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Impact of Water Losses and Maintenance of Canal Irrigation System on Agriculture (Case Study: Urmar Minor of Warsak Gravity Canal Pakistan)

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Authors' contributions

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ABSTRACT

A study was conducted in May-August 2005 to assess the conveyance losses, seepage losses, maintenance status and impact of water losses and maintenance on the agricultural yield in case of irrigation channels. In this regard, a case study was conducted on three watercourses, at Urmar Minor of Warsak Gravity Canal irrigation system in Pakistan. The Inflow-outflow and ponding methods were used to determine conveyance and seepage losses respectively. Local farmers were interviewed to inquire about the maintenance condition of the selected water courses. A considerable decrease i.e. more than 50% in the yield of wheat and maize was observed while moving along the channels from head to tail. The irrigation system of Urmar Minor is evaluated as a guiding study and remedial measures are suggested to handle widely spread reduction in agricultural production due to these losses.

Keywords: Watercourses; conveyance; seepage; outlets; head; tail; leakage; nulkas.

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1. INTRODUCTION

Water is the basic input for crop production of the developing world. A large amount of irrigation water is conveyed over large distances by watercourses which may be entirely unlined or partly lined. For an uninterrupted supply of water to the land, it is important that the watercourse prism should not only be hydraulically capable of conveying the designed discharge but the banks should also be strong enough to ensure adequate supply to the fields. Since the hydraulic efficiency of the water course section depends largely on the efficient operation and maintenance of the water course; their importance cannot be ignored. It is, therefore, essential that the watercourse should be operated and maintained properly. A study of maintenance impact carried out by Khan [1] revealed that farmers having more water available for their crops pay less attention towards the maintenance of watercourses and socio-economic factors like job, shop-keeping and other such engagements also influence this maintenance process. As such, huge quantity is lost during conveyance from canal heads to fields via minors and water channels. Water conveyance loss consists mainly of operational losses, evaporation and seepage into the soil from the sloping surfaces and bed of the canal due to poor water management in the distribution network. The most important of these is seepage. Evaporation loss in irrigation networks is generally not taken into consideration [2,3,4,5]. The correct estimation of conveyance water losses from an irrigation system is vital for the proper management for the system. Seepage is the most dominant process by which water is lost in the canal. Thus, for the effective operational planning and management of an irrigation system, a dependable forecasting of the seepage is very important. Seepage rates are obtainable either by direct measurement or by estimation. The problems resulting from water conveyance loss due to seepage in canals are divided into 2 groups. The first is prodigality of water, which is obtained at a high cost and with difficulty from various sources. The second is the problem of drainage, salinity, and alkalinity, which result from a rising water table [6]. It has been stated that it is necessary to take some action to prevent seepage, such as changing broken concrete flumes, sealing joints between concrete flumes, and using mastic asphalt and shotcrete in the lining of canals [7]. According to [8], the efficiency of rigid canal lining (concrete) may decline rapidly over time, especially when low construction standards and poor operation procedures are used. Geo synthetics (geomembranes and geotextiles) provide a long-term solution to the control of seepage loss.

It is obvious from a number of research studies that most of the watercourses in Khyber Pakhtunkhwa province, Pakistan are improperly designed, carelessly operated and poorly maintained [9]. This eventually causes considerable water wastage and contributes largely to the water-logging and salinity. Hagan [10] found that one-fourth to one-third of all the water diverted for irrigation purposes was lost during conveyance to the field. Rehmat [11] reported conveyance losses of 15 watercourses in three districts of Khyber Pakhtunkhwa ranging from 25 to 45 percent. Similarly, Kamper [12] measured 0.24 cusecs water losses using cut throat flume and 0.33 cusecs by ponding method in a series of studies. Ejaz [13] during his research on five high water tertiary units and Alam [14] in his research on five low water tertiary units in Kabul River command area found cumulative conveyance losses in terms of seepage and leakage losses. Khan [1] measured conveyance losses of 6 watercourses at Pabbi Minor of River Kabul Canal and Sheikh Yousaf Minor of Lower Swat Canal ranging from 27.3 to 42.5 percent.

Corey and Clyma [15] attributed the physical causes for watercourse losses as inadequate hydraulic capacity, leaky nukkass, thin channel walls, inadequate free board, obstructions

such as debris, weeds and sediments, poor alignment and excessive ditch system required to serve many small fields.

This study is focused on the conveyance and real operational losses in the irrigation/farmer channels at the selected outlets. Measurement of conveyance losses in this study gives the loss rate of water per unit length of channel. A considerable reduction in the agricultural production results from two types of losses; one is the steady state water losses due to seepage through the channel sections and direct evaporation from the channel; the second is operational or transient losses due to change in the operation of system such as advance and recession times of the channel and, opening and closing of outlets. The operational or management losses in the conveyance system are related to: the size of the irrigation scheme; and the level of irrigation management, communication systems and control structures, i.e. manual versus automatic control. Besides, poor maintenance and absence of due attention by farmers further aggravate this deficiency in agricultural growth.

In the canal head areas silting is lesser than that of middle and tail reaches. Moreover, huge amount of water is lost or spoiled by seepage, leakage, percolation, evaporation, theft, animals, pollution and many pilfering activities while flowing from head to middle and tail. So, farmers at middle and tail reaches have to face more risks of shortage and quality. Estimated production of farmers living at tail reaches is more than the left areas because they have no fear of shortage and loss. Silting of canals and watercourses, paucity (water is not available on time when available not in adequate quantity), theft, unlined watercourses and canals, damages done by animals to watercourses and canal lines, leakage, seepage, high percolation rates and pollutants are major problems farmers face as far as our irrigation system and its management are concerned.

1.1 Conveyance and Canal Seepage

Seepage is defined as the process of movement of water from the bed and sides of the canal into the soil. Seepage in irrigated agriculture has been defined as the movement of water in or out of earthen irrigation canals through pores in the bed and bank material. There are many factors that affect seepage from canals [16]: texture of the soil in the canal bed and banks, water temperature changes, siltation conditions, bank storage changes, soil chemicals, water velocity, microbiological activity, irrigation of adjacent fields, and water table fluctuations. Proper design and construction of conveyance systems are necessary to minimize seepage, due to the limited available water supply and ever increasing demand for water. Seepage is not only a waste of water, but also may lead to other problems such as waterlogging and salinization of agricultural land. Canal seepage varies with: the nature of the canal lining; hydraulic conductivity; the hydraulic gradient between the canal and the surrounding land; resistance layer at the canal perimeter; water depth; flow velocity; and sediment load. The canal seepage can be calculated using empirically developed formulae or solutions derived from analytical approaches [17]. Canal seepage might also be estimated on the basis of Table 1.

Table 1. Seepage losses in percentage of the canal flow (USBR, 1978)

Type of canal	Seepage losses (%)
Unlined canals	20-30
Lined canals	15-20
Unlined large laterals	15-20
Lined large laterals and unlined small laterals	10-15
Small lined laterals	10
Pipelines	0

Excessive seepage can occur due to poor canal maintenance.

In Pakistan seepage losses are usually high and are about 8 to 10 cusec per million square foot of the wetted area of the cross section and amounts to 35 to 40% of diversion into the canal. Studies carried out by the WAPDA indicate a total annual loss of 18.3 MAF [18] of valuable irrigation water to the ground from unlined canals and watercourses in Pakistan through seepage alone. This huge loss of supplies if prevented can irrigate approximately an additional 3.0 million acres annually.

The Indus river system is prime source of irrigation water in Pakistan. If we reduce the losses from canals and water courses, more area can be cultivated. It is estimated that about 25% water (26 MAF) is lost through canals, distributaries and minors. And about (45 MAF) water is lost from water courses through seepage, evaporation, transpiration and overtopping etc. In Pakistan including Sindh province water management program is started from 1976–1977, which is known as “On Farm Water Management”; the main objective of this program is to control the water losses, which are 40–50% in water courses, to mitigate water logging and salinity.

Keeping in view the problems of water losses in irrigation channels, the following objectives are likely to be achieved from this work:

1. To report and assess the conveyance losses and conveyance efficiency of the selected watercourses at Urmar Minor
2. To determine seepage and leakage losses
3. To find the effect of conveyance losses on crop production at the selected outlets
4. To suggest measures for minimizing the water losses involved
5. To check the maintenance status of watercourses under study
6. To investigate the socio-economic factors affecting watercourse maintenance
7. To see the overall impact of the identified problems on agricultural growth

The irrigation system of Urmar Minor is evaluated as a guiding study and the remedial measures are suggested to handle widely spread reduction of agricultural production due to these global issues.

1.2 Study Area

1.2.1 Warsak gravity canal

Fig. 1 shows the branches of River Kabul identifying Warsak Canal in the Peshawar region. The canal, 34°9'53" N 71°25'8" E, starts at the exit of the 5.6 kilometers tunnel

through the Mulkagori Hills on the right bank of the River Kabul and upstream of Warsak Dam (shown in Fig. 2). The total length of this canal is 72.8 kilometers (45.2 miles) and its full supply discharge is 8.807 cumecs (311 cusecs). The culturable command area of this canal is 238.87 km² (59,000 acres). It is located in the Peshawar Valley, the capital of Khyber Pakhtunkhwa.

Warsak Canal consists of seven minors with a total length of 1984 kilometers (12.4 miles). These minors include Urmar minor, Pabbi minor, Warsak minor, Shahibala minor, Palosi minor, Tehkal minor and Surizai minor. Wheat, sugarcane and maize are the main crops grown from this water.

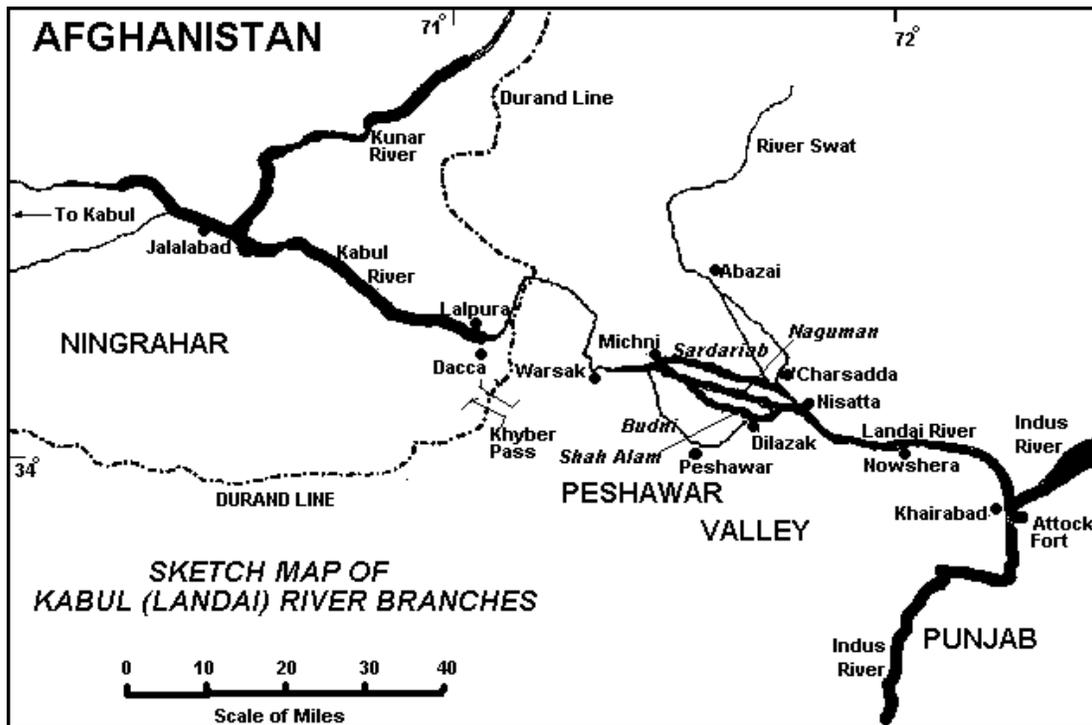


Fig. 1. Kabul River branches identifying Warsak Gravity Canal

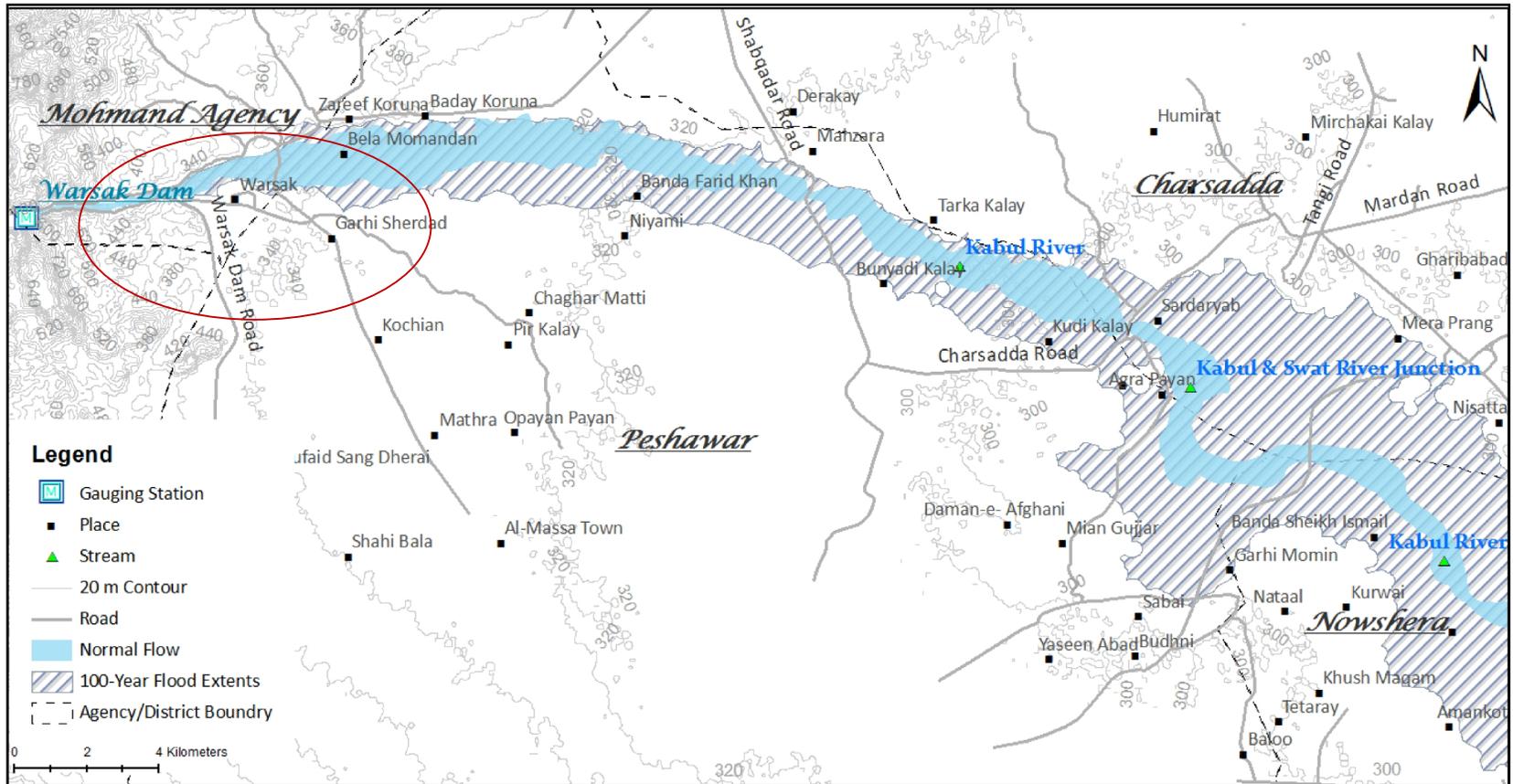


Fig. 2. Map identifying the Warsak gravity canal upstream of Warsak Dam

1.2.2 Urmar minor

The Urmar Minor takes off from the right side of Warsak Gravity Canal at RD 127100 m. It is located in the middle towards tail of the canal. The minor consists of 15 outlets; 6 on the right and 9 on the left. The total length, design discharge and culturable command area of the minor are respectively 6461.76 m, 0.35 cumecs and 13.12 km².

Table 2. Detailed description of outlets at Urmar Minor

Watercourse number	Design discharge (cumecs)	CCA (Km²)	Total length (m)
2640/L	1.34	1.47	4850
20000/L	0.57	0.63	1352
21200/L	0.5	0.55	2080
8425/L	0.8	0.87	1725
10200/R	0.402	0.43	4710
1700/L	1.06	1.16	2587
13260/L	0.34	0.37	812
14200/L	0.58	0.64	1258
15750/L	0.35	0.38	850
17880/L	0.332	0.36	789
18290/R	1.41	1.55	2857
21200/R	0.95	1.04	3130
8650/R	1.09	1.19	2275
14100/R	1.276	1.39	2850
3520/R	0.99	1.09	4374

R – Right, L – Left

Out of the above 15 outlets, three watercourses i.e. 10200/R, 21200/L and 21200/R were selected for undertaking this study. The watercourse no. 10200/R was completely unlined. The head of watercourse no. 21200/R was lined up to 50 meters and the rest remained unlined.

2. METHODOLOGY

Methods for measuring the rate of seepage from canals include: inflow-outflow method and the ponding method. The ponding method is considered the most accurate [19,20,21].

2.1 Inflow–Outflow loss Measurement

We have used this method for measuring the conveyance losses. This method involves measuring the amount of water flows into a channel at inlet of the section and amount which flows out at the tail of the section when no water is being usefully directed between the two measuring points. The loss is the difference between these two measured points. The measurement can be either of total volumes of water or if the channel is flowing steadily with its little change in the measured flow rate at either end directly of flow rates.

To measure steady state (constant flow) conveyance losses in a channel section, the flow measurement devices should be installed at the beginning and end of the channel section. The same type and size of device should be used if possible, so that any biased errors in the devices are cancelled out. The flow should be monitored in both devices until the steady flow is obtained. The flow measurement device will generally change the depth of flow and

channel storage upstream from the device, therefore five minutes to an hour may be required depending upon the slope of the channel/watercourse to reach constant measurements in a channel flow under steady state condition.

If the flow in channel is fluctuating, it will affect the measurements at the head of the section earlier than the downstream measurements.

2.2 Ponding Loss Measurement Method

The most dependable and reliable method for measuring the quantity of water loss through seepage in a particular reach is by the ponding method. It consists of constructions of a temporary water tight dyke of bulk head across the canal. The canal above the dyke is filled with water to a certain measured level. After allowing the water to stand for some time, the level of water in the canal is recorded. Any drop in the level is obviously due to seepage through the section of canal. The volume of level drop is equal to the total seepage loss during the particular time interval. The volume of water divided by the time determines the rate of seepage loss through the canal.

2.3 Conveyance Loss Determination

The inflow-outflow technique was used to determine water losses by conveyance using the following equations:

$$Q_{\text{loss}} = Q_{\text{in}} - Q_{\text{out}} \quad (1)$$

$$\text{Water losses percentage (\%)} = (Q_i - Q_o)/Q_i \times 100 \quad (2)$$

$$\text{Losses (\% per 100m)} = [(Q_i - Q_o)/Q_i \times 100] \times (100/L) = (\% \text{ losses/total length}) \times 100 \quad (3)$$

Where: Q_{in} and Q_{out} are the measured discharges at the head and tail respectively and L is the watercourse length under consideration.

In order to measure discharges at head and tail, a 12" x 4" cut throat flume (typical section shown in Fig. 3) was placed in a straight section of channel in the center, parallel to the direction of flow. Bottom of channel was leveled under the flume and the bottom of flume was placed lower than that of channel. After placement, flume was leveled in both longitudinal and transverse directions. The bottom and sides of flume were sealed to avoid leakage and the inside bottom of flume was cleaned from any sediment or trash to get precise gauge reading. The upstream reading was taken as h_u and the downstream reading was taken as h_d . These values were then converted to flow values by using the appropriate tables from discharge measurement manual by OFWM [22].

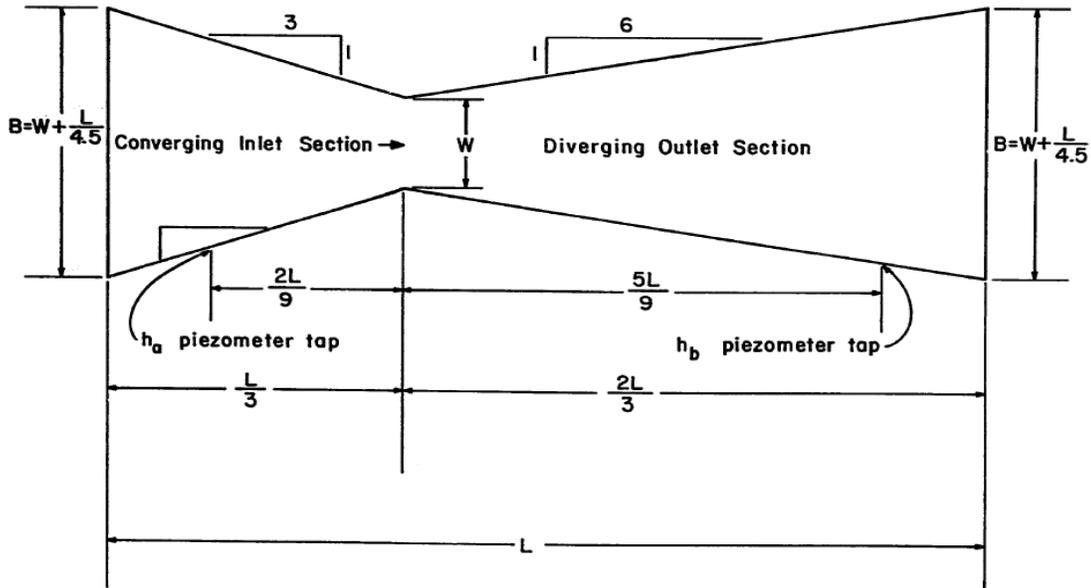


Fig. 3. Typical section of cut throat flume

2.4 Seepage Losses Determination

Ponding method is assumed to be the most accurate and dependable method [23]. Seepage rate was determined by ponding method using the equation,

$$S \text{ (m}^3\text{/m}^2\text{/day)} = 24W(d_1-d_2)/PLT \quad (4)$$

Where

S = seepage rate, $\text{m}^3\text{/m}^2\text{/day}$. W = m, Average width of water surface. d_1 = m, Depth of water at the start. d_2 = m, Depth of water after time T . L = m, Length of ditch. P = m, average wetted perimeter. T = hour, time interval between two depths.

Since loss rates were highly variable, several measurements with different time intervals (10 to 60mins) were made. Time intervals were short at the beginning due to high seepage rate but were longer as the seepage rate went on decreasing. The measurements were stopped when the seepage reached steady state.

Seepage losses (l/sec) were calculated using the formula,

$$\text{Seepage Loss (l/sec)} = 0.01157 \text{ SPL} \quad (5)$$

Where

S = seepage rate, $\text{m}^3\text{/m}^2\text{/day}$. P = m, wetted perimeter. L = m, total watercourse length

Leakage losses were calculated by subtracting the steady state seepage losses from the total conveyance losses. A greater portion of the selected watercourses was parabolic in shape and it took 8 to 10 minutes to fill the ponding ditch up to the normal depth.

3. RESULTS AND DISCUSSION

3.1 Water Losses

It is evident from the results presented in Tables 3 and 4 that the lowest conveyance losses were recorded in water course no. 21200/R. This was due to the fact that the section under consideration was totally in shady area and evaporation losses were, therefore, negligible. Moreover, siltation in the watercourse also maintained a low seepage rate. Secondly, it might be due to the reason that it was straight and below the natural surface line and as such the banks and beds were sealed with little leakage and seepage.

The maximum losses in watercourse no.10200/R were mainly due to numerous turn-outs increasing leakages at junctions, higher elevation in absence of suitable gradient causing an increase in vertical and horizontal seepage and sharp curves contributing to frictional losses. The overtopping due to high discharge also contributed.

Table 3. Water losses, conveyance efficiency and channel usage of the selected water courses

Watercourse no.	10200/R	21200/L	21200/R
Measured discharge at head (l/sec)	42.65	31.63	45.93
Measured discharge at tail (l/sec)	31.05	27.18	42.30
Water losses percentage	27	14	8
Water losses percentage per 100 meters	0.57	0.67	0.23
Conveyance efficiency percentage	73	86	92

Table 4. Seepage losses in the selected water courses

Watercourse no.	10200/R	21200/L	21200/R
Average Depth, cm	14.10	24.12	28.86
Wetted perimeter, cm	53	207	189
Infiltration rate, cm/hr	2.15	3.43	2.83
Width, cm	72.57	54.95	73
Seepage, m ³ /m ² /day	0.384	0.22	0.28

The main reason of the conveyance losses was poor maintenance and silt deposition in the head of outlets as farmers lacked cooperation and had little technical know-how; as such the watercourse were not de-silted on a regular basis. Moreover, hindrance in the flow due to vegetation and trees on the banks and high water requirement through evapotranspiration greatly decreased the conveyance efficiency of watercourses.

Such results were reported by Ejaz [13] who found average losses of 24%, while Whiting and Javed [24] reported 22 percent losses in Balu Village Peshawar after sealing the nukkas with mud. Khan [1] estimated 21.8% losses in Pabbi Minor of Kabul River Canal due to poor maintenance of watercourses and 14.5% losses in Sheikh Yousaf Minor due to leaky nukkas. Langely and Roob [25] measured average water losses of 40 percent in

Coloradowhereas Eire and Leonard [26] mentioned 42 percent water losses in irrigation system from mogha to the farm.

3.2 Watercourse Maintenance and Operation

It was revealed from the interviews of farmers conducted through a questionnaire that the frequency of watercourse clearance was variant based on the extent of silt deposition but the frequency was higher at the tail than that at the head for the selected watercourses. At watercourse no. 10200/R, 50% respondents reported watercourse cleaning twice a year, 10% once a year, 10% thrice a year and 30% four times a year. Tail was cleaned twice a year as area was sandy and sand was deposited in the tail section. At watercourse no. 21200/L, 50% of the respondents reported watercourse cleaning once a year and 40% thrice a year. At watercourse no. 21200/R, the frequency of watercourse clearance was once a year reported by 40% farmers, twice a year by 50% farmers and thrice a year by 10%. It was observed that the watercourses were not cleaned for the last two years.

It was reported that in the past there was some kind of informal schedule for water distribution and watercourse periodical cleaning. That was devised and monitored by the senior citizens of that area who besides resolving other disputes, decided about the time and mode of watercourse clearance. Defaulters were subjected to huge fines but with the passage of time, change in the family structure, introduction of new technologies and economic independence due to the jobs gave away to individual dominancy. These days only few farmers belonging to the tail section of watercourses are involved in the cleaning but cannot fine the free riders and cannot monitor those who do not cooperate in maintenance. In Surizai village of Peshawar district, an integrated water management organization was established by the social organizers with the main function to enforce water related policy like water distribution, water course maintenance and collection of water charges. This type of organization is required to settle such disputes. According to the questionnaire, all farmers reported disputes related to maintenance. Tail section farmers considered it injustice that the head and middle section farmers did not participate in maintenance. There was scarcity of cooperation among the farmers for the watercourses maintenance.

3.3 Agricultural Deterioration

The water losses and inadequate watercourse maintenance and operation have led to the deterioration of agriculture. The crops production has reduced by a considerable amount as shown in Table 5.

Table 5. Percent reduction in yield

Watercourse number	% reduction in yield at tail
10200/R	56%
21200/L	47%
21200/R	30%

4. CONCLUSION

From the aforementioned results, it can be inferred that major causes of the water losses were leakage, heavy vegetation on the banks, sharp curves, huge silt deposition, poor

design, irresponsible attitude and negligence of farmers, sediment debris in the water channels, and poor maintenance of watercourses and lack of cooperation between farmers regarding periodic clearance. As such, only 40 percent of the farmers get their livelihood from the agriculture in the selected watercourses command area. There was a considerable decrease of 56 percent in the yield of maize and wheat at the tail of watercourses due to these losses. If the average water losses of 32.4 percent are saved through improving these courses, about 65 cusecs more water could be made available which will be sufficient for irrigating an additional area of nearly 13,000 acres.

In order to minimize water losses, government should take an initiative to form an association comprising of agricultural experts and farmers for creating awareness regarding periodical maintenance and clearance of watercourses, settling the water distribution disputes among the farmers and eventually increasing water conveyance efficiency. Growth of excessive vegetation on the banks should be strictly avoided and measures should be taken to seal the holes made by insects, reptiles and rodents. Periodical removal of silts and sediments should be made on a regular basis. Banks should be well compacted and moghas should not be submerged. As water losses are comparatively more in earthen watercourses, efforts should be made to line these. In case of financial constraints, at least head portion of the watercourses should be lined to increase discharge at the tail. The effect of soil texture on conveyance losses is recommended for the future study.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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