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Assessment of wadi distributory of WRP with MIKE11

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ABSTRACT : A research project entitled as hydraulic assessment of Wadi distributory of Wan River Project using MIKE 11' was undertaken with the objective to assess the hydraulic performance of Wadi distributory using validated MIKE 11 model. The MIKE 11 model was calibrated and validated for the period December 2007 to April 2008 and December 2008 to March 2009. The average discharge variation was found to be 4.34 per cent, while Nash Sutcliffe co-efficient, RMSE and co-efficient of determination was found to be 0.92, 0.0263 m^3/s and 0.94, respectively. Water delivery performance ratio was calculated for the validation period. Average decline in the average WDPR was from 1.0 to 0.72, 0.72 to 0.68 and 0.68 to 0.64 for head, middle and tail reaches, respectively along the canal path.

KEY WORDS : Unsteady flow, 1-dimensional flow, Rivers modeling, MIKE 11 HD

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Interacting in a complex manner to influence human lives and activities, soil and water are among the major resources impacting upon the Earth's hydro geological and biological systems (Singh, 1995). To cope with the rising food demand under a rapidly increasing world population, the need to develop land and water resources is gaining momentum at an alarming rate. At the watershed level, an efficient, equitable and, most importantly, sustainable development of such resources is a very demanding task. In the current age of information, engineer's responsibility extends beyond building various irrigation tools and facilities, to precisely allocating and scheduling irrigation water to the agricultural fields. Tail-end deprivation is a common problem caused by excess withdrawal of water at the head reach in major irrigation schemes that result in poor performance of canal system. MIKE 11 is developed for simulating basic or complex hydrodynamic conditions found in rivers, lakes and reservoirs, irrigation canals and other inland water systems. The hydrodynamic module (HD) represents the heart of MIKE 11 and contains all the core functionality for simulating hydrodynamic processes in the canals. It uses an implicit, finite difference solver that calculates water level and flow from rivers and estuaries. In ideal system the distribution of water over the length of canal should be equal, but it is never the case. Tail end deprivation is common problem associated with canal irrigation system. Thus, for improvement of performance of canal irrigation system, assessment of it's performance become essential. Therefore a study was undertaken to assess the performance of canal network of Wadi Distributory of Wan River Project using MIKE 11.

METHODOLOGY

The study area comprised of command of Wadi Adampur distributory which takes off from branch canal of Wan River Project (Fig. A). The details of the distributory are given in Table A. The command receives an average annual rainfall of 890 mm. The minimum and maximum temperatures range from 9.9 to 28.0°C and 28.6 to 46.5°C, respectively. The climate of area is Semi-Arid. The soils of command are clayey in nature. Two crop seasons, *viz*., *Kharif* (June to October) and *Rabi* extending to summer (November to April) are followed in the command. Major crops grown are cotton, soybean, pigeonpea, wheat, chickpea and vegetable. The canal water is generally released for irrigation during November to April.

Data requirement:

Following data in respect of Wadi Adampur distributory were collected and given in the Table B.

Governing equations:

MIKE 11 HD solves the Saint-Venant equations using finite difference scheme to obtain the hydrodynamic state of

Table A : Details of distributory

Name of distributory	Off take point at branch canal (m)	Length of distributory (m)	Design discharge at head of the distributory (m^3/sec)	Total command area (ha)
Wadi	1205	6580	2.79	1634
M3	2665	1220	1.54	
M4	4380	5500	1.94	
M5	4750	5650	1.96	

Table B : Data requirement of various components of MIKE 11

Component	Data	Nature of data
River network	Horizontal discretization (Grid size)	L sections of canal
Cross section	Cross section of canal, structure	L section map,
Boundary file	Daily discharge data, water level	Time Series (T_0)
Hydrodynamic parameter	Roughness coefficient, ground water leakage coefficient	Spatially varying value

the canal system. The Saint-Venant equations for conservation of mass and momentum are as follows:

$$\frac{\partial \mathbf{Q}}{\partial \mathbf{x}} + \frac{\partial \mathbf{A}}{\partial \mathbf{t}} = \mathbf{q} \qquad (1)$$

$$\frac{\partial \mathbf{Q}}{\partial \mathbf{t}} + \frac{\partial (\propto \frac{\mathbf{Q}^2}{\mathbf{A}})}{\partial \mathbf{x}} + \mathbf{gA}\frac{\partial \mathbf{h}}{\partial \mathbf{x}} + \frac{\mathbf{gQ}|\mathbf{Q}|}{\mathbf{C}^2\,\mathbf{AR}} = \mathbf{0} \qquad (2)$$

where,

Q = Discharge, m^3/s;

A = Flow area, m^2;

q = Lateral inflow, m^2/s;

h = Stage above datum, m;

C = Chezy's resistance co-efficient, $m^{1/2}$/s;

R = Hydraulic or resistance radius, m;

α = Momentum distribution co-efficient;

g = Ratio of weight to mass, 9.81 m/s^2;

x = Longitudinal distance in the direction of flow, m; and

t = Elapsed time, s.

MIKE 11 model setup:

The MIKE 11 model setup was specified by defining the canal layout, canal cross-sections, initial conditions, and boundary conditions. The model was setup using network, cross section, hydrodynamic parameter and boundary editor, provided in the HD module of MIKE 11 model.

Canal network definition:

Canal network was defined by name and chainage of the canal, upstream and downstream connections, topographical identification and maximum selected distance between two neighboring points (dx-max) *i.e.* 100 m. The longitudinal profile of the Wadi distributory shows the relative distance of the locations, where the cross sectional data, bed levels and full supply level are entered in the model setup (Fig. A). Wadi distributory runs over distance of 6.580 km. 26 falls with magnitudes ranging from 0.45 to 1.2 m are in the system inspite of gradual decrease in the elevation.

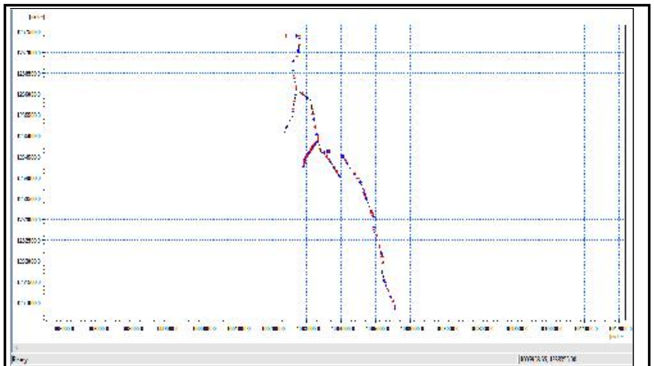

Fig. A : Canal network for Wadi Adampur Distributory

Cross-section data definition:

A large number of canal cross-sections are defined with individual cross-section identified by canal name, topographical identification and the chainage. Since the cross-section data are available at discrete points in the canal system,

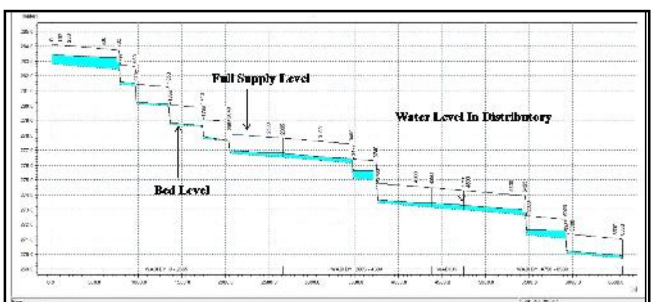

Fig. B : Longitudinal profile of the Wadi Adampur distributory

cross-sections are defined in the model setup at locations where the distributaries are off taking and falls (drop in elevation) exists in the canal.

Boundary conditions:

Boundary conditions are required to close the system of equations to be solved by the double Sweep method. Boundary conditions were specified with daily discharge data at system source and water level at tail end points.

Hydrodynamic parameters:

Parameters like initial conditions, type of wave, bed resistance etc. were defined in hydrodynamic parameter editor file that was used by the model during simulation. The initial conditions are specified as global values of water levels and discharges for the entire canal network.

Simulation control parameters:

After defining the canal system, the simulation control parameters such as simulation time, simulation time step, data storage time and data to be stored was specified using simulation editor. The simulation period is specified by a start and end dates. The time step was finalized as one minute by trial and error method.

Calibration and validation of the model:

After successful simulation, the model was calibrated and validated with resistance number *i.e.* Stickler's co-efficient *i.e.* M and ground water leakage co-efficient as the model calibration parameters using AUTOCAL, a generic tool under MIKE ZERO. Locations at 100 m along the Wadi, M3, M4 and M5 distributory are selected for calibration based on the availability of observed flow data. The model was calibrated for the period December 2007–April 2008 (having six irrigation - 84 days). Calibrated model was validated for the period December 2008–March 2009 (having five irrigation periods – 75 days).

Model performances:

The performance of model was judged using two goodness-of-fit criteria recommended by the ASCE Task Committee (ASCE, 1993a), *i.e.*, per cent deviation of discharge (Q_{PD}) and Nash-Sutcliffe co-efficient (R^2_{NS}); as well as root mean square error (RMSE), co-efficient of determination (r^2).

Percentage deviation of discharge (Q_{PD}):

The percentage deviation of the simulated discharge from designed discharge data for each location was calculated using the following relationship:

$$\mathbf{QPD} = \left(\frac{Q_o - Q_{sim}}{Q_o}\right) \mathbf{x\,100} \qquad (3)$$

where,

Q_{PD} = percentage deviation of discharge at selected location.

Q_o = observed discharge at specific location.

Q_{sim} = simulated discharge at the particular location

The value of Q_{PD} should be zero for a perfect model.

Nash-sutcliffe co-efficient of efficiency (Nash and Sutcliffe, 1970):

Nash-Sutcliffe Co-efficient of efficiency (R^2_{NS}) is used to assess predictive power of hydrological models. R^2_{NS} is described by the following formula :

$$R^2_{NS} = 1 - \frac{\Sigma(Q_0 - Q_S)^2}{\Sigma(Q_o - Q_{av})^2} \qquad (4)$$

where,

Q_o = observed discharge (m^3/s);

Q_s = simulated discharge (m^3/s); and

Q_{av} = mean of the observed discharge (m^3/s).

R^2_{NS} value of 1 therefore indicates perfect fits.

Root mean square error:

The root mean square deviation (RMSD) or root mean square error (RMSE) is a frequently-used measure of the differences between values predicted by a model or estimated. RMSE was calculated by using following equation :

$$\mathbf{RMSE} = \sqrt{\frac{1}{N}\sum_{i=0}^{N}(P_i - Q_i)^2} \qquad (5)$$

where,

N = the number of observations,

P_i = the estimated inflow,

O_i = the observed inflow.

Co-efficient of determination:

Co-efficient of determination (r^2) is a statistical measure of how well the regression line approximates the real data points. It was determined by using following formula :

$$r^2 = \frac{\left[\sum_{i=1}^{N}\left(P_i - \bar{P}\right)\left(O_i - \bar{O}\right)\right]^2}{\sum_{i=1}^{N}\left(P_i - \bar{P}\right)\sum_{i=1}^{N}\left(O_i - \bar{O}\right)^2} \qquad (6)$$

An r^2 of 1.0 indicates that the regression line perfectly fit the data.

System performance measures:

In major irrigation schemes in India, tail-end deprivation is a common problem caused by excess withdrawal of water at the head reach. Therefore, an attempt is made here to study the degree of uniformity or equity in flow delivery over the space in the main canal system. In Wan River project, releases are decided based on available supply. A substantial degree of flow fluctuation from day to day is observed at the system source and at different locations in the main canal. Considering these facts, the following performance indicators are used for analyzing the performance of the system.

$$\text{WDPR} = \frac{Q_{sim}}{Q_{sl}} \qquad (7)$$

where,

Q_{sim} = simulated discharge at the particular location and

Q_{sl} = scheduled discharge at a particular location, which is the ideal flow rate that would occur if the shortage from the design discharge are proportionally distributed over the space. Qsl at different locations is calculated as follows:

$$Q_{sl} = \left(1 - \frac{Q_{CS} - Q_O}{Q_{ds}}\right) Q_{dsl} \qquad (8)$$

where,

Q_{ds} = designed discharge at the system source;

Q_o = observed discharge at the system source and

Q_{dsl} = designed discharge of a specific location.

If the delivery performance ratio is close to unity, then the management inputs are effective.

RESULTS AND DISCUSSION

The experimental findings obtained from the present study have been discussed in following heads:

Calibration of MIKE 11 models:

MIKE 11 model was calibrated during December 2007 to April 2008 using MIKE ZERO toolbox. Calibrated global resistance number *i.e.* Stickler's roughness co-efficient 'M' and global ground water leakage co-efficient was found as 55 and 0.00015, respectively, for Wadi distributory of Wan River Project. While the local resistance numbers and global leakage co-efficient (seepage loss) incorporated in the system, were found to be ranged between 55 to 80, and 4.00E-05and 0.009, respectively. Such a variation in local resistance number and global leakage co-efficient could be due to unlined sections of the canal, growth of water hyacinths and other weeds, and various soil types encountered over the canal length. The observed and simulated discharges for the calibration period at four locations, *i.e.*, at 100 m, along Wadi, M3, M4 and M5 distributory are presented (Fig. 1). The simulated discharge values are in close agreement with the observed discharge values at most of the locations. However, some mismatch was observed at M3 and M5 distributory.

Table 1 presents the results of the statistical tests between the observed and simulated discharges for the calibration period. Percentage deviations of discharge (Qpd) values were found ranging between 1.63 to 7.34% while average variation was 4.34%. Nash-Sutcliffe co-efficient (R^2) values ranged from 0.75 to 0.99, while average value was found to be 0.92 for the locations at 100 m from the system source of Wadi distributory, M3 Wadi distributory, M4 Wadi distributory, and M5 Wadi distributory. Root mean square error value ranged between 0.0036 to 0.0453 m^3/sec while average value was found to be 0.0263 m^3/sec.

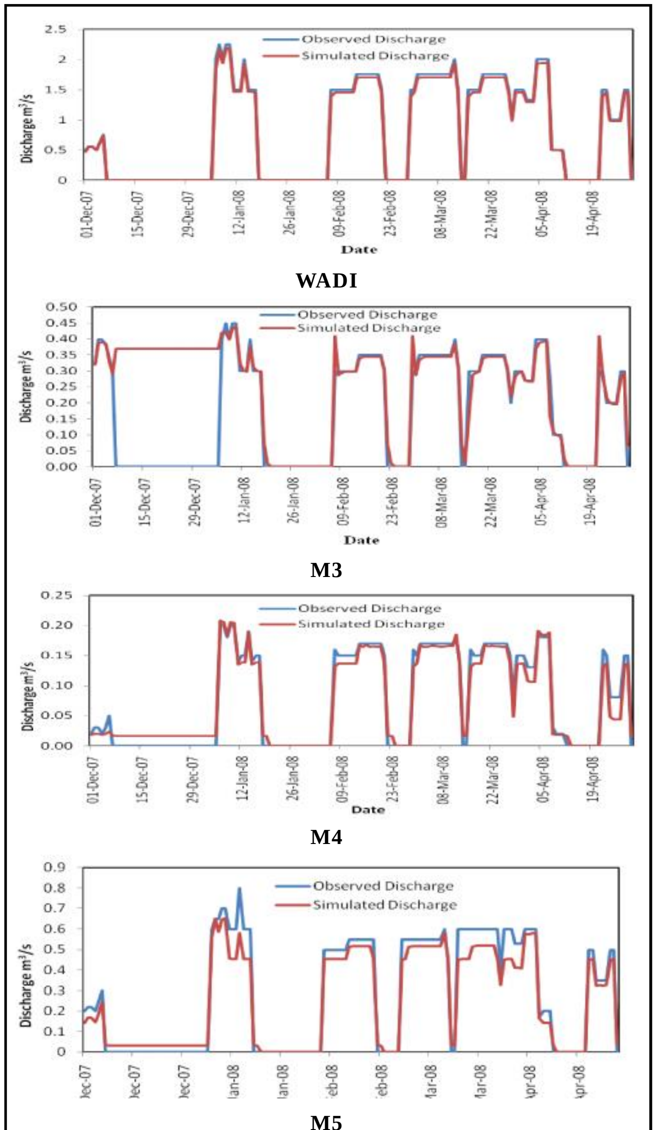

Fig. 1 : Comparison between observed and simulated discharges for calibration period

Table 1 : Statistical analysis of calibrated results

Name of distributory	RMSE	r^2	R^2_{NS}	Qpd
Wadi	0.0393	0.99	0.99	1.63
M3	0.0453	0.86	0.75	2.68
M4	0.0036	0.93	0.99	5.73
M5	0.0172	0.97	0.95	7.34
Average	0.0263	0.94	0.92	4.34

Validation of MIKE 11 model:

Calibrated MIKE 11 model was validated manually for the period from December 2008 to March 2009. The observed and simulated discharges for the validation period are presented (Fig. 2), at 100 m along Wadi, M3, M4 and M5 Distributory. The simulated discharges were in close agreement with the observed values for the most part of the system as evidenced in the Fig.2. But mismatch between observed and simulated discharges were seen in M3 and M4 distributory.

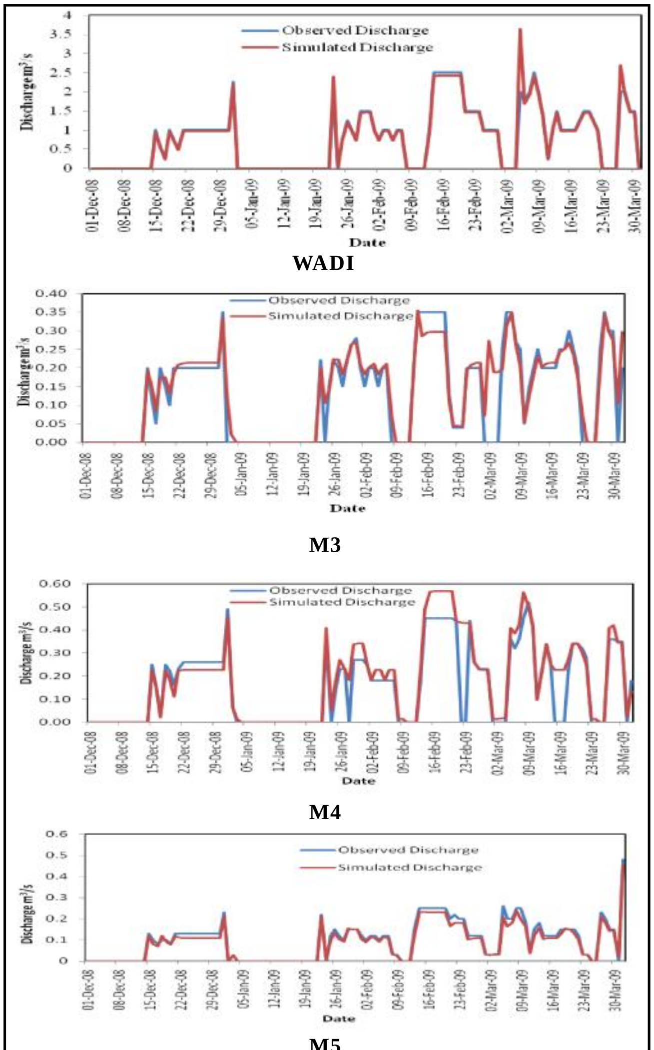

Fig. 2 : Comparison between observed and simulated discharges for validation period

Table 2 : Statistical analysis of validated results

Name of distributory	RMSE	r^2	R^2_{NS}	Qpd
Wadi	0.0421	0.96	0.98	3.07
M3	0.0111	0.84	0.88	5.99
M4	0.0189	0.74	0.79	6.91
M5	0.0088	097	0.94	6.95
Average	0.0202	0.88	0.90	5.73

Table 2 presents the result of statistical tests for the validation period of 1st December 2008 to 31st March 2009. It is seen that Q_{pd} values are within 3.07 to 6.95% while average value is found to be 5.73%. Whereas, Nash-Sutcliffe co-efficient values were ranged from 0.79 to 0.98 while average variation was 0.90. Root mean square error value is found within 0.0088 to 0.0421 while average value was 0.0202 m^3/sec.

Performance analysis of system:

Water delivery performance ratio considered as a performance indicator is calculated for the validation period *i.e.* December 2008 to March 2009. For ideal system performance, this ratio should be one for all locations. Decline in the average ratio was from 1.0 to 0.71, 0.71 to 0.67 and 0.67 to 0.62 for head, middle and tail reaches, respectively along the Wadi distributory (head, 0 to 2.19 km; middle, 2.19 to 4.38 km and tail, 4.38 to 6.57 km). For M3 Wadi distributory decline in the average ratio was from 1.0 to 0.68, 0.68 to 0.66 and 0.66 to 0.64 for head, middle and tail reaches, respectively. (head, 0 to 0.40 km; middle, 0.40 to 0.81 km and tail, 0.81 to 1.2 km). For M4 Wadi distributory decline in the average ratio was from 1.0 to 0.73, 0.73 to 0.66 and 0.66 to 0.63 for head, middle and tail reaches, respectively (head, 0 to 1.83 km; middle, 1.83 to 3.66 km and tail, 3.66 to 5.49 km). And For M5 Wadi distributory decline in the average ratio was from 1.0 to 0.77, 0.77 to 0.73 and 0.73 to 0.68 for head, middle and tail reaches, respectively (head, 0 to 1.88 km; middle, 1.88 to 3.76 km and tail, 3.76 to 5.64 km). This indicates that only approximately 64 per cent water of the intended is available at the tail reach of canal. So there is need of proper schedule to increase the WDPR and thereby the performance of the canal.

The water delivery performance ratio (Table 3) clears that the water delivery losses were 29%, 33% and 38% in head reach, middle reach and tail reach of Wadi distributory, respectively. In M3 Wadi distributory losses were 32%, 34% and 36% for head reach, middle reach and tail reach, respectively. In M4 Wadi distributory losses were 27%, 34% and 37% for head reach, middle reach and tail reach, respectively. And in M5 Wadi distributory losses were 23%, 27% and 32% for head reach, middle reach and tail reach,

Table 3 : WDPR for head, middle and tail reach of the distributory

Name of distributory	Head reach	Middle reach	Tail reach
Wadi distributory	1.0 to 0.71	0.71 to 0.67	0.67 to 0.62
M3 wadi distributory	1.0 to 0.68	0.68 to 0.66	0.66 to 0.64
M4 wadi distributory	1.0 to 0.73	0.73 to 0.66	0.66 to 0.63
M5 wadi distributory	1.0 to 0.77	0.77 to 0.73	0.73 to 0.68
Average	1.0 to 0.72	0.72 to 0.68	0.68 to 0.64

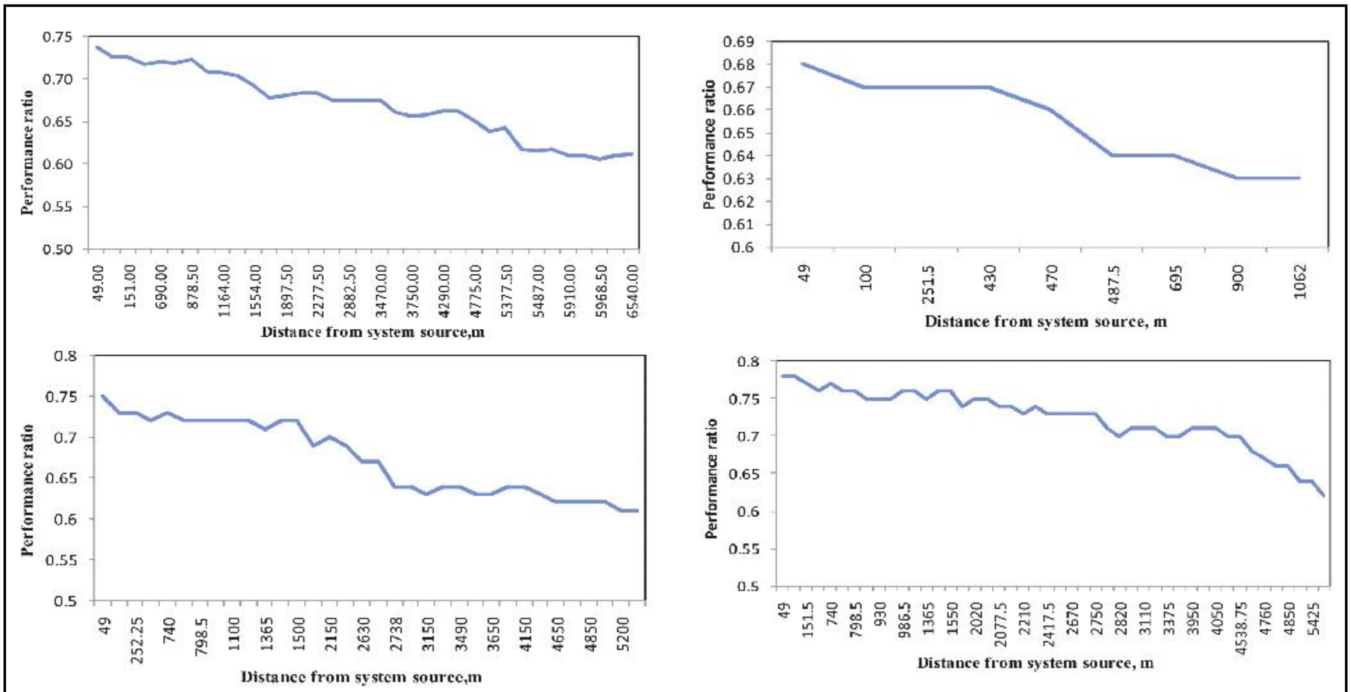

Fig. 3 : Photograph of operation of dhal mill through rotary mode by using bullock power

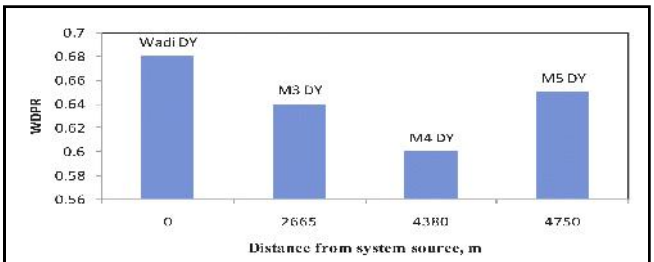

Fig. 4 : Spatial variation of distributaries' discharge

respectively.

Spatial distribution of water to distributory:

For ideal or most equitable flow distribution, the ratio should be one. Fig. 3 presents the performance level of distributaries during the validation period *i.e.* December 2007 to March 2008. From Fig. 4, it is evident that among all distributaries *i.e.* wadi, M3, M4 and M5 distributory is not near to be one, whereas M3 wadi distributory and M4 wadi is drawing very less amount of water. Thus, the system performance results clearly indicate that the irrigation distribution was considerably non-uniform in the command of different distributaries. Therefore, there is a need to reschedule the canal releases to obtain equity in irrigation distribution.

Conclusion:

The MIKE 11 model is calibrated and validated for the period December 2007 to April 2008 and December 2008 to March 2009. The average discharge variation was found to be 4.34 per cent, while Nash Sutcliffe co-efficient, RMSE and co-efficient of determination were found to be 0.92, 0.0263 m^3/s and 0.94, respectively. The statistical analysis associated with graphical presentation confirmed the closed agreement between observed and simulated discharges. Water delivery performance ratio considered as a performance indicator was calculated for the validation period *i.e.* December 2008 to March 2009. The average ratio for each location was also calculated and plotted along the length of canal. For ideal system performance, this ratio should be one for all locations. Average decline in the average WDPR was from 1.0 to 0.72, 0.72 to 0.68 and 0.68 to 0.64 for head, middle and tail reaches, respectively along the canal path. This study concluded that, water delivery performance ratio was found 64 per cent of the intended is available at the tail reach of canal. So there is need of proper schedule to increase the WDPR and thereby the performance of the canal.

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