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Performance Evaluation of Irrigation Canals in the Middle Gujarat Region

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ABSTRACT

The study was undertaken to assess the performance of the irrigation project in terms of adequacy, dependability, equity and efficiency. Seasonal volumetric gross irrigation requirement was estimated by using standard methodology. Daily water delivery of the different canals for the crop period 2014-15 and 2015-16 was collected from potential sources and converted to monthly volumetric flow. The average values of adequacy, dependability, equity and efficiency were found to be 0.72, 0.40, 0.38 and 0.88, respectively that indicates overall "poor" performance of the irrigation project. Hence, it needs to be improved by proper management and adequate maintenance including the incorporation of right irrigation scheduling strategies in order to achieve this immediate objective.

Key words *performance measure; adequacy; dependability; equity; efficiency; gross irrigation requirement; Wadhwana irrigation project*

Pre-independence India suffered from repeated famines and drought and the country was far from food self-sufficiency because most of the agriculture was mainly rain-fed and the rainfall was highly erratic due to vagaries of the monsoon. Many reservoir-based irrigation projects, therefore, became operational in India in order to overcome severe drought conditions. The irrigated agriculture in India that accounts for nearly 56% of all food grain production in the country (Planning Commission 2002) consumes around 87% of the developed water resources of the country (WWAP 2015). Besides providing water for irrigation, canals also act as a source of intensive seepage into the groundwater in highly pervious tracts. Continuous seepage from canals and percolation losses from field irrigation including inadequate maintenance results in poor performance of the canal system, thus for project planning and management, the objectives of water-delivery systems often are viewed in terms of the desire to best meet these water requirements. The irrigation performance studies have to be carried out with the objective of improving the system operation, to assess the general health of the system, to assess the impact of intervention, to diagnose the constraints and to compare the performance of the system with other systems or with same system over time. Water delivery system design has traditionally focused on specifying the carrying and regulating capacity of the delivery structures and on increasing the water conveyance efficiency. Keeping all these aspects in consideration following objective was proposed for the Wadhwana tank irrigation system like adequacy, dependability, equity and efficiency and evaluate the overall performance of the irrigation canals.

Water delivery performance of a minor under the left main canal of Som-kagdar irrigation project was examined by Singh *et al.* (2006). Outlets wise performance was evaluated, using the adequacy, equity, dependability and relative water supply indicators. Digital current meter was used to measure the outlet discharge during the season. Crop water requirements were calculated using CROPWAT. The outlet wise water delivery performance indicators showed poor performance of the system. The analysis of results of the spatial and temporal dimensions of these indicators showed that factors causing the problem are derived partly due to physical state of system and partly due to improper operation and management.

A study was conducted in the command area of Guvvalagudem major distributary of the Nagarjunasagar Left Canal, Andhra Pradesh by Rao and Rajput (2006) to determine weekly canal water supplies and demands and their possible imbalances. It was concluded that most of the times canal supplies were lesser than the design capacity and there were wide gaps between weekly canal water demands and supplies. The mismatch between the annual supplies and the annual demands were lesser in magnitude (up to 20%) when compared to the weekly mismatches, which went up to 100% in some cases. similar study(Bahramloo (2007), Korkmaz *et al.* (2009), Akkuzu (2012), Sarojini Devi *et al.* (2012)),have been done performance regarding to canal over all efficiency performance, seepage analysis and mover about the command area development and irrigation water management study.

Study Area

The study area is located very near to the Wadhwana village, which comes under the periphery of Vadodara district in Gujarat state covering an area of 7,380 ha. It is situated at 22.17° N latitude and 73.48° E longitude. The altitude of the study area is about 96 m above mean sea

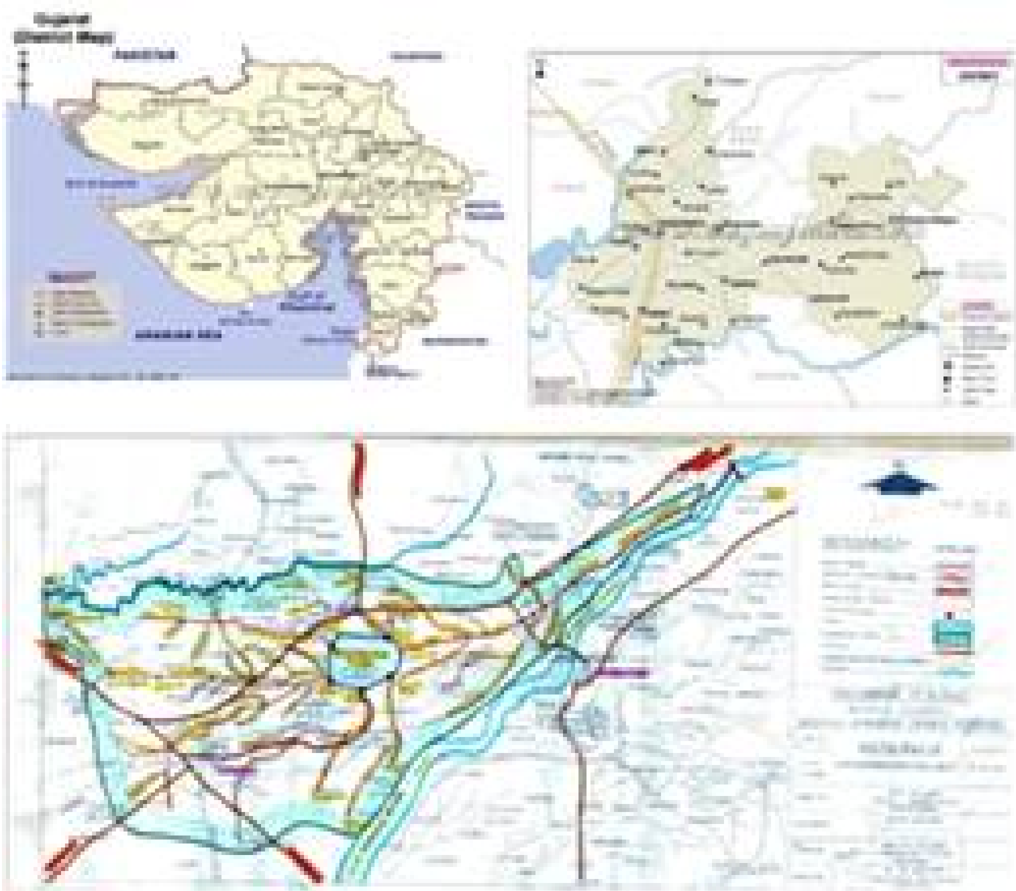

Fig.1. Study area map.

Table 1. Properties of Soils in the Study Area

Sr. No.	Soil properties	Value
A	Physical	
	Bulk density (gm/cc)	1.3 – 1.5
	Maximum water holding capacity (%)	46.5 – 54.7
	Soil Type	Medium Black
B	Chemical	
	EC (micromhos/cm)	1100
	pH	7.9 – 8.2
	Available N_2 (kg/ha)	95
	Available P_2O_5 (kg/ha)	55
	Available K_2O (kg/ha)	545

Table 2. Details of the Main Canals under Wadhwana Tank

Canal No.	Canal Name	Length (km)	CCA (ha)
C1	Bhimpura main canal	3.24	431
C2	Wadhwana Boriad main canal	5.61	824
C3	Dabhoi main canal	7.06	2398
C4	Vasai Dangiwada main canal	8.59	847
C5	Simliya canal	1.21	112

level. The location map of the study area is presented in Fig. 1. The climate of this district is characterized by sub-tropical and semi arid. Summer is very hot and winter is too cold. The annual rainfall of the area varies between 800 to 1000 mm. On an average there are only 35 to 40 rainy-day per annum, which mostly falls during the period mid – June to mid –September. There are frequent dry spells occurring over years. January is the coldest month of the years with mean monthly temperature varying from 7 to 25^{o}C, whereas may is the hottest month of the year with maximum temperature varying between 30 to 45^{o}C. Mmajor crop of this area are paddy, bajara, juvar, cotton and wheat. The CCA of the command is 4,612 ha. Paddy is the major crop cultivated during *Kharif* season covering around 60 to 65% of CCA, whereas wheat is the major crop practiced during *Rabi* season covering about 40 to 45% of CCA. The soil property of the study area is shown in tablel(1) which is self explinary. The canal irrigation system is mostly in use for irrigation water is diverted from the Jojva-Wadhwana reservoir through a main canal for storage in the Wadhwana tank. The storage capacity and the wetted area of the tank are around 453.6 million cubic feet and 1,430 acres, respectively. The water from the tank is diverted to five main canals Table 2, which are mostly unlined, through separate outlets, from where it is conveyed to the agricultural lands either through direct outlets or through a network of unlined canals .

MATERIALS AND METHODS

A current meter is the best instrument for measuring the velocity of flow, and is generally and universally adopted for this purpose. the most common and widely used in India is the Price's current meter, which is used to measure the velocity of flow in the Wadhwan main canal (Fig.2). The formula for calculating the flow velocity by a current meter at any depth is given by:

$$V_d = a + bN \qquad \ldots (1)$$

where, V_d = velocity of flow at any depth (m/s); N = Number of revolutions made by the wheel per second; a & b are constants given by the manufacturer. The values of a and b are 0.0397 and 0.2993, respectively, for the current meter used in this study. The depth of flow in the channel was found to be more than 1.0 m, hence the following was used to estimate the flow velocity at any section formula (Murty and Jha, 2009).

$$V = \left(\frac{V_{0.2} + 2V_{0.6} + V_{0.8}}{4}\right) \qquad \ldots (2)$$

where, $V_{0.2}$ = flow velocity at 20% depth of flow; $V_{0.6}$ = flow velocity at 60% depth of flow; and $V_{0.8}$ = flow velocity at 80% depth of flow.

Canal flow rate was then estimated by using the following equation.

$$Q = A \times V \qquad \ldots (3)$$

Fig.2. Canal Flow Velocity Measurement

Fig.3 Measurement of Flow Cross-sectional Area

Table 3. Performance Standards for Irrigation Systems

Measure	Performance Classes		
	Good	Fair	Poor
PI_A	0.90 - 1.0	0.80 - 0.89	< 0.80
PI_{EF}	0.85 - 1.0	0.70 - 0.84	< 0.70
PI_E	0 - 0.10	0.11 - 0.25	> 0.25
PI_D	0 - 0.10	0.11 - 0.20	> 0.20

where, Q = canal flow rate (m^3/s) and A = cross-sectional area of flow (m^2).

Computation of Irrigation Water Requirement

The head and middle reach farmers draw more water from the canal system, resulting in tail-reach farmers being deprived of the minimum quantity of irrigation water. Hence it is required to compute net irrigation requirement (*NIR*) of crops for better water management.

$$NIR = ET_c - R_e \quad \text{.......................... (4)}$$

where, ET_C = crop evapotranspiration (mm), which is equal to $(ET_0 \times K_c)$; ET_0 = reference crop evapotranspiration (mm); K_C = crop coefficient; and R_e = effective rainfall (mm).

Total water requirement at the field level, which is termed gross irrigation requirement (*GIR*) can be estimated as (Raul *et al*., 2008).

$$GIR = \frac{NIR}{E_a} + SPR - SMC - GWC \quad \text{............ (5)}$$

where, SPR = special purpose water requirement (mm) (200 mm for paddy and 70 mm for other crops); E_a = irrigation system efficiency (product of conveyance and field application efficiencies) (fraction); SMC = soil moisture contribution (mm); GWC = contribution from groundwater (mm).

Canal Performance Measures

The performance measures for analysis of irrigation water delivery systems in terms of adequacy (PI_A), efficiency (PI_{EF}), dependability (PI_D) and equity (PI_E) of water delivery. The performance indicators expressed in terms of measurable quantities are called state variables. The major state variables that determine water-delivery-system performance may be defined in terms of an amount of water *Q,* which may refer to either rate, volume, frequency, or duration of water delivery. In the present study, we focus on rates and volumes of water delivery. At a point *x* in the system and at time *t*,

$Q_D(x, t)$: Actual amount of water delivered to the system at a point '*x*' in time '*t*'.

$Q_R(x, t)$: Actual amount of water required for consumptive and other uses downstream of the delivery point *x*.

CV_T: Temporal coefficient of variation over the standard time period *T*.

CV_R : Spatial coefficient of variation over the region *R*.

These state variables are combined in various forms to develop indicators of performance viz. PI_A, PI_D, PI_E and PI_{EF} (Molden and Gates, 1990).

The Point Performance function relative to adequacy (PI_A) is given by:

$$PI_A = \frac{1}{T}\sum_T\left(\frac{1}{R}\sum_R P_A\right) \quad \text{... (6a)}$$

where ,

$$P_A = \frac{Q_D}{Q_R}, \text{ if } Q_D \text{ d" } Q_R \quad \text{... (6b)}$$

P_A = 1, otherwise

... (6c)

where, P_A = Point performance function relative to adequacy

Water-delivery efficiency incorporates the concept of conveyance efficiency, since water requirements at a point of delivery include expected downstream losses are given by;

$$PI_{EF} = \frac{1}{T}\sum_T\left(\frac{1}{R}\sum_R P_{EF}\right) \quad \text{... (7a)}$$

where, $P_{EF} = \frac{Q_R}{Q_D}$, for Q_R d" Q_D ... (7b)

P_{EF} = 1, otherwise ... (7c)

A farmer can plan for a dependable delivery of an inadequate supply of water by planting less or growing different crops or adjusting other farming inputs. However, a farmer cannot easily plan when the supply of water is unpredictable.

$$PI_D = \frac{1}{R}\sum_R CV_T\left(\frac{Q_D}{Q_R}\right) \quad \text{... (8)}$$

where, $CV_T\left(\frac{Q_D}{Q_R}\right)$ = temporal coefficient of variation (ratio of standard deviation to mean) of the ratio $\left(\frac{Q_D}{Q_R}\right)$ over the time period *T*. Equity has been defined as spatial uniformity of the ratio of the delivered amount of water to the required or scheduled amount. Performance measure relative to equity is given by,

$$PI_E = \frac{1}{T}\sum_T CV_R\left(\frac{Q_D}{Q_R}\right) \quad \text{................ (4.9)}$$

where,

$CV_R\left(\frac{Q_D}{Q_R}\right)$ = spatial coefficient of variation (ratio of standard deviation to mean) of the ratio over the region

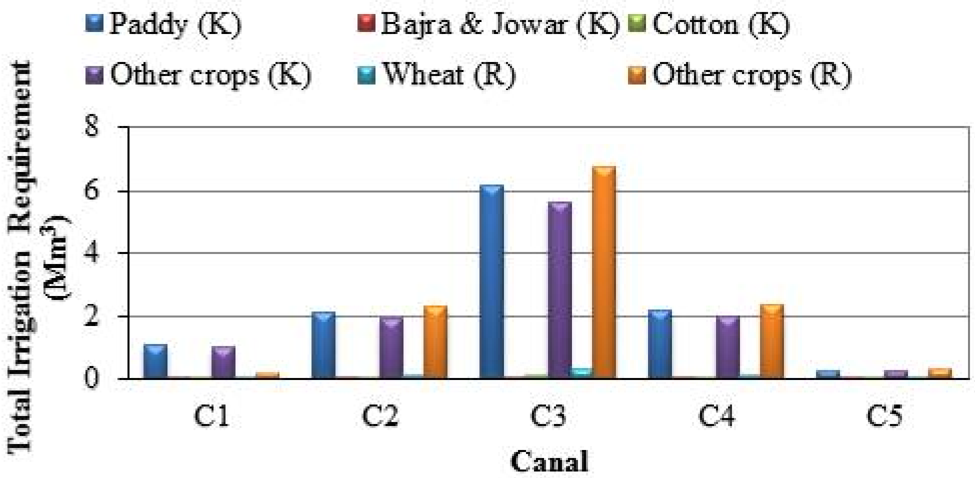

Fig. 4. Gross Irrigation Requirement of Crops during 2014-15

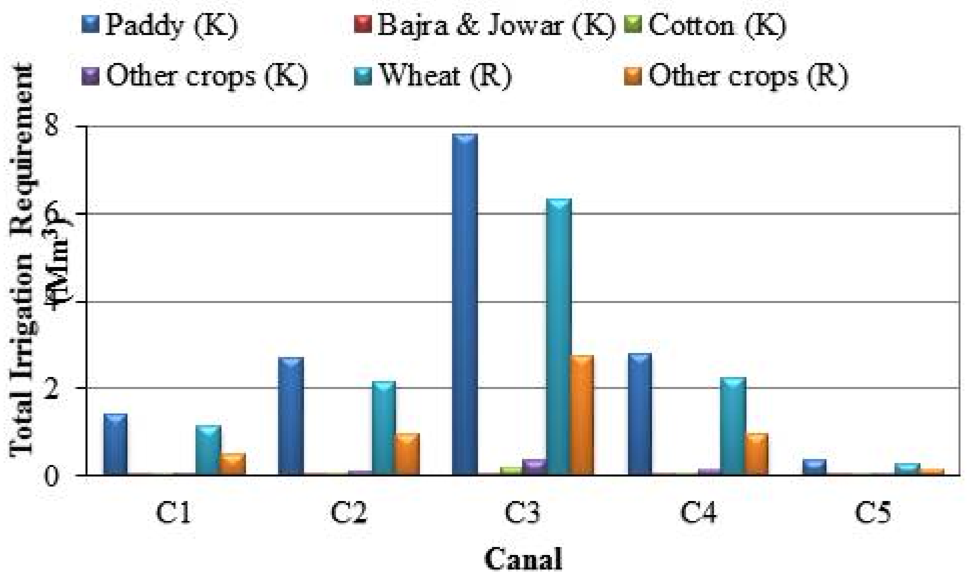

Fig. 5. Gross Irrigation Requirement of Crops during 2015-16.

R. The standards for these indicators are furnished in Table 3.

RESULT AND DISCUSSION

The results obtained from the analysis of secondary data such as canal flow, rainfall and cropping pattern and estimation of irrigation water requirement for deriving the canal performance measures. The Rainfall data were taking during the period 2014 and 2016 was collected from the Irrigation department, Wadhwana Tank site, Wadhwana, Vadodara. which was used to estimate effective rainfall (R_e) by the USDA-SCS method. Wetted area of flow was calculated by prismoidal method. Flow velocity was measured in the head, middle and tail reach of a 880 m length canal. Discharge in the three sections was found to be 32, 29 and 27 cusec, respectively. Accordingly, the conveyance efficiency of the selected reach of the Wadhwana Boriad main canal was estimated as 84% and due to unlined nature of the canal as well as poor maintenance causing siltation, excessive weed growth and damage by the rodents and reptiles resulting in huge water loss.

Computation of Gross Irrigation Requirement

Total volume of irrigation water required by paddy, bajra & jowar, cotton and other crops during the *Kharif* season and wheat and other crops during the *Rabi* season of 2014-15 were 15.1, 0.37, 0.42, 0.71, 12.1 and 5.32 Mm^3, respectively (Fig.4). Total volume of irrigation water required by paddy, bajra & jowar, cotton and other *Kharif* crops and wheat and other *Rabi* crops during 2015-16 were 11.82, 0.074, 0.27, 0.67, 10.8 and 11.93 Mm^3, respectively (Fig.5).

Performance Measures of Wadhwana canal during 2015-16

The total operation periods during the crop year 2014-15 & 2015-16 for the canals C1, C2, C3, C4 and C5 were

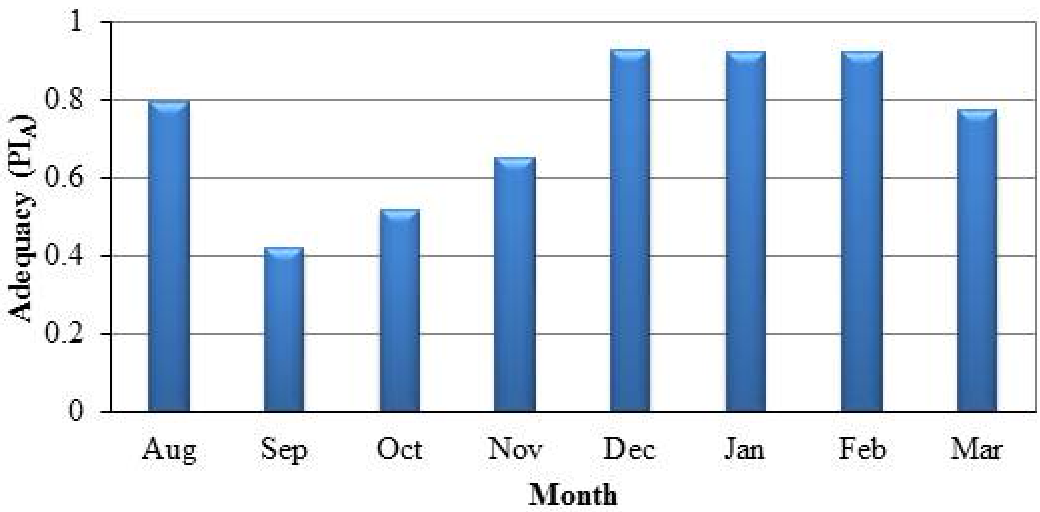

Fig 7. Adequacy Index of Wadhwana canal during 2015-16

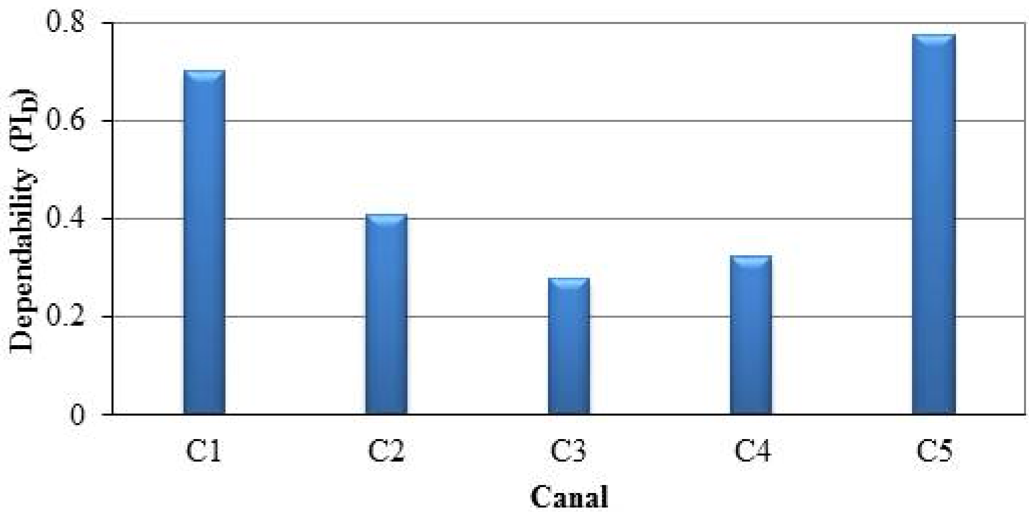

Fig. 8. Dependability of Wadhwana Canal during 2015-16

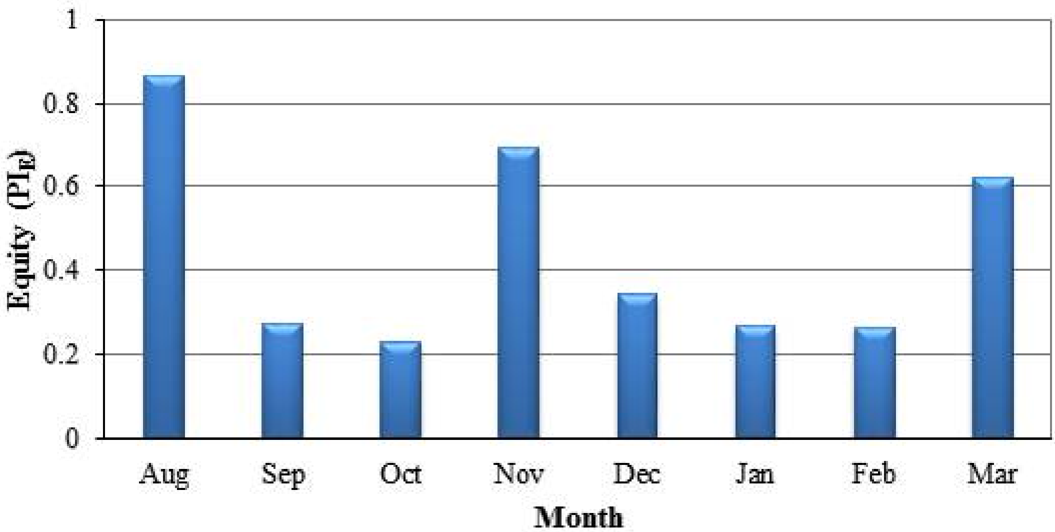

Fig. 9. Equity index of Wadhwana canal during 2015-16

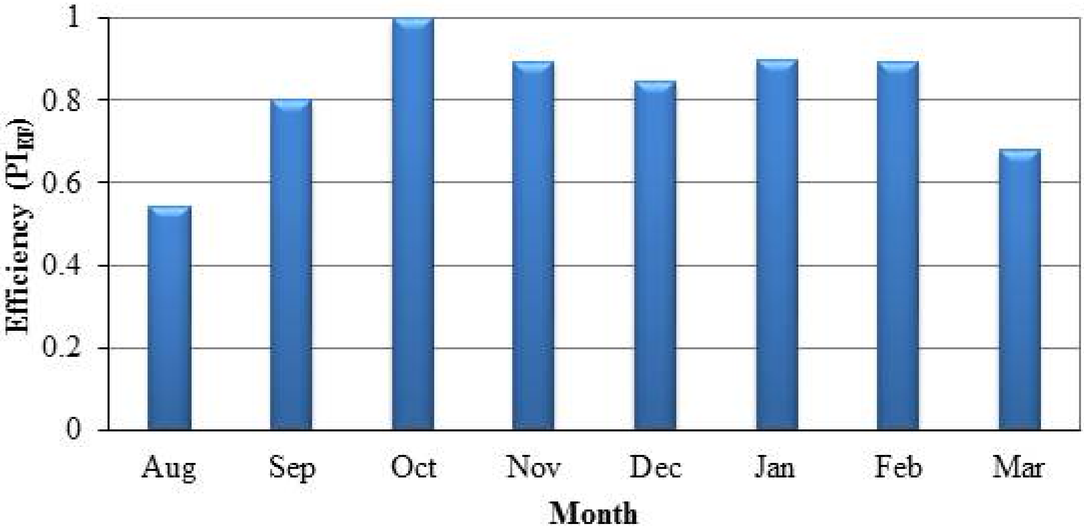

Fig.10. Efficiency Index of Wadhwana canal during 2015-16

Table 4. Performance Measures of Water Delivery in the Wadhwana Canal

Year	Adequacy (PI_A)		Dependability (PI_D)		Equity (PI_E)		Efficiency (PI_{EF})	
2014-15	0.69	poor	0.30	poor	0.31	poor	0.95	good
2015-16	0.74	poor	0.49	poor	0.44	poor	0.81	fair

flowing average a 131, 140, 148, 128 and 68 days, respectively. This variation was mainly due to supply position in the Wadhwana tank.

Adequacy (PI_A)

The adequacy during the months December, January and February for the crop year 2015-16 was greater than 0.9 whereas other months possessed values between 0.4 and 0.8 (Fig.6). The average value of PI_A in Wadhwana canal was 0.74 indicating a 'poor' performance as far as the adequacy is concerned. The low values of PI_A were mainly due to uneven distribution of rainfall in the season.

Dependability (PI_D)

The average value of PI_D for the year 2015-16 was 0.49, which fall above the upper limits accounting to 'poor' performance (Fig.8). This indicates that the water deliveries were not in accordance with the demand over the area. Also, sometimes, closure of irrigation canal in response to high rainfall during the months of July, August and September might have resulted in high PI_D values.

Equity (PI_E)

The average values PI_E in Wadhwana canal for the year 2010-11 were 0.44, which fall above the upper limits that accounting to "poor" performance. The PI_E values were less than 0.25 for the month October which indicate equitable distribution of canal water in the Wadhwana canal, whereas higher values in other months indicate inequitable distribution (Fig. 6).

Efficiency (PI_{EF})

The average values efficiency in Wadhwana canal for the year 2015-16 was 0.81 that indicates a "fair" performance. The lower value of PI_{EF} indicates that the system was not efficient to meet the requirements of the region. The PI_{EF} value was 1.0 during the month of October (Fig. 10).

The average values of the performance measures like adequacy, dependability, equity and efficiency of the Wadhwana canal during 2014-15 and 2015-16 are summarized in Table 4. It can be concluded that the overall performance of the Wadhwana tank irrigation system is 'poor', which needs to be improved by proper maintenance. Proper irrigation scheduling also required to be followed for achieving this goal.

CONCLUSIONS

The following conclusions have been derived from the present study are;

1. The conveyance efficiency in 880 m reach of a main canal is only 84%, indicating very poor level of conveyance resulting from unlined nature of the canal and poor maintenance.
2. Uneven spatio-temporal distribution of rainfall results in wide variation in irrigation water requirements over years that needs attention in regard to proper irrigation scheduling.
3. Wide gap in supply and demand has resulted in "poor" performance of the irrigation project. Proper

care and maintenance of the canal system is highly essential to improve the overall performance of the project.

Future Scope of Study

Future investigations may be carried out in consideration to the following aspects:

- Performance of the irrigation project in view of water use efficiency.
- Loss of water due to either over-irrigation or seepage from canals leading to land degradation.

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