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Appraisal of canal hydraulics and field water balance components at distributary level in Hirakud canal command

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ABSTRACT

Seepage being the most governing process by which water is lost from the canal system and creates hindrance for efficient distribution in crop fields, the accurate estimation of conveyance loss is of paramount importance for proper management. A case study was carried out in Hirakud canal command area at distributary level to assess the prevalent canal hydraulics and its impact on overall distribution in irrigating the crop fields. While studying the conveyance loss in lined and unlined canal reaches in Bargarh distributary, total 84.8% less conveyance loss was obtained in lined canal sections with respect to unlined canal sections, when it was observed as 181.25 ls^{-1} in 100 m in unlined canal sections. Seepage losses computed by Davis-Wilson and Moritz equations for lined and unlined canal sections were found to be less than the measured values. Similarly, irrigation application efficiency was observed 28.75%, when ET_{crop} was 3.66 mm day^{-1}. Thus there is priority requirement to augment canal infrastructure to increase the performance. Further, evaporation, transpiration and deep percolation rates are measured within 1.15 - 2.15, 3.0 - 4.55 and 1.0 - 2.35 mm day^{-1}, respectively while studying through field scale water budget experiments in paddy fields during 2012 and 2013 *rabi* seasons, which are pre-requisite information for scheduling irrigation for crops in the command area.

1. INTRODUCTION

Of India's total net irrigated area of 60.2 mha, 15.3 mha (25%) (Kulkarni *et al.,* 2011) are covered by the canal irrigation schemes. However, the proportion of canal irrigated area has been constantly shrinking. Major reason is attributed to a rapid deterioration of irrigation infrastructure and declining quality in bestowing the irrigation services. Consequently, performance of these schemes becomes bleak due to inequitable water distribution, resulting to poor crop productivity (Kulkarni *et al.,* 2011). While quantifying the loss of water in the canal system, Akkuzu *et al.* (2007) reported that the average water conveyance loss at the main canal and secondary canal level in the Menemen open canal irrigation network in Turkey is 3.0% *i.e.* 0.0141 $ls^{-1}m^{-2}$ km^{-1} and 2.0% (0.0615 $ls^{-1}m^{-2}$) 100^{-1} m. Similarly, Akkuzu (2012) estimated the seepage loss as 32.1 ls^{-1} in 100 m length for the secondary concrete lined trapezoidal canals in same irrigation network while estimating through Moritz and Davis-Wilson empirical equations. Empirical formulae and graphical solutions are generally used to estimate seepage losses in proposed canals, whereas the direct measurements such as inflow-outflow method, ponding method, seepage meter method are used to evaluate seepage from existing canals (Sarki *et al.,* 2008).

Similarly, extensive measurements from farm channels in Pakistan showed that about half of the water leaving the canals is lost before it reached the farmers' field (Kahlown and Kemper, 2004). It is also observed that 80% of the water losses occurred within the top 8 cm of the banks of the old channels while reconstructed channels with moderately compacted banks reduced the water losses to less than 2% of the flowing water per 100 m length of the channels. Compacted soil cores in channel banks reduced water losses to less than 25% of the losses prior to compaction. While modeling water balance components and irrigation efficiencies for double cropping systems, Ali *et al.* (2000)

reported that the mean conveyance efficiency from the Pedu dam to the Pelubang barrage (67 km reach), Malaysia is 66% with the average overall project efficiency as 25%. While determining the conveyance losses of the concrete-lined main secondary and tertiary canals in the Irrigation System of the Ahmetli Regulator in the Gediz Basin (Turkey), Kilic and Tuylu (2011) reported the average conveyance losses of the main, secondary and tertiary canals as 0.067, 0.119 and 0.030 $ls^{-1}m^{-2}$, respectively, which were found higher than the seepage standard of the Bureau of Reclamation. Clemente *et al.* (2013) reported that Irrigation canals placed in natural soil or fine and coarse sediments are characterized by water losses ranging from 20% to more than 50%. They opined that even if employing inflow-outflow tests are considered the best tool for seepage loss study, rigorous method based on the quantification of artificial tracers mass losses is found more accurate.

A number of studies are also reported in India also. Singh *et al.* (2012) while evaluating minor irrigation project in Mehgawan Irrigation project (MIP) in Jabalpur district of Madhya Pradesh using physical, Bio-economical and Social organizational indicators observed that lack of proper irrigation water management is the most important factor for poor performance of irrigation systems. While studying the impact of WUAs on efficiency, equity and reliability using Garrett ranking approach to find constraints to participation in WUAs, Arun *et al.* (2012) observed the overall participation in WUAs satisfactory and the participation increases as farm-size increases. The lack of unity, cooperation and interest among water users has been found to be the most limiting factor, followed by the inequity in water allocation for the active participation in the WUAs. Similarly, Singh *et al.* (2006) while studying the Amarpura minor located in Som-kagdar irrigation project in Rajasthan outlet wise through indicators like adequacy, equity, dependability and relative water supply opined the water delivery performance as "poor". The analysis of results of the spatial and temporal dimensions of these indicators showed that factors causing this problem are derived partly due to physical state of system and partly due to improper operation and management.

Keeping this in background, an assessment study on canal hydraulics and field water balance component was carried out at Bargarh distributary level in Hirakud canal command area of Odisha, India.

2. MATERIALS AND METHODS

Study Area

The study district of Bargarh (Odisha) lies between 20°43' to 21°41' N latitude and 82°39' to 83°58' E longitude. The district is surrounded by Chhattisgarh state on the north, Sambalpur district on the east, Balangir and Subarnapur on the south and Nuapada district on the west in Odisha. The present culturable command area (CCA) of Hirakud multi-purpose river valley project is 1,59,076 ha and the command area is irrigated by three canal distribution systems, namely; Bargarh main canal, Sason main canal and Sambalpur distributary (Fig. 1). The climate of the study area is tropical monsoon in nature. The average annual rainfall is about 1250 mm, out of which 76% is received during monsoon period. The annual temperature variation is about 10-45°C. The command area falls under the agro-climatic zone of Western Central Table Land. The soils of the area comprise light to medium texture, red soils and heavy textured calcareous soils.

The groundwater table fluctuates from 1.5 to 6 m with surface irrigation in practice in the command area. Water is supplied to the command area throughout the year except in the month of May and periodically the canals are closed for 30 days in the month of November and December for maintenance. Due to field to field irrigation and rolling topography of the command area, it creates waterlogged situation in the lower part of the crop fields. Paddy is the predominant crop cultivated both in *kharif* and *rabi* seasons. *Kharif* paddy is transplanted during June/July and harvested in October/November. In *rabi* season, paddy is transplanted during January/February and harvested in May/June. Apart from paddy, arhar, mung, groundnut and mustard are also grown in the command area.

Bargarh main canal off takes from right dyke (84.28 km in length) and with 108.16 cum discharge, it irrigates 1,30,255 ha. The present study is taken up in the command area of Bargarh distributary.

Fig. 1. Bargarh distributary shown in Hirakud command area

Inflow/Outflow method for conveyance loss

Inflow-outflow method was used for measurement of conveyance loss in various canal reaches in the distributary. This method was preferred as the flow in the canal was undisturbed.

The following formula is used to calculate conveyance loss in defined canal reaches [Australian National Committee on Irrigation and Drainage (ANCID, 2003]:

$$S = Q_i - Q_o - E - D + I$$

Where, S is conveyance loss in the canal segment (ls^{-1}), Q_i is inflow to the segment (ls^{-1}), Q_o is outflow from the segment (ls^{-1}), E is evaporation (ls^{-1}), I is inflow to the segment from other sources (ls^{-1}), and D is water diverted from the segment (ls^{-1}). In the present study, water conveyance loss in the canal reaches was calculated in three different ways: i) conveyance loss per unit of canal length (ls^{-1} 100 m^{-1}), ii) conveyance loss as a percentage of inflow (% 100 m^{-1}), and iii) conveyance loss per unit of wet area of the trapezoid canals per unit of time ($ls^{-1}m^{-2}$) (LWRRDC, 2002). In the present study evaporation loss was ignored as from the open surface of the water of the canal per unit time will be minimal.

The velocity of the flow is measured using pigmy type current meter. Flows are measured at the beginning and end section according to the velocity-area flow measurement method. The cross section of the canal at the measurement points was divided into elemental strips of equal width and the current meter was lowered to a depth of 0.6d below water surface in shallow depths and to depths of 0.2d and 0.8d in deep waters to measure the flow velocity. The discharge in each elemental strip is determined and the discharge in the canal section was computed as the sum of the discharged in all the elemental strips. The rate of loss is derived from the difference of the inflow and outflow discharges in a particular canal reach.

Two empirical equations namely; Davis and Wilson equation (Kraatz, 1977; Akkuzu, 2012) and Moritz equation (Hagan, 1973; Millette, 1989; Kraatz, 1977; Akkuzu, 2012) are used for computation of seepage loss in lined and unlined canal sections for comparison with the measured value. The unlined canal in the study area is predominated with clayey loam soil. The equations are as follows:

Davis and Wilson empirical equation:

$$S = 0.45 \text{ x } C \text{ x } \frac{P_w \text{ x } L}{4 \text{ x } 10^6 + 3650 \sqrt{V}} \text{ x } H_w^{1/3}$$

Where, S = seepage losses (m^3 $length^{-1}$ of canal day^{-1}); L = length of canal (m); P_w = wetted perimeter (m); H_w = water depth in the canal (m); V = velocity of flow in the canal (ms^{-1}); C = constant value depending on lining. For concrete lined canals and clayey loam soils (unlined canals), C is taken as 1 and 15, respectively.

Moritz empirical equation:

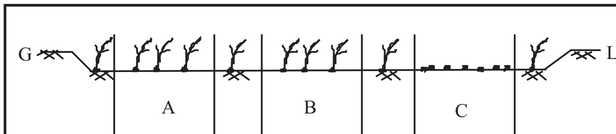
$$S = 0.037 \text{ x } C \text{ x } \frac{Q}{V}$$

Where, S = seepage losses (m^3s^{-1} km^{-1}); Q = discharge (m^3s^{-1}); V = velocity of flow (ms^{-1}); C = constant value depending on soil types. C is taken as 0.1 for concrete lined canals and 0.125 for clayey loam soils (unlined canal).

Field Water Balance Components

Field scale agronomic water balance study was carried out in paddy fields using three drums during *rabi* season 2012 and 2013 (Fig. 2). Different components of irrigation water in rice field like percolation, evaporation, and transpiration were measured by the drum culture technique. Three drums of 50 cm diameter with 120 cm height were used. Out of the three drums, the bottom of one drum was exposed to soil continuum and other two drums were closed from the bottom. Two drums were transplanted with equal number of rice plants (equal plant density was maintained as maintained outside the drums), where as one drum with closed bottom was kept without plants. A constant water level of 10 cm was maintained in the drums. The water level in each drum was measured in every two days interval to ascertain the loss of water. The losses due to ET and percolation were replenished to maintain 10 cm continuous submergence. The different components of water losses were calculated as follows:

Percolation loss = Difference between drums B and A; Evaporation = Daily loss in drum C; Transpiration = Difference between B and A



(A) Drum without bottom (B) Drum with bottom (C) Drum without plant

Fig. 2. Experiment on field scale water balance

3. RESULTS AND DISCUSSION

Bargarh Distributary and its Minors/Sub-Minors

The command area of the Bargarh distributary is 12165 ha with 169 authorized outlets, 10 nos. and 5 nos. of minors and sub minors, respectively. The CCA of the minors and sub minors vary between 331.8 - 4010 ha. The length and design discharge varies between 0.2-4.4 km and 0.22-1.67 m^3s^{-1}, respectively (Table 1).

Conveyance Loss

The study on the conveyance loss in lined and unlined canal sections of the distributary are made keeping the following considerations: (a) the flow is in normal operating condition (b) no change in water level during measurement; (c) no water flow either from outside into the segment or from the segment to the outside; and (d) the length of segment is sufficient for measurement of conveyance loss. As most of the canal sections in Hirakud canal command are unlined, only two lined sections of 100 m stretch are considered for studying the conveyance loss. However, total four unlined sections of 100 m stretch were used for computing the conveyance loss. In order to define the positions of the segments of the canal sections, coordinates of the beginning and end of segments were determined by GPS. The results revealed that average water conveyance loss in the lined canal sections are as 27.5 ls^{-1} in 100 m or (0.49% in 100 m) or (0.0264 $ls^{-1}m^{-2}$). Similarly, the average water conveyance loss in unlined canal sections are computed as 181.25 ls^{-1} in 100 m or (15.43% in 100 m) or (0.409 $ls^{-1}m^{-2}$) (Table 2 and Table 4). There has been 84.8% less conveyance loss in lined channel with respect to unlined channels. However, it is noticed that the conveyance loss determined for the study is higher than the seepage limit value given by Kraatz (1977) (0.03 m^3m^{-2} day^{-1} *i.e.* 0.0003 $ls^{-1}m^{-2}$) and that given by LWRRDC (2002) (0.0005 m^3 m^{-2} day^{-1} *i.e.* 0.00001 $l\,s^{-1}m^{-2}$). Seepage losses are estimated through two empirical equations namely Davis and Wilson equation and Moritz equation. The seepage looses estimated through both the methods are computed as very less in comparison to the measured values for lined and unlined canal sections (Table 3 and Table 5). Hence, calibration is suggested before using the empirical methods. However, maintenance of the canals is required to be given priority to increase the overall efficiency.

Table: 1
Details on Bargarh distributary and its minors and sub minors

Details	Discharge (m^3s^{-1})	Length (m)	Command Area (ha)
1. Bargarh Distributary	9.393	29.718	12165.00
2. Padhanpali Mr.	1.673	0.835	1186.58
2.1 Jamurda S. Mr.	0.275	1.828	4010.05
2.2 Barahgoda S. Mr.	0.244	1.524	370.70
2.3 Amsada S. Mr.	0.237	1.371	350.47
3. Tora Mr.	0.266	0.990	354.11
4. Dhanger Mr.	0.380	2.133	618.38
5. Malipali Mr.	1.090	4.419	1056.67
5.1 Khandahata S. Mr.	0.390	2.133	618.38
6. Argaon Mr.	0.458	2.499	696.08
7. Patrapali Mr.	0.283	3.108	431.41
8. Talpali Mr.	0.228	1.828	385.27
9. Pipilipali Mr.	0.322	2.743	378.39
10. Dekulba Mr.	0.674	1.752	331.85
10.1 Dekulba S. Mr.	0.346	0.194	466.61
11. Jamdol Mr.	0.222	1.298	382.84

Irrigation Application Efficiency

Irrigation application efficiency, which is the ratio of the average water depth applied to the water consumed by the crop was computed at outlets in Malipali minor having CCA ranging between 25.779.4 ha. Water consumed by the crop was determined by Hargreaves *et al.* (1985) and Hargreaves (1994) used methodology. The daily reference evapotranspiration (ET_0), which requires extraterrestrial solar radiation, mean daily maximum and minimum temperature data for ET_0 estimation only is computed by the following:

$$Et_0 = 0.0023\, R_a\,(T_{mean} + 17.8)\,(T_{max} - T_{min})^{0.5}$$

Where, ET_0 *is* reference evapotranspiration (mm day^{-1}); R_a is extraterrestrial solar radiation (MJ $m^{-2}day^{-1}$); T_{max} is

Table: 2
Measured conveyance loss in lined canal section

Name of the canal section	Section	Coordinates	Water depth (m)	Water surface width (m)	Average wetted perimeter (m)	Inflow (m^3s^{-1})	Outflow (m^3s^{-1})	Conveyance losses		
								ls^{-1} in 100 m	% in 100 m	ls^{-1} m^{-2}
Bargarh										
	Start segment	21°18′03.2″N 83°40′06.5″E	1.49	10.2	13.98					
						9.130	9.115	15.0	0.16	0.0108
	End segment	21°18′13.2″N 83°40′04.3″E	1.50	10.8	13.86					
Nuagarh										
	Start segment	21°16′21.2″N 83°41′52.0″E	1.10	7.83	9.77	4.87	4.83	40.0	0.82	0.0419
	End segment	21°16′23.2′N 83°41′47.0″E	1.03	7.67	9.33					
	Average							27.5	0.49	0.0264

Table: 3
Estimated seepage losses in lined canal sections

Canal name	Average wetted perimeter (P_w) (m)	Average water depth (H_w) (m)	Average velocity (V) (ms^{-1})	Inflow (Q) (m^3s^{-1})	Davis-Wilson Eqn.	Moritz Eqn.
					ls^{-1} in 100 m	
Bargarh	13.92	1.495	0.655	9.13	2.07E-06	5.16
Nuagarh	9.55	1.065	0.645	4.87	1.27E-06	2.80
Average					1.67E-06	3.98

Table: 4
Measured conveyance loss in unlined canal section

	Canal name	Coordinates	Water depth (m)	Water surface width (m)	Average wetted perimeter (m)	Inflow (m^3s^{-1})	Outflow (m^3s^{-1})	Conveyance losses		
								ls^{-1} in 100 m	% in 100 m	ls^{-1} m^{-2}
	Start segment	21°13'57.6" N 83°42'55.0" E	0.75	3.85	5.41					
Andhratikra						1.890	1.595	295	15.61	0.569
	End segment	21°13'35.0" N 83°42'57.9" E	0.676	3.51	4.95					
	Start segment	21°16'21.2" N 83°41'52.0" E	1.032	5.83	7.1					
Sanharatikra						1.775	1.665	110	6.19	0.162
	End segment	21°16'23.2" N 83°41'47.0" E	0.928	5.56	6.52					
	Start segment	21°12'56.3" N 83°43'39.4" E	0.492	2.9	4.12					
Kubedega						0.84	0.70	140	16.67	0.347
	End segment	21°12'52.6" N 83°43'39.9" E	0.48	2.9	3.94					
	Start segment	21°13'21.4" N 83°43'8.8" E	0.542	2.3	3.32					
Negitikra						0.775	0.595	180	23.23	0.556
	End segment	21°13'21.9" N 83°43'7.9" E	0.514	2.5	3.16					
	Average							181.25	15.43	0.409

Table: 5
Estimated seepage losses in unlined canal sections

Canal name	Average wetted perimeter (P_w) (m)	Average water depth (H_w) (m)	Average velocity (V) (ms^{-1})	Inflow (Q) (m^3s^{-1})	Davis-Wilson Eqn.	Moritz Eqn.
					ls^{-1} in 100 m	
Andhratikra	5.18	0.713	0.67	1.89	9.03E-06	1.30
Sanharatikra	6.81	0.98	1.76	1.78	1.32E-05	0.47
Kubedega	4.03	0.486	0.55	0.84	6.19E-06	0.71
Negitikra	3.24	0.528	0.59	0.78	5.11E-06	0.61
Average					8.38E-06	0.77

daily maximum air temperature (°C); T_{min} is daily minimum air temperature (°C); and T_{mean} is daily mean air temperature (°C).

The crop evapo-transpiration, ET_{crop} is calculated using the crop coefficient values, K_c (Doorenbos and Pruitt, 1975). Similarly, application of amount of water is computed through the outlets per day basis using pigmy type current meter. The total water consumed is computed as 492.3 mm in a crop period of 100 days. The results revealed that irrigation application efficiency is observed within the range between 28.7-53.1%, when ET_{crop} varied between 3.6-6.5 mm d^{-1} (Table 6).

Similar observation was reported by Singh *et al.* (2012), while assessing performance of irrigation project in Mehgawan Irrigation project (MIP) in Jabalpur district of Madhya Pradesh, India using physical, bio-economical and social organizational indicators. The overall efficiency of project was reported as 23.4% whereas conveyance, application and distribution efficiency were reported as 52, 64.8 and 69.8%, respectively.

Table: 6
Irrigation application efficiency, %

Details of the outlet	Q (m^3s^{-1})	Water applied (mm)	CCA (ha)	Irrigation Application Efficiency (%)
O_L	0.0089	177.93	43.217	36.14
O_L	0.0042	141.35	25.673	28.71
O_R	0.007	150.87	40.051	30.67
O_R	0.024	261.16	79.362	53.07
O_L	0.01	217.05	39.800	44.09

Field Water Balance Components

Field scale agronomic water balance study made in paddy fields using drum culture technique during *rabi* crop season 2012 and 2013 (Fig. 2). Different components of irrigation water in rice field like percolation, evaporation, and transpiration were computed and found within the range of 1.15-2.15, 3.0-4.55 and 1.0-2.35 mm d^{-1}, respectively (Fig. 3).

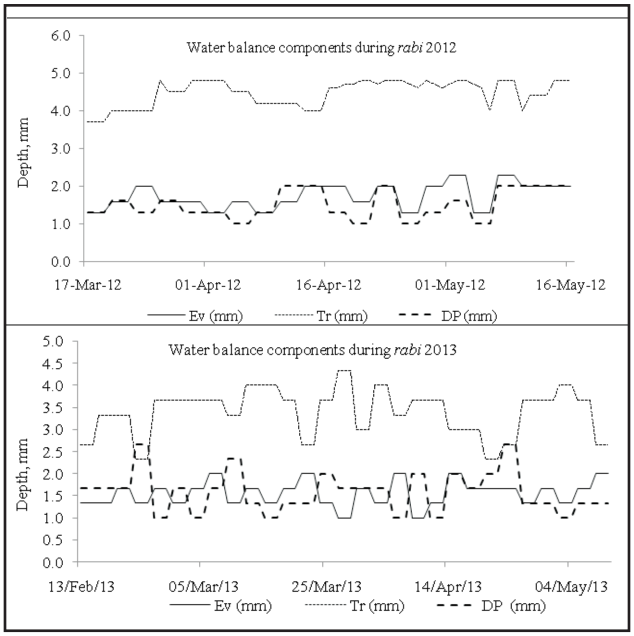


Fig. 3. Measured water balance components during *rabi* season 2012 and 2013

4. CONCLUSIONS

The command area of Bargarh distributary in Odisha is provided with irrigation water through canals fed directly from Hirakud reservoir by gravity flow on field to field flooding basis. The misfortune is that the canals are mostly unlined and at many sections ill maintained, thereby causing enormous loss of water on its flow. Thus, there is need of augmenting irrigation infrastructures to increase the overall efficiency. As a result, improvement in irrigation efficiency will help in proper crop planning with equitable water distribution in the command area.

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