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Water Delivery Performance of A Secondary Canals in terms of Equity and Reliability in Sindh Pakistan

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Abstract: This study was conducted on three secondary canals (namely Belharo, Bareji and Mirpur distributaries) of Nara Canal command, Mirpurkhas, Sindh Pakistan. Study was conducted for two consecutive years i.e.; 2014-15. Gauges were installed at head, middle and tail reaches of these canals and discharges were monitored on weekly basis. It was observed that, on the average, distributaries were carrying excessive volumes of water during the year thus the total efficiency and PF was poor. The excessive volumes of water in the distributaries suggest that the water among the end users was not distributed judicially. Generally, the parity of water supply was also 'poor' thus the reliability was also graded as 'poor' In order to increase the performance of irrigation system, there is need to minimize system's conveyance losses and improve water application efficiency. This could be done through proper management and water distribution plans at tertiary canal levels. There is need to continuously monitor and measure the water diverted to the canals and make sure that water reaches at middle and tail reaches.

Keywords: Secondary Canals in Sindh Pakistan, Bareji, Mirpurkhas and Belharo

1. INTRODUCTION

Over 1800 million people are expected to be living in the regions with 'absolute' water shortfall by year 2025. This accounts for about 2/3rd of the total water stressed population of the world (FAO, 2013). Unavailability of water will be a foremost limitation to agriculture and that in turn will result in reduced production. This alarming scenario dictates that the overall performance of irrigation schemes would have to be improved in order to cope up the water shortages. The irrigation systems should be so designed and operated that they must deliver water to the potential beneficiaries i.e. farmers of command areas in fair and equitable manner. Water must be efficiently utilized and water diversions per unit of irrigated land need to be reduced. In Pakistan, the distribution, operation and maintenance of irrigation schemes were planned to meet the irrigation challenges and maximize crop production (Bhutta *et al.,* 1992). The main aim of irrigation schemes was focused to increase irrigated land but unfortunately the anticipated pace was very slow due to mismanagement at secondary and tertiary levels. Therefore, there is need to focus on improvement, effective long-term operation and maintenance of existing irrigation systems. Chambers (1988) and Smith (1990) have describes the complexities of the canal irrigation system in terms of domains (physical, human, bio-economic and water), dimensions (space and time) and the linkages between the domains and the elements within them. Performance of a system can be determined by some fixed parameters based on achievement which are chosen as measurement gauges of the systems' objectives (Abernethy, 1989).

In many least developed and emerging countries of the world where large-scale gravity irrigation systems are manually operated, pitiable hydraulic performance is a big challenge to government. This is largely attributed to lack of information and knowledge on multifarious hydraulic behavior of these systems. Therefore knowledge on multifarious hydraulic behavior of canal systems is required for its effective operation. The engineers and water users must be trained and aware of working and management decisions on water distribution on an irrigation system (Renault, 2000). They must be provide information required by end users so that they can properly operate and assess systems performance Researchers (Molden *et al.,* 1990 and Seckler *et al.* 1988) agree that adequate irrigation water supplies, their equitable and reliable distribution, are indispensable to achieve productivity. All the stakeholders must be involved to asses, determine and regulate some aspects of systems performance so that it must be viable on the long term basis. During the past few decades, irrigation management researchers (Bos *et al.* 1994; Small and Sevenden 1990 and Seckler *et al.* 1988) have attempted to understand various aspects those result in poor performance irrigation system. They have established numerous investigative outlines, standards and gauges that enumerate the performance of water delivery and suggested various management and physical measure to improve the performance of irrigation system. According to Molden and Gates, (1990) and Bos *et al.,* (1994) an adequacy indicator will not be able to address the issue with delivery system if it were carrying excessive water than designed one.. In such cases, a maximum value of 1.0 has been taken as

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adequacy indicator (Sakthivadivel *et al.,* 1999, Kazbekov *et al., Kazbekov et al.,* 2009). However, if adequacy indicator were not properly addressed, the system would be inefficient and additional water transport would result in grave apprehensions of water logging.In fact, the actual calculated value of delivery indicators “relative delivery indicators” with value of greater than1.0 have been taken this study. Equity determines the equality of water distribution to diverse portions of an irrigation channel. It designates the spatial dispersal of water distribution at various points is a conveyance system. Water distribution in manually operated through structures in large-scale gravity irrigation systems. In Pakistan, it is a major concern for engineers and operators in order to ensure equal distribution of water to end users. However, the water delivery performance has been assessed through equity and reliability of system in this study. This study will be beneficial for water mangers while they evaluate the secondary canal performance

1.1 Methodology.

1.2 Study Area Description

The selected distributaries Belharo, Bareji and Mirpur are situated in Mirpurkhas irrigation sub division as shown in figure 1. While salient features of the selected distributaries is given in **(Table 1).**

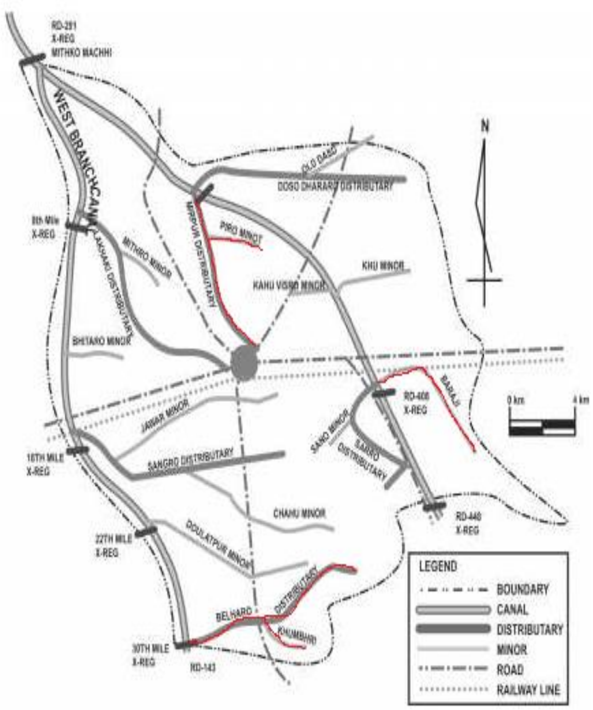

Fig. 1. Location of distributaries on the command area map of irrigation sub-division Mirpurkhas (adopted from Mirjat *et al,* 2017)

Table 1. Salient features of Distributaries (adopted from Mirjat *et al,* 2017)

Patent Channel	Distributary/ Minor	Off-take (RD)	Discharge (cfs)	CCA (acres)
Jamrao Canal (East Branch)	Mirpurkhas	343	64	16815
	Bareji Distry	408	41.5	14032
West Branch	Belharo Minor	143	54.78	17124

1.3 Data Collection

Historical data was collected from the offices of Nara Canal Area Water Board and Sindh Irrigation and Drainage Authority (SIDA) offices. For detail please refer Mirjat *et al,* 2017.

1.4 Measurement of Flow Rates

Flow measurements were taken using a current meter near each calibrated gauge section in a distributary. The details on gauge calibration could be found in Mirjat et al, 2017, Part-I. The flow rates in the channels were computed using the average of different measurements at each section. The cross section of a channel was alienated into a number of verticals. The depths of water at each vertical and corresponding velocity were measured. The velocity measurements were taken using the method explained by Sheng *et al.* (2003). A two-point (0.2d and 0.8d, where d is the depth of flow) method was used for measure velocity for depth exceeding 2.5 ft, while, one point method was used when depth of flow was less than 2.5 ft. The average of the two measurements was taken as the mean velocity in the vertical section. The velocity at each point was recorded with an exposure time of 40-70 seconds. The flow (q) between any two adjacent verticals is a product of distance between verticals (W), the average of water depths of two contiguous verticals and average velocities over those two verticals (Figure 1). The total discharge (Q) at the section is the sum of the discharges (q) in each sub section. The total discharge was then calculated using equation 1.

$$Q = \sum_{x=1}^{n} W_x \left(\frac{\bar{V}_x + \bar{V}_{x+1}}{2}\right)\left(\frac{y_x + y_{x+1}}{2}\right) \quad \ldots\ldots \text{(i)}$$

Where,
Q = total discharge,
W = width between two adjacent verticals,
$\tilde{V}$ = depth averaged velocity,
y = flow depth, and
x = the number of verticals.

For calibration of gauges please refer Mirjat *et al,* 2017.

1.5 Water delivery performance indicators

Two water delivery performances has been assessed through equity and reliability of system in this study. Data on these indicators for three distributaries were collected. If a water delivery system meets required targets for a given period of time, the system is termed as adequate one. The time frame is set to be on daily basis, weekly basis, monthly, seasonal or annual basis as case may be.

Adequacy indicator is termed as perfect when its value is equal to 1.0 and the system's delivery is termed as efficient. In practice its value never equals one, under the circumstances when amount of water delivered in distributary is greater than the water required in the system its value becomes more than 1. Generally, coefficient of variation (CV) determines any disparity in water water delivery system. Molden and Gates (1990).have suggested that it is the proportion between water delivered (Q_D) to water required (Q_R), over an area (A) and time (T). Another indicator is termed as Reliability defines the volume of water delivered in the system to meet the desired results. Reliability includes two components: reliability in terms of amount delivered and reliability in terms of proper delivery timing. Molden and Gates (1990) has defined reliability (dependability) indicator as coefficient of variation of water distributed to thewater demand over time for a given area.

$$P_E = \frac{1}{T}\sum_T CV_A\left(\frac{Q_D}{Q_A}\right) \text{ ………..(i)}$$

$$P_D = \frac{1}{A}\sum_A CV_T\left(\frac{Q_D}{Q_A}\right) \text{ ……(ii)}$$

Where

P_E and P_D are equity and dependability indicators, respectively; T is time, A is Area, CV_T is coefficients of variation with respect to time T and CV_A is coefficient of variation with respect to area (A).

Table 2. Water delivery performance indicators suggested by Molden and Gates, (1990)

Indicator	Good	Fair	Poor
P_E	≤ 0.10	0.11-0.25	> 0.25
P_D	> 0.20	0.11-0.20	≤ 0.10

2. RESULTS

2.1 Irrigation supply and demand

Results of this study are based on weekly discharge measurement through gauges installed at head, middle and tail reaches of the distributaries. These outcomes are the averages of two consecutive year's i.e, 2014 and 2015 for eleven months as there is a closure period for maintenance of about three weeks in the month of January. Also, there are rotational closures as well, which are not fixed. However, these are scheduled on irrigation water availability at the head of main canal. Results show that Bareji distributary received more than 35% of designed supplies specially during Rabi season other two distributaries es also received in excess or equal to their designed discharges. Mostly four months of Kharif are the critical months when supplies are reliable. Out of eleven months Bareji distributary received less supply of water during May, June and August as compared to its designed discharge while, almost similar trends were observed at Mirpur and Belharo distributaries. Mirpur distributary was under supplied during the months of April, May, June, July and August while, during rest of the months of the year water supply remained as per design or in excess. Similarly, Belharo distributary received less supply during May, June, July and August whereas; it received supplies as per design or in excess during rest of the months of the year. (For detail please refer Mirjat *et al*, 2017, Part-I).

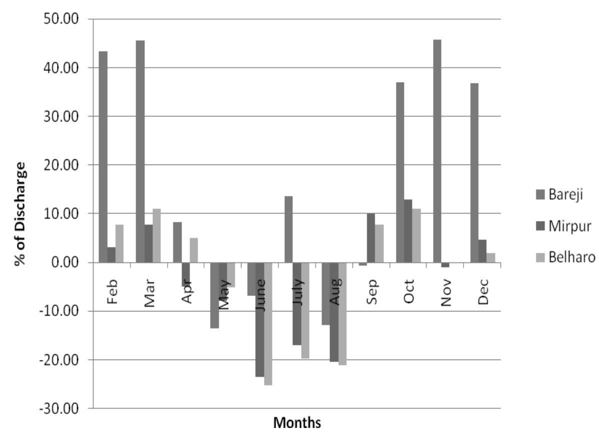

Fig. 2. Monthly discharge fluctuation percentage in all three distress

2.2 Water delivery performance

Spatial and temporal scales were used to determine performance of water delivery of a system.. The spatial indicators determine the water delivery performance at head, middle and tail reaches of the distributaries in its command area (A), while the temporal indicators are used to determine water delivery performance in time (T).

2.2.1 Spatial performance indicators

To determine spatial performance, the indicators such as relative delivery, efficiency and equity were taken into account. The data in Figure 3 suggest that the average relative delivery values ranged Equity was evaluated over four seasons (2 rabi and 2 kharif) of 2014 and 2015 (Figure 2). The observed equity indicator (PE) for all the distributaries was compared with performance standard given by Molden and

Gates, (1990). Data show that the observed equity levels for different distributaries were rated as 'poor'. Compared to 2014, equity levels were better in 2015, even though the equity levels for both years were rated as 'poor'.

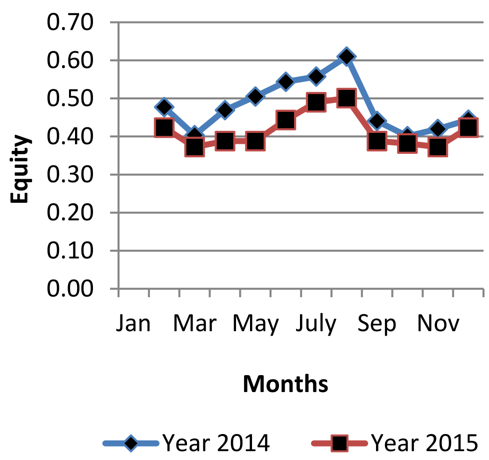

Fig. 3. Monthly Equity Indicator

Fig. 4 shows dependability indicator of water delivery in each reach for three distributaries. It involves probability and irregularity; where probability deals with consistency of the timing and the irregularity accounts for the variable amount of water available in the system. It was observed that flow of water at each reach was extremely anticipated, because head reach receives the maximum flow even more than their share, while middle reach gets less water as compared to head reach but in some cases both reaches received more than their due share. However, the tail reaches receive minimum share. As a result head and middle were getting excessive flows consistently over time than the designed one , while tail reaches suffer specially during months with minimum flows in the system.

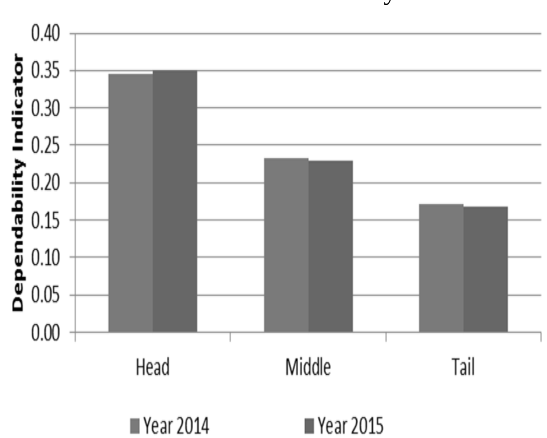

Fig. 4. Reach wise dependability indicator

3.2.2 Overall water delivery indicators

The overall water delivery indicators for the years 2014 and 2015 are shown in **(Table 3).** Data reveal that the relative deliveries averaged over the year, the overall efficiency and PF is poor. This shows that the water supplied to each distributary was in excess but it is not distributed judicially among the end users. Likewise, the equity of water supplied in the system is rated as 'poor' so that the reliability is also rated as 'poor'. All these delivery indicators suggest that system is not functioning properly and need proper attention so that its efficacy could be improved.

Table 3. Water delivery indicators at Bareji, Mirpur and Belharo distributaries

	PE	PD
2014	0.48	0.25
2015	0.42	0.25

3. DISCUSSION

Water shortage is main limitation to agricultural production thus there is a need to improve overall performance of irrigation schemes. Proper and sensible use of available water in a system is need of time to resolve the issue of water shortages. This study determines the hydraulic performance and evaluation of secondary canal levels of the Nara Canal, situated in southern province of Pakistan.

Results show that Bareji, Belharo and Mirpur distributaries the observed equity levels for different distributaries were rated as 'poor'. Compared to 2014, equity levels were better in 2015, even though the equity levels for both years were rated as 'poor'. It was also observed that consistent over flow than the designed at head and middle reaches, while tail reaches suffer specially during months with minimum flows in the system.

Bhutta and Velde (1992) identified inequitable water supplies at the tail outlets of irrigation system of Lower Chanab Canal. The outlets located at tail ends of distributaries were inferior than those located at head and middle outlets. 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 consumption (Skogerboe *et al.,* 1997). 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). 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 delivery performance ratio (DPR) value equal to unity observed in Peru. Similarly, the delivery performance ratio for main to secondary canals is almost unity (i.e. 1.0) 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 secondary canal level was rated from fair to poor by Korkmaz *et al.* (2009). 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). This reliability value is treated as unsatisfactory as evaluated by Murray-Rust *et al.* (2000) for the same area.

5. Suggestions (How to improve water delivery performance at secondary canal level)

Optimum utilization of limited water resources is very important to attain the maximum beneficial use. This could be done through improvement in water delivery systems. The adequate supply of water should be mandatory in the delivery systems. The water should be equally distributed among end users as per their share. The system should be operated efficiently and water availability, required amount and timing must be reliable. Some operational measure should be taken that can make a significant progress in hydraulic performance of off taking distributaries. Results on the water delivery performance of three distributaries suggest that there is a need to make significant operational changes in the distribution system. The closure periods of distributaries shall be so devised that they do not affect the overall performance of system. The crop water requirement varies according to its growth stages; hence the rotation shall be based on crop water demands in the area. The physical restoration and implementation of new management technique must be included in the operational changes, while the policies, priorities and management of institution at agency level must be addressed under strategic changes. Farmers' must be made part and parcel of system management, operation and maintenance through farmer organizations. If suggested measures are implemented, both operational and strategic changes will ultimately bring a significant improvement in the delivery systems (Thoreson *et al.,* 1997). The additional irrigation supplies will only be possible through water saving in the present systems (Tariq and Kakar, 2010) and proper operation and management of conveyance systems at main, secondary and tertiary levels

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5.1 Remodeling of Distributaries and Outlet structures

With the passage of time, the hydraulic characteristics of most distributaries in the study area have been altered and need proper remodeling. They must be redesigned in such a way that their water delivery improves. They must provide required amount to each outlet according to its designed discharge. Similarly, most of the outlets structures have either been damaged or altered. Some of them draw more water while others take fewer shares. The outlet structures must be remodeled so that each should operate properly and take its share according to its design.

5.2. Proper Management and Operation

The hydraulic characteristics of flow at head middle and tail reaches play a vital role in equal distribution and delivery of irrigation water. Effective management and proper operation of system is another issue that needs to be addressed for better performance. The old aged distributaries and their improper maintenance is a major limitation to operative management. These distributaries must be managed and maintained to ensure proportional distribution of water during excessive or under flow conditions in canal supply.

5.3 Continuous Flow Monitoring and Measurement

Continuous flow measurement at middle and tail reaches is absent at these distributaries. Flow measurement is not being made at head reach as well; just gauge readings are continuously monitored by SIDA employee on daily basis. Installation and proper management and monitoring of head, middle and tail reaches would improve water delivery equity. Thus, re-calibration of these gauges must be done after each de-silting activity or after every season.

4. CONCLUSION

The existing irrigation water management at Bareji, Belharo and Mirpur distributaries is poor. For their long term sustainability, water distribution, equity, reliability and water saving, continuous monitoring and maintenance of is required. There are times during year, when water supply is in surplus and much portion of that is used at head reach that ultimately increases water logging and salinity. Based on classification by Molden and Gates (1990), water deliveries during month of August, 2014 were rated as 'good' whereas, during June and July, 2014 water supplies were rated as 'fair'. While for rest of the months of 2014 and 2015 the water supplies were rated as 'poor'. The water use efficiency was higher at head reach, whereas it was near to reasonable at middle reach and inadequate at tail reach during both the years. As a result of consistent over flow than the designed one at head and middle reaches; the tail reaches were affected during months with fewer flows.

The equity of water supplied in the system was rated as 'poor' so that the reliability was also rated as 'poor'. Multi-sectorial water demands in the area are intensifying and putting more pressure on water demands. The increasing water demands dictate large scale development of irrigation systems to meet rising domestic and industrial water needs.

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