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Impact of lining of irrigation canals on groundwater recharge: A case study from Punjab province in Indus River basin of Pakistan

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ABSTRACT

The Canal irrigation network of Pakistan's Indus River Basin (IRB) is one of the world's largest gravity-flow networks, with a significant portion located in Punjab province. The conveyance, delivery, and application of this water to the irrigated crops in the basin result in the loss of more than 50% of its water. This loss of water from the irrigation system is a major source of recharge for the large alluvial aquifer underlying the IRB. Canal lining is carried out as a measure to reduce seepage losses from the conveyance system of irrigation water. On the other hand, canal lining is considered a barrier to aquifer recharge. A study titled "Impact assessment of canal lining in Punjab," funded by JICA, has been carried out in order to interrogate the comparative performance of lined and unlined canals and their impact on groundwater recharge. We measured seepage losses from 14 selected irrigation-lined canals in Punjab province under actual field conditions using ponding and/or inflow-outflow methods. Results have been compared with pre-lining seepage rates. The results indicate that canal lining has reduced seepage losses by 78%. The heavy pumping in fresh groundwater areas invites saline groundwater from adjacent saline zones. The canal flows at the head have reduced the recharge to groundwater by 9%. Nonetheless, saving from seepage losses by canal lining has increased available water for crops, but it has decreased groundwater recharge.

Contribution/Originality: The lining of irrigation channels remained questioned due to its impact on groundwater recharge. Some experts support it, while others oppose lining canals because it reduces the aquifer's recharge. This study is unique, especially in the Indus River basin in Pakistan, where the canal network is the biggest source of groundwater recharge. This article is a guiding document for policymakers and decision-makers while investing in lining irrigation channels.

1. INTRODUCTION

Irrigated agriculture is the backbone of Pakistan's economy, which is dependent on both surface and groundwater resources (Mekonnen, Siddiqi, & Ringler, 2016). Seepage from the irrigation system is one of the major sources of recharge to the alluvial aquifer underlying the Indus Basin Irrigation System (IBIS) in Pakistan (Hassan & Bhutta, 1996). The Indus Basin Irrigation System (IBIS) is one of the largest contiguous systems in the world and irrigates an area of about 16 million ha (Mha) by diverting about 122 km^{3}of water from the rivers annually. A major part of this network lies in the Punjab province (Qureshi & Perry, 2021). Irrigated agriculture has moved towards the conjunctive use of surface and groundwater during the last few decades due to a shortage of

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surface water (Kahlown, Raoof, Zubair, & Kemper, 2007; Muzammil, Zahid, & Breuer, 2020). There is about 69 billion cubic meters (BCM) of potential groundwater in the Basin (Hassan, 1993; Kamal, Amir, & Mohtadullah, 2012). Recharge to the aquifer is mainly contributed by seepage from irrigation canal networks, rainfall, and return flows from field irrigation (Hassan, 1993; Hassan, Bhutta, Javed, & Wolters, 1995; Qureshi & Perry, 2021). At present, the overall efficiency of irrigation systems is very low owing to many factors, of which one major attribute is the huge amount of seepage losses (Watto & Mugera, 2015). On-farm irrigation efficiency in IBIS is very low, and farming communities can play a vital role in improving it Chaudhry (2018). Canal lining is considered a remedial step to control seepage losses and improve the delivery efficiency of the irrigation system to achieve the overall objective of water conservation (IWASRI, 1995; Kraatz, 1973). As reported by Sepaskhah and Salemi (2004), seepage is the major component of total water losses during the conveyance and distribution of irrigation water. As such, the economics of canal lining are directly linked with the amount of water lost as seepage (IRI, 1996). Seepage from irrigation canals is a major hurdle in efficient use of limited available surface water and therefore reduces the crop productivity by increasing the cost of production of agricultural crops (Engelbert, Hotchkiss, & Kelly, 1997).

Reduced seepage losses, improved equitable and reliable irrigation water supplies, and lower maintenance costs are just a few benefits of canal lining (Kraatz, 1973). Water saved by reducing seepage/percolation can be used to increase crop yield and intensity (IRI, 2019). However, lining may have negative effects on biodiversity, social, and environmental issues, reduce groundwater recharge, and require significant investments. According to Alam and Bhutta (2004) and Swamee, Mishra, and Chahar (2000), it is impossible to completely control seepage from canals, and even a canal with 99% perfect lining can only reduce seepage losses by about 30–40%. They have also reported that seepage losses from a canal leading to the farm gate are about 45% in India. In Pakistan's Indus Basin, seepage losses from irrigation systems are a major source of groundwater recharge. Punjab estimates total abstraction of groundwater at more than 50 million acre feet (MAF). Agriculture uses the majority of this groundwater. However, more than 90% of Punjab's population depends on groundwater for drinking and domestic uses. At present, groundwater has become the mainstay of the economy of Pakistan, as it contributes about 40–50 percent to irrigation water requirements (IRI, 2019; Zakir-Hassan, Allan, Punthakey, & Baumgartner, 2020). Pakistan has become 4th largest user of groundwater after India, China, and USA (Zakir-Hassan et al., 2020). Groundwater underpins food security and livelihood for a multitude of tinny rural communities in Punjab (Anjum et al., 2021; Hassan, Allan, & Hassan, 2019). It has helped the cropping intensity to boost from 60% to 150% or more during the last 5-8 decades (Punthakey et al., 2021).

Considering the benefits of lining, more than 1000 Km of irrigation distributary canals have been lined under the Punjab Irrigation System Improvement Project (PISIP) (IRI, 2019). Moreover, many channels with a total length of about 4000 km have been lined from time to time through the Lower Chenab Canal Projects, the Command Water Management Project, the Fordwah Eastern Sadiqiah South (FESS) Project, the Public Sector Development Programs (PSDP) by Federal Government and different Annual Development Programs (ADPs) of provincial government schemes (IRI, 2019). Despite the lining of several channels, a comprehensive study on the impact assessment of these lining schemes remains unconducted (IRI_PISIP, 2020). The Government of Punjab of the Islamic Republic of Pakistan, through the Irrigation Department implemented the Punjab Irrigation System Improvement Project (PISIP), financed by Japan International Cooperation Agency (JICA). Under this project, a component of “Study on Impact Assessment of Canal Lining in Punjab” has been executed by Irrigation Research Institute (IRI). We completed the task by conducting seepage tests, monitoring groundwater levels and quality, and comparing them to the pre-established values of these attributes. The current paper focuses on the effects of lining on groundwater recharge, a topic that continues to be extensively discussed due to its complex nature. In addition to investigations carried out in the field under this study, previous investigations conducted by IRI (1996), IRI (1998), IWASRI (1995), and IWMI (2008) by other research organizations (Alam & Bhutta, 2004) have also been compiled to arrive at more comprehensive recommendations (Try to Reduce Introduction to One Page).

2. MATERIAL AND METHODS

2.1. Study Area and Selection of Sites

The assessment of the impact of canal lining was carried out in Faisalabad, Bahawalpur, Dera Ghazi Khan, and Sargodha irrigation zones in Punjab Province, Pakistan. The present study selected 14 canals across the province for field surveys, investigations, and seepage loss measurement (Figure 1). Various parameters were considered when selecting the channels, including channel discharge, geographical location, pre-lining data availability, groundwater levels and quality, lining age, and lining material (IRI, 2019). Zone-wise selected channels and their main features are given in Table 1 and 2, respectively. Generally, PISIP selects channels with small discharge for lining; therefore, the majority (about 58%) of selected channels for investigations have discharge less than 50 cusecs (cfs-cubic feet per second), as shown in Figure 2 (IRI, 2019).

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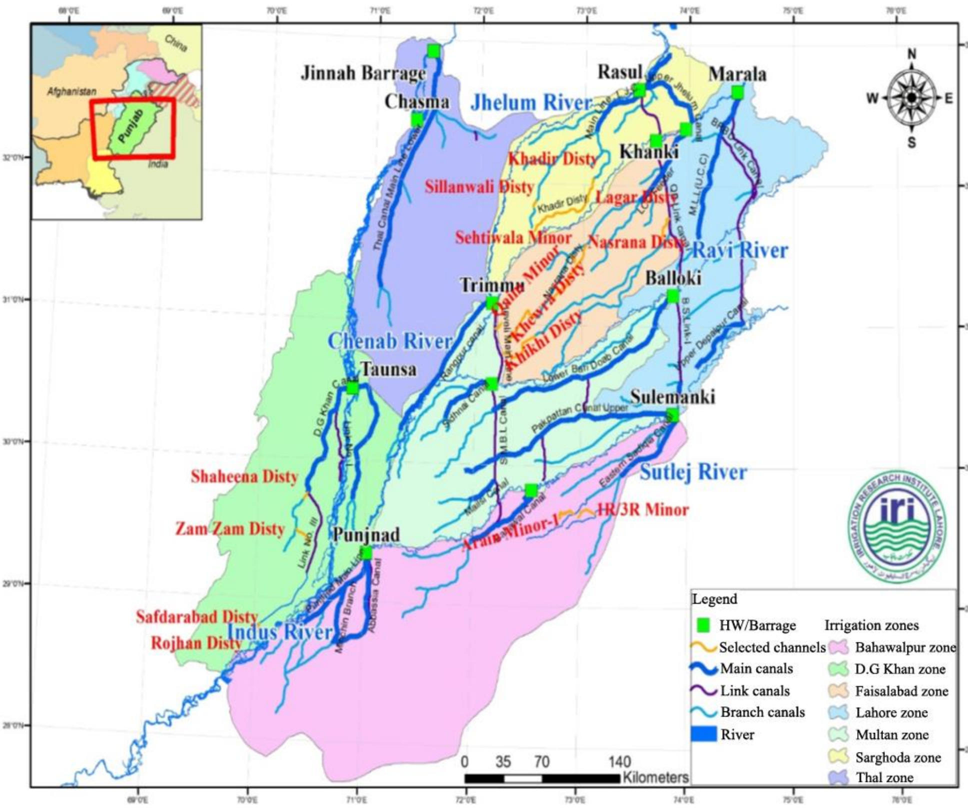

Figure 1. Location map of study area showing selected channels.

Table 1. Zone-wise summary of number of channels selected.

Zone	Discharge ranges (cfs)			Total
	<50	51-200	>200	
Faisalabad	3	0	3	6
Sargodha	2	0	0	2
D.G. Khan	3	1	0	4
Bahawalpur	0	2	0	2
Total	8	3	3	14
%age	58	21	21	

Table 2. Some features of selected channels.

Name of zone	Sr #	Name of channel	Discharge (Cusecs)	Lined length (ft.)	Year/ Month of lining	
					Start date	End date
Faisalabad zone	1	Nasrana disty	275	57662	25.02.2011	29.03.2014
	2	Saithy Wala minor	14	24095	23.09.2011	31.10.2014
	3	Khewra disty	372	76100	30.04.2011	21.10.2014
	4	Qaim minor	9.01	25420	25.05.2011	21.10.2014
	5	Lagar disty	38	62215	2014	2015
	6	Khikhy disty	321	131635	2014	2015
Sargodha zone	7	Silanwali disty	17	17580	2006	2006
	8	Khadir disty	235		2018	2018
DG Khan zone	9	Shaheena disty	9.7	11500	18.05.2011	28.03.2014
	10	Zam disty	133	24974	13.05.2011	31.03.2014
	11	Safdar Abad disty	21.71	21200	15.04.2011	05.05.2014
	12	Rujhan minor	47	35000	15.04.2011	05.05.2014
Bahawalpur zone	13	Arain minor-1	58	65547	22.08.2011	18.09.2014
	14	1R/3R minor	80	60375	1998	1999

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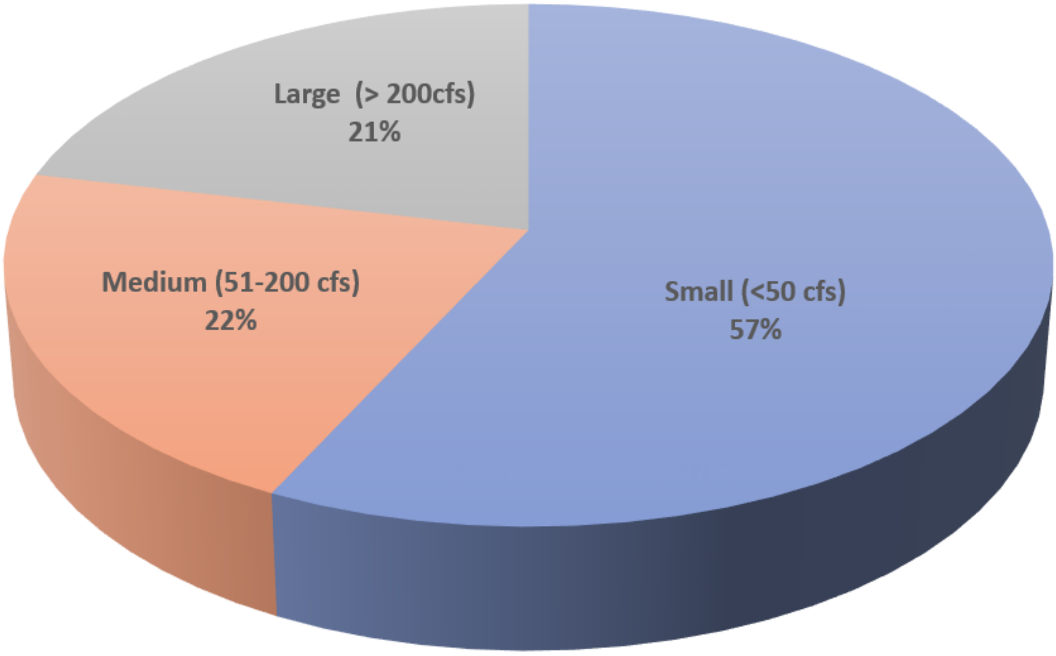

Figure 2. Capacity wise selected channels.

2.2. Field Testing and Data Collection

The major activities carried out include the selection of channels, measurement of actual seepage losses data from canals, field surveys, collection of pre-lining seepage rates from previous studies, observation of groundwater levels and quality in the field, and comparison of pre- and post-lining seepage rates and consequent impacts on groundwater levels and quality.

2.2.1. Measurement of Seepage Losses

Estimation or calculation of volume of water that is lost during conveyance of irrigation water from source to farm level is a complex phenomenon and depends upon many local factors and general scientific theories (Trout, 1979). Zhang, Chai, Xu, and Qin (2017) have documented that the most commonly used methods for calculation of seepage losses are field testing/experiments, empirical formulas, and numerical models. Sepaskhah and Salemi (2004) developed an empirical formula for estimating the conveyance efficiency of irrigation canals in Iran for different soil types and observed that the conveyance efficiency of sandy loam soil was 67.3% and that of clay loam soil was 95.8%. They suggested lining earthen canals with medium to heavy soils, a recommendation that lacks economic justification. Engelbert et al. (1997) introduced the use of geophysical methods integrated with other suitable techniques to locate potential seepage sites from canals in the United States and recommended that electrical resistivity surveys by vertical soundings and horizontal profiling are the most effective, fast, and financially viable methods. A number of units can be used to show the amount of water that leaks out of irrigation canals. These include loss per unit area of wetted perimeter (cusec per million square feet, cfs/msf), loss per unit length of the system (ft3/day per 1000 ft), and percent of inflow in the system (%age of channels discharge at head) (Alam & Bhutta, 2004). Singh (1983) discovered that the unlined canals lose a significant amount of water through seepage, with the main canal and its branches accounting for approximately 17 percent, distributaries for 8 percent, and the water courses for 20 percent. Arshad, Ahmad, Usman, and Shabbir (2009) conducted a study comparing seepage losses from lined and unlined water courses in Rechna Doab in Pakistan's Indus River Basin (IRB) and recommended that the inflow-outflow method is reasonable, accurate, and practicable under actual flowing-water conditions in the field at any specific site. Alam and Bhutta (2004) looked at different ways to measure seepage in canals. These included empirical formulae, analytical or analogue studies, and direct seepage measurement methods like seepage meters, ponding tests, and inflow-outflow methods. They found that the ponding method is more accurate compared with the inflow-outflow method and recommended that the inflow-outflow method be avoided where anticipated seepage rates are low, and it is difficult to use the longer reaches for testing.

Forrdwah Eastern Sadiqia South Considering significance of physical measurement techniques, both ponding and inflow–outflow methods were used to evaluate the seepage losses under the present study. We replicated both tests to obtain more representative and reliable seepage rate values from all the selected channels. We prefer the ponding method wherever possible. The ponding method is more suitable during canal closure, while the inflow-outflow method is suitable for running canals (IRI, 1996, 2019).

2.2.2. Depth to Water-Table

We monitor the depth to watertable and groundwater quality in the existing observation wells of the Water and Power Development Authority (WAPDA) and Punjab Irrigation Department (PID) on a biannual basis, specifically during the pre-monsoon and post-monsoon. We have available data for the pre-lining period, spanning

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from 2003 to 2016. The present study monitors all observation wells for post-lining data. Table 3 provides a list of observation wells measuring depth to watertable and groundwater quality for each channel under study.

Table 3. Observation wells for selected distributaries/ minors.

Sr n0.	Name of channel	Discharge (Cusecs-ft³/sec)	Lined length (ft.)	Observation wells for depth to water-table	Water quality monitoring wells
1	Nasrana disty	275	57662	89,97,96,110,115,94,114, 116, 117, 467, 476 (11 Nos)	89,91, 129, 137,138, 151,166,167 (8 Nos)
2	Sehtiwala minor	14	24095	67, 79, 93 (3 Nos)	106, 127, 139 (3 Nos)
3	Khewra disty	372	76100	491,555,547,557,558,559 ,536 (7 Nos)	49,53,56,333, 587, 588, 591,395,593,594,597,598,599 (13 Nos)
4	Qaim minor	9.01	25420	176,178,196 (3 Nos)	414,415 (2 Nos)
5	Lagar disty	38	62215	454,455,459 (3 Nos)	43,41 (2 Nos)
6	Khikhi disty	321	131635	539,543,542,534,390 (5 Nos)	388,365,367,359,360,361,362,363,378 (9 Nos)
7	Sillanwali disty	17	17580	69,70,71,77 (3 Nos)	9,14,15,95,96,97,99,100,101,102,104,106,109,107,111 ,112,113,114,115,117 (20 Nos)
8	Khadir disty	235	273600	17,4,6,5,7,1,3,2,10 (9 Nos)	64,67 (2 Nos)
9	Shaheena disty	9.7	11500	14,10 (2 Nos)	231,236 (2 Nos)
10	Zam-Zam disty	133	24974	3,15,24,25,40,45 (5 Nos)	326,258,257,256 (4 Nos)
11	Safdarabad disty	21.71	21200	73,74 (2 Nos)	*
12	Rojhan minor	47	35000	68,69,70,71 (4 Nos)	*
13	Arain minor-1	58	65547	109,123 (2 Nos)	*
14	1R/3R minor	80	60375	191,204,207 (3 Nos)	*
	Total			41	41

Note: * indicates There are no observation wells on these canals for monitoring of groundwater quality.

2.2.3. Groundwater Quality

PID has a regular monitoring network for monitoring groundwater quality in the canal-commanded areas of the province. Water samples are collected to test the water quality for irrigation use. Laboratory analysis determines the groundwater quality, specifically the total dissolved solids (TDS), residual sodium carbonate (RSC), and sodium adsorption ratio (SAR). One-time water samples were collected from the entire length of selected distributaries.

Table 4 presents the PID irrigation water quality parameters and their respective limits. Samples were taken from command areas of all selected distributaries and tested for major parameters for the suitability of groundwater for irrigation.

Figure 3 shows the locations of groundwater quality monitoring points in different zones.

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Table 4. Irrigation water quality parameters (IRI, 1996).

Sr. no.	Parameter	Limits range		
		Fit	Marginal	Unfit
1.	pH	6.0-8.5	-	-
2.	TDS (mg/l)	0-1000	1000-1250	>1250
4.	Residual sodium carbonate(RSC)	<1.25	1.25-2.50	>2.50
5.	Sodium adsorption ratio(SAR)	< 6.0	6-10	> 10

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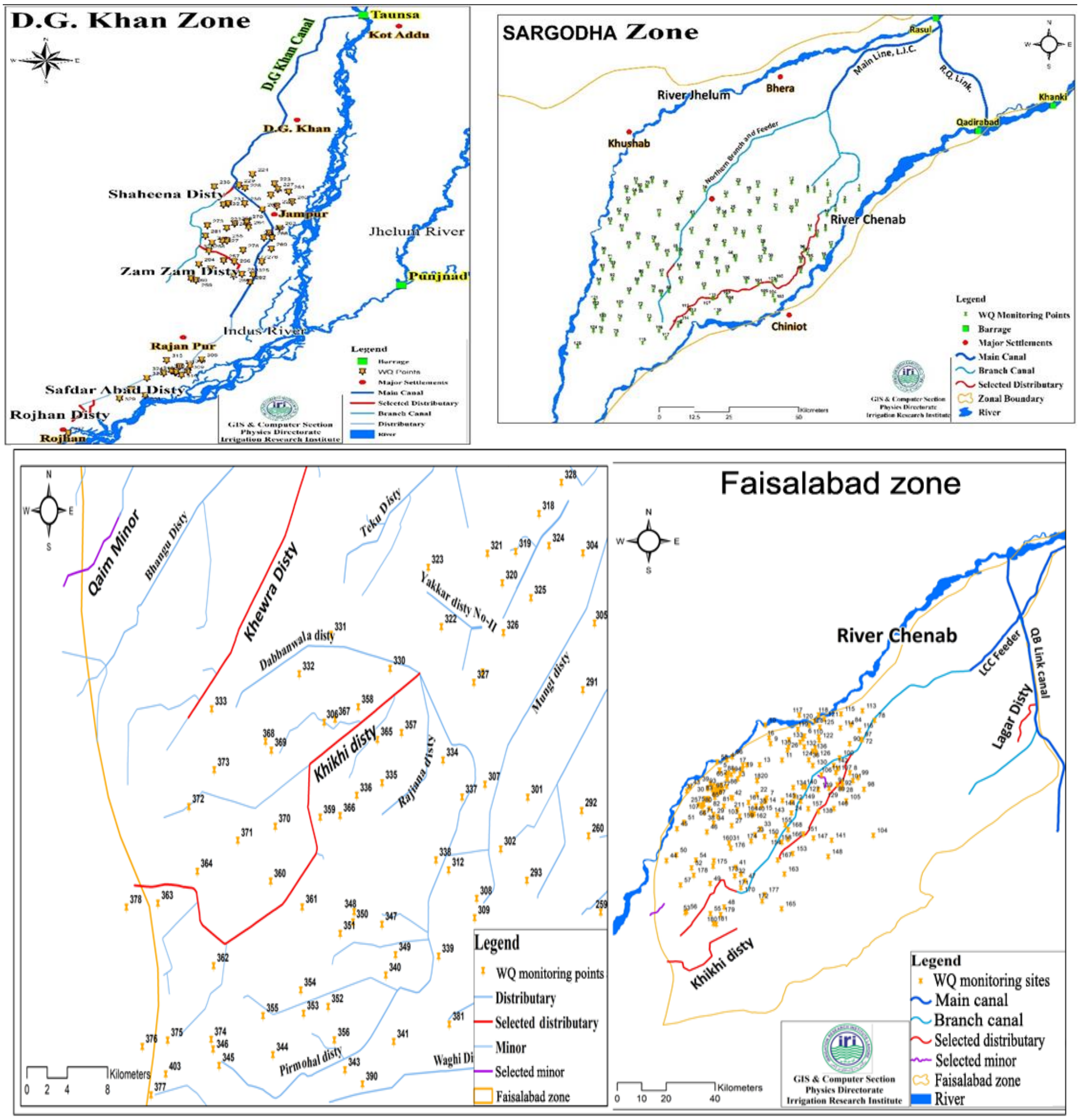

Figure 3. Locations of water quality monitoring points.

3. RESULTS AND DISCUSSIONS

3.1. Seepage Losses

Pre-lining seepage loss data for selected distributaries was obtained from previous reports of IRI (1996) and IRI (1998), and post-lining data was collected from other sources as given in Table 5. Results have indicated that under pre-lining conditions, the seepage losses ranged from 3.5 to 14.8 with an average value of 6.29 cfs/msf, while for the post-lining scenario, these losses ranged from 0.2 to 2.03 with an average of 1.25 cfs/msf. Estimates indicate a 78% reduction in seepage losses between pre- and post-lining conditions in the selected channels. Figure 4 illustrates the reduction in seepage losses for various channels. Which indicates the seepage losses and reduction due to lining with respect to the wetted area of the canals. Another option for representing seepage losses is loss with respect to the design discharge of the channels, such results are depicted in Figure 5. Results in Figure 5 indicate that there is a significant reduction in seepage losses due to canal lining. Pre- and post-lining losses as percent of the design head discharge of the channel were calculated for five channels, for which the entire length wetted area was available, as given in Table 6. Average pre-lining and post-lining losses have been estimated at 11 percent and 2 percent of the design discharge of the selected channels, respectively. In this way, the saving of water or reduction in seepage losses was estimated to be 9 percent of the head discharge of the channels. Both 4 & 5 figures indicate that canal lining has reduced the seepage losses significantly.

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Table 5. Comparison of seepage losses per unit wetted area of channels.

No	Channel	Pre-lining loss (Alam & Bhutta, 2004; IRI, 1996, 1998, 2019; IWASRI, 1995)		Post lining loss (IRI, 2019)			Reduction
		Cfs/msf	Feet/Day	Cfs/msf	Feet/Day	Cfs/msf	% of original seepage
1	Nasrana disty	5.90	0.51	1.85	0.16	4.05	69
2	Sehtiwala minor	9.87	0.85	2.03	0.18	7.84	79
3	Khewra disty	6.33	0.55	1.28	0.11	5.05	80
4	Qaim minor	6.18	0.53	0.82	0.07	5.36	87
5	Lagar disty	7.34	0.63	1.53	0.13	5.81	79
6	Khikhi disty	5.76	0.50	1.93	0.17	3.83	66
7	Sillanwali disty	14.8	1.28	1.01	0.09	13.8	93
8	Khadir disty	5.02	0.43	*			
9	Shaheena disty	9.16	0.79	1.51	0.13	7.65	84
10	Zam disty	4.13	0.36	0.38	0.03	3.75	91
11	Safdarabad disty	3.50	0.30	0.2	0.02	3.3	94
12	Rojhan minor	3.51	0.30	1.07	0.09	2.44	70
13	Arain minor	4.75	0.41	1.90	0.16	2.85	60
14	1R/3R minor	1.79	0.32	0.75	0.06	1.04	58
Max.		14.8	1.28	2.03	0.18	13.79	94
Min.		3.5	0.30	0.20	0.02	1.04	58
Avg.		6.29	0.46	1.25	0.1	4.18	78
STD.		3	0.26	1	0.05	3	12

Note: *: Data not available

Figure 4. Comparison of pre and post lining seepage losses and reduction.

Table 6. Comparison of seepage losses as percentage of design discharge of channels.

Sr no.	Channel	Wetted area (ft²)	Design Q (cfs)	Seepage losses pre-lining		Seepage losses post-lining		Seepage reduction
				(cfs)	Percent	(cfs)	percent	Percent
1	Nasrana disty	2,449,342	275	17.34	6.3	4.53	1.6	4.7
2	Sehtiwala minor	107,501	13.5	1.27	9.4	0.22	1.6	7.8
3	Lagar disty	524,769	38	4.62	12.2	0.80	2.1	10.1
4	Khikhi disty	2,220,000	321	15.34	4.8	4.28	1.3	3.4
5	Sillanwali disty	273,414	17	4.86	28.6	0.28	1.6	26.9
6	1R/3R minor	1,530,443	70	8.72	12.5	2.91	4.2	8.3
7	Arain minor	1,329,565	65	2.86	4.4	1.00	1.5	2.9
Max.			321	17.34	28.6	4.53	4.2	26.9
Min.			13.5	1.27	4.4	0.22	1.3	2.9
Avg.			114.2	7.9	11.2	2.0	2.0	9.2
STD.			119	6	8	2	1	8

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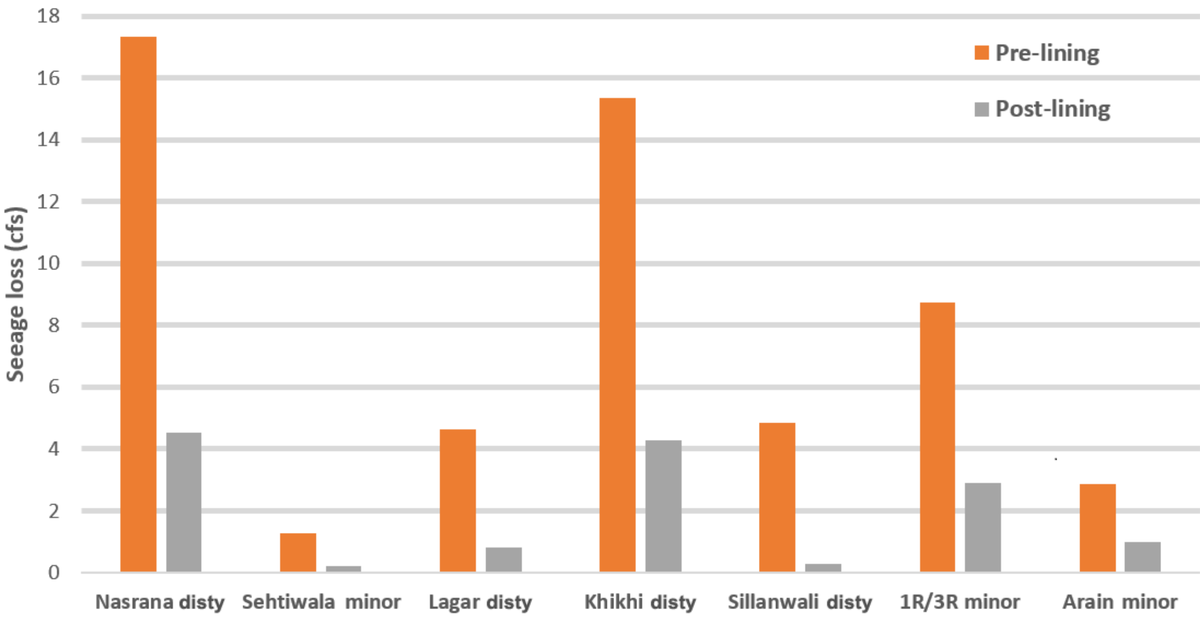

Figure 5. Reduction in-seepage losses as percentage of design discharge (cfs)

3.2. Impact of Lining on Watertable

The impact of lining on the watertable has been evaluated based on depth-to-watertable data from 41 piezometers installed and monitored in canal commands of selected channels. The results have been summarized in Table 7. As can be seen from the table, most of the channels, i.e., 12 out of 14 (86%), have shown no impact of lining on the watertable. Only one channel (1R/3R) has indicated a minor rise in the groundwater table. It can be concluded that lining has no significant impact on the depth of the watertable or waterlogging in the study area. The reason appears to be the unconfined aquifer nature of the aquifer (Greenman, Swarzenski, & Bennett, 1967), which underlies the IBIS in Pakistan. The water that is saved through seepage losses can be used to water more land. This is where percolation happens, and groundwater from higher elevations moves towards cones of depression. Because of this, the lining of any specific channel cannot be blamed for a significant drop in the aquifer level at the local level. Similarly, lining a distributary may result in seepage losses from main canals, minor canals, water courses, or even from irrigated fields. Research has also demonstrated that without proper construction quality and post-lining maintenance, seepage losses from lined channels could match or surpass those from unlined channels (Arshad, Ahmad, & Usman, 2009). Therefore, we can infer that only a reduction in seepage losses can justify the large investments in canal lining. Rather, a multi-parameter analysis is required before investing in canal lining.

Table 7. Impact of lining on groundwater levels.

No	Watertable rise		No change in watertable	Falling watertable	
	Significant	Minor		Minor	Significant
1	-	-	Nasrana disty	-	-
2	-	-	Sehtiwala minor	-	-
3	-	-	Khewra disty	-	-
4	-	-	Qaim minor	-	-
5	-	-	Lagar distributary	-	-
6	-	-	Khikhi disty	-	-
7	-	-	Sillanwali disty	-	-
8	-	Khadir disty (Not lined yet)	-	-	-
9	-	-	Shaheena disty	-	-
10	-	-	Zam disty	-	-
11	-	-	Safdar Abad disty	-	-
12	-	-	Rojhan minor	-	-
13	-	-	Arain minor-1	-	-
14	1R/3R minor	-	-	-	-
Total	1	1	12	0	0

3.3. Impact of Lining on Groundwater Quality

When we talk about the potential of groundwater, both its quantity and quality are equally important. Generally, in fresh groundwater zones, more pumpage takes place, causing depletion of the aquifer, while problems of waterlogging and salinity prevail in brackish groundwater zones (Bhutta & Smedema, 2007; Swarzenski, 1968).

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Lab analysis obtained groundwater quality data for 118 groundwater samples from command areas of selected channels, followed by parameter calculation. The fitness of groundwater was evaluated based on three parameters, viz., electrical conductivity (Ec), sodium adsorption ratio (SAR), and residual sodium carbonate (RSC), and the criteria of PID (IRI, 1996, 1998) given in Table 8. Figure 6 graphically presents the Ec values at various channels.

Table 8. Impact of canal lining on groundwater quality.

Name of channel	Sr #	Name of channel	Quality of groundwater (No of samples)		
			Fit	Marginal	Unfit
Faisalabad zone	1	Nasrana disty	6	1	3
	2	Sehtiwala minor	5	2	0
	3	Khewra disty	6	1	1
	4	Qaim minor	7	1	2
	5	Lagar disty	4	4	2
	6	Khikhi disty	5	0	1
Sargodha zone	7	Sillanwali disty	3	2	0
	8	Khadir disty	6	0	0
DG Khan zone	9	Shaheena disty	8	1	1
	10	Zam disty	0	1	9
	11	Safdar Abad disty	3	1	5
	12	Rojhan minor	4	2	4
Bahawalpur zone	13	Arain minor-1	6	0	5
	14	1R/3R minor	0	1	5
Total			63 (53%)	17 (15%)	38 (32%)

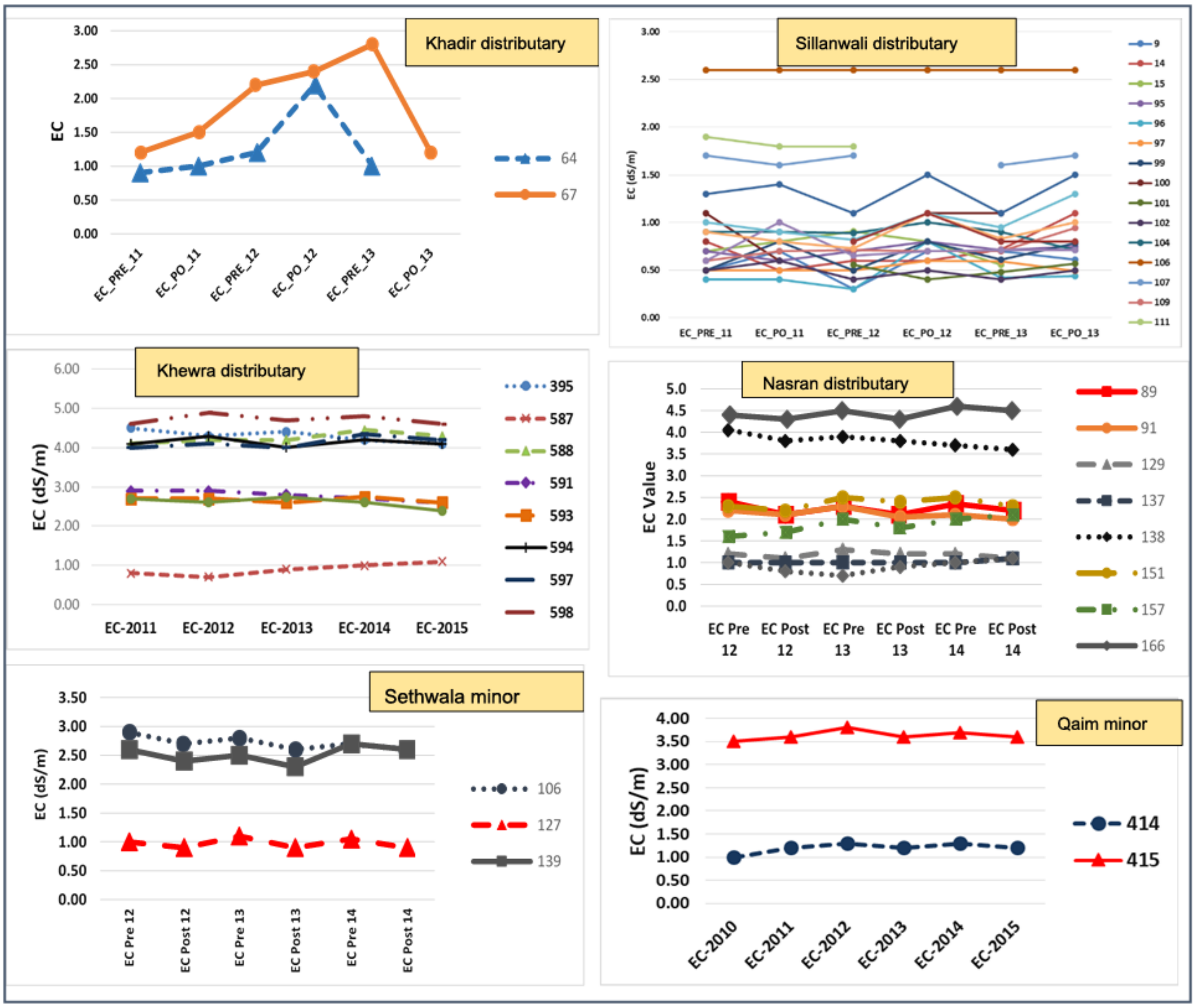

Figure 6. Variation of Ec (ds/m) in the vicinity of selected channels.

In saline groundwater areas, local communities install hand pumps and tubewells close to canals. Despite the lining of the Nasrana distributary, people continue to use water for drinking from hand pumps installed on the

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distributary's bank (Figure 7). This practical example in the study area creates evidence that even after the lining of the canal, groundwater is being extracted for drinking purposes.

Figure 7. Hand Pumps installed on Nasrana canal for drinking water.

3.4. Impact of Lining on Groundwater Quality

Table 9 summarizes the impact of lining on groundwater quality. According to available data for six distributaries and minors, five lined channels have no impact of lining on groundwater quality, and one distributary has a minor improvement in groundwater quality after lining. It can be concluded that the lining of canals has no adverse impact on groundwater quality or salinity.

Table 9. Impact of lining on groundwater quality.

No	Groundwater quality deterioration		No change in watertable	Groundwater quality improvement		No Data
	Significant	minor		Minor	significant	
1			Nasrana disty			
2			Saithywala minor			
3			Khewra disty			
4						Qaim minor
5						Lagar distributary
6						Khikhy disty
7			Sillanwali disty			
8			Khadir disty			
9						Shaheena disty
10						Zam Zam disty
11						Safdar Abad disty
12						Rujhan minor
13						Arain minor-1
14						1R/3R minor
15				Jalwala disty		
Total	0	0	5	1	0	

4. CONCLUSION AND RECOMMENDATIONS

The findings of this study have indicated that: i) concrete lining has reduced the seepage losses in the selected channels in the range of 58 to 94%, with an average of about 78%. This holds significant importance in areas where irrigation pumps groundwater. ii) Estimates place the losses from unlined and lined channels at 11% (6.29

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cusec/msf) and 2% (1.25 cusec/msf) of the head discharge, respectively. As a result, the water saved by lining is 9 percent of the head discharge. Taking into account the canal command's water budget, lining the distributary canal increased the available water for crops by 3%. iii) The conclusion is that lining does not affect the watertable's depth or cause waterlogging. iv) Based on the limited available data, we conclude that lining has no effect on groundwater quality or salinity. v) Groundwater's role in the livelihood of the area will not significantly change due to lining, as the total reduction in groundwater recharge is only 3% due to lining of distributaries. vi) The reduction of groundwater recharge by about 3% will lead to a corresponding decrease in groundwater availability for various uses. It will also increase the minor cost of pumpage due to the increase in depth of the water table.

It is recommended that for long-term and more concrete findings, continuous data on groundwater levels, groundwater quality, and seepage losses be observed and maintained in a database. For determining the life of irrigation distributary canals, long-term data on the performance of channels, including sedimentation and maintenance costs, is recommended. Future lining projects should incorporate a monitoring component for both pre- and post-lining. Consider a multi-range of parameters, not just seepage losses, when conducting a feasibility study before investing in canal lining. The preparation of an Atlas of groundwater levels and quality should occur at least every five years. A study under semi-field conditions shall be conducted to compare the performance and financial implications of different lining materials like concrete, geosynthetics, bricks, bentonite clays, and other innovative materials on a wider and larger scale.

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