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Optimizing lining length of watercourses for increased water saving in Punjab, Pakistan

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Abstract

The concern of water losses through the irrigation system has significant impact on the supply through of surface water. There is a high quantum of surface water losses in unlined watercourses that reduces the efficiency of water supply system and makes it uneconomical. An extensive study has been carried out to calculate conveyance losses using operational inflow and outflow approach. The losses from both lined and unlined watercourses of a similar geographical area, has been calculated and compared to compute the percentage saving of water. The percentage of water saving against increase in percentage lining were modeled using polynomial regression and optimum lining length for unlined water courses has been computed as 50% and it is found that maximum economic benefits can be obtained using this length that corresponds to 80% of water saving.

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Introduction

Water is one of the main factors for agricultural productivity in developing countries especially in Pakistan where almost 70% population has agriculture as an occupation. The main source of Surface water supply in Pakistan is the Indus Basin Irrigation system (IBIS) that consists of a network of reservoirs, barrages, head works, link canals, main canal, distributaries, minor and watercourses. The IBIS is an aged system running without sufficient and necessary maintenance resulting in high water losses during its conveyance from reservoirs to agricultural farms. These water losses must be minimized in order to increase the efficiency of the system.

Water losses in watercourses occur due to numerous reasons. The main causes include evaporation, operational and seepage losses (Thomas 1980). Other causes are leakage, spillage, vegetation, dead storage, zigzag shape, hole made by rodents, poor maintenance and stealing losses (Zeb *et al.*, 2000; Arshad *et al.*, 2009). Among these, seepage significantly contributes towards losses.

The intensity of losses varies with the length of the watercourse, variation in discharge, time of retention, soil type and compactness of soil. Lining of an irrigation channel is most commonly used practice for saving water, which also helps salinity control and to improve system efficiency. An increase of 25% conveyance efficiency was observed due to lining on entire canal length (Arshad and Ahmad, 2011).

The delivery losses ranged from 38 to 62% in the watercourses of Khushab district were observed (Copland, 1987). Alam and Bhutta (2004) investigated the seepage losses in canals of Bahawalpur and Bhawalnagar districts of Punjab, Pakistan with the help of physical measuring techniques. The emphases of their investigated study were to reduce the irrigation system losses and they found the variation of seepage losses/ per day was from 9.76 to 17.54 cm/day. Akkuzu (2012) also carried a similar research for calculation of seepage loss in Turkey using. Mortiz and Davis empirical equations and found the average seepage losses were 107.61 cubic meter/second/kilometer, 32.1 liter/second/ 100 m and 11.7 liter/second/100 m for main canals, branches and distributaries, respectively. He further suggested lining of canals as an economical solution for this purpose. Numerical modeling has also been applied for estimation of conveyance losses in canals by Wachyan and Rushton (1987).

Water losses from minor and distributaries were varies from 1.8 to 2.0 m^3/day/meter, respectively. Uncertainty and non-linearity in seepage losses was observed by Martin and Gates (2014) using flowing water balance with acoustic Doppler devices. The study also investigated the severity of seepage and potential benefits of seepage reduction and the main conclusion was that the losses were increased as the wetted perimeter increases.

Similarly other researchers like Chatha *et al.* (2014) and Shaikh and Lee (2016) estimated the earthen water channel seepage losses and recommended the use of lining to save the water during conveyance process. Further the inflow and outflow method was considered as the most reliable method which is able to measure the most of the losses except evaporation (Planning and Development, 1988). Skogerboe *et al.* (1979), Moghazi and Ismail (1997), Alam and Bhutta (2004) and Arshad *et al.* (2009) have also supported this inflow-outflow method and concluded that this is the only method that can be applied under all operational condition (free and submerged) of watercourses.

Greater the length of lining, greater will be the saving of water and ultimately it will produce an incremental effect on agriculture crop productivity. On the other hand lack of lining increases the rate of ground water abstraction, reduction in salinity and water logging. It leads towards degradation of soil and effect the crop yields by decreasing the channel's design capacity. (Reuss *et al.*, 1979; Trout, 1983). Kahlown and Kemper (2004) evaluated the different types of lining for the reduction of water losses from watercourses. Arshad *et al.* (2009) studied the comparison of water losses in unlined watercourses in Indus basin of Pakistan.

The study was carried out to emphasize the importance of water saving for Pakistan. It was revealed that average loss from the unlined watercourse varies from 64 to 68% and can significantly be reduced through lining. Javaid *et al.* (2012) also carried a similar research and assessed the performance of watercourses in Jhang district, Pakistan. Although the percentage of water saving increases with the increase of lining but providing lining for the whole length of watercourse will be highly uneconomical. Also the relation between these two parameters is highly nonlinear and dependent upon many geological as well as geographical parameters. Not only this, the length of lining is more critical near outlets rather on tail or far end of water courses. The study has been carried out to provide an economical solution by finding optimum length of lining that ultimately results in reduction of water loss and increased water saving.

The study is unique in a sense that its first of its kind that covers a large area (contains 8 districts) and provides a general idea of selecting lining length in the watercourses of province Punjab.

Methodology

Study Area

As shown in Fig.1, Punjab province has 36 districts. The study areas are Bhakkar, Bhawalnagar, Chiniot, D.G. Khan, Hafizabad, Kasur, Sahiwal and Vehari districts. The land of Punjab province mostly contains of productive alluvial plains. It is the part of Indus valley, fed by Indus River and its four major tributaries in Pakistan, the Jhelum, Chenab, Ravi, and Sutlej rivers. Most areas of Punjab observe harsh extremities in weather with fog in winters, frequently accompanied by rain. From the mid of February, the temperature begins to rise, spring season weather continues until mid-April. Punjab's region temperature averagely ranges from −2° to 45°C, but can reach 50°C (122°F) in summer and −10°C in winter. Cotton, wheat, rice, gram, sugarcane and citrus are the major crop grown in the area. Water losses are more and tremendous effort are required to develop the route of watercourse, such that the losses could be reduced to minimum.

Fig. 1. Map of Punjab province showing the selected study areas (Source: PC-I PIPIP, 2012).

Data Set

Twelve (12) sample watercourses including Eight (8) unlined and Four (4) lined were located in eight districts of Punjab province. Table 1. Detail layout (command area map) of each sample watercourse was obtained from the Punjab Irrigation Department, Pakistan. The warabandi list (rotation manual) of the command area was also obtained and verified against the actual rotation practice.

The average length of watercourses is 5000 meter (5Km). Average command area of watercourse is 500 acres.

Table 1. Water Courses location Information and respective Command Areas.

Stations	Status	Outlet Location	Distributary	Main Canal	Length	Command Area
Sahiwal	Unlined	21780-R	9L	LBDC	5310	400
Kasur	Unlined	72432-R	Kasur Disty	BRBC	3420	275
Vehari	Unlined	49173-L	2BR	Pakpattan	6717	453
Chiniot	Unlined	35409-L	Gilotran	Jhanng Branch	6716	430
Hafizabad	Unlined	15461-L	Fethki	LCC	9889	707
Bhawalnagar	Unlined	6-R	Fateh	Sadqia Canal	4645	369
Bhakkar	Unlined	31250-R	Mahota	Thal	4908	708
Dera Ghazi khan	Unlined	16594-R	Oorwaahi	DG Khan Canal	6777	550
Bhawalnagar	Lined	3-AL	Madrassha	Sadiqia Canal	3800	291
Dera Ghazi khan	Lined	32000-R	Qasim Wala	DG Khan Canal	3500	224
Bhakkar	Lined	56610-R	Khansar	Thal Canal	3100	546
Kasur	Lined	14260-L	Handal	BRBC	3350	275

Inflow-Outflow Method

The inflow-outflow method provides direct measurement of water losses. This method is based on measuring the rates of water flowing in and out of a selected section of watercourse. The difference between inflow and outflow is attributed to losses (Planning and Development, Punjab, 1988). The inflow-outflow method was a practical approach and it responds well under dynamic conditions of flow. Furthermore, continuous measurements can be performed without any interference in system operation. (M. Arshad, et, al., 2009) Accuracy in the results depends on accuracy of in-flow and outflow measurements.

$$Q = C_s \, {(H_u - H_d)^{nf}} \big/ {(-\log S)^{ns}} \quad Eq.(1)$$

$$Loss\big/100m = {(Q_i - Q_o)100} \big/ {Measured\ Length} \quad Eq.(2)$$

Where Q is the discharge in cubic meter per second; Q_i and Q_o represents inflow and outflow, respectively. H_u is upstream head and H_d is head at downstream. E is the evaporation loss and S is the seepage loss from reach. Cut throat flume having dimensions (8″x36″) has been used to measure inflow and outflow discharge on the designated points. The main watercourse was divided into three sections i.e. head, middle & tail sections by installing three cut throat flumes. The flume is commonly suited in both flow conditions free and submerged for measurement (Skogerboe *et al.*, 1973).

Also, it can be used for varied range of flow discharges. The collected data for seepage loss was applied to the entire watercourse system using water rotation time (called warabandi) of each watercourse under study to estimate the total loss. Distances between flumes were measured as a segment length and loss/100 meters for each segment was also calculated. The loss rates so obtained were further used to calculate the volumes of water loss for each segment.

Polynomial Regression Analysis

Royston and Altman (1994) introduced the regression procedures based upon fractional polynomial (FP) transformation of continuous predictors. It is beneficial method of examination which keeps predictors as unbroken in the model. The application of nonlinear regression has been gauged in the numerous fields of water resources for instance, demands of irrigation canals (Ticlavilca *et al.* 2013), low flow guides (Joshi *et al.* 2013), watershed modeling (Marshall *et al.* 2007), loading of nutrients (Wellen *et al.* 2012; Vigiak and Bende-Mich 2013), and stream flow modeling (Block and Rajagopalan 2009; Liang *et al.* 2013).

Polynomial regression models are usually fit using the method of least squares. The least-squares method minimizes the variance of the unbiased estimators of the coefficients, under the conditions of the Gauss–Markov theorem. Although it fits a nonlinear relationship between the value of independent variable (x) and the corresponding conditional mean of dependent variable (y), despite of the fact that it has a linear regression function applied on unknown parameters. Mathematically, it can be expressed as;

$$y_i = a_o + a_1 x_i + a_2 x_i^2 + \cdots + a_m x_i^m + \epsilon_i \quad Eq. (3)$$

Where a_o, a_1, a_2 .....a_n are constant coefficients, m is the non-negative integer and x is an argument.

Results and discussions

The identified watercourses including lined and unlined were located in the same geographical region thus it can be considered that all of these watercourses would be subjected to same geotechnical as well as hydraulic properties. The loss rates were determined through inflow outflow method for every watercourse by dividing each watercourse in three sections, head, middle and tail Table 2.

Table 2. Water Loss per 100m (liters/sec) calculated using Cut Throat Flume (Inflow Outflow Method).

Stations	Status	Outlet Location	Water loss lps per 100 meter at			
			Head	Middle	Tail	Average
Sahiwal	Unlined	21780-R	1.34	2.26	1.59	1.73
Kasur	Unlined	72432-R	1.85	1.20	1.10	1.38
Vehari	Unlined	49173-L	1.3	1.2	0.90	1.13
Chiniot	Unlined	35409-L	1.25	1.34	0.48	1.02
Hafizabad	Unlined	15461-L	2.57	1.85	1.09	1.84
BWN	Unlined	6-R	1.20	0.94	0.94	1.03
Bhakkar	Unlined	31250-R	1.37	1.72	0.90	1.33
DG khan	Unlined	16594-R	1.45	1.37	1.17	1.33
BWN	Lined	3-AL	0.3	0.15	0.15	0.20
D. G. Khan	Lined	32000-R	0.3	0.28	0.22	0.27
Bhakkar	Lined	56610-R	0.45	0.4	0.3	0.38
Kasur	Lined	14260-L	0.3	0.25	0.2	0.25

In case of unlined water courses, highest average loss rate/ 100m = 1.84, was observed in watercourse No.15461-L of district Hafizabad and Lowest loss rate/100m = 1.02 in watercourse No.35409-L of district Chiniot.

After determining losses from every water course difference of losses from lined and unlined water courses was considered as a saving of water achieved through lining. The comparison of both types of watercourses in terms of annual water loss in acre-ft. is presented Table 3.

Table 3. Percentage Saving of Water.

Stations	(1)	(2)	$(3) = (2) - (1)$	$(4) = (3)/(1)\, x100$
	Un-lined	Lined		
	Annual loss acre-ft	Annual loss acre-ft	Saving of Water acre-ft	Save %
Sahiwal	757.55	60.37	697.17	92.03
Kasur	386.44	37.52	348.92	90.29
Vehari	624.22	67.94	556.28	89.12
Chiniot	401.41	45.72	355.69	88.61
Hafizabad	980.04	62.11	917.93	93.66
BWN	433.85	55.56	378.29	87.19
Bhakkar	468.85	47.57	421.29	89.83
DG khan	723.23	72.01	651.22	90.04

As the age of lined water courses have an average of 2 years. As the age of lining increases, the capacity of lined watercourses reduces due to silting, that causes overtopping of flows at many locations. Consequently, it has reduced the percentage of saving of water, still on average 90 % saving has been observed as shown in above table.

The % increase of total length of unlined water courses "x" was considered as independent variable with % increase of saving of water "y" as dependent variable. A polynomial regression analysis has been performed to develop equations for each district of Punjab Table 4.

Table 4. Polynomial Regression Equations for % water saving.

Sr. No.	Stations	Equation
1	Sahiwal	$y = -0.0143x^2 + 2.2421x + 6.1584$
2	Kasur	$y = -0.0141x^2 + 2.1767x + 6.9751$
3	Vehari	$y = -0.0084x^2 + 1.4111x + 29.647$
4	Chiniot	$y = -0.0151x^2 + 2.1609x + 14.472$
5	Hafizabad	$y = -0.0139x^2 + 2.0975x + 15.957$
6	BWN	$y = -0.0124x^2 + 1.9454x + 11.925$
7	Bhakkar	$y = -0.0172x^2 + 2.4525x + 7.6429$
8	DG khan	$y = -0.0145x^2 + 2.2263x + 6.7796$

Table 5. Shows the performance, bias and variance among the actual and forecasted values. Over efficiency of the polynomial regression is satisfactory as shown in the table 5. Random errors were varies from 30.07 to 4.47. Systematic error are not much in the whole study area.

Table 5. Performance of the polynomial regression forecasting.

Sr. No.	Stations	Bias	Variance	R.Sq.
1	Sahiwal	3.36	4.47	98.68
2	Kasur	1.87	9.40	98.34
3	Vehari	0.80	2.87	97.87
4	Chiniot	2.14	30.07	94.14
5	Hafizabad	1.01	20.35	96.59
6	BWN	2.06	6.60	97.47
7	Bhakkar	1.84	14.77	97.23
8	DG khan	-0.08	8.52	98.54

A graph was also been formed between increase in percentage lining length and corresponding increase in percentage water saving for every water course. Fig. 2.

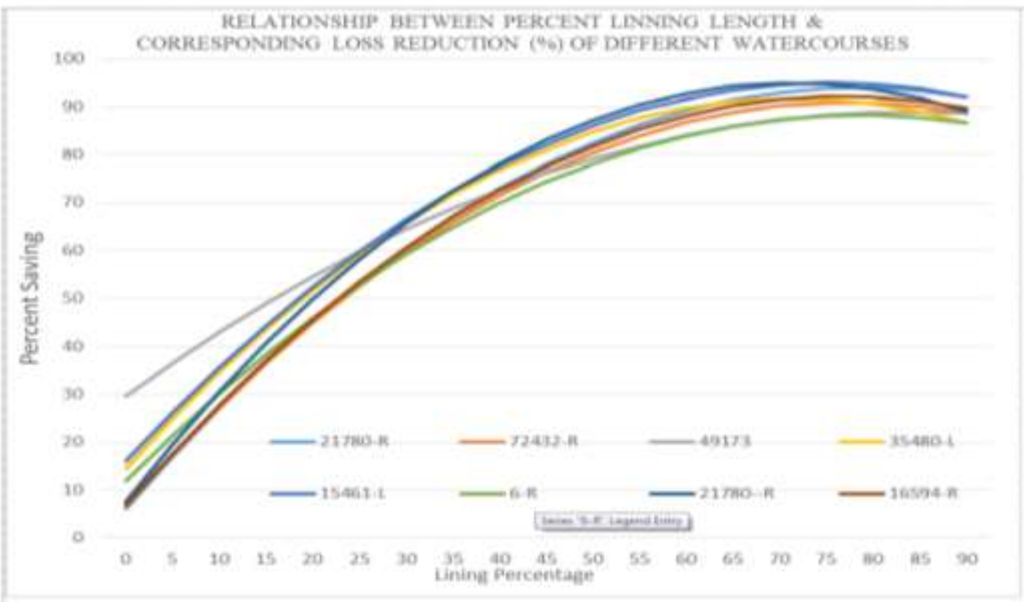

Fig. 2. Relationship between lining and saving percentages.

It is well clear from the Fig. 2. that at the start there is a rapid increase in water saving with incremental change of length for unlined water courses but after 50% lining there is no significant change in water saving. So the maximum economic benefits can be obtained using only 50% of total length for lining as it can save water up to 80%. This 80% water saving establish volumes of 308 to 786 acre-ft (which constitute vetted average as 472 acre-ft) of water which can be used to irrigate an additional area of 92 acres of crops in Rabi and 62 acres in Kharif.

Conclusions

The study aims at the finding of optimum length of lining of water courses and ultimately to increase the conveyance efficiency by saving water and thus making the operation more viable and economical. For this purpose, a total of 12 stations of similar geographical conditions was chosen, including 8 for unlined watercourses and 4 for lined watercourses. The implementation of inflow outflow method has been made using cut throat flume and losses for both types of watercourses has been calculated. The difference in losses provides the percentage of saving water that was modeled with the percentage increase in length of watercourses using polynomial regression method. After interpreting the results, it is recommended that the lining of any watercourse is viable up to 50%, which may save the maximum water losses of about 80%, beyond that the marginal saving is very negligible and only about 20% in total against the remaining 50% of lining. Thus, it is concluded that the lining of watercourse be done to the maximum level of about 50%. For further research it is recommended to use advance non-linear techniques like Artificial Neural Networking (ANN), Fuzzy or genetic algorithms for modeling process.

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