.04	3.80	1.74	1.25	0.56	0.53	0.58	0.43	0.28

Table 7. Operational canal roster for selected off-take points of *Jhajjar* distributary

Sl. No.	Month	Date	Discharge ($m^3.s^{-1}$)											
			A	B	C	D	E	F	G	H	I	J	K	L
1.	June	8 to 15	0.37	0.62	1.84	0.27	1.58	0.72	0.63	0.17	0.10	0.10	0.09	0.14
2.	July	18 to 25	0.37	0.62	1.84	0.27	1.58	0.72	0.63	0.17	0.10	0.10	0.09	0.14
3.	August-September	27 to 3	0.37	0.62	1.84	0.27	1.58	0.72	0.63	0.17	0.10	0.10	0.09	0.14
4.	October	6 to 13	0.37	0.62	1.84	0.27	1.58	0.72	0.63	0.17	0.10	0.10	0.09	0.14
5.	November	15 to 22	0.37	0.62	1.84	0.27	1.58	0.72	0.63	0.17	0.10	0.10	0.09	0.14
6.	December-January	25 to 1	0.37	0.62	1.84	0.27	1.58	0.72	0.63	0.17	0.10	0.10	0.09	0.14
7.	February	3 to 10	0.37	0.62	1.84	0.27	1.58	0.72	0.63	0.17	0.10	0.10	0.09	0.14
8.	March	14 to 21	0.37	0.62	1.84	0.27	1.58	0.72	0.63	0.17	0.10	0.10	0.09	0.14

the command area in both middle and tail reaches. The off-take points E, F, G, H, I, J, K and L located in the tail and lower middle reaches had more water deficit as compared to the off-take points A, B, C and D located in the head and upper middle reaches of the distributary.

Supplementing Canal Water Deficit with Ground Water

Based on the crop water demand analysis, the irrigation from ground water sources in the region was quantified to fill the gap in water supply as per the current canal roster. It was observed during field survey and acquisition of ground truthing data that the farmers predominant towards the tail end of the distributary use tube wells for irrigation. Accordingly, the depth of water to be supplied from groundwater sources for delineated regions under each off-take point on monthly basis was estimated , Table 8. The required groundwater depths were estimated in terms of percentage of total water requirement, and is shown in Table 9.

It was observed from these two tables that the percentage of ground water use was more during the month of June at all the off-take point of the distributary for puddling of soil before transplanting of rice crop. The off-take point A and B located at the head-end of the distributary required more water during the entire rice growing period, whereas the off-take point C required ground water supply only during the month of June. However, the off-take points A, B and C located at the head-reach of the distributary did not require water from ground water sources for the wheat growing period from November to February. Moreover, it was also observed that off-take points located in the middle and tail reaches of the distributary necessitated irrigation from ground

Table 8. Required groundwater irrigation for different off-take points of the distributary to meet deficit in canal water supply

Month	Ground water depth, mm											
	A	B	C	D	E	F	G	H	I	J	K	L
June	232.9	238.5	173	323	306	305.6	295.81	317.1	329.4	332.1	326.7	295.2
July	0	0	0	143	126	126	116.21	137.5	149.8	152.5	147.1	115.6
August	0	0	0	99.2	82.6	82.17	72.349	93.64	105.9	108.7	103.3	71.77
September	34.6	40.22	0	124	108	107.4	97.549	118.8	131.1	133.9	128.5	96.97
October	50.48	56.1	0	140	124	123.3	113.43	134.7	147	149.8	144.4	112.8
November	0	0	0	0	0	0	0	1.8	14.1	16.9	11.5	0
December	0	0	0	58.9	34.9	41.9	32.0	53.3	65.6	68.4	63.0	31.5
January	0	0	0	79.5	62.9	62.5	52.6	73.9	86.2	89.0	83.6	52.1
February	0	0	0	83.8	67.2	66.8	56.9	78.2	90.5	93.3	87.9	0

Table 9. Required percentage of ground water use to meet total crop water requirement at different distributary off-take points

Month	Percentage of groundwater in terms of total crop water requirement											
	A	B	C	D	E	F	G	H	I	J	K	L
June	80.4	81.3	70.4	95.3	92.6	92.5	90.9	94.4	96.5	97	96	90.8
July	0	0	0	72.6	56.1	55.8	46	67.1	79.2	82	76.6	45.5
August	0	0	0	72.4	56	55.6	45.9	66.9	79	81.7	76.4	45.3
September	60.9	62.7	41	90.7	85.2	85.0	81.8	88.8	93	93.8	92	81.6
October	60.5	62.4	40.6	90.3	84.8	84.6	81.4	88.5	92.5	93.4	91.7	81.2
November	0	0	0	0	0	0	0	5.2	40	47.7	32.4	0
December	0	0	0	67.8	40.1	48.2	36.9	61.4	75.5	78.7	72.5	36.2
January	0	0	0	74	58.5	58.1	49	68.8	80.2	82.8	77.7	48.4
February	0	0	0	75	60.1	59.7	50.9	70	81	83.4	78.6	0

water source for rice and wheat crops in almost all months during the entire crop growing period. The percentage of ground water irrigation varied from a minimum of 5.2 % (for off-take point H in the month of November) to 97% (for off-take point J in the month of June) for off-take points D to L located at middle and tail reaches of the command (Table 9). Above all, the present investigation revealed considerable use of ground water resources in nine off-take points located in the middle and tail reach of the command during the rice-wheat growing season. However, the ground water salinity played a significant role in deciding the quantity of irrigation and need to be investigated before its use both under non-availability and in conjunction with the canal water.

CONCLUSIONS

Geospatial data base of the canal network, soil texture, land use and land cover, location of different off-take points along with their discharge pertaining to *Jhajjar* distributory was prepared for subsequent data analysis. CROPWAT model was operated to develop the protocol for crop water demand-based irrigation schedule for rice and wheat, which was validated for the study region. Further, the developed schedule was compared with the currently operational roster of the *Jhajjar* distriburtary and the deficit in canal water supply was estimated. Based on this study, it was recommended to use the modified roster for ensuring supply of desired quantity of irrigation to meet the crop water demand of rice and wheat in the canal command. It was revealed from the study that preparation of the canal water release roster using crop water demand-based irrigation scheduling protocol would enhance water productivity of canal command and prevent waterlogging and salinity problems in the canal command. Nonetheless, the developed protocol can be replicated to other canal command under different crops and cropping systems to enahance the water productivity of different canal commands in our country.

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REFERENCES

Ackermann R. 2012. New directions for water management in Indian agriculture. Global J. Emergy Market Econ., 4, 227-228.

Al-Nazer H. 2011. The integration of FAO CROPWAT model and GIS techniques for estimating irrigation water requirement and its application in the Gaza strip. Nat. Resour., 2, 146-154.

Anon. 2010. FAO Agristat Database. http:// www.indiastat.com /table /agriculture /2/ irrigationbysource19951996to20082009/449345/10539/ data.aspx (last accessed on 6th August 2015).

Anon. 2011. Canal roster and capacity statement of Jhajjar distributary. Jhajjar Water Services Division, Jhajjar, India, pp. 20.

Dash J. 2011. Modelling nitrate pollution of groundwater at IARI farm. Unpublished Ph.D. thesis, IARI, New Delhi.

Erdas Imagine. 2010. Erdas Imagine software. Erdas, Inc., Atlanta, Georgia, USA. http:// www. hexagongeospatial.com/products/producer-suite/erdas-imagine.

ESRI. 2011. ArcGIS Desktop: Release 10. Environmental System Research Institute, Redlands, USA. http:// www.arcgis.com/features (Last accessed on 1st April 2016).

Fortes P S; Platonov A E; Pereira L S. 2005. GISAREG - A GIS based irrigation scheduling simulation model to support improved water use. Agric. Water Manage., 77, 159-179.

George B A; Raghuwanshi N S; Singh R. 2004. Development and testing of a GIS integrated irrigation scheduling model. Agric. Water Manage., 66, 221-237.

Jurriens M; Mollinga P; Wester P. 1996. Scarcity by design: Protective irrigation in India and Pakistan. ICID J., 45(2), 31-53.

Kuo S; Ho S; Liu W. 2006. Estimation irrigation water requirements with derived crop coefficients for upland and paddy crops in ChiaNan Irrigation Association, Taiwan. Agric. Water Manage., 82, 433–451.

Pakhale G; Gupta P; Nale J. 2010. Crop and irrigation water requirement estimation by remote sensing and GIS: A case study of Karnal District, Haryana, India. Int. J. Eng. Technol., 2, 207-211.

Raidu C R; Giridhar M V S S. 2011. Geo-spatial database creation for Wazirabad canal command area. J. Geog. Inf. Syst., 3, 290-297.

Rao B K; Rajput T B S. 2009. Decision support system for efficient water management in canal command areas. Current Sci., 97, 90-98.

Rao N H; Brownee S M; Sharma P B S. 2004. GIS-based decision support system for real time water demand estimation in canal irrigation systems. Current Sci., 87, 628-636.

Ray S S; Dhawal V K. 2001. Estimation of crop evapotranspiration of irrigation command area using remote sensing and GIS. Agric. Water Manage., 49, 239–249.

Rowshon M K; Kwok C Y; Lee T S. 2003. GIS-based scheduling and monitoring of irrigation delivery for rice irrigation system. Agric. Water Manage., 62, 105–116.

Salmah Z; Aminuddin Y; Marzuki H; Azizah J. 1994. Research requirements in agricultural drainage of Malaysia. In: Proc. 7th ICID International Drainage Workshop, Penang, Malaysia, 3,10-14.

Santhi C; Pundarikanthan N V. 2000. A new planning model for canal scheduling of rotational irrigation. Agric. Water Manage.*,* 43, 327–343.

Shah A. 2003. Tail-Enders and other deprived in canal irrigation systems: Gujarat. National Workshop on Tail-Enders and Other Deprived in Canal Irrigation Systems, Ahmedabad, India.

Singh A; Krause P; Panda S N; Flugel W. 2010. Rising water table: A threat to sustainable agriculture in an irrigated semi-arid region of Haryana, India. Agric. Water Manage., 97, 1443–1451.

Smith M. 2006. CROPWAT, a computer program for irrigation planning and management. FAO Irrigation and Drainage Paper No. 46, Rome, pp:133.

Tyagi N K; Sharma D K; Luthrea S K. 2010. Determination of evapotranspiration and crop coefficients of rice and sunflower with lysimeter. Agric. Water Manage.*,* 45, 41–54.

Yarahamdi J. 2003. The integration of satellite images, GIS and CROPWAT model to investigation of water balance in irrigated area: A case study of Salmas and Tassoj plain, Iran. Unpublished M.Sc. Thesis, International Institute for Geo-information Science and Earth Observation, Enschede, The Netherlands.