Research Article

Water Availability and Productivity in the Command Area of Improved /Unimproved Watercourses of Civil Canals in District Peshawar

Muhammad Adnan Fahad[1], Muhammad Jamal Khan[1], Sheraz Ahmed[2*] and Imtiaz Ali[2]

[1]*Department of Water Resources Management, The University of Agriculture, Peshawar, 25130, Khyber Pakhtunkhwa, Pakistan;* [2]*Department of Plant Breeding and Genetics, The University of Agriculture, Peshawar, 25130, Khyber Pakhtunkhwa, Pakistan.*

Abstract | A substantial part of the valuable water is wasted in form of conveyance losses in earthen watercourses. To assess the effect of watercourses improvement on water availability and productivity, ten watercourses were selected randomly. Out of which, five improved and other five were found unimproved. Water losses in both watercourses were measured to find water saving from improved watercourses. Conveyance losses were measured in improved and unimproved watercourses by current meter and cutthroat flume, respectively. Farmers were interviewed to find out the effect of watercourse improvement on crop productivity and water management practices using questionnaire proforma. The losses in five improved watercourses (lined sections) were 9, 28, 5, 11 and 20% per 1000 meter, respectively while that of unlined sections of the same watercourses were 23, 30, 50 and 21 % per 1000 m, respectively. Losses in unimproved watercourses were 27, 62, 55, 55 and 40 % per 1000 m, respectively. The conveyance efficiencies of five improved watercourses (lined sections) were 91, 72, 95, 89 and 80 % per 1000 m, respectively while that of unlined sections were 77, 70, 50 and 79 % 1000 m, respectively. The conveyance efficiencies of unimproved watercourses were 73, 37, 45, 45 and 60 % 1000 m, respectively. Based on the results, it can be concluded that watercourse improvement caused significant effect on irrigation water and it is therefore justified from economic perspectives.

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***Correspondence** | Sheraz Ahmed, Department of Plant Breeding and Genetics, The University of Agriculture, Peshawar, 25130, Khyber Pakhtunkhwa, Pakistan; **Email:** drsheraz@aup.edu.pk
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Introduction

The canal irrigation system in the Indus Basin of Pakistan has a wide range of operational problems, due to severe losses of water conveyed to the agricultural lands. The losses of water so formed results in limited supplies of canal water in the Indus Basin. These losses of water have a great impact on the supplies of surface water and require proper management so that the losses should be minimized. This is perhaps the most economical method of enhancing water supplies (IDWR, 2005).

Water losses in watercourses could be associated with many factors such as leakages from turnouts (structure constructed in the bank of a canal to divert part of the water from the canal to a smaller one), curves in the watercourses, high density of weeds in the unlined watercourses, siltation problems, sediments depositions, partially compacted banks, lack of proper maintenance and holes made by rodents (Zeb *et al.*, 2000). According to a survey conducted in Bhakkar, Bahawalpur (Punjab) and Moro (Sindh) the losses of water which were measured in the conveyance system of the watercourse were up to 40- 51% (WAPDA and

CSU, 1978). By the inflow-outflow method, the losses of water were estimated and the total operational losses were determined by measuring the volume of water that enters the irrigation fields during a complete rotation. It was found that total operational losses were 45 % of the inflow (Thomas, 1980). A study was conducted to evaluate 45 watercourses selected randomly at different places of Khyber Pakhtunkhwa (formerly known as N.W.F.P), Sindh, and Punjab provinces. The procedure used was the inflow-outflow method and use of cutthroat flumes, the delivery losses was found to be 45 % (WAPDA, 1984). Similarly, another study was conducted, and the conveyance losses were found up to 38 -62 % in the watercourses of Khushab district (Copland, 1987). To minimize losses of water that occurs in the irrigation system, a series of On-Farm Water Management (OFWM) projects including the Command Water Management Project (CWMP) were launched formally in the country during 1981. These projects aimed to improve watercourses, overcome losses of irrigation water, and increase the supply of quality water for irrigation of crops (Khan, 2010).

The country is facing a colossal shortage of water resources. The available water for irrigation is gradually decreasing. Though the canal irrigation system of Pakistan is one of the best irrigation systems in the world. However, the conveyance efficiency of water is still decreasing continuously. National Program for improvement of watercourses aims at conserving that water by improving the watercourses.

The national program for improvement of water-courses in Pakistan was launched back in 2004 on the special directives by the Country's President to improve the conveyance efficiency of irrigation channels along with providing considerable employment opportunities in the Private as well as to the Public Sector. Khyber Pakhtunkhwa was interested in the gigantic task of improving 10000 watercourses in all 24 districts. By the end of the completion date of the project, i.e. 30th June 2008, Khyber Pakhtunkhwa emerged as the only province/executing agency that exceeded the PC-1 (project cycle) targets against the national average achievement of 66 %.

Overall, the government of Pakistan has spent a hefty amount of Rs. 66 billion on the lining of watercourses under the National Program for Improvement of Watercourses. However, it is unknown whether the money spent on these watercourses was worthwhile to improve water availability and ultimately agricultural productivity or not. Keeping in view the above-narrated facts, assessment of water availability and water management practices in improved and unimproved watercourses is essential to evaluate and enhance agricultural productivity. Therefore, this research work was designed with the specific objectives to; (i) assess the water availability in selected improved and unimproved watercourses, (ii) compare water productivity in improved and unimproved watercourses, and (iii) study the water management practices in the command areas of improved and unimproved watercourses.

Materials and Methods

Description of the study area

The research site is located in the command area of Joe Sheikh Canal, Mia Gujar Minor, and Warsak Gravity Canal, in the villages of Balu, Nazar Kalay, Lala Kaly, Wadpaga, and Telaband in District Peshawar.

Research work was carried out on improved and unimproved watercourses at different places in Peshawar. Total watercourses improved under the national program for improvement of watercourses are 10385. Under the same project, the total watercourses in Peshawar are 4633, in which 687 are improved and 3946 are unimproved (Khan, 2010). Ten watercourses were selected at random in which five were improved and five were unimproved. Their different parameters were measured which include conveyance efficiency, discharge measurements of selected watercourses, conveyance losses, water productivity of improved and unimproved watercourses, and changes in the water management practices in the command areas of improved and unimproved watercourses.

Description of the selected watercourses

Six watercourses are located in Joe Sheikh Canal, two in Mia Gujar Minor, and two in Warsak Gravity Canal. The locations of these watercourses are shown in Figures 1 and 2. Conveyance losses, conveyance efficiency, water availability, water productivity, and water management practices were determined in these watercourses. The detail of these watercourses are discussed below:

Watercourse No 15315/R: This watercourse was improved, which emerged from Joe Sheikh Canal and was situated in the village Balu (Figure 2). The total length of the watercourse was 1300 m in which the lined portion was 627 m and the unlined portion was 673 m. It was improved on 8th May 2007 of concrete lining and its cross-section was parabolic. Its design discharge was 1.70 cubic foot per second (cusecs) with a culturable command area of50.58 hectares.

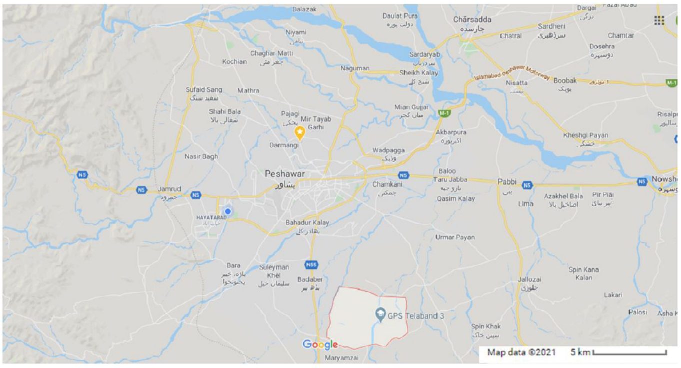

Figure 1: *Location map of the study area. Heavy blue lines showing location of different water channels in study area.*

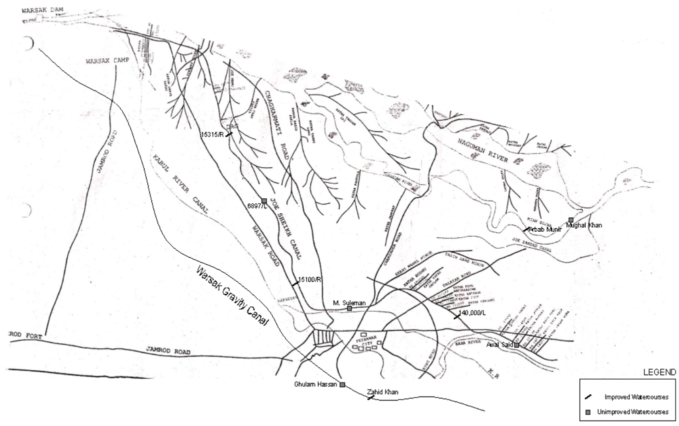

Figure 2: *Location map of selected watercourses.*

Watercourse No 15100/R: This watercourse was improved, which emerged from Joe Sheikh Canal and was situated in the village Nazar Kalay (Figure 2). The total length of the watercourse was 1450 m in which the lined portion was 584 m and the unlined portion was 866 m. It was improved on 8th May 2007 of concrete lining and its cross-section was parabolic. Its design discharge was 1.50 cusecs with a culturable command area of 32.37hectares.

Watercourse No 140,000/L: This watercourse was improved, which emerged from Joe Sheikh Canal and was situated in the village Lala Kalay (Figure 2). The total length of the watercourse was 2000 m in which the lined portion was 1500 m and the unlined portion was 500 m. It was improved on 15th April 2006 of concrete lining and its cross-section was parabolic. Its design discharge was 3.50 cusecs with a culturable command area of 141.64 hectares.

Arbab Munir watercourse: This watercourse was improved, which emerged from Mia Gujar Minor and was situated in the village Wadpaga (Figure 2). The total length of the watercourse was 1000 m and was fully lined. It was improved on 13th September 2007 of concrete lining and its cross-section was parabolic. Its design discharge was 2.80 cusecs with a culturable command area of 12.14hectares.

Zahid Khan watercourse: This watercourse was improved, which emerged from Warsak Gravity Canal and was situated in the village Telaband (Figure 2). The total length of the watercourse was 1350 m in which lined portion was 634 m and unlined portion was 716 m. It was improved on 18th May 2006 on the basis of concrete lining and its cross-section was parabolic. Its design discharge was 0.35 cusecs with a culturable command area of 24.28 hectares.

Watercourse No 6897/L: This watercourse was unimproved, which emerged from Joe Sheikh Canal and was situated in the village Balu (Figure 2). Total length of the watercourse was 1200 m with culturable command area of 5.06 hectares.

M. Suliman watercourse: This watercourse was unimproved, which emerged from Joe Sheikh Canal and was situated in the village Nazar Kalay (Figure 2). Total length of the watercourse was 1300 m with a culturable command area of 12.94 hectares.

Awal Said watercourse: This watercourse was unimproved, which emerged from Joe Sheikh Canal and was situated in the village Lala Kalay (Figure 2). Total length of watercourse was 1250 m with culturable command area of 16.18 hectares.

Mughal Khan watercourse: This watercourse was unimproved, which emerged from Mia Gujar Minor and was situated in the village Wadpaga (Figure 2). Total length of watercourse was 1100 m with culturable command area of 12.14 hectares.

Ghulam Hassan watercourse: This watercourse was unimproved, which emerges from Warsak Gravity Canal and was situated in the village Telaband (Figure 2). Total length of watercourse was 1000m with culturable command area of 10.11 hectares.

Flow measurement

For measuring the discharge various methods like velocity area method, flumes and various flow measuring structures can be used. In this research, current meter and cutthroat flumes were used for discharge measurements in improved and unimproved watercourses.

Cutthroat flume has a rectangular cross-section, a level floor, a uniformly converging inlet and a diverging outlet section. It is simple, low cost, easy to carry, and install. Cutthroat flume has two operating characteristics, which are important:

- Operation is satisfactory under both free and submerged flow conditions.
- Head loss through the flume is low.

Cutthroat flume

The Cutthroat flume a fixed hydraulic structure developed during 1966/1967 is used to measure the flow of surface waters, sewage flows, and industrial discharges (Skogerboe *et al*., 1966). A 36-inch × 4-inch cutthroat flume was used for discharge measurement. It was placed in the straight section of a channel, parallel to the direction of flow. It was placed in the centre of the channel. Bottom of the channel was leveled under the flume. The soil was placed on both side of the flume so that the sides and bottom were properly sealed to prevent leakage. Flume levelness was checked once again both in the longitudinally and transverse direction. Before taking gauge reading the inside bottom of the flume was cleaned of any sediment or trash. Once the above conditions were reached, then gauge readings were taken. The upstream reading was referred to as Ha and the downstream reading was referred to as Hb. The submergence ratio was then calculated by the formula:

$$S=Hb/Ha$$

When the submergence ratio was more than 0.58, the flow was considered as submerged and when the submergence ratio was less than 0.58, the flow was considered as free flow. The upstream and downstream readings were then converted to flow values by using the appropriate tables.

Current metering

A current meter is oceanographic device used for measuring the velocity of flow of a fluid (as water) in a stream. Flow discharge was measured with the help of a current meter in all the lined channels. The discharge was determined by velocity-area method, using the following formula:

$$Q= \Sigma^{AV}$$

Where; Q= Discharge (m^3/s); A= Area of cross section (m^2); V= Mean velocity in the vertical section (m/s).

Cross section area of vertical section of the channel was calculated by multiplying width of vertical sections with the depth of water in the vertical sections. Flow velocity was determined at 0.6d (one-point method) when the depth (d) of flow in the channel was below 25 cm and at 0.2d and 0.8d (two-point method) when the depth(d)was above 25 cm. Flow velocity at two point method was calculated by averaging the values obtained at two depths. Observation was made over 30 seconds intervals and was repeated three times on each vertical section of the channel.

The current meter with propeller suitable for flows up to 60 Ls^{-1} was used for flow discharge in all the sampled watercourses. The propeller revolved, when immersed into the running water, at a speed proportional to the water velocity. Flow velocity was determined by noting the number of revolutions per 30 seconds on each vertical section and a velocity calibration table was used which related the speed of meter rotation to the water velocity.

Conveyance losses

It is the loss of water from a canal that is caused by leakage, seepage, evaporation, or evapotranspiration. So, the difference between inlet and outlet flow of water in a water channel is termed as conveyance losses. The conveyance losses were measured by inflow-outflow method. The discharge at inlet and exit locations of each watercourse was measured. The difference between the two values gave the conveyance losses in the watercourses. To determine the water saving of watercourses, the losses between lined and unlined watercourses were compared to know that how much water has been saved due to lining of watercourses.

Conveyance losses was determined by using the following equations:

$$Qloss = Qin - Qout$$

$$Loss\ (\%)= (Qin - Qout\ )/\ Qin \times 100$$

$$Loss\ (\%)/1000m= Loss\%/L$$

Where, *Qin*= Inflow rate (Ls^{-1}); *Qout*= Outflow rate (Ls^{-1}); *L*= Length of the selected section of watercourse over which measurements will be taken (m).

Conveyance efficiency

Water conveyance efficiency is the ratio of the volume of water delivered for irrigation to the volume of water placed in the conveyance system. This ratio is normally less than 1.0 for open channel conveyance systems, but it may be approximately 1.0 for pipeline conveyance systems. To assess the conveyance efficiency of channel, inflow and outflow was measured by using current metering data. Conveyance efficiency of channel was calculated by using the following formula:

$$Ec = Qout/\,Qin \times 100$$

Where Ec= Conveyance efficiency of the channel (%); Q in= Inflow rate (Ls^{-1}); Qout= Outflow rate (Ls^{-1}).

Water productivity

Water productivity is generally defined as crop yield per cubic metre of water consumption. Water productivity was measured by dividing seasonal agricultural production on seasonal volume of irrigation water inflow (Molden *et al*., 2009).

$$Water\ Productivity = \frac{Seasonal\ agricultural\ production\ (kg)}{Seasonal\ water\ inflow\ (m^3)}$$

Data on seasonal agricultural production of wheat and maize crops were collected from farmers' interviews using questionnaire proforma and seasonal water inflow for those crops was determined from discharge measurement data by area-velocity method using questionnaire proforma.

Water management practices

Cleaning of watercourses, etc of improved and unimproved watercourses were determined during the research work from interviews with farmers in the fields using questionnaire proforma No. 1. For this purpose, farmers were interviewed from head, middle and tail reaches of the selected watercourses. Data about the following parameters was collected:

- No. of times watercourses were cleaned per year
- No. of labour days used for cleaning of watercourses
- No. of litigation cases related to watercourses
- No. of tampering cases related to watercourses etc.

Results and Discussion

A comparative study of improved and unimproved watercourses was conducted in the command area of civil canals. Their water availability, water productivity and water management practices were compared, and the results of these parameters are presented and discussed in the following sections.

Water availability

Conveyance losses: Figure 3 shows the conveyance losses in improved and unimproved watercourses. Conveyance losses in lined sections of five improved watercourses were 9, 28, 5, 11 and 20 % per km, while in unlined section were 23, 30, 50 and 21 % per km. Similarly, conveyance losses in five unimproved watercourses were 27, 62, 55, 55 and 40 % per km. Results show that due to improvement of watercourses conveyance losses were greatly decreased. In a similar study, Virk *et al*. (2019) evaluated water availability and losses at Murre and Havellian and reported 25% conveyance losses. It was concluded that apart from other issues, mismanagement was the key factor of these losses. The losses found by Ahmad *et al*. (2009) ranged from 35-52 % in lined section while in

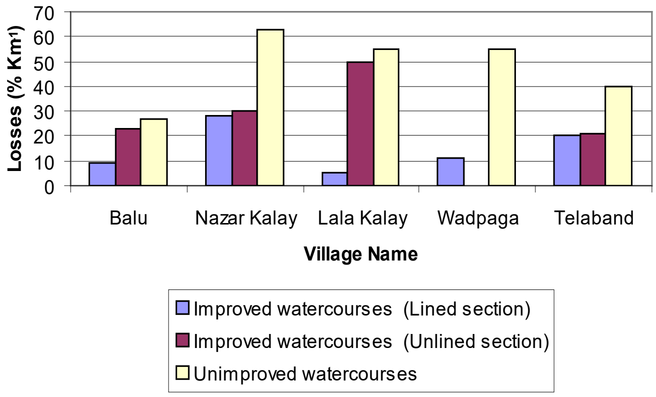

Figure 3: *Conveyance losses of improved and unimproved watercourses.*

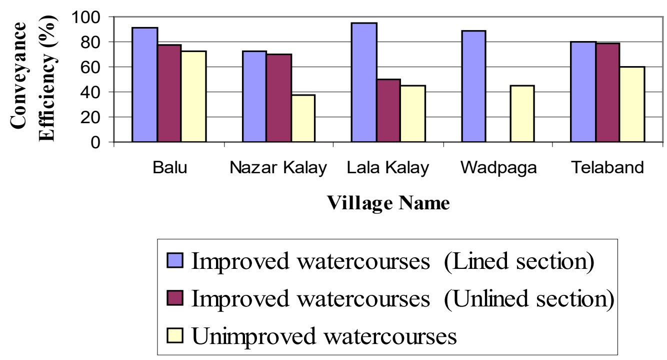

Figure 4: *Conveyance efficiency of improved and unimproved watercourses.*

unlined section; losses ranged from 64-68 % which showed that losses in lined and unlined section were much higher. The possible reasons for higher losses in lined sections were due to leakage from the cracks and lack of maintenance and repairs. Higher losses in unimproved watercourses were due to siltation, weeds growth and rodent holes, resulting in overtopping of flows at various places.

Conveyance efficiency: Figure 4 shows that at villages Balu, Nazar Kalay, Lala Kalay, Wadpaga and Telaband, the conveyance efficiencies of five improved watercourses (lined sections) were 91, 72, 95, 89 and 80 % per km, and that of unlined sections were 77, 70, 50, and 79 % per km. The conveyance efficiencies of five unimproved watercourses were 73, 37, 45, 45 and 60 % per km, respectively. Results show that the conveyance efficiencies of improved watercourses of the five villages were higher than that of unimproved watercourses. The conveyance efficiency of unimproved watercourse at village Balu was comparatively higher 73 % per km which indicate that losses in watercourse were less than that of other unimproved watercourses. Also, the conveyance efficiency of unimproved watercourse at the village Nazar Kalay was 37 % per km. The reason is that losses were very higher which significantly decreased the conveyance efficiency of watercourse. Reasons for higher losses were leakage from naccas and bends in watercourse. Similar results were found by Zeb *et al*. (2000) for unimproved watercourses 69-74 % per km. Losses found in unimproved watercourses of the present study were high therefore the conveyance efficiencies were low. Khan (2019) reported 13.38% water losses in Malik Branch Canal, Bahawalnager and reported that seepage and evaporation losses were the main problems in earthen canals. Hence, it was concluded that lining should be installed at sections where seepage was prominent.

Weekly water availability per unit area: Table 1 shows weekly availability of water to the farmers at head, middle and tail reaches of improved and unimproved watercourses in m^3ha^{-1}.

The average weekly water availability at the head, middle and tail reaches of improved watercourses were 442, 465 and 385 m^3ha^{-1} while in unimproved watercourses were 613, 412 and 307 m^3ha^{-1}.

Results showed variations in water availability at the head, middle and tail of the improved and unimproved watercourses. In improved watercourses, water availability increased from head to middle and then decreased from middle to tail. In unimproved watercourses, the water availability decreased gradually as we move from head to tail reaches of watercourses. The percent reduction in water availability of improved watercourses was less than that of unimproved watercourses which clearly indicated that improved watercourses could sustain more water than unimproved watercourses.

Water productivity

Tables 2 and 3 show water productivities of wheat and maize in the command area of improved and unimproved watercourses.

Water productivity of wheat: The water productivity of wheat in improved watercourses ranged from 0.43-1.20 kg m^{-3} while in unimproved watercourses ranged from 0.50-0.76 kg m^{-3}. The water productivity of wheat in improved and unimproved watercourses generally decreased from head to tail. The average water productivities of wheat at the head, end of lined section and tail of improved watercourses were 0.96, 0.71 and 0.55 kg m^{-3}, respectively. At the head, middle and tail of unimproved watercourses the average water productivities were 0.66, 0.67and 0.59 kg m^{-3}, respectively.

Table 1: *Weekly water availability at head, middle and tail of improved and unimproved watercourses (m^3/ha).*

S. No.	Village Name	Watercourse No./ Name	Improved watercourses				Watercourse No./Name	Unimproved watercourses			
			Head	End of lining	Tail	% reduction		Head	Mid	Tail	% reduction
1.	Balu	15315/R	352	391	312	11	6897/L	775	650	505	35
2.	Nazar Kalay	15100/R	409	417	337	18	M. Suliman	497	267	141	72
3.	Lala Kalay	140,000/L	539	630	530	2	Awal Said	484	444	320	34
4.	Wadpaga	Arbab Munir	512	518	408	20	Mughal khan	723	357	204	72
5.	Telaband	Zahid Khan	398	367	338	15	Gulam Hassan	586	341	366	38
	Average		442	465	385	13		613	412	307	46

Table 2: *Water productivity of wheat at improved and unimproved watercourses (kgm^{-3}).*

S. No.	Village name	Improved watercourses water productivity (kgm^{-3})				Unimproved watercourses water productivity (kgm^{-3})			
		Watercourse No./Name	Head	End of lining	Tail	Watercourse No./Name	Head	Mid	Tail
1.	Balu	15315/R	0.86	0.94	0.68	6897/L	0.75	0.76	0.74
2.	Nazar kalay	15100/R	1.04	0.82	0.59	M. Suliman	0.78	0.77	0.59
3.	Lala kalay	140,000/L	0.79	0.62	0.50	Awal Said	0.57	0.52	0.62
4.	Wadpaga	Arbab Munir	1.20	0.54	0.53	Mughal khan	0.69	0.74	0.52
5.	Telaband	Zahid Khan	0.89	0.61	0.43	Gulam Hassan	0.50	0.56	0.50
Average			0.96	0.71	0.55		0.66	0.67	0.59

Table 3: *Water productivity of maize at improved and unimproved watercourses (kgm^{-3}).*

S. No.	Village Name	Improved watercourses water productivity (kgm^{-3})				Unimproved watercourses water productivity (kgm^{-3})			
		Watercourse No./Name	Head	End of lining	Tail	Watercourse No./Name	Head	Mid	Tail
1.	Balu	15315/R	0.80	0.94	0.67	6897/L	0.83	0.78	0.80
2.	Nazar kalay	15100/R	0.99	0.80	0.57	M. Suliman	0.80	0.83	0.52
3.	Lala kalay	140,000/L	0.73	0.58	0.47	Awal Said	0.50	0.37	0.55
4.	Wadpaga	Arbab Munir	1.16	0.48	0.48	Mughal khan	0.63	0.71	0.43
5.	Telaband	Zahid Khan	0.84	0.57	0.39	Gulam Hassan	0.40	0.55	0.52
Average			0.90	0.67	0.52		0.63	0.65	0.56

Table 4: *Respondent (%) reported desilting of watercourses.*

S. No.	Village Name	Improved watercourses					Unimproved watercourses			
		Watercourse No./Name	Once	Twice	Thrice	>Thrice	Watercourse No./Name	Twice	Thrice	>Thrice
1.	Balu	15315/R	11	55	33	0	6897/L	11	67	22.
2.	Nazar Kalay	15100/R	0	55	33	11	M. Suliman	22	55	22
3.	Lala Kalay	140,000/L	0	44	33	11	Awal Said	0	44	55
4.	Wadpaga	Arbab Munir	67	44	0	0	Mughal Khan	33	44	22
5	Tela Band	Zahid Khan	44	33	22	0	Gulam Hassan	22	67	11
Average			24	46	24	4		18	55	26

Water productivity of maize: The water productivity of maize in improved and unimproved water courses generally decreased from head to tail. The water productivity ranged from 0.39-1.16 kg m^{-3} in improved watercourses while 0.40-0.83 kg m^{-3} in unimproved watercourses. The average water productivities of maize at the head, end of lining and tail of improved watercourses were 0.90, 0.67 and 0.52 kg m^{-3}, respectively. Whereas, at the head, middle and tail of unimproved watercourses were 0.63, 0.65 and 0.56 kg m^{-3} respectively.

Climate change has posed a serious threat of water scarcity in many countries which needs to be addressed on priority basis by enhancing water productivity in irrigated agriculture (Chaudhari *et al*., 2020). Likewise, in Pakistan, water availability in the country has decreased from 5630 m^3 per capita in 1950 to 1000 m^3 per capita in 2017. This downfall is expected to further drop to 838 m^3 by 2020, if no water storage is constructed on the major rivers and the available water resources are not wisely used (Culas and Baig, 2020). Improving irrigation water productivity through better delivery efficiency supports rural development, farm income, and food security worldwide (Habteyes and Ward, 2020). Generally, the water productivity at head and middle of improved watercourses was higher than unimproved watercourses while at tail it was low. The reason is that at the head and middle sections of unimproved watercourses the water availability was higher than improved watercourses. However, at tail, it was slightly low, due to which the farmers at head and middle of unimproved watercourses over irrigated their fields which ultimately decreased the water productivity in unimproved watercourses and crop yields. Recent studies on the water distribution of irrigation systems also showed that disparity of water distribution between head- and the tail-enders is closely associated with poor crop production and salinity problems (Latif and Ahmad, 2009; Culas and Baig, 2020). Lower water productivity at tail section of improved watercourses could be due to more water availability which resulted in over irrigation. Overall, results showed that over irrigation had significantly decreased water productivity.

Water management practices

Annual watercourses desilting: Table 4 shows the number of times watercourses were desilted in a year. Silting is a major problem in unimproved water courses. Khan *et al.* (2018), while evaluating water management systems and its impact on agricultural production, reported that silt deposition in water courses was one of the major problems in poor productivity. In improved watercourses 24, 46, 24 and 4% farmers said that they desilted their watercourses once, twice, thrice and more than thrice, respectively while in unimproved watercourses, 18, 55 and 26 % farmers said that they desilted their watercourses, twice, thrice and more than thrice, respectively.

Majority of the farmers desilted their watercourses once in a year due to improvement of watercourses while fewer of them desilted once per year due to unimproved watercourses. Similarly, few farmers desilted their watercourses more than thrice in a year due to improvement of watercourses while in unimproved watercourses many farmers desilted their watercourses more than thrice in a year. Over, all the number of times improved watercourses were desilted in a year by the farmers was less than that of unimproved watercourses.

Number of labour days used for desilting of watercourses: Table 5 shows that the number of labour days used for desilting of five improved watercourses were 3, 3, 4, 1 and 1, while that of five unimproved watercourses were 5, 4, 5, 3 and 2. The average number of labour days in improved watercourses was 2 while that of unimproved watercourses was 4. Results show that the number of labour days used for desilting of improved watercourses was less than that of unimproved watercourses. Moreover, Solangi *et al.* (2018) reported that improved watercourses can also save labour while controlling/diverting water to the fields. Mostly, two men per hectare were required to control water and irrigate the field using unimproved watercourses. However, after watercourse improvement, diverting water to the field became much easier which could be handled by even single man. It can be said that improvement of watercourses has a remarkable effect not only on the number of labour days used for desilting of watercourses but also water management.

Number of litigation cases related to watercourses: Table 6 shows the number of litigation cases related to improved and unimproved watercourses. The litigation cases related to five improved watercourses were 4, 8, 2, 2 and 13 %, while that of five unimproved watercourses were 13, 22, 22, 11 and 22 %. Average number of litigation cases in improved watercourses was 6 % while that of unimproved watercourses were 22 %. Results show that the number of litigation cases related to improved watercourses was less than that of unimproved watercourses.In a similar kind of study in Sindh, Soomro *et al.* (2018) reported that despite many economic benefits, watercourse improvement has many sociological benefits. Farmers in general, believed that watercourse improvement has significantly eliminated many disputes and litigation cases over irrigation water. Based on these results, it can be concluded watercourse improvement has also solved sociological wrangles over water use and hence, litigation cases have decreased considerably.

Table 5: *Number of labour days used for desilting of watercourses.*

S. No.	Village Name	Improved watercourses		Unimproved watercourses	
		Watercourse No./Name	Labour days	Water course No./Name	Labour days
1.	Balu	15315/R	3	6897/L	5
2.	Nazar Kalay	15100/R	3	M. Suliman	4
3.	Lala Kalay	140,000/L	4	Awal Said	5
4.	Wadpaga	Arbab Munir	1	Mughal khan	3
5.	Telaband	Zahid Khan	1	Gulam Hassan	2
Average			2		4

Table 6: *Litigation cases reported by farmers (%).*

S. No.	Village Name	Improved watercourses		Unimproved watercourses	
		Watercourse No./Name	Litigation cases	Water course No./Name	Litigation cases
1.	Balu	15315/R	4	6897/L	33
2.	Nazar Kalay	15100/R	8	M. Suliman	22
3.	Lala Kalay	140,000/L	2	Awal Said	22
4.	Wadpaga	Arbab Munir	2	Mughal khan	11
5.	Telaband	Zahid Khan	13	Gulam Hassan	22
Average			6		22

Table 7: *Tamperingcases reported by farmers (%).*

S. No.	Village Name	Improved watercourses		Unimproved watercourses	
		Water course No./Name	Tampering cases	Water course No./Name	Tampering cases
1.	Balu	15315/R	3	6897/L	55
2.	Nazar Kalay	15100/R	8	M. Suliman	33
3.	Lala Kalay	140,000/L	2	Awal Said	33
4.	Wadpaga	Arbab Munir	4	Mughal khan	22
5.	Telaband	Zahid Khan	18	Gulam Hassan	44
Average			7		37

Number of tampering cases related to watercourses: Table 7 shows the number of tampering cases related to improved and unimproved watercourses. The numbers of tampering cases related to five improved watercourses were 3, 8, 2, 4 and 18 %, while those of five unimproved watercourses were 55, 33, 33, 22 and 44 %. Average number of tampering cases related to improved watercourses was 7 % and that of unimproved watercourses was 37 %. Results shows that the numbers of tampering cases related to improved watercourses were less than that of unimproved watercourses which indicates that tampering cases were greatly decreased due to the improvement of watercourses. Zubair *et al.* (2016) also reported that improved watercourse was not only efficient in saving water but had also significantly declined tampering cases related to watercourses.

Conclusions and Recommendations

The conveyance efficiencies of improved watercourses were more than that of unimproved watercourses which indicated that the improvement of watercourses was the effective strategy to increase the conveyance efficiencies. The water productivities of wheat and maize in improved watercourses were more than that of unimproved watercourses. Based on the finding of the present study, it can be concluded that watercourses should be lined in order to reduce losses, maintain desired water availability and crop water productivity. The following recommendations are being made in light of the current findings.

- To reduce losses, watercourses should be properly maintained. Where desirable, lined watercourse (pacca nakkas) should be installed to avoid leakage.
- The lined segments of the improved watercourses should be properly maintained to sustain the water availability.
- To reduce losses in unimproved watercourses, the holes made by rodents should be sealed.
- Farmers should avoid over irrigation to the fields so that they could get maximum production.
- Water User Association should be established or strengthened in order to carry out the best water management practices.

Novelty Statement

This study was important to compare water availability and productivity of agricultural lands in improved and unimproved watercourses.

Author's Contribution

Muhammad Adnan Fahad: Conducted research, data collection and wrote the first draft.
Muhammad Jamal Khan: Supervised the research

study.

Sheraz Ahmed: Helped in language proofreading and format setting.

Imtiaz Ali: Helped critical corrections in the manuscript.

Conflict of interest

The authors have declared no conflict of interest.

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