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PERFORMANCE EVALUATION OF IRRIGATION SYSTEM AT SECONDARY CANAL LEVEL

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ABSTRACT

Performance of irrigation system, in terms of reliable supply and equity in water distribution at secondary canals has been assessed in this study. Mirpurkhas subdivision in Jamrao canal command within Nara Canal Area Water Board was selected for the study. All the 11 head regulators of distributaries and minors were calibrated and new equations for discharge were developed for respective head regulators. By using these equations discharges were measured at head regulators of offtaking irrigation channels for two years i.e. 2010-11 and 2011-12. Study revealed that the reliability of water supply at the heads of secondary canals in the Jamrao canal command is very poor. The analysis on canal operation indicates that 70% of delivery performance ratio (DPR) values fall under poor performance categories. Only 33% reliable supply was released to distributaries and minors. On the average, variation in discharges was very high i.e. 33% in Kharif and between 50% and 57% in Rabi. While, the degree of equity in water distribution among secondary canals was very poor. The most favored canals received 50% to 150% greater discharge of their designed share as compared to least favored canals, whereas, the least favored canals received between 50% and 90% of their designed share. The study suggests that there is a serious need to improve the system's performance and water supplying agency must pay attention to provide designed share to each distributary and minor.

Keywords: Discharge, delivery performance ratio, design share, equity, reliability.

INTRODUCTION

River Indus is the main source of surface water for agriculture in the country. Its basin area of 1.12 million km^2 extends from the Himalayan mountains in the north to the dry alluvial plains of Sindh province in Pakistan and then to the river delta at the Arabian Sea. Its basin covers parts of Pakistan (47%), India (39%), China (8%) and Afghanistan (6%). Inside Pakistan, the basin covers around 520,000 km^2 which is almost 65% of the country, including all of Punjab and Khyber Pakhtunkhwa provinces, most of Sindh, and part of eastern Balochistan

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(Franken, 2012). Under Indus basin irrigation system, there is a continuous-flow, fixed-rotation system with a network of infrastructure regulated by 2 major multi-purposes storage reservoirs (Mangla and Tarbela), 19 of barrages, 12 inter-river link canals, 45 major irrigation canal commands and over 120,000 watercourses delivering water to farms (Yu *et al.,* 2013).

The management of surface water resources in Pakistan is considered at a critical stage. It is seventh-most important country which is under serious challenge of distribution equity that requires improvement in terms of both the “hardware” and “software” of agricultural water management. The water scarcity is growing rapidly because of increasing demand from all water consuming sectors (Ringler and Anwar, 2013). Irrigated agriculture in Pakistan is the main user of surface as well as groundwater resources. Irrigation is important among the strategies for increasing agricultural production in Pakistan. Efficient management of irrigation water is more important, as the new sources of irrigation supplies are scarce and new irrigation development work requires huge investments. Thus, optimum utilization of limited water resources is very important to attain the maximum beneficial use. The time may soon come, when additional irrigation supplies will only be possible through saving of water being lost in the present system (Tariq and Kakar, 2010). To meet the targeted food demands, it is mandatory to improve performance of the irrigation system through operational management. In the existing system, the agencies responsible for supplying irrigation water are not paying proper attention to the operation and maintenance of the system, hence it has failed to meet the design requirements. Though, the data on operation and regulation is being collected at the departmental level, it is not being analyzed and utilized to improve the system’s operational performance. Unreliable and inequitable water distribution, especially at secondary and tertiary levels, is either triggering an abundance of water at head reaches or shortages at the tail reaches during peak demand periods (Khan *et al.,* 1998). At present, the operation and management of the irrigation systems are under serious criticism due to low water-use efficiency (i.e. 30-35%) and inequitable water distribution. Most of the major irrigation command areas in Sindh province suffer from problems of inadequate and unreliable water supply, having wide gaps between irrigation potential and utilization (Skogerboe *et al*., 1997).

The performance of an integrated irrigation system can be judged by several indicators such as, water productivity, reliable supply and equity in water distribution within a canal command. Large irrigation command areas, mostly suffer from inequitable water distribution and mismanagement in canal operation (Guar *et al*., 2008). Several other factors such as soil, climate, system design, institutional capacity, operation and maintenance also affect the irrigation performance (Bolaños *et al.,* 2011). An attempt has been made to evaluate the degree of equity and reliability in the selected area so as to develop some guidelines to improve the performance of the irrigation system in terms of equitable distribution among secondary canals. Adopting the methodology in this research would assist managing agencies to measure and control the matters related to equity in canal commands.

MATERIALS AND METHODS

Study area

The research was conducted at Mirpurkhas subdivision located in Jamrao canal command area. This command area is located at global position between 25^0 44' 08.96" N, 68^0 53'11.58"E and 25^0 25'14.22"N 69^0 09'34.79"E in the Nara Canal Area Water Board. The Jamrao canal command area is surrounded by Mithrao, Rohri and Thar canal commands areas. Jamrao canal off takes from Nara canal at RD 575. The discharge of canal at the start of study area is 35.43 cusec. Jamrao canal division is divided into five units such as Khadro, Jhole, Mirpurkhas, Kot Ghulam Muhammad and Digri subdivisions. Among them, Mirpurkhas subdivision was selected for this study. It starts at RD 291 and extends to RD 443 of Jamrao canal and at RD 0+00 and extends to RD 143 of West Branch canal. It is the largest among other subdivisions in the Jamrao canal system and encompasses the command area of 95795 ha. Jamrao and West Branch canals are the main source of irrigation. There is a network of distributaries and minors (secondary canals) that cover a total length of 160 km. There are 11 distributaries that directly off take from main canal system and 8 minors which off take from these distributaries. They supply irrigation water to 500 watercourses in the subdivision. Salient features of study area are given in Table 1 and command area map of the subdivision is shown in Fig. 1.

Table 1. Salient features of Mirpurkhas subdivision.

Main Canal	Off taking Channel	Global Position		Off taking RD	Design Q (cusec)	CCA (ha)	No. of Outlets
		Latitude	Longitude				
Jamrao	Mirpur Distributary	25^0 38'35.8''	68^0 59' 52.15"	343.00	1.83	7219	49
	Doso Distributary	25^0 38' 33.75"	68^0 59' 51.16"	343.00	1.98	9181	37
	Kahu Visro Minor	25^0 34' 19.95"	69^0 05' 16.84"	383.01	0.51	1466	08
	Kahu Minor	25^0 34' 01.55"	69^0 05' 28.40"	385.14	1.23	4865	18
	Bareji Dsitributary	25^0 30' 30.21"	69^0 07' 14.81"	408.40	1.95	5640	23
West Branch	Lakhaki Distributary	25^0 38' 22.06"	68^0 54' 38.18"	37.220	2.01	7502	55
	Bittaro Minor	25^0 33' 06.90"	68^0 53' 36.90"	66.000	0.3	1494	09
	Sangro Distributary	25^0 30' 09.16"	68^0 54' 11.71"	88.000	2.94	12387	35
	Daulatpur Minor	25^0 26' 33.49"	68^0 56' 48.18"	115.00	1.39	4359	28
	Belharo Minor	25^0 21' 40.42"	68^0 56' 48.18"	146.52	1.66	6914	30

Two methods are usually employed to evaluate the equity and efficiency in water supply at heads of secondary canals; i.e (i) through water level fluctuation data on the head of channel and (ii) discharge measurement in the channels.

In the first method, variation in water level fluctuation is evaluated to check the degree of variation. It fails to measure the quantum of water delivered to distributaries for crops. In the second method, discharge in channels is measured, that computes the exact volume of water delivered to the channels. In the present study, the second method was applied to assess the equity and reliability of irrigation water supply to secondary canals.

Calibration of head regulators of secondary canals

Bench marks (BM) were established on the permanent structure of the head regulators of each distributary and minor. The opening of sluice gate and water depths at upstream and downstream of the channel was recorded. This data was then used to develop calibrated equations. Bench marks for gate opening were marked at the top of gates whereas, the bench marks on wing walls of head regulators were fixed for upstream and downstream water depths with respect to crest level.

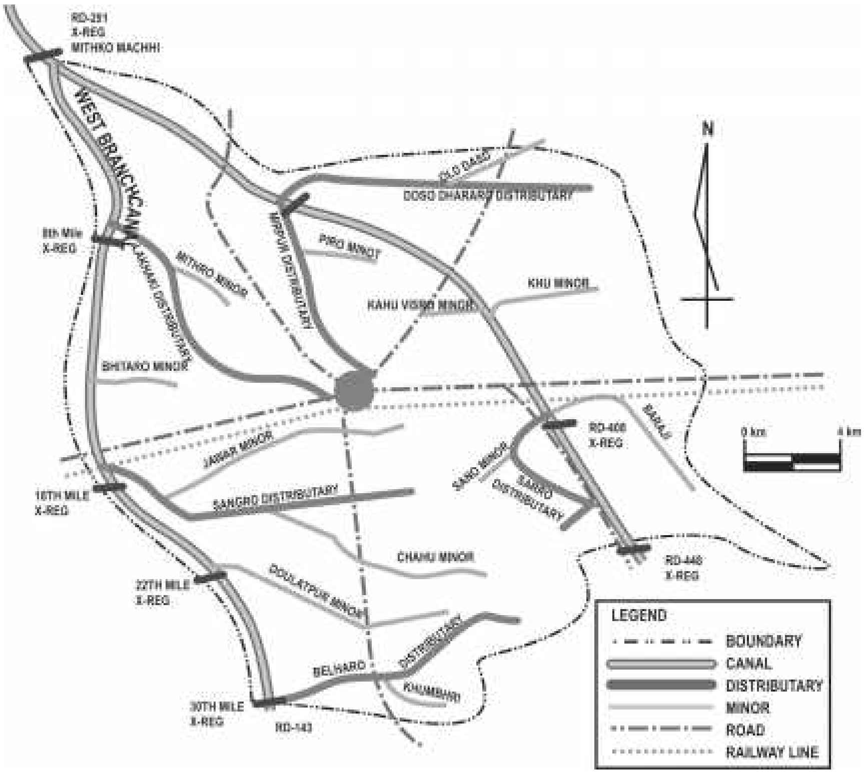

Figure 1. Command area map of Mirpurkhas subdivision.

Normally, the water discharging from the sluice gate attains two types of flow i.e. free flow or submerged flow. Under free flow condition, the head loss is greater, that reflects the higher water level difference between upstream and downstream of the structure whereas, under submerged flow condition, this difference is very small. Under submerged flow condition, effect of downstream water level on upstream water levels is quite visible and in certain cases; water touches the lower tip of sluice gate. While, under free flow condition, the downstream water level is independent and it doesn't touch the lower tip of sluice gate (Khan *et al*., 1998). Both conditions were taken into consideration during the calibration process.

The value of C_d was obtained by dividing measured discharge with the theoretical discharge calculated by known parameters of the gate structure. Cd values were used in developed equations for each distributary and minor.

Weekly data for secondary canal discharges

The discharges at head regulators of secondary canals were collected on a weekly basis for two years during 2010-11 and 2011-12. The data collection started from the month of October 2010 and continued till October 2012. Data was collected with the assistance of Area Water Board (AWB) staff Mirpurkhas subdivision through coordination of Director Nara Canal Area Water Board. The discharge related parameters such as gate opening, upstream and downstream water depths were taken with the coordination of Tandel (the gate operator of AWB). During data collection Tandel was trained to collect the data on discharge related parameters.

These parameters were then used in calibrated equations to calculate the actual discharge to be delivered. The weekly data was converted into average monthly discharges in order to set the seasonal discharges for Kharif and Rabi seasons.

Reliability and equity analysis

Reliability of water supply at the head of distributaries and equity in water distribution was measured using Delivery Performance Ratio (DPR), Interquartile Ratio (IQR) and coefficient of variation (CV).

Delivery performance ratio (DPR)

Delivery performance ratio is defined as the ratio of actual measured discharge to the design discharge. It was calculated by using relation given by Murray- Rust *et al.* (2000).

$$DPR = \frac{Q_a}{Q_D}$$

Where

DPR = Delivery performance ratio
Q_a = Actual discharge in cumec
Q_D =Designed discharge in cumec

Discharge variations

Temporal coefficient of variation is an indicator to determine the variation in discharge in secondary canals. It indicates the degree to which variation reaches. The coefficient of variation was calculated by using the relation given as under:

$$Coefficient\ of\ Variation\ (CV) = \frac{Standard\ deviation\ of\ discharge}{Average\ discharge}$$

The values of CV were used to evaluate the performance in terms of discharge variation. The criteria was set by combining Molden and Gates (1990) and Murray-Rust *et al*. (2000), keeping in view the irrigation department rules, which suggests that the minimum discharge at secondary canals should not be less than 70% or more than 30% of design discharge value.

Good performance: CV < 0.10
Fair performance: CV < 0.30
Poor Performance: CV > 0.30

The variations in secondary canals discharges during Kharif and Rabi seasons for two years were analyzed. Collected data was analyzed to visualize the equity in water distribution between secondary canals, along the main canals.

Interquartile ratio (IQR)

Interquartile ratio is considered as the best indicator to understand the equity. IQR compares the ratio of highest 25% of values to the lowest 25% of values. It is the ratio of the least favored canals (getting lowest discharges) to the highest favored canals (getting highest discharges). If the value of IQR is 1.0, the equity among secondary canals is rated as the best. If it increases, there is greater inequity. Therefore the values of DPR for each season were used to calculate the IQR to evaluate the degree of equity.

RESULTS AND DISCUSSION

Development of discharge flow equations for secondary canals

The discharges at the heads of secondary canals were measured and then hydraulic structures were calibrated at their respective heads. The coefficient of discharges varied between 0.54 and 0.86. It reveals that the equations theirselves over estimate the discharges, hence use of Cd will result in actual discharges. Thus, calibration of head regulators is of paramount importance to measure the actual discharges. The decrease in discharge through structures occurs due to side contractions, mismatch between sluice gate and frame and crest surface roughness. These factors cause some leakage of water from sides and beneath the sluice gate.

Discharge measurement of secondary canals

Based on the developed equations, the discharge of secondary canals was measured on a weekly basis and then converted into an average monthly rate. Table 2 shows the average seasonal discharges of distributaries and minors. On the average, the discharge was less than the design value; whereas in the Kharif season, the average discharge values recorded were higher than the design discharges.

Variation in discharges of secondary canals

Coefficient of variation (CV) is the measure of variability, which is independent of actual average values. It is the measure that suggests the variability in spatial and temporal coefficient of variation, to check how variability changes at a single location. It is very difficult to set the ranges of CV values in order to set the variation limits, as there are no specified rules set by area water boards for accepted variation in discharge. Molden and Gates (1990) developed three categories of variability, which they termed as reliability that if CV were less than 0.1 it is termed as good, if it ranges between 0.10 and 0.20 it is considered as fair, when it is more than 0.2, it is designated as poor. Discharge variations in distributaries and minors located in Mirpurkhas subdivision were calculated and results are shown in Table 3. The results reveal that discharge variations recorded during four seasons were significantly high.

Table 2. Average discharge (measured) at secondary canals in Mirpurkhas subdivision.

Main canal	Secondary Canal	Design discharge	Average seasonal discharge (cumec)			
		[m^3/sec]	Rabi 2010-11	Kharif 2011	Rabi 2011-12	Kharif 2012
Jamrao	Mirpur Distributary	1.83	1.60	1.91	1.56	2.08
	Doso Distributary	1.98	1.56	2.09	1.65	2.09
	Kahu Visro Minor	0.51	0.44	0.54	0.46	0.64
	Kahu Minor	1.23	1.03	1.50	1.12	1.58
	Bareji Distributary	1.95	1.69	1.66	1.69	2.13
	Sanhro Distributary	1.36	1.40	1.38	1.38	1.60
West Branch	Lakhaki Distributary	2.01	1.70	1.79	1.95	2.19
	Bhittaro Distributary	0.3	0.45	0.58	0.33	0.37
	Sangro Distributary	2.94	2.71	3.68	3.13	3.54
	Daulatpur Minor	1.39	1.03	1.28	1.23	1.51
	Belharo Minor	1.66	1.36	1.70	1.51	1.82

Maximum variation in discharges was observed at two minors (Kahu and Daulatpur) during Rabi 2010-11 as compared to remaining 9 distributaries. While in Kharif 2011, the variation in discharges at four distributaries (Sanhro, Lakhaki, Sangro, Belharo) were within satisfactory limits whereas in Kharif 2012, the discharge of only two minors (Bhittaro and Belharo) remained within satisfactory limits out of eleven distributaries. During both Rabi seasons, discharges in all secondary canals varied between 40% and 72%, which reveals inconsistency in operation. Data on average values of spatial coefficient of variation along the secondary canals, in all four seasons, clearly indicates that the discharges in secondary canals attained 33% variation in two Kharif seasons, while those were 50% and 57% during Rabi 2010-11 and Rabi 2011-12, respectively.

Table 3. Coefficient of variation in discharges of channels in Mirpurkhas subdivision.

Secondary Canal	Coefficient of Variation of Discharge				Total Average
	Rabi 2010-11	Kharif 2011	Rabi 2011-12	Kharif 2012	
Mirpur Distributary	0.61	0.40	0.64	0.32	0.49
Doso Distributary	0.50	0.44	0.51	0.32	0.44
Kahu Visro Minor	0.49	0.37	0.44	0.48	0.44
Kahu Minor	0.72	0.30	0.64	0.32	0.50
Bareji Distributary	0.52	0.23	0.60	0.32	0.42
Sanhro Distributary	0.47	0.28	0.52	0.31	0.39
Lakhaki Distributary	0.50	0.27	0.59	0.41	0.44
Bhittaro Distributary	0.48	0.55	0.47	0.30	0.45
Sangro Distributary	0.50	0.23	0.52	0.32	0.39
Daulatpur Minor	0.40	0.38	0.72	0.33	0.46
Belharo Minor	0.62	0.20	0.65	0.23	0.42
Overall average	0.50	0.33	0.57	0.33	0.44

The average seasonal coefficient of variation in individual secondary canals is illustrated in Fig. 2. It shows that during study period all secondary canals attained very high variability. The observed variability line is significantly above the allowable variability line. Thus, Kahu minor and Mirpur distributaries had the highest variation in discharges. In general, the seasonal or annual performance in terms of reliability is very poor.

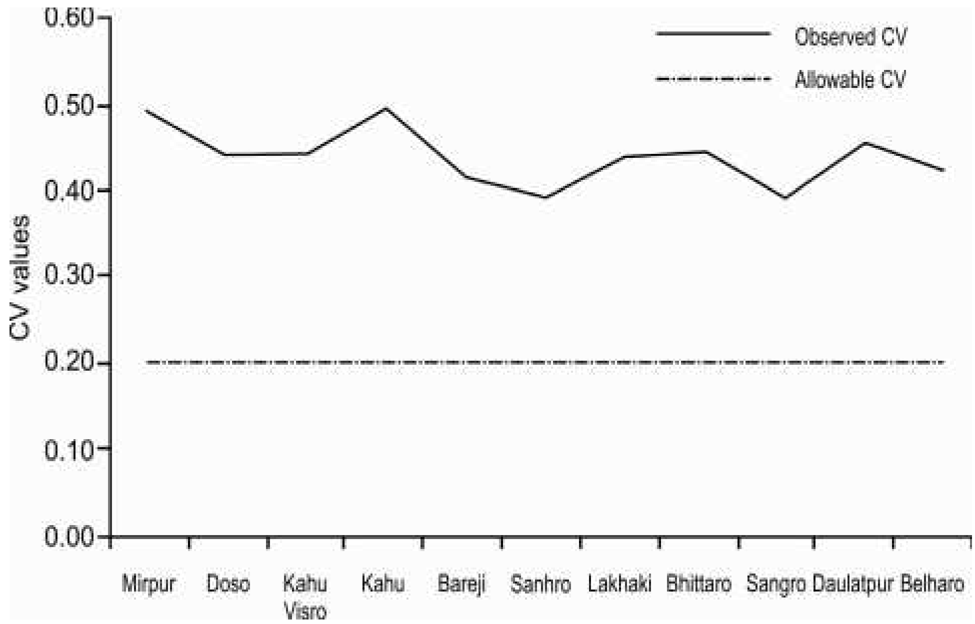

Figure 2. Discharge variation in distributaries and minors located in Mirpurkhas subdivision.

Table 4. The seasonal equity of water distribution in secondary canals in Mirpurkhas subdivision.

Ranges of CV values	< 0.1	< 0.3	> 0.3	Good	Fair	Poor
Rabi 2010-11	0	3	52	0%	5%	95%
Kharif 2011	0	39	38	0%	51%	49%
Overall (whole the year) 2010-11	0	42	90	0%	32%	68%
Rabi 2011-12	0	1	54	0%	2%	98%
Kharif 2012	0	30	47	0%	39%	61%
Overall (whole the year) 2011-12	0	31	101	0%	23%	77%

The discharge variation in secondary canals is categorized in Table 4, which depicts that most of the CV values remained under the category of poor performance. The degree of poor performance was 68% and it increased to 77% during 2010-11 and 2011-12. The major portion of poor performance was observed during Rabi season. It is postulated that Farmer Organizations (FOs) put lot of pressure on AWB during Kharif season to receive water than in Rabi season, hence lot of care is taken in water deliveries. Whereas, during Rabi season less water is needed against high discharges, hence canal performance is poor during this season. The variation in water supply to secondary and main canal seems almost same as calculated by Habib and Kuper (1998). CV values ranged between 0.4 and1.05 in Chishtian subdivision. The variation in water supplied to secondary canals in this subdivision was very high as compared to Gediz basin irrigation system in Turkey where, the CV values for secondary canals ranged between 0.14 and 0.3 (Akkuzu *et al*., 2007). Similarly, the variation in discharges at tertiary level could be high due to unexpected variability at secondary canal level as indicated by Tariq and Kakar (2010).

Delivery performance ratio for secondary canals

The reliability of irrigation water supply at the heads of channels can be indicated by calculating the Delivery Performance Ratio (DPR). The DPR values have been calculated for each secondary canal located in Mirpurkhas Subdivision. Fig. 3 shows the DPR values of each secondary canal during 4 seasons. The pattern of DPR values is quite dispersive during the study period. Only few values are touching with the line of equity which indicates the unreliable supply to off taking distributaries and minors. The DPR values during the Rabi 2011-12 show the reliability to some extent among secondary canals as compared to Rabi 2010-11 and Kharif 2011 and 2012. In Kharif season, the fluctuation in DPR values is very high. Comparison of the individual channel reveals that, Bittaro minor has got maximum discharge as about 50 and 100% more in Rabi 2010-11 and Kharif 2011, respectively (Fig. 3). Whereas, in Kharif 2012 almost all secondary canals have received higher discharge than design share.

This analysis has been made on the rule fixed by irrigation department; which suggests that the channels should at least get 70% but not greater than 10% of the design (allocated) discharge. Therefore, the DPR values less than 0.7 and greater than 1.1 show the unreliable supply at heads of secondary canals.

Table 5 shows DPR values for all secondary canals in the study area. During the years 2010-11 and 2011-12, the 70 % values of DPR were rated under poor performance category. The average reliable supply to the channels remained only 33% during the period of study. This reliability value is treated as unsatisfactory as evaluated by Murray-Rust *et al*. (2000) for the same area. Table 5 shows very interesting results for a maximum period during two year's time and supply at heads of secondary canals remained unreliable. The inequity in water distribution can be indulgent easily. The same type of lower performance for the canals in Khyber Pakhtunkhuwa province is also pointed out by Ghumman *et al*. (2011). Considering the sensitivity of performance under this scenario, Murray-Rust *et al*. (2000) suggested that the deliveries to secondary canals could be adjusted to keep DPR values at 0.7 and 1.3 on alternate days. This modification is the result of combining the rules adopted by the irrigation department and the ranges given by Molden and Gates (1990). The delivery performance measured in the study area is very low as compared to other Asian countries analyzed during periods between 2002 and 2006 (FAO, 2014). Vos (2005) suggested a DPR value equal to unity observed in Peru. Similarly, the delivery performance ratio for main to secondary canals is almost unity (i.e. 1) in the countries like India, Nepal, China, Cambodia, Indonesia, Malaysia, etc, suggesting a reliable supply. Whereas, the DPR values for secondary canals in Turkey were lower in hot months and higher than unity in cold months. The water delivery service at this level was rated from fair to poor as indicated by Korkmaz *et al*. (2009).

Interquartile ratio (IQR) for delivery performance

The Interquartile ratio is the best indicator to evaluate the equity. Interquartile ratio is the ratio of the highest 25% of values to the lowest 25% of values of DPR. For actual equitable supply of water, the IQR should be unity. If this ratio increases beyond unity, the inequity increases. Fig. 4 shows the interquartile ratio of 11 secondary canals during four seasons. Values of interquartile ratio reveal that all channels have crossed the equity line, suggesting that the supply to secondary canals is unreliable and inequitable. This IQR in case of Kahu minor and Bareji (in Rabi 2010-11) and Daulatpur minor (in Rabi 2011-12) remained very high (more than 2.5 and 3), showing that most favored canals received 150% to 200% more water than least favored canals during same season. The seasonal trend in unreliability is invisible.

Table 5. Seasonal analysis of DPR of secondary canals in Mirpurkhas subdivision.

Range of DPR/ Season	< 0.7	> 1.1	0.7-1.1	Total	Poor	Satisfactory
	No. of values				%age	
Rabi 2010-11	20	23	12	55	78%	22%
Kharif 2011	11	40	26	77	66%	34%
Overall (whole the year) 2010-11	31	63	38	132	71%	29%
Rabi 2011-12	15	16	24	55	56%	44%
Kharif 2012	5	45	27	77	65%	35%
Overall (whole the year) 2011-12	22	70	40	132	70%	30%

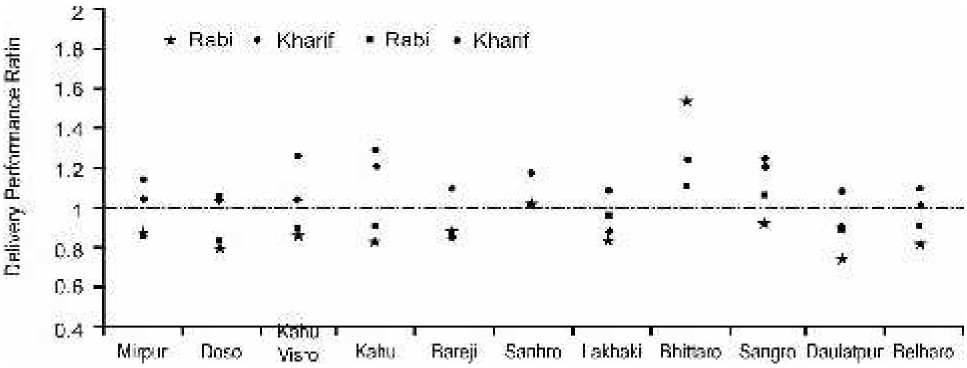

Figure 3. Delivery performance ratio of channels of Mirpurkhas subdivision during four seasons.

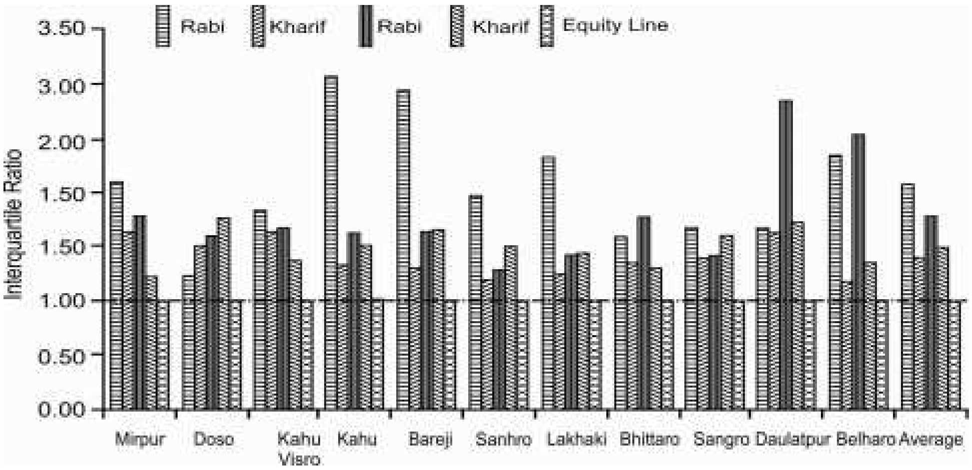

Figure 4. Interquartile ratio of DPRs of secondary canals in different seasons.

Table 6. Interquartile ratios for DPRs of secondary canals.

Season	1st Quartile (Low 25%)	3rd Quartile (High 25%)	Interquartile Ratio (IQR)
Rabi 2010-11	0.50	1.25	2.50
Kharif 2011	0.88	1.33	1.51
Overall (whole the year) 2010-11	0.71	1.28	1.80
Rabi 2011-12	0.65	1.32	2.01
Kharif 2012	0.91	1.36	1.49
Overall (whole the year) 2011-12	0.80	1.35	1.68

Analysis of DPR values in terms of the seasonal interquartile ratio has been made and results are given in Table 6. The data reveal that the secondary canals having highest discharge and DPR values ranged between 1.2 and 1.36 and averaged to 1.31. Data shows that they were getting 130% of the design discharge. The secondary canals having lowest discharge attained DPR values ranging between 0.5 and 0.91 with an average of 0.73.These results suggest that they are getting 73% of design discharge. It is evident from these results that the interquartile ratio was extremely high and ranged between 1.49 and 2.5 at most favored canals and they received more water by about 150% as compared to least favored canals and there was very high inequity among secondary canals in the study area. The seasonal trend in IQR variation is invisible; however, on the average, the IQR value in 2011-12 decreased by about 6.7% as compared to 2010-11. The IQR for the study area is lower as compared to Chishtian Subdivision in Punjab Pakistan where, these values varied between 2.05 and 2.8 that is sign of inequitable water distribution among secondary canals (Habib and Kuper, 1998). This inequity indicates the efficiency of old and new FOs. The FOs those were formed 14 years back might have approached AWB for equity than the FOs which were formed later. This generally happens due to personal affiliation of FO leaders or farmers with sub divisional officer (SDO) or Executive Engineer (X.EN).They also have political influence and get sufficient discharge at the heads of distributaries and minors.

CONCLUSION

The reliability of water supply at the heads of secondary canals in the study area was very poor. About 70% of DPR values fall under poor performance category. Only 33% were rated as reliable supplies released to distributaries and minors. The variation in discharges remained very high as 33% in Kharif and 50% to 57% in Rabi. The degree of equity in water distribution among secondary canals remained very poor. Most favored channels get 50% to 150% more discharge than the least favored canals whereas; they received 50% to 90% of design share. There is no mechanism to measure the discharge at head regulators of secondary canals. The downstream gauges have either been vanished or they are not calibrated. Only water levels at main and secondary canals are monitored that provide no sense to water measurements. Head regulators must be regularly calibrated to develop rating curves for monitoring discharges and for releasing the desired quantum of flow to off-taking canals.

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