J. Indian Soc. Coastal Agric. Res. 40(1): 63-73 (2022) https://doi.org/10.54894/JISCAR.40.1.2022.115831

Assessment of Crop Water Demand and Irrigation Water Supply in a Run-off-the-river Based Canal System

A. DALAI[1]*, A. MISHRA[2] and M. P. TRIPATHI[1]

[1]Swami Vivekanand College of Agricultural Engineering & Technology and Research Station
Indira Gandhi Krishi Vishwavidyalaya, Raipur - 492 012, Chhattisgarh, India
[2]ICAR-Indian Institute of Water Management, Bhubaneswar - 751 023, Odisha, India

Received: 23-09-2021 Accepted: 07.04.2022

Proper assessment of irrigation water need for a canal command is required for long term planning and management of water resources. The present study was carried out in the Phulnakhara distributary command of the Puri main canal system distributed in Cuttack and Khurda districts of Odisha. During *Kharif* season, the Phulnakhara distributary command receives more than the required amount of irrigation water. However, during *Rabi* season, the canal does not flow at its full supply level as a result of which the total irrigation demand of the canal command area is not met leading to lower cropping intensity and poor crop productivity. The year-wise highest irrigation water demand in *Kharif* season was found to be 48646195 m^3 during 2015-16 and the lowest was 22291100 m^3 in 2017-18. Whereas the highest *Kharif* irrigation supply at the head regulator was 43402176 m^3 during 2015-16 and the lowest was 29831328 m^3 during 2013-14. The highest *Rabi* irrigation water demand was found to be 21700766 m^3 during 2008-09 and the lowest was 9570257 m^3 in 2017-18. Whereas the highest *Rabi* irrigation supply at head regulator was 26379648 m^3 during 2008-09 and the lowest was 615168 m^3 during 2009-10. As evident, there is a mismatch between the supply and demand in both the seasons and it is more prominent in the *Rabi* season. In order to bridge this gap, conjunctive use of canal water with groundwater is found to be a promising solution.

(***Key words:*** *Cropping intensity, Crop water demand, Irrigation demand, Productivity*)

Water resources assessment and understanding the relationships and interconnectivities between the demand and supply are inexorable for sustainable water management. The surface water and groundwater resources play a vital role in agriculture, livestock production, hydropower generation, fisheries, forestry and recreational activities. The uneven distribution of rainfall can be overcome by the conjunctive use of water. It helps in value addition to water conservation (demand management) for satisfying water needs during droughts and interruption of water supply. Out of 140.13 Mha of net sown area in India (Directorate of Economics and Statistics, 2018), 39 Mha area is irrigated by groundwater resources, 22 Mha area is irrigated by surface water resources (Dhawan, 2017) and rest 53% area is rainfed (Deshpande, 2016). Rapid industrialization, urbanization, and exponentially rising population coupled with rising demand for food grains are the prime factors putting more and more pressure on land and water resources. Further, India has a per capita water availability of 1545 cubic meters per annum and is categorized as a water stressed country (Agriculture Census Commissioner, 2015). As per the international norms, the countries with per capita water availability of less than 1700 cubic meter per year is categorized as water stressed (Gangwar, 2013). By 2025 and 2050, the average annual per capita water availability in India will be 1340 and 1140 cubic meters, respectively (CWC, 2011).

Assured irrigation in conjunction with other technological and policy guidelines has played a catalytic role in the growth of Indian agriculture over the years. In order to achieve self-sufficiency in food grain production, irrigation development has always been the priority area of the national agricultural development strategy. Consequently, the gross irrigated area of the country has increased from 22.56 Mha in 1950-51 to 96.46 Mha in 2014-15. This has contributed substantially to increasing the overall production and productivity. In spite of these gains, the performances of the irrigation projects remain below satisfactory. One of the major reasons for the poor performance of these irrigation systems is the spatial and temporal mismatch between irrigation water supply and crop water demand.

**Corresponding author:* E-mail: dalaiabinash500@gmail.com

Against the backdrop of these above-stated facts, this study was carried out in an irrigation system located in the coastal belt of Odisha state. Here, it is believed that during *Kharif* season, more than the required amount of water is delivered in the canal system as the irrigation systems are mostly runoff-the-river scheme. On the contrary during *Rabi* season, due to inadequate supply in the canal system, a sizeable area in the command remains fallow and the productivity of the crops grown is poor. Therefore, in this paper, an attempt has been made to ascertain/quantify the mismatch between canal water supply and crop water demand with the hypothesis that if a deficit exists at any given time in a year that can be met through conjunctive use of groundwater which is available in plenty in the coastal deltaic belt.

MATERIALS AND METHODS

Study area

The study was carried out in the Phulnakhara distributary command of the Puri main canal system spread in Cuttack and Khurda districts of Odisha with 20° 19′ 15.6″ N to 20° 14′ 56.4″ N latitude, 85° 52′ 51.6″ E to 86° 0′ 0″ E longitude and 28 m above from MSL (Fig. 1). The Phulnakhara distributary off takes from Kakatpur branch canal of Puri main canal system and runs for 21.410 km. The distributary has 7 minors and 33 sub-minors. It has a verified cultivable command area of 4903.29 ha and a design discharge of 6.03 cumec. Its command area consists of 3 blocks of Cuttack district *viz*., Cuttack Sadar (372 ha), Kantapada (2208 ha) and Baranga (1047 ha) and 2 blocks of Khurda district *viz*., Balianta (1147 ha) and Bhubaneswar (129 ha). The soils of the head reach are comparatively heavier than the middle and tail reaches. The soil in the command area can be classified into clay loam, sandy loam and sandy clay loam (Mishra *et al*., 2008). About 33% of the command area consists of clay loam soil, 8% area consists of sandy loam and the remaining 58% area consists of the sandy clay loam soil. The bulk density of the soil ranged from 1.42 to 1.64 g cm^{-3} (Mishra *et al*., 2008). Normally, the southwest monsoon onsets from the middle of June over the command area and lasts up to the end of September. The average annual rainfall of the study area is about 1530 mm. In the distributary command area, during *Kharif* season, more than the required amount of irrigation water is delivered (Mishra

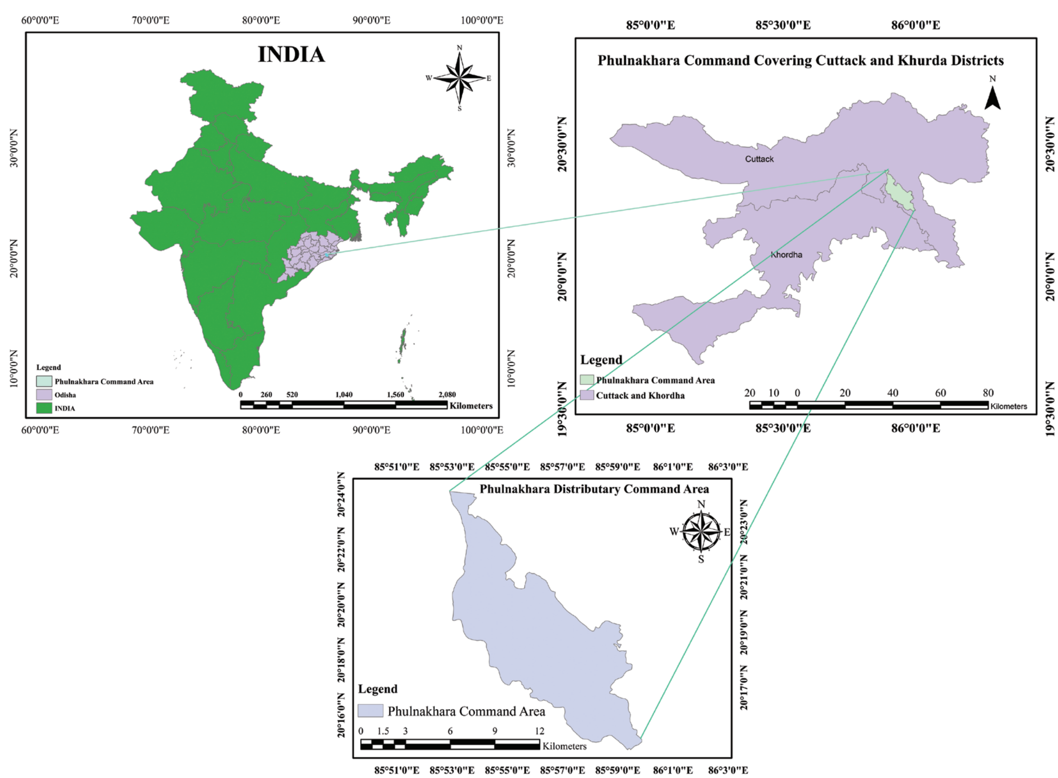

Fig. 1. *Location map of study area*

et al., 2008). During *Rabi* season, the canal flow was substantially below the full supply level, thereby the irrigation demand of the crops could not be met. Mishra *et al*. (2008) revealed that as the canal water during *Rabi* and summer is not adequate to meet the crop water demand, a sizeable area remained fallow within the command during *Rabi* season.

Data requirement and processing

Meteorological data such as daily rainfall, maximum & minimum temperature, relative humidity, sunshine hour and average wind speed were collected from OUAT meteorological observatory, Bhubaneswar. Daily canal discharge data at the head regulator of Phulnakhara distributary was collected from the sub-division office of Water Resources Department, Pratapnagari, Govt. of Odisha for understanding the canal delivery schedule

Block-wise agricultural data *viz*., cropping practices, crop coverage, yield and production were collected from the office of Deputy Director Agriculture, Cuttack and Khurda, Govt. of Odisha for assessing the crop water requirement (Deputy Director Agriculture, 2017). The major crops grown in the command area are paddy, vegetables in large areas and maize, ginger, and turmeric in small areas during *Kharif* season. Similarly, summer paddy, green gram, black gram, groundnut, sugarcane, potato, other vegetables, mustard, sesamum and chilly are grown in *Rabi* season. The crops grown during *Kharif* and *Rabi* season in the study area are presented in Tables 1 and 2, respectively. The geographical area of 5 blocks (coming under the study area) and the cultivable command area are collected from the office of the Deputy Director of Agriculture (DDA), Cuttack and Khurda and are verified with the data of National Remote Sensing Centre (NRSC), Hyderabad.

Estimation of the reference evapotranspiration (ET_0)

The reference evapotranspiration is the rate of evapotranspiration from the reference surface of a hypothetical crop *i.e*., green grass with an assumed crop height of 0.12 m, constant surface resistance of 70 s m^{-1} and an albedo of 0.23. In the present study the reference evapotranspiration has been computed by using FAO Penman-Monteith equation as expressed below:

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

where, ET_0 = reference crop evapotranspiration (mm day^{-1}); R_n = net radiation at the crop surface (MJ m^{-2} day^{-1}); G = soil heat flux density (MJ m^{-2} day^{-1}); T = mean daily air temperature at 2 m height (°C); u_2= wind speed at 2 m height (m s^{-1}); e_s = saturation vapour pressure (kPa); e_a = actual vapour pressure (kPa); (e_s–e_a) = saturation vapour pressure deficit (kPa); Δ = slope of vapour pressure curve (kPa °C^{-1}); and γ = psychrometric constant (kPa °C^{-1}).

Table 1. *Crop coverage in Phulnakhara distributary command during Kharif season*

Year	Area (ha)						
	Paddy	Maize	Other Vegetable	Chilly	Ginger	Turmeric	Total Area
2008-09	3950	24	853	34	9	10	4881
2009-10	3964	6	236	18	4	14	4242
2010-11	3934	7	286	25	6	12	4271
2011-12	3834	28	948	43	9	21	4883
2012-13	3839	23	943	44	10	19	4877
2013-14	3790	23	1009	40	6	20	4888
2014-15	3726	8	1092	41	6	17	4891
2015-16	3781	7	1047	43	4	14	4895
2016-17	3817	5	1009	43	4	13	4890
2017-18	3798	6	1026	41	6	13	4890
10 Years Avg.	3843	14	845	37	6	15	4761

Source: Office of the Deputy Director Agriculture, Cuttack, Govt. of Odisha

Table 2. *Crop coverage in Phulnakhara distributary command during Rabi season*

Year	Area (ha)															
	Paddy	Wheat	Maize	Green gram	Black gram	Gram	Field pea	Groundnut	Sesamum	Sunflower	Mustard	Potato	Onion	Other Vegetables	Chilly	Sugarcane	Total Area
2008-09	405	8	6	737	879	8	19	376	52	17	36	120	21	1328	84	153	4247
2009-10	371	2	4	772	429	3	4	191	35	3	28	78	18	649	56	102	2746
2010-11	231	1	4	727	403	4	6	268	62	2	47	84	20	825	48	116	2846
2011-12	257	7	15	1115	905	5	20	410	56	18	39	151	22	1401	88	140	4650
2012-13	220	5	8	987	824	5	18	335	27	42	33	145	22	1478	82	22	4252
2013-14	170	1	9	1067	860	5	16	379	85	12	25	112	22	1528	83	124	4500
2014-15	144	0	5	1120	660	3	8	188	18	9	20	106	18	1534	66	123	4022
2015-16	208	0	4	948	603	3	6	69	8	6	21	113	44	1214	61	122	3430
2016-17	49	0	3	859	608	3	10	65	6	3	22	98	46	1241	63	87	3165
2017-18	50	1	5	1287	608	5	8	49	22	2	24	75	36	1233	59	118	3581
10 Years Avg	210	3	6	962	678	4	11	233	37	11	30	108	27	1243	69	111	3744

Source: Office of the Deputy Director Agriculture, Cuttack, Govt. of Odisha

Crop evapotranspiration

The crop evapotranspiration (ET_c) is calculated by multiplying the reference crop evapotranspiration (ET_0) with the crop coefficient (K_c) (Allen *et al*., 2004).

$$ET_c = K_c \times ET_0 \qquad (2)$$

where, ET_c = crop evapotranspiration [mm d^{-1}]: K_c = crop coefficient; and ET_0 = reference crop evapotranspiration [mm d^{-1}].

The crop coefficient for different growth stages, duration of each stage, the date of planting or sowing and date of harvesting of *Kharif* and *Rabi* crops are given in Tables 3 and 4, respectively (Chadha, 2003; Allen *et al*., 2004; ICAR, 2011).

Canal flow operation

The details of canal flow operation for different years under consideration are presented in Table 5. The average flow rate of *Kharif* and *Rabi* season vary from 4.04 to 5.37 $m^3 s^{-1}$ and 1.19 to 2.94 $m^3 s^{-1}$, respectively, against the design discharge of 6.03 $m^3 s^{-1}$.

The daily canal discharge data at the head regulator of Phulnakhara distributary was recorded for 10 years period in order to understand the canal delivery schedule and compare irrigation water supply with crop water demand of the canal command. The canal flow data is given in Table 6 to ascertain the surface water availability in the command area.

Out of the 10 years, canal water was supplied for 4 years in *Rabi* season and all 10 years for *Kharif* season. Thus, there is a 40 % probability that the canal would run during the *Rabi* season. The *Rabi* season supply begins mostly by the last week of January and closes in the first or second week of May.

Estimation of irrigation water demand at the head regulator of the distributary

The command area shape file was prepared first by digitizing the Survey of India toposheet. Then the digitized toposheet was geo-referenced by collecting the known geo-coordinates (latitude and longitude), and by editor tool in ArcGIS, mapping of the canal command was done. Thereafter, the percentage of area from different blocks lying within the command area was determined. Subsequently, the cropped area within the command area of each block area for *Kharif* and

Table 3. *Stage wise crop coefficient for Kharif crops*

Sl No.	Name of crops	K_c Initial	K_c Mid season	K_c Late Season	Duration of initial stage (days)	Duration of mid season stage (days)	Duration of late season stage (days)	Total (days)	Crop growth period
1	Paddy	1.05	1.20	0.90	55	85	25	165	1 Jul - 12 Dec
2	Maize	0.30	1.20	0.60	25	50	35	110	15 Jul - 1 Nov
3	Other vegetables*	0.35	1.05	0.55	25	40	20	85	15 Sept - 8 Dec
4	Chilly	0.60	1.15	0.80	30	60	30	120	1 Jun - 28 Sept
5	Ginger	0.55	1.00	0.60	50	135	40	225	1 Jun - 11 Jan
6	Turmeric	0.55	1.00	0.60	40	140	60	240	15 Oct - 11 Jun

Table 4. *Stage wise crop coefficient for Rabi crops*

Sl No.	Name of crops	K_c Initial	K_c Mid season	K_c Late Season	Duration of initial stage (days)	Duration of mid season stage (days)	Duration of late season stage (days)	Total (days)	Crop growth period
1	Paddy	1.10	1.25	1.00	60	45	30	135	1 Jan - 15 May
2	Wheat	0.70	1.15	0.45	25	50	45	120	15 Dec - 13 Apr
3	Maize	0.40	1.15	0.70	25	50	35	110	15 Nov - 4 Mar
4	Green gram	0.40	1.05	0.60	20	30	20	70	1 Jan - 11 Mar
5	Black gram	0.40	1.05	0.35	20	35	20	75	1 Jan - 16 Mar
6	Gram (Chickpea)	0.40	1.00	0.35	25	65	30	120	15 Nov - 14 Mar
7	Fieldpea	0.50	1.15	0.30	25	60	25	110	15 Nov - 4 Mar
8	Groundnut	0.40	1.15	0.60	25	55	25	105	15 Nov - 27 Feb
9	Sesamum (Til)	0.35	1.10	0.25	20	40	20	80	15 Nov - 2 Feb
10	Sunflower	0.35	1.05	0.35	25	45	25	95	1 Dec - 5 Mar
11	Mustard	0.35	1.05	0.35	25	45	20	90	1 Dec - 28 Feb
12	Potato	0.50	1.15	0.75	15	50	20	85	15 Oct - 7 Jan
13	Onion	0.70	1.05	0.75	60	60	40	160	15 Oct - 23 Mar
14	Other vegetables*	0.35	1.05	0.55	20	50	25	95	1 Nov - 3 Feb
15	Chilly	0.60	1.15	0.80	35	60	30	125	1 Nov-5 Mar
16	Sugarcane	0.65	1.05	0.60	60	240	60	360	15 Nov-9 Nov

Source: Chadha (2003), Allen *et al*. (2004), ICAR (2011)

*Other vegetables mentioned in the above table include spinach, pumpkin, water melon, cassava and potato etc. For small vegetables like spinach, the total crop duration varies from 70-100 days. For large vegetables like pumpkin, the total crop duration is 100 days. The crop coefficient for small vegetables and large vegetables varies from 1.0 to 1.2 during mid-season. For watermelons, total crop duration is 80 days and the crop coefficient for initial stage is 0.4. For roots and tubers vegetable, crop coefficient for initial stage varies from 0.3 (cassava) to 0.5 (potato) and for late season it varies from 0.3 to 0.75. (Allen *et al*., 2004). So, on an average, crop coefficient values and duration of each stage for these crops have been taken under other vegetables as the area covered under each of them is relatively small.

Rabi seasons for the different years was obtained. After estimation of reference crop evapotranspiration, the crop coefficient values were multiplied for obtaining crop evapotranspiration. Then effective rainfall was subtracted from the crop evapotranspiration and the water demand in depth unit was determined. Thereafter, multiplying with the command area, we found out the water demand on a volume basis, at the field level.

Table 5. *Canal release details in different years*

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Average flow rate of *Kharif* ($m^3 s^{-1}$)	4.74	4.54	4.67	5.37	5.35	4.21	4.98	4.45	4.04	4.68	4.63
Average flow rate of *Rabi* ($m^3 s^{-1}$)	2.17	2.94	1.19	0.00	2.40	0.00	0.00	0.00	1.42	0.00	0.00
Canal opening in *Kharif*	01/08/2008	02/08/2009	24/07/2010	28/07/2011	01/06/2012	28/07/2013	16/08/2014	27/07/2015	24/07/2016	28/07/2017	09/08/2018
Canal closing in *Kharif*	14/11/2008	16/11/2009	12/11/2010	17/11/2011	04/11/2012	17/11/2013	18/11/2014	17/11/2015	14/11/2016	12/11/2017	17/11/2018
Canal opening in *Rabi*	04/02/2008	30/01/2009	01/05/2010	No Run	27/05/2012	No Run	No Run	No Run	18/04/2016	No Run	No Run
Canal closing in *Rabi*	21/05/2008	14/05/2009	06/05/2010	No Run	31/05/2012	No Run	No Run	No Run	30/04/2016	No Run	No Run
Number of operational days in *Kharif*	79	96	99	82	87	82	81	113	113	94	79
Number of operational days in *Rabi*	98	104	6	0	5	0	0	0	10	0	0
Total water supplied in *Kharif* (m^3)	32363712	37672128	39985056	38022912	40249440	29831328	34856352	43402176	39480480	37998720	33220886
Total water supplied in *Rabi* (m^3)	18340906	26379648	615168	0	1036800	0	0	0	1230627	0	0

Source: Assistant Executive Engineer (2018)

Table 6. *Monthly canal release volume for different years at the head regulator*

	Canal release volume (m^3)									
Months	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18
June	0	0	0	0	439776	0	0	0	0	0
July	0	0	1450656	1403136	100224	843264	0	1321056	1538784	1244160
August	5796576	8157888	12455424	12100320	10112256	9955008	7152192	13348800	13176000	12462336
September	5861376	9866880	10032768	778464	12426912	12026880	6721920	6774624	8722080	11779776
October	14382144	11059200	11412576	15877728	15291072	2738016	12920256	15665184	11984544	8001504.00
November	6323616	8588160	4633632	7863264	1879200	4268160	8061984	6292512	4059072	4510944
December	0	0	0	0	0	0	0	0	0	0
January	253152	0	0	0	0	0	0	0	0	0
February	7150464	0	0	0	0	0	0	0	0	0
March	8118144	0	0	0	0	0	0	0	0	0
April	7744896	0	0	0	0	0	0	1230627	0	0
May	3112992	615168	0	1036800	0	0	0	0	0	0
Total	58743360	38287296	39985056	39059712	40249440	29831328	34856352	44632803	39480480	37998720

Source: Assistant Executive Engineer (2018)

Taking into account the conveyance efficiency (70%) and application efficiency (60%), the crop water demand at the head regulator of the distributary was calculated (Brouwer *et al*., 1989). Daily canal flow release at the head regulator of the study distributary was used for determining the monthly and seasonal irrigation water supply quantum. Then comparison was made between irrigation water supply and crop water demand (monthly and seasonal) for the years under consideration.

RESULTS AND DISCUSSION

Determination of monthly irrigation water requirement for *Kharif* crops

Mean monthly irrigation water requirement (10 years average) for various crops was calculated at the head regulator of the distributary considering conveyance efficiency of 70% (Brouwer *et al*., 1989). Monthly irrigation water demand (in volume unit) during the *Kharif* season at the head regulator of the study distributary is presented in Table 7. The highest irrigation water demand was observed in the month of July (12.30 million m^3) followed by November (9.26 million m^3) and October (8.61 million m^3). The highest irrigation demand is primarily because of transplanting of paddy during the month of July. Owing to a good amount of rainfall in the month of August and September, the irrigation water requirement is observed to be quite low in these two months. After the cessation of rain by the end of September, the water requirement in the month of October and November was high. The lowest irrigation water demand (0.09 million m^3) was found in the month of June.

Comparison of irrigation water supply with crop water demand during *Kharif* season

The highest mean monthly *Kharif* irrigation water demand was found to be 12.30 million m^3 during July, and the lowest was 0.09 million m^3 in June; whereas the highest mean monthly *Kharif* irrigation supply at the head regulator was 11.93 million m^3 during October and the lowest of 0.04 million m^3 was observed during June (Fig. 2). The supply at the head regulator was 10.47, 8.50, 11.93 million m^3, which was more than the irrigation water demand of 2.77, 3.44, 8.61 million m^3 during August, September and October, respectively. The supply is less *i.e*., 0.79 million m^3 in the month of July when compared to the demand of 12.30 million m^3. Thus, in order to meet crop water demand in the month of July, irrigation supply need to be provided from the groundwater source in addition to the surface water. The difference between the mean monthly *Kharif* irrigation water demand and irrigation water delivered ranged from -11.51 million m^3 in July to 7.70 million m^3 in August.

The irrigation water supply and crop water demand during *Kharif* season are presented in Fig. 3 for different years. The highest *Kharif* irrigation water demand was found to be 48.65 million m^3 during 2015-16 and the lowest of 22.29 million m^3 in 2017-18. Similarly, the highest *Kharif* irrigation supply at the head regulator was 43.40 million m^3 during 2015-16 and the lowest was 29.83 million m^3 during 2013-14. The 10 years average supply at the head regulator was found to be 37.39 million m^3, which was little more than the irrigation

Table 7. *Irrigation water demand (m^3) on monthly basis during Kharif season at head regulator of study distributary*

Months	June	July	August	September	October	November
2008-09	0	16358001	1777990	0	13746754	11418549
2009-10	206424	8762297	0	4488796	10471817	8551818
2010-11	39912	17197786	3987596	2435301	5840310	7105612
2011-12	54477	11136116	0	2062222	12779560	12273529
2012-13	59710	9188651	3872273	9155447	11874999	3421141
2013-14	6816	14059815	7555908	508970	0	11411787
2014-15	167770	8387680	4208244	0	7081912	11345220
2015-16	195872	16474831	2708822	7931665	10985687	10349317
2016-17	0	15699595	3638428	3528761	8290412	9735681
2017-18	135312	5777608	0	4301065	5042649	7034465
10 Years Average	86629	12304238	2774926	3441223	8611410	9264712

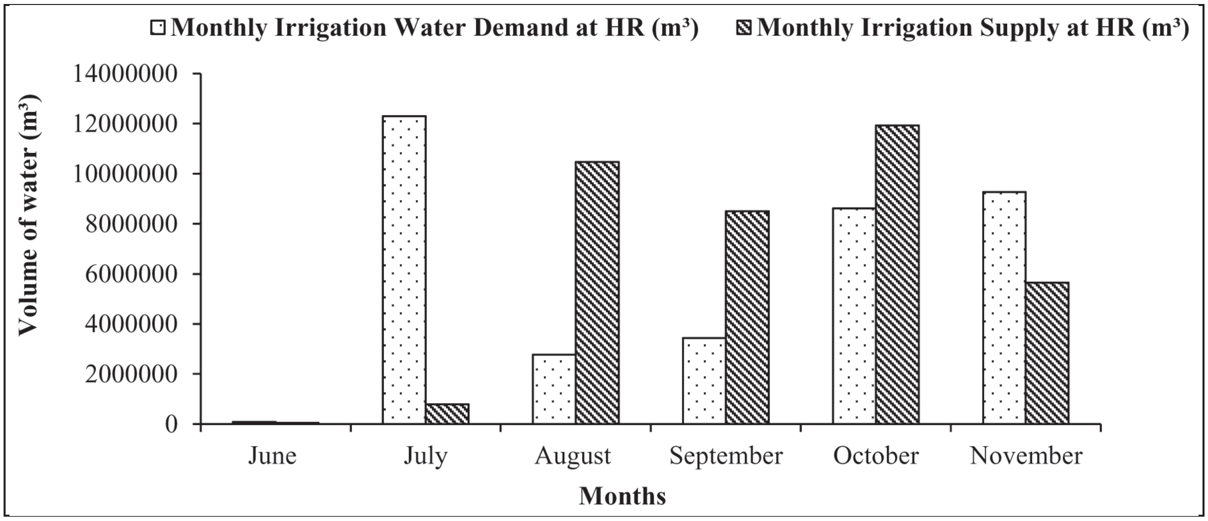

Fig. 2. *Monthly Irrigation water supply and crop water demand during Kharif season (based on mean data of 10 years)*

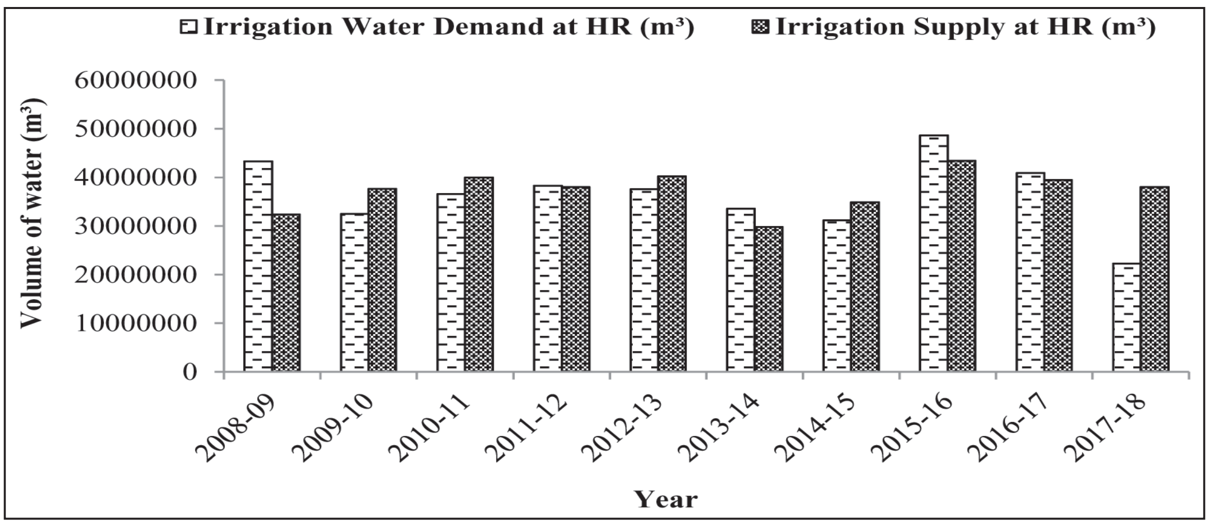

Fig. 3. *Irrigation water supply and crop water demand during Kharif season*

water demand of 36.48 million m^3. The decadal average of *Kharif* irrigation water demand was 36.48 million m^3, and the supply was 37.39 million m^3. The difference between the *Kharif* irrigation water demand and irrigation water delivered ranged from -10.94 to 15.71 million m^3. Though there exists a gap between *Kharif* irrigation water demand and supply from year to year, the decadal average value of the gap is small (0.90 million m^3).

Determination of monthly irrigation water requirement for *Rabi* crops

The irrigation water demand on a monthly basis during the *Rabi* season at the head regulator of the distributary was calculated and shown in Table 8. The highest irrigation water demand (4.19 million m^3) was found to be in the month of January followed by February (3.66 million m^3) and December (3.51 million m^3). The lowest irrigation water demand was found in the month of May (0.38 million m^3).

Comparison of irrigation water supply with crop water demand during *Rabi* season

The highest mean monthly *Rabi* irrigation water demand was found to be 4.19 million m^3 during January, and the lowest was 0.38 million m^3 in May; whereas the highest mean monthly *Rabi* irrigation supply at the head regulator was 0.90 million m^3 during March. There was no supply in the months of December and January. It is evident from Fig. 4, that during *Rabi* season, the demand

Table 8. *Irrigation water demand (m³) on monthly basis during Rabi season at the head regulator of distributary*

Months	December	January	February	March	April	May
2008-09	4385078	6413632	4885193	3090251	2054985	871627
2009-10	3024610	4641838	3930202	2419384	1493599	144236
2010-11	953109	3874426	2481846	1872386	1050887	153007
2011-12	4722305	3791129	5467056	2627301	1077681	725341
2012-13	6139660	5048477	3732077	1991976	855596	268592
2013-14	4693639	4907507	3405087	907813	1039844	326047
2014-15	4102021	3214324	3119345	1582512	546087	482237
2015-16	2827465	4048616	3547643	1933681	1224011	515570
2016-17	3017170	2840285	2649190	420251	385636	268426
2017-18	1211268	3166938	3363217	1359171	425190	44473
10 Years Avg.	3507632	4194717	3658086	1820473	1015352	379956

in most of the months is more than the supply barring only May. In most of the months, the difference between the irrigation supply and crop water demand is huge *i.e.*, the decadal average value of the gap is -11.65 million m^3. Thus, for meeting the crop water demand, alternate source of irrigation water *i.e.*, groundwater should be tapped in addition to the surface water. The difference between the mean monthly *Rabi* irrigation water demand and irrigation water delivered ranged from -4.17 to 0.09 million m^3. A similar result was reported by Mishra *et al*. (2008) *i.e.*, in the case of the prevailing continuous canal delivery schedule, the irrigation water requirement was more than the actual canal water supplied during the dry season. The results are corroborated with the results of Raul *et al*. (2011) who compared annual irrigation water supply and demand, which showed that up to 40% probability of exceedance (PE), the supply exceeded the demand, whereas, at 90% PE, the annual irrigation water supply was only 54% of the demand. The deficit was predominant during the non-monsoon season. In order to mitigate the irrigation water deficit from canal water, groundwater was considered as a supplemental source.

The irrigation water supply and crop water demand for different years during the *Rabi* season are shown in Fig. 5. The crop water demand was found to be ranging

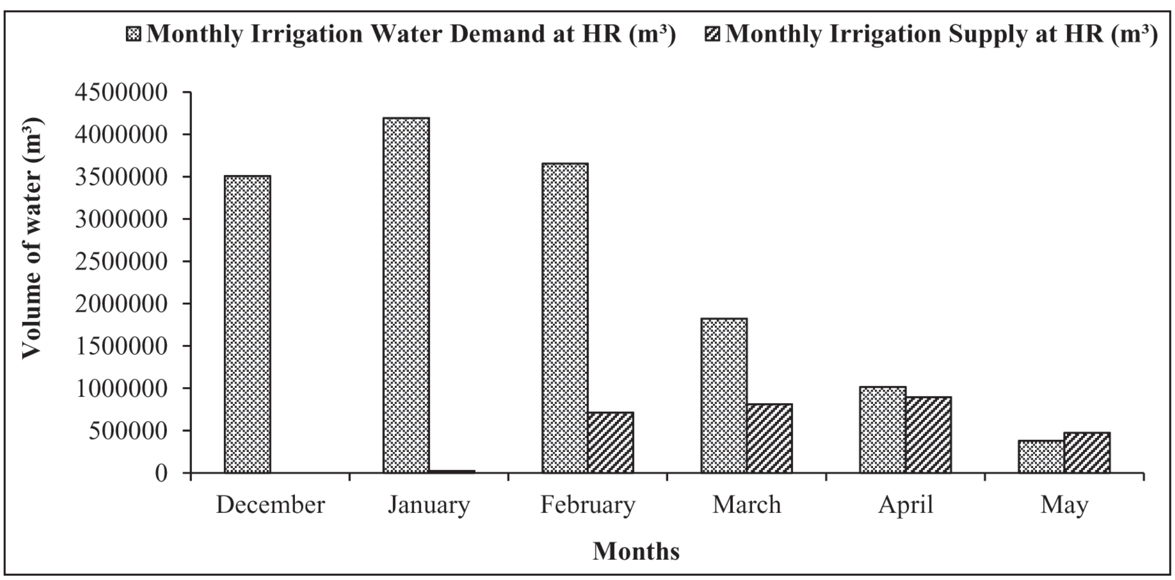

Fig. 4. *Monthly Irrigation water supply and crop water demand during Rabi*

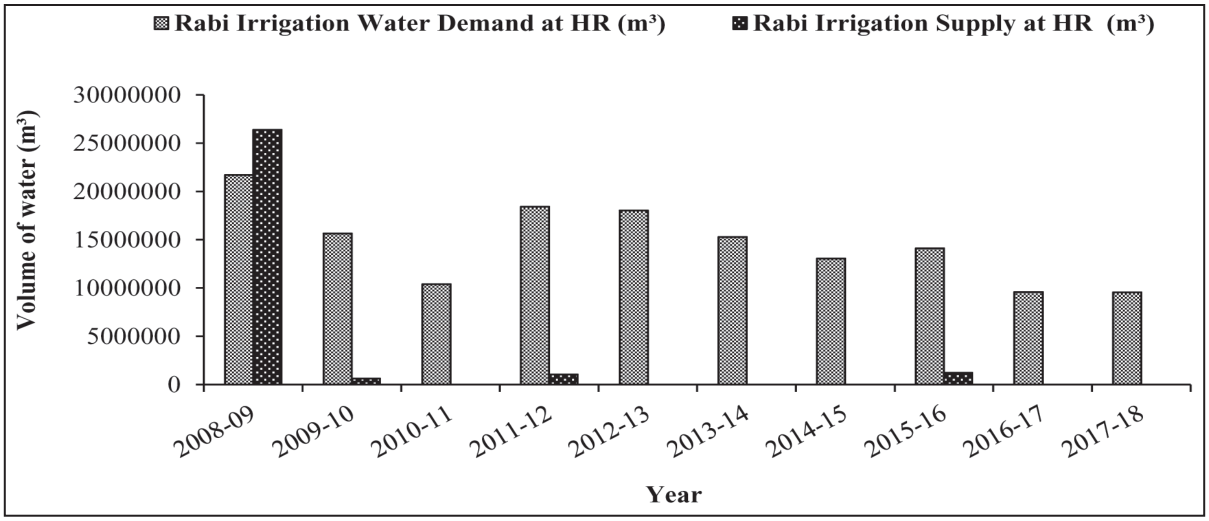

Fig. 5. *Irrigation water supply and crop water demand during Rabi season*

from 9.57 million m^3 in 2017-18 to 21.70 million m^3 during 2008-09. Similarly, the *Rabi* irrigation water supply at the head regulator was found to be ranging from 0.62 million m^3 during 2009-10 to 26.38 million m^3 during 2008-09. It is evident that supply at the head regulator was always less than the irrigation water demand barring one year. The decadal average of *Rabi* irrigation water demand was 14.58 million m^3 whereas the supply at the head regulator was 2.93 million m^3. The difference between the *Rabi* irrigation water demand and irrigation water delivered ranged from 4.68 to -18.04 million m^3. Since in most of the years, there was no supply in the canal during *Rabi*, there is a need to look for an alternate source of irrigation water to meet the crop water demand. Raul *et al*. (2008) revealed that at 10% probability of exceedance of irrigation water requirements, canal water availability during the monsoon season is just sufficient to meet demand, whereas, during the non-monsoon season, water demand exceeds canal water availability by more than 1050 million m^3.

The year-wise analysis reveals that during *Kharif* season there is a mismatch between canal irrigation water supply and crop water demand, but the decadal average value indicates that there is not much difference between supply and demand. Therefore, effort should be made to match the supply with that of demand for each year through precise assessment of crop coverage and crop water demand and efficient flow delivery through improved canal operation. In *Kharif* season, July is the critical month, where a huge difference between the supply and demand has been noticed. Therefore, this month needs special attention with regard to irrigation water supply to bridge the gap. In *Rabi* season, the canal hardly runs and there is a huge difference between the irrigation supply and the demand, as a result of which there is poor productivity and cropping intensity. It is therefore recommended to meet the required demand from the groundwater resources, as it is abundantly available in the study area. Thus, there is a need for conjunctive use of surface water and groundwater to meet the crop water demand in the canal command. Improved canal delivery scheduling also can reduce the gap between supply and demand to a certain extent.

CONFLICTS OF INTEREST

There are no conflicts of interest.

REFERENCES

Agriculture Census Commissioner. (2015). *All India Report on Agriculture Census 2010-11*. Agriculture Census, Department of Agriculture Co-operation & Farmers Welfare, Ministry of Agriculture and Farmers Welfare, Government of India, New Delhi, India. 441 p.

Allen, R.G., Pereira, L.S., Raes, D. and Smith, M. (2004). *Crop Evapotranspiration. Guidelines for Computing Crop Water Requirements*. FAO Irrigation and Drainage Paper No. 56, FAO, Rome, Italy. 300 p.

Assistant Executive Engineer. (2018). *Water Supply in Kharif and Rabi Record Register*. Pratapnagari Irrigation Sub-Division, Department of Water Resources, Govt. of Odisha, Odisha. pp 1-161.

Brouwer, C., Prins, K. and Heibloem, M. (1989). *Irrigation Water Management: Irrigation Scheduling*. AGLW Training Manuals, Training Manual No. 4, FAO, Rome, Italy. 66 p.

Chadha, K.L. (2003). *Handbook of Horticulture*. Directorate of Information and Publications on Agriculture, Indian Council of Agricultural Research, New Delhi, India. 1031 p.

CWC. (2011). Support to the National Water Mission, National Action Plan on Climate Change, Central Water Commission (CWC), New Delhi, India. 147 p.

Deputy Director Agriculture (2017). *Fully Revised Estimate of Area, Yield and Production of Different Crops Grown and the Associate Information of Cuttack District*, Land Utilisation Statistics of Cuttack District, Office of the Deputy Director of Agriculture, Govt. of Odisha, Cuttack, Odisha. 26 p.

Deshpande, T. (2016). *Vital Stats: Status of Water Availability for Agriculture in India*. PRS Legislative Research, Institute for Policy Research Studies, New Delhi, India.

Dhawan, V. (2017). *Water and Agriculture in India*. Background paper for the South Asia expert panel during the Global Forum for Food and Agriculture (GFFA), OAV - German Asia-Pacific Business Association, Hamburg, Germany. 27 p.

Directorate of Economics & Statistics (2018). *Agricultural Statistics at a Glance 2018*, Directorate of Economics and Statistics, Department of Agriculture, Cooperation & Farmers Welfare, Ministry of Agriculture & Farmers Welfare, Government of India, New Delhi, India. pp 287-307.

Gangwar, S. (2013). Water resource of India: From distribution to management. *International Journal of Information and Computation Technology* **3**(8): 845-850.

ICAR. (2011). *Handbook of Agriculture*. Indian Council of Agricultural Research (ICAR), New Delhi, India. 1617 p.

Mishra, A., Verma, H.C. and Singh, R. (2008). Alternative rotational delivery scheduling for better water regime in canal command. *Journal of Irrigation and Drainage Engineering* **134**(2): 175-184.

Raul, S.K., Panda, S.N., Hollaender, H. and Billib, M. (2008). Sustainability of rice-dominated cropping system in the Hirakud canal command, Orissa, India. *Irrigation and Drainage* **57**: 93-104.

Raul, S.K., Panda, S.N., Hollander, H. and Billib, M. (2011). Integrated water resource management in a major canal command in eastern India. *Hydrological Processes* **25**: 2551-2562.