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Assessment of equity in water distribution at watercourse level and the impact on water productivity

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Abstract

The impacts of water variation differ in their magnitude in different canal irrigation systems, mainly due to variations in water availability (timings and amounts), crop types and soil fertility status. These necessitates conducting site-specific research and studies to evaluate the impact of variations in water availability at the farm level for specific crops. The findings of such studies will then be utilized to rationalize the irrigation supplies at the farm level keeping in view the level of variation. Accordingly, this study was undertaken for the assessment of inequality in canal water distribution and its impacts on the yield and water productivity of maize in the command area of the Khikhi distributary, Pakistan. For this purpose, three water courses at the head, middle and tail reaches of the distributary were selected. On each of the selected watercourse, three maize fields at the head, middle and tail were chosen. Discharges measurements were taken and the yield of the maize crop was recorded. A significant variation in design and measured discharges were observed in the head reaches (inlet point) of watercourses off taking from the head, middle and tail of distributary that was 13.79%, 12.0% and 7.30% reduction in the flow against the allocated discharges, respectively. The discharge variation along the distributary varies from 0 to 38% from head to tail end, similarly, the variation in discharge for the watercourse located at the head of the distributary was from (100 %) 2.90 cfs to (85.86 %) 2.49 cfs i.e. 0.41 cfs (14.14%) reduction in discharge from head to tail end and for the watercourses located at the middle (WCM) and tail (WCT) the discharge reduction was (31.72%) 1.02 cfs and (37.08 %) 0.66 cfs, respectively. These variations in discharge ultimately reduced the maize crop yield and production from 11 to 54%. The percentage gap in yield from head to tail was up to 54% and the water productivity decreased up to 26% for tail end section of watercourses. These results clearly showed the inconsistency in canal water distribution at tertiary level (watercourse) as well as secondary (distributary) irrigation system leading to reduce the crop production of tail end farmers.

Keywords: Canal Water Distribution; Irrigation System; Khikhi Distributary; Water Course; Water Distribution; Water Productivity

INTRODUCTION

Globally it is found that water resources are considered the most critical and acute natural resource in terms of their mismanagement. Water resources are the most important for agricultural and livestock production which plays a key role in the economic growth of any region. Crop production and water application are intimately related. Water is the resource of crop production in areas where rainfall is not enough to fulfil the existing demand. According to High Level Panel of Experts on Food Security and Nutrition (HLPE), it is the need of the day to improve the water use efficiency and water productivity, to safeguard the future food safety and study

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the fears linked with water shortage (HLPE, 2015).

The agricultural sector in Pakistan is the paramount source of its economy and accounts for 26 percent of gross domestic product (GDP) (Rehman *et al*., 2015). Irrigation is one of the essential inputs required for sustainable irrigated agriculture in countries like Pakistan and out of 81 mha (million hectares) land, 31 mha is suitable for agriculture and approximately 20 mha are cultivated of which 16.2 mha being irrigated (Saeed, 1994). The irrigation system of Pakistan is facing many problems, one of which and most severe is the unequal distribution of the canal water i.e. under exiting conditions, the farmers are not receiving their due share of water. It has been observed that the farmers on the head reaches of irrigation channels (watercourse and distributaries) get more share of water as compared to those at the tail-end. The reasons behind this problem are mostly due to not preventing the convenience and seepage losses in the present water distribution system or over flooding of the field located at the head which has a direct impact on crop yield as well as farmer's income. Poor maintenance and the cleanliness of water channels result in inequitable water distribution. Certain other reasons cause inequity in water distribution, such as siltation in water channels, change in longitudinal slopes of channels, weed growth, an increased number of outlets and illegal tampering of water. Seepage losses also have a remarkable effect on the equitable supply of water (Tareen *et al*., 1996).

Unpredictable and varying flows complicate the performance and evaluation of farm irrigation, especially in a country where fluctuations in canals reach 10-20 percent daily, adversely affecting the water distribution from a distributary to a watercourse. This inequitable water distribution along the watercourse affects the crops yield which ultimately reduces the water productivity and income of tail end users. Therefore, there is a need to accelerate more efforts to increase the productivity of water in agriculture to meet the future food demand of the increasing population (Sarwar and Bastiaanssen, 2001). A large number of factors cause hindrances to increase the agricultural production, such as small and fragmented landholdings, deficient water supplies, severe waterlogging and salinity, traditional cultivation methods and practices, and illiteracy (Khan, 2006). Of these, inequitable water supplies and fluctuations in distributaries and minors are the major factors being neglected.

Several research studies have been conducted in Pakistan on water distribution to distributaries, minors, and watercourses as discussed below. According to the baseline survey carried out by NESPAK in 1989, water distribution to distributaries and minors lack equity. Flows to the watercourses are also unequal, with some watercourses drawing more water than the designed quantity and some less (NESPAK, 1992). According to Latif (2007), there is a significant variation in water productivity along with the irrigation system. This situation becomes worst for the watercourse level. The farmers at the tail of the watercourses suffer more due to unavailability or less amount of allocated. Therefore, the income and the water productivity decreases along with the irrigation system due to decreasing availability of allocated water (Latif, 2007; Rizvi *et al*., 2012). Chambers (1998) stated that "the irrigation system of Pakistan has the deficiency of tail-enders is notorious and it is confirmed again and again". Bhatti (2006) conducted a study on the equitability of canal water distribution. The results showed up to 30 to 50 percent discharge variation from head to tail. Siddiqi *et al*. (2018) and Wescoat *et al*. (2018) studied the socio-hydrology of complex Indus Basin Irrigation System (IBIS) for equity and reliability of surface water. They have highlighted the problems of the irrigation system. Firstly, the overall production of Punjab province has shown significant variation in crop production due to the low levels of equity of water allocation which requires an additional level of entitlement and delivery relationship across the canal commands area. Secondly, the overall system equity and reliability are moving in wavering instead of improving. Thirdly, the consistency and reliability are declining from upstream to downstream locations, which is raise the question of equity and pragmatic aspects of water supply more in Southern Punjab (downstream territory of IBIS). Similar water allocation conflicts exist in the other parts of the world such as China, India, Australia, The United States, and others in agriculture and cooperate sector that has rebound effect on sustainable development (Syme, 2014; Singh, 2017; Sattar *et al*., 2018; He *et al*., 2018).

Water productivity of irrigated crops is "the production of crop per unit of water drop". Further, it is the optimum crop yield with less amount of water. For a farmer, water productivity means getting more crop per drop of water and at a basin or country's scale, this means getting more value than water resources used (Kijne *et al*., 2003). Improving agricultural water productivity is central for both economic and social development. Therefore, there is every motivation to designate more efforts to increase the productivity of water in agriculture to meet the future food demand of the increasing population (Sarwar and Bastiaanssen, 2001). The present study has, therefore, been conducted in the command area of the Khikhi irrigation canal receiving water from the Lower Gugera Branch canal of the Indus Basin, Pakistan to identify the problems and constraints affecting the water productivity. The specific objective of this study is to assess equity in water distribution at the watercourse level and its impact on water productivity. This study is limited to Khikhi distributary. Field and secondary system has been used for the evaluation of the water productivity.

MATERIALS AND METHODS

Assessment of equity in water distribution

Equity in water distribution can be defined as the distribution of a fair share of water to users throughout the system (Kijne *et al*., 2003). Water distribution is a set of activities to deliver water to secondary and tertiary off-takes to satisfy the schedule with a certain degree of precision (Ahmad *et al*., 2014).

For successfully achieving the objectives of this research, the following data was required:

- Collection of Field Data:
  a) Selection of distributary
  b) Selection of watercourse
  c) Selection of cropping field

- Discharge measurement and water distribution within watercourse
- Crop yield data collection
- Water productivity estimation and volume of water applied

Collection of field data

The collection of field data consists of three data types as discussed below:

Selection of distributary: Khikhi Distributary is an irrigation canal located in District Toba Tek Singh Punjab, Pakistan was selected. The estimated terrain elevation above sea level is 156 meters. The canal originates at a reduced distance RD-0 from the Lower Gugera Branch canal. The length of the canal is 26.2 km and has 88 water outlets to irrigate 14891 hectares of land. The present sanctioned discharge of the canal is 267 ft^3/sec (Irrigation and Power Department, Faisalabad Zone).

Selection of watercourse: For the selection of watercourses, the canal was divided into three parts along the lengths, the start of the canal section is designated as the head (H), the centre as the middle (M) and the end section as the tail (T) towards the downstream end as shown in Figure 1. At each section of the canal, one watercourse (W.C) was selected at the head (WCH) RD-9956, at the middle (WCM) RD -75011, and at the tail (WCT) RD-111395, respectively. Each marked watercourse was again divided into three lengths and the part closer to the canal, at the outlet of the W.C was designated as the head (h) followed by middle (m) and the distant section as the tail (t).

Selection of cropping fields: A total of nine maize fields (1 acre/each) sown on ridges were selected based to see the effect of discharge variation on crop yield along the length of distributary and watercourse while keeping all the other parameters constant, i.e. seed rate, seed variety, fertilizer application and field preparation. The location of the maize fields is designated as FHh, FHm, FHt, FMh, FMm, FMt, FTh, FTm and FTt. Here F represents the location of the maize field selected at (H, M and T) head middle and tail of the distributary and h, m, t head, middle and tail of the watercourse. In each section, a representative maize field was randomly marked to record the grain yield after harvesting.

Figure 1 shows the command areas of watercourses at the head, middle and tail end of the distributary. WCH have a total length of 4.75 km, ended at Chak # 340 GB. This watercourse is situated on the left side of the distributary. The first maize field at the right side of the head of the watercourse (FHh) is 0 km from the distributary. The second maize field located on the left side of the watercourse (FHm) is at 2.75 km and the third field (FHm) is also on the left side of the watercourse 4.75 km away from the distributary. WCM is situated on the left side of the distributary near Chak # 332 GB. Three of the maize fields are located on the right side of the watercourse at 0.5 km, 3 km and 5 km from the distributary respectively. WCT is situated at the right side of the distributary near Chak # 328 G.B. First maize field is at 0.2 km from the head, the second field is at 2.2 km and the last maize field is at 3.2 km from the distributary. All of the selected maize field are on the left side of the watercourse. The salient features of the maize crop and selected watercourses are listed below in Tables 1 and 2, respectively.

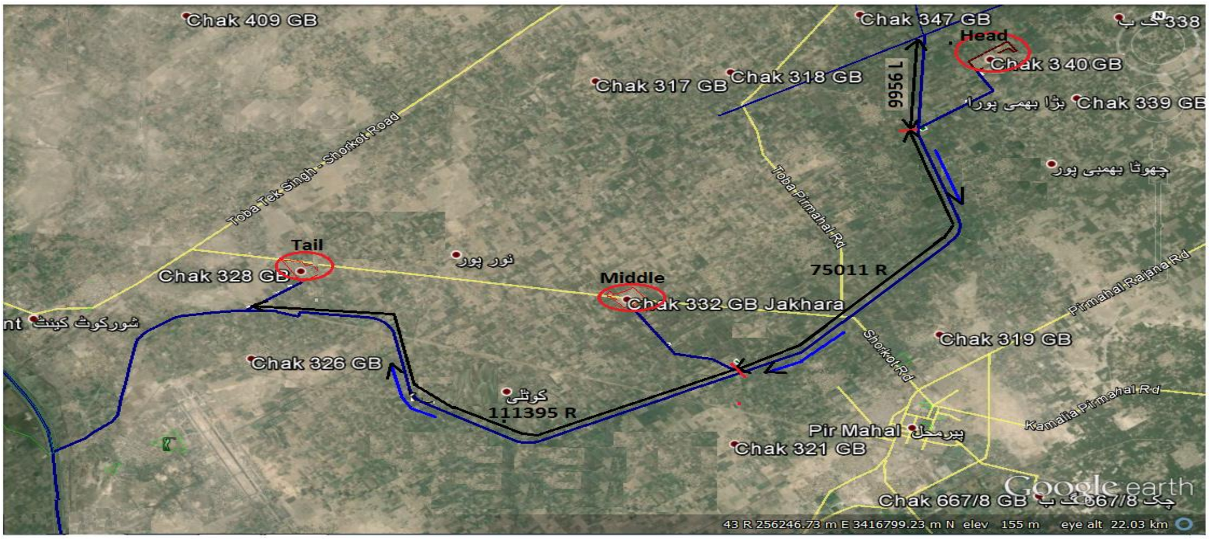

Fig. 1. Location map of the watercourse and selected maize fields at the head, middle and tail of distributary. Figure is not to scale

Table 1. Salient features of Maize Crop (Soomro *et al*., 2018)

Salient features of maize crop grown in Khikhi distributary								
Name of Crop	**Botanical Name**	**Rooting Depth (mm)**	**Sowing Month**	**Harvesting Month**	**Potential water requirements for Khikhi Distributary (mm)**	**Average National yield (kg/ha)**	**Potential yield (kg/ha)**	**Potential Water Productivity (kg/m3)**
Maize	Zea mays	90-150	July	Sept-Oct	376	2984	8700	2.51

Table 2. The salient features of selected watercourses and maize fields

Distributary Sections	W/C No. and Location	Maize variety	Fertilizer applied	Village Name	Name of Farmer	The distance of maize field from distributary (km)	Location of Maize Field
Head (H)	9956(L) (WCH)	Pioneer 302287	NPK	340 G.B	Nazir Ahmad	0	FHh (R)
					M. Ameen	2.75	FHm (L)
					Jamal Din	4.75	FHt (L)
Middle (M)	75011(R) (WCM)	Pioneer 302287	NPK	332 G.B	Khalid Mahmood	0.5	FMh (R)
					N. Jaffir	3	FMm (R)
					Seth Muhammad	5.5	FMt (R)
Tail (T)	111395(R) (WCT)	Pioneer 302287	NPK	328 G.B	M .Ahad	0.2	FTh (L)
					M. Zakria	2.2	FTm (L)
					Master Liaqat Ali	3.2	FTt (L)

Discharge measurement and water distribution within watercourse

To assess the equity in water distribution within the watercourse, the discharge was measured at the head, middle and tail of every sample watercourse. The authorized discharges of the sample watercourses were compared with the actual discharges available at the head of every sample watercourse. The difference between the authorized and actual discharges indicates whether the water was distributed equitably within the watercourse or not. The discharge measurements were done using the velocity area method and velocity was measured using the current meter.

Crop yield data collection

A total of nine maize crop fields were selected having 1 acre of an area each. The yield of the maize crop was calculated for each field and the yields of all the fields were compared to determine the difference in yields at the head, middle and tail sections of watercourses. A wooden frame with 1 m length and 1m width was placed in each field at three random places and an average yield of these three sections was noted by using a weighing balance. This produced yield (Kg/m^2) of each maize field was converted to Kg/acre.

Water productivity estimation and volume of water applied

The estimation of water productivity was done using the following relation:

$$W.P = \frac{Crop\ Yield}{Total\ Volume\ of\ water\ applied} \qquad (1)$$

Where W.P = water productivity (Kg/m^3)

The total volume of water applied was calculated by using the following equation:

$$Q \times t = A \times d = Constant \qquad (2)$$

Where Q = discharge (ft^3/s) of each watercourse for a time t (sec) during each irrigation applied, and Constant = A×d where A is the cultivated area (acre) and d is the constant depth of water applied (79 mm).

RESULTS AND DISCUSSION

An assessment of water equity in water distribution along watercourse

The discharge variation analysis on monthly basis has been done along the length of distributary at the head middle and tail of selected sample watercourses i.e. (WCH, WCM and WCT) during July, August and September months i.e. the cropping season of maize crop.

Average monthly discharges at WCH, WCM and WCT

WCH watercourse is located at the head of the distributary. The daily discharge of this watercourse usually remained higher than its design discharge, except occasional low discharges at the time of canal closure. The average monthly discharge of July, August and September were 16, 13 and 10 percent higher than the design discharge respectively as shown in Figure 2a.

WCM is the watercourse in the middle of distributary and similarly have higher monthly discharges than design. The average monthly discharges of the selected months were 15, 11 and 8 percent higher than design discharge respectively as shown in Figure 2b. Similarly, the average monthly discharge analysis of tail watercourse (WCT) showed that actual discharges are higher than design discharge. The average monthly discharges of July, August and September were 10, 7 and 4 percent higher than design discharge respectively.

The obtained results of the study are in comparison with the previous studies conducted in other distributaries of Punjab, Pakistan. For example, according to Wahaj (2001), the water distribution along the minor remained inequitable and watercourses at the head of the minor had been getting more, and the outlets at the tail, had been drawing less than their designed discharges. This availability affected the crop yields. The watercourses at the head had a good yield of sugarcane, but watercourses at the tail had a comparable low yield of sugar production. Bhutta (1990) extensively studied the distributaries of Upper Gugera Branch of Lower Chenab Canal, in Punjab province. He pointed out that deliveries at the head of the distributaries were rarely in accordance with original design criteria. Field measurements revealed that distribution of canal water among the outlets of distributaries was inequitable. He concluded that spatial variation of these distributaries was more profound at tail reaches where farmers were mostly deprived from their due share.

Average monthly discharge variations of selected watercourses of distributary

The discharge variations (i.e. percentage difference between actual measured monthly discharge and design discharge) at WCH, WCM and WCT along the length of distributary are given in Table 3.

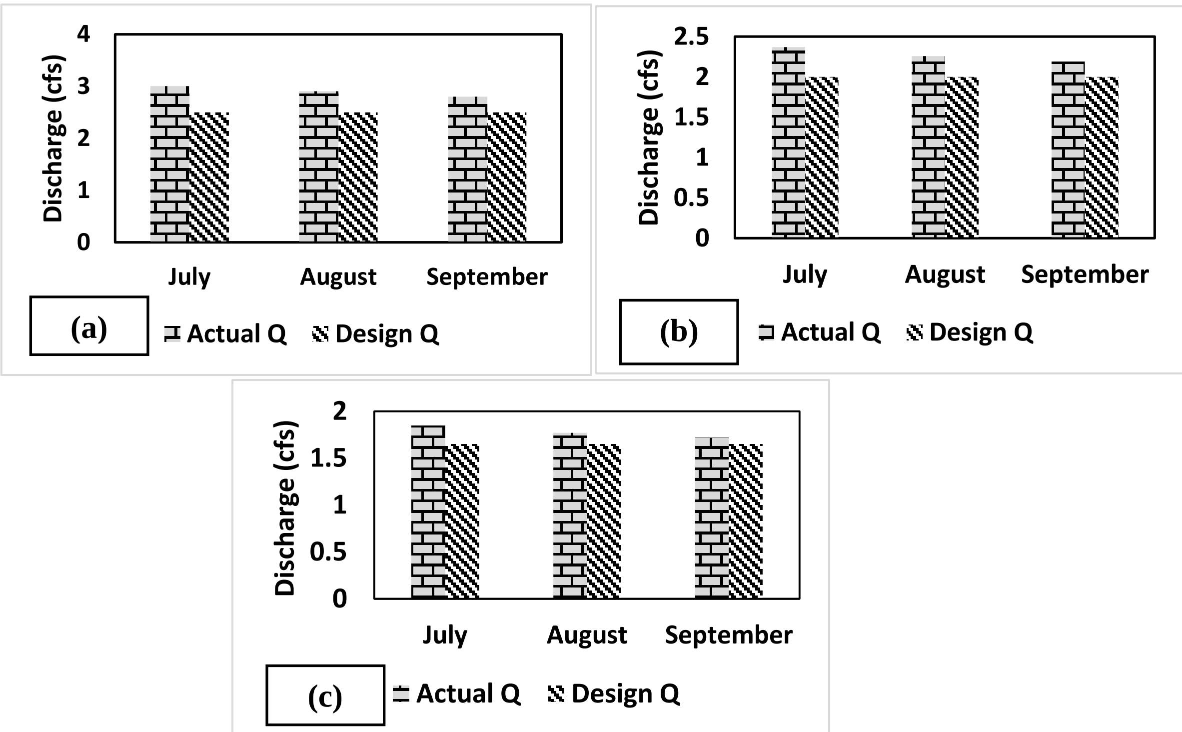

Fig. 2. Average monthly discharge variations at (a) WCH, (b) WCM and (c) WCT and comparison with design discharge.

Table 3. Percent variation between measured and design discharge along the distributary

W/C No.	Design discharge (Q_d) (cfs)	Measured discharge (Q_m) (cfs)	Percentage variation Q_d and Q_m	Percentage Variation in Discharge
WCH	2.50	2.90	13.79	0
WCM	2.0	2.27	12.0	21
WCT	1.65	1.78	7.30	38

Table 3 indicated that all watercourses have measured discharges higher than the design and the average percentage variation between Q_d and Q_m were 13.79, 12 and 7.30 at WCH, WCM and WCT respectively. The discharge variations of three watercourses at the head, middle and tail of distributary along the length can also be depicted from Table 3, at WCH the discharge variation is zero percent and as the move away from the head, this variation is going to increase i.e. WCM has 21% less discharge and WCT 38% less as compared to WCH. According to study conducted in the Bhakra canal system (BCS) in the Kaithal irrigation circle in India and the Lower Jehlum canal system (LJCS) in the Chaj sub-basin in Pakistan by Hussain *et al*. (2003), there is a significant inequity in distribution of canal water both within watercourses and across watercourses in BCS-India and LJCS-Pakistan, with tail reaches receiving less canal water than head and middle reaches. This study results verified the results obtained in present study.

Water distribution variations within the selected watercourse

The discharge measurement within the watercourses at the head middle and tail were done at each irrigation applied to the maize crop. The average discharge variations are shown below Table 4.

The variation for the watercourse located at the head of the distributary was from (100 %) 2.90 cfs to (85.86 %) 2.49 cfs i.e. 0.41 cfs (14.14%) reduction in discharge from head to tail. Similarly, for the watercourses located at the middle (WCM) and tail (WCT) the discharge reduction was (31.72%) 1.02 cfs and (37.08 %) 0.66 cfs, respectively. Keeping in view these results it is determined that tail ends of watercourses get less amount of discharge and the farmers at these sections suffer by getting a low yield of crop as compared to middle and head section farmers. The discharge variation for the tail watercourse end is more as compared to head and middle reaches. This low amount of water is due to reasons, for example, theft of water and conveyance losses etc. This discharge gap ultimately affects the yield of the crop particularly at the tail end side of watercourses/ distributary. The obtained results are inline with findings of Hussain (2005), i.e. the distribution of irrigation water poses inequality at different levels of the Lower Chenab Canal (LCC) irrigation system, i.e. along main canals, distributaries and within watercourses. The farmers situated at the head of the irrigation system have access to sufficient water; however, the farmers situated in the middle and the tail reaches of the irrigation system do not get their share of water (Hussain, 2005).

The measured discharge variations revealed that as going away from the head to the tail reach of the distributary as well as from head to tail of the watercourses the discharge decreases. It is also concluded from the analysis of discharge variations along the distributary and watercourses that the variation of discharge along the watercourse was more than the variation of discharge along the distributary. The reasons behind are more, theft of water, conveyance losses and poor maintenance in watercourses as compared to that of distributary.

Discharge variation with respect to time of application

During the study, it was observed that

there is an inverse relationship between discharge and time of application as discharge increases the time of application decreases. The maize field located at the tail end of the distributary as well as watercourse (FTt) thus require more time of application (2.23 hours) as compared to head and middle fields of the selected watercourses but farmer normally gets the water for the similar time at the head, middle and tail reach of the watercourse. Keeping the area and depth of water constant according to the equation $Q \times t = A \times d = Constant$, the tail end fields required more water application time due to reduction in discharge as compared to the fields located at the head of the watercourse. Discharge variation with respect to time of application is shown in Table 5.

Crop yield estimation and its variation

Hybrid varieties of maize are mostly grown in this area and these varieties under optimum conditions of temperature, soil, fertilizer and water, provide a maximum yield of up to 9,880 kg/ha (Soomro *et al.*, 2018), which is about three times more than the synthetic maize varieties. Hybrid varieties require water and water inputs as compared to synthetic varieties. Synthetic varieties are very sensitive to water shortage. Therefore, the application of water in the right amount and at the right time is very important to get higher yield and productivity. Higher yields were observed in the fields located at the heads of watercourses whereas yields were reduced in the fields at the middle of the watercourses that were followed by the more reduction in yields in the fields located at the tail of the watercourses. Though the pattern of yield reduction reviews, the same on the watercourses there were significant yield differences due to the variation of flow in the distributary. Comparing the yields at all watercourses the yields were higher on all locations (Head, Middle, and Tail) on the watercourse which was at the head of the distributary as compared to the same locations on the watercourse off taking from the middle of distributary which was followed by the yields of similar locations of the tail end watercourse of the distributary. These differences showed that moving away alongside the watercourse or distributary deprives the farmers from yield and subsequently the income as shown in Table 6. The yield of the maize crop was 8398 kg/ha at the head of the distributary (FHh) which was reduced to 3952 kg/ha at the tail of the watercourses off taking from the tail of distributary (FTt). The later was 54% less than the former one.

Table 4. Percentage discharge variation of selected watercourses

W/C No.	Location of W.C on distributary	Field discharge within W.C (cfs)		
		H	M	T
1 (9956 L)	Head	2.90 (100%)	2.79 (96.20%)	2.49 (85.86%)
2 (75011 R)	Middle	2.27 (100%)	1.71 (79.73%)	1.25 (68.28%)
3 (111395 R)	Tail	1.78 (100%)	1.35 (75.84%)	1.12 (62.92%)

Table 5. Variation in time of application and discharge reduction at Khikhi Distributary

Location of Maize Field	Time of Application (hours)	Volume of Water (m^3)	Discharge (m^3/s)
FHh	1.09	324.6	0.082
FHm	1.17	333.08	0.079
FHt	1.35	341.86	0.070
FMh	1.32	305.51	0.064
FMm	1.56	185.32	0.033
FMt	1.65	256.25	0.043
FTh	1.51	271.87	0.050
FTm	1.78	243.58	0.038
FTt	2.23	249.53	0.031

Table 6. Maize yield at the head and tail location of watercourses off taking from the head, middle and tail of Khikhi canal area

Maize field location at W.C	Distance from distributary (km)	Yield (kg/ha)	% Difference in yield
	0	8398	0
Head	2.75	8002.8	4.70
	2.75	7410	11
	0.5	7706.4	8.23
Middle	3	6817.2	18
	5	5928	29
	0.2	6125.6	27
Tail	2.2	5532.8	34
	3.2	3952	54

It was observed that there is a relationship between the percentage variation of discharge and yield. It is shown that if the discharge is higher, the yield is higher and vice versa. The same is shown in Figure 3. As compared to the average discharge and yields at the head (when taken as 100 %) of the watercourse there was a 12% average decrease in discharge and 14 % decrease in yields at the middle and 24 % decrease in discharge and 30 % yield reduction at tail end watercourse.

Some recent studies on the water distribution of irrigation systems showed similar results that the inequality of water distribution between head- and the tail-enders is closely correlated to decreasing crop yields and increasing salinity problems, due to increasing distance from the canal (Latif and Pomee, 2003; Latif and Ahmad, 2009).

Assessment of water productivity

The water productivity (W.P.) of a crop is the yield of a specific crop per unit of applied water (kg/m^3). Generally, it was found that water productivity is lower as compared to the potential water productivity in the semi-arid region of Punjab province, Pakistan and in this case the overall water productivity of maize crop is also low. The potential water productivity of maize crop is reported as 2.51 kg/m^3 and W.P. for Khikhi distributary has estimated 0.88 kg/m^3 during this study. This shows a gap of more than 65% in the potential and actual water productivity. There is a great potential to increase the existing crop yields with the proper management of water and non-water inputs with the same quantity of water applied. The trend of water productivity according to field location on the watercourse is shown in Figure 4. This revealed that at the head of watercourse/distributary, water productivity is higher than those fields located at middle and tail sections.

Variation in crop yield and water productivity with volume of water applied

The crop yield and water productivity varied with the application of water to the fields. There is a direct relationship between the volume of water applied, crop yield and water productivity. This is shown in Table 7. Similar trends were obtained by different researchers related to low crop yields due to inequality of water allocation among water users at the head, middle and tail reaches of the irrigation system (Hussain, 2005; Baig, 2009).

It is to be noted that the existing system in Pakistan remains plagued with significant inefficiencies and deficiencies in control and distribution of irrigation water, with increasingly adverse impacts on crop yields and production (Briscoe and Qamar, 2006). The need to improve ‘water security’ in the country’s large irrigation system is important from not only a local standpoint, but also from a larger national agricultural production and food security

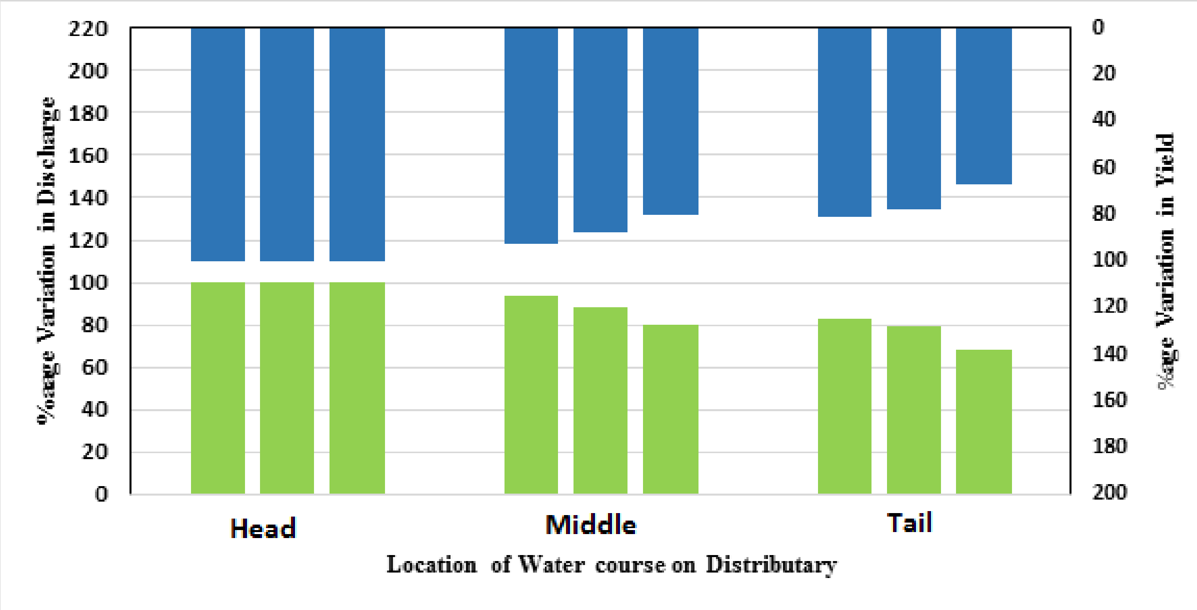

Fig. 3. Percentage variation of discharge and yield

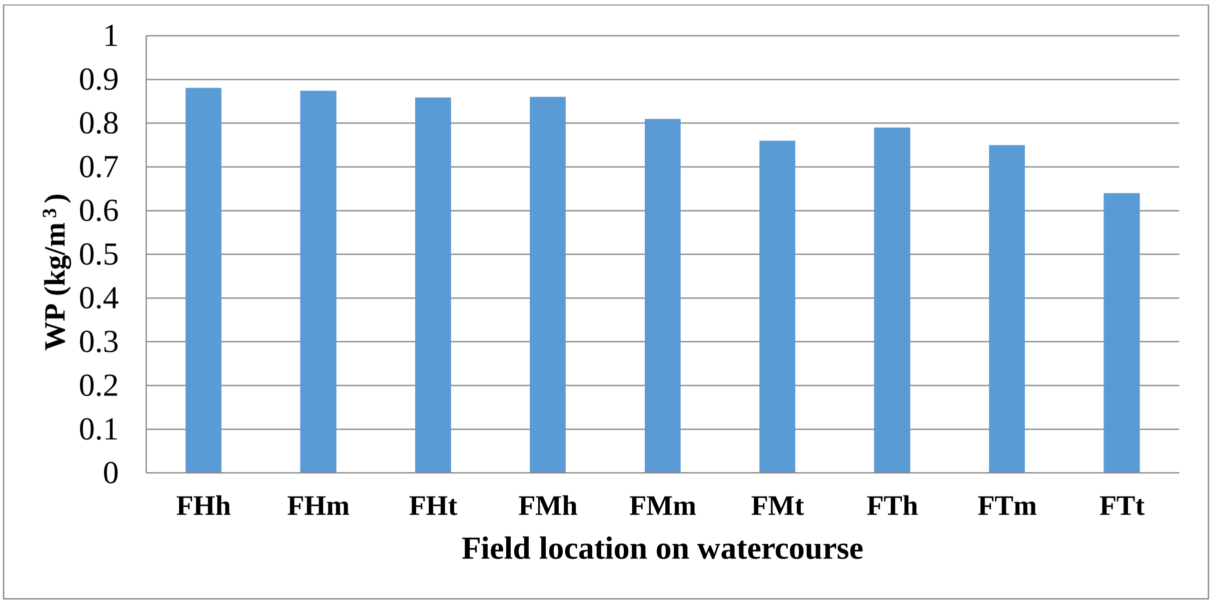

Fig. 4. Water productivity of maize crop along watercourses at different locations of Khikhi Distributary

Table 7. Relationship between Volume of Water with Crop Yield and W.P. Observed at Khikhi Distributary Area

Total Volume of Water Applied (m^3)	Crop Yield (kg/ha)	WP (kg/m^3)
3862	8398	0.88
3720.	8002	0.87
3492	7410	0.86
3626	7706	0.86
3394	6817	0.81
3125	5928	0.76
3123	6125	0.79
2950	5532	0.75
2475	3952	0.64

perspective. In a positive development, the Government of Punjab Irrigation Department (PID) has posted canal entitlements and deliveries online to help improve transparency, analysis, and thereby water security. Culas and Baig (2020) concluded that a redistribution of the water use (optimal scenario) could improve water productivity and crop productivity in the Lower Chenab Canal (LCC) irrigation system in Pakistan.

CONCLUSION

A significant variation in discharge was observed in Khikhi Distributary along the canal/watercourse length from the head towards the tail which has ultimately reduced the crop production. The variation in design and measured discharges were observed in the head reaches (inlet point) of watercourses off taking from the head, middle and tail of distributary which was 13.79%, 12.0% and 7.30% reduction in the flow against the allocated discharges, respectively. The discharge variation along the distributary varies from 0 to 38% from head to tail end. Similarly, the variation in discharge for the watercourse located at head of the distributary was from (100 %) 2.90 cfs to (85.86 %) 2.49 cfs i.e. 0.41 cfs (14.14%) reduction in discharge from head to tail end and for the watercourses located at the middle (WCM) and tail (WCT) the discharge reduction was (31.72%) 1.02 cfs and (37.08 %) 0.66 cfs, respectively.

The variation in the maize yield was 0 - 11.76 % for the head, 8.24-29.14% for the middle and 27-52 % for tail reaches. The overall percentage gap in yield was found up to 54 % between the fields at the head of the watercourse to the field off taking from the head of the distributary to the field at the tail of the watercourse off taking from the tail of the distributary. The water productivity of the head watercourse was 0.88 kg/m^3. The water productivity decreases up to 26 % for tail reaches. These results clearly showed the inconsistency of canal water distribution along the system leading to reduce crop production and water productivity. Similar studies can be planned for the entire irrigation system of Pakistan on a small or large scale irrigation system to evaluate the site-specific variation in water productivity for various crops under more affecting variables (e.g. fertilizer application, seed varieties, cropping patterns, climate change).

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