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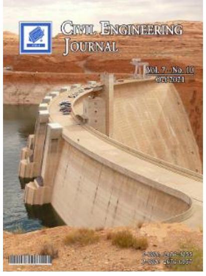

Analysis of Conveyance Losses from Tertiary Irrigation Network

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Abstract

Irrigation canals are generally made through porous soil formations, since the soil is loose porous media – a huge amount of canal water is lost to conveyance losses. The situation becomes direr when these losses result in non-beneficial losses. The Sindh province of Pakistan has more than 70% saline groundwater, conveyance losses to such areas in the province not only become unusable but also creates water management problems. Perhaps the only cost-effective way to address these losses is canal lining. The present study was conducted in the command area of Belharo distributary, Sindh, Pakistan with an aim to determine the extent of losses from the tertiary irrigated network as these water channels are less considered in the literature with regards of conveyance losses. Using water balance method, conveyance efficiency and conveyance losses at 30% lined and 50 and 75% unlined length of the watercourses was observed. The results revealed that the tertiary irrigation channels face an average of 43% conveyance losses and major proportion of these losses is lost to non-beneficial losses from the study area. The study further suggests 75% lining of watercourses in order to minimize non-beneficial losses. This study also infers that with the use of geo-membrane lining, sizeable amount of fresh water can be saved.

Keywords: Canal Lining; Conveyance Efficiency; Conveyance Losses; Non-beneficial Losses; Waterlogging; Salinity; Brackish Groundwater.

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1. Introduction

Earthen irrigation channels are usually made through loose soil formations, since irrigation channels convey water to farmers' fields over large distances; in the process a significant amount of irrigation water is lost [1, 2]. Such losses are technically termed as conveyance or operational losses and are mainly caused due to seepage into soil or evaporation. Most important of these conveyance losses are the seepage losses, whereas evaporation losses from irrigation infrastructure are generally not taken into consideration as these losses only account to be around 0.3 % of the total losses [3, 4]. Various research studies suggest that conveyance losses vary between 30 to 60% from source to farmlands [5]. In Pakistan, network of more than 120,000 tertiary level watercourses is used to irrigate 19.02 Mha of agricultural lands, huge amount of water is lost to conveyance losses in the process [1, 6].

According to Arshad et al. (2015) [7], Pakistan faces conveyance losses of about 35-40% of the total canal flows diverted for irrigation, whereas 50% of these losses occur from secondary and tertiary level canal networks. Saeed

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(2014) and Soothar et al. (2015) [8, 9] reported that the conveyance losses in earthen tertiary irrigation network are about 44%, and around 18 MAF of conveyance losses occur annually from the earthen tertiary irrigation system in Pakistan. Ghumman et al. (2011) [10] reported that the excessive conveyance losses degrade agricultural lands due to waterlogging and salinization, resulting in ultimate yield losses for majority of crops. They also reported that 38 and 14% of the total land area in Pakistan is characterized by waterlogging and salinity, respectively. According to Kahlown et al. (2002) [11], yield of different crops decreases with increasing waterlogging and salinity rates. Impacts of waterlogging are not limited to agricultural production. It causes public health concerns, in the form of different waterborne diseases (such as typhoid and diarrhea to name a few). Waterlogging also hurts animal and livestock health. Damp conditions created by waterlogging damages housing and infrastructure [12]. Besides, the increasing groundwater table in return creates water management disasters. Groundwater becomes saline due to high conveyance losses or where the groundwater aquifers are already saline, conveyance losses to such aquifers becomes unusable in the shape of return flows or downstream usage [13].

The impacts of conveyance losses caused waterlogging extends beyond agricultural productivity to fresh drinking water supplies. Waterlogging increases groundwater table close to the surface water, leaving behind no source of fresh drinking water. The main source of drinking water in many rural areas of Sindh, Pakistan is the polluted water [12]. According to van Steenbergen et al. (2015) [14], about 70% of the land area in Sindh, Pakistan is underlain by saline groundwater making the use of groundwater not only unsuitable for irrigation purposes but also for other beneficial uses. While, according to van Steenbergen (2020) [12], about 35% of the total area in Sindh has groundwater table within 1.5m making most of the land resource in the province waterlogged. Current situation makes lining of irrigation network compulsory in the province to avoid loss of fresh water via seepage into brackish groundwater. Reducing conveyance losses using appropriate techniques will protect land degradation from waterlogging and salinization, minimize irrigation return flows, reduce mobilization of salts and other trace elements into the streams, protect water quality for downstream usage of lower riparian, no non-beneficial losses of fresh water, decrease water table and conserve water for other beneficial services, decrease drainage requirements, increase water use efficiency (WUE) and enhance crop yields resulting in more cropping intensities [15, 16]. Reducing seepage losses by some effective interventions, such as canal lining, is the best way to reduce climate change impacts while still maintaining food security; this is one strategy for making our agriculture more competitive and productive. An integrated strategy for water resource management and efficient water resource use for optimal crop production should address the growing industry's needs, human and livestock sustenance, flood control, hydroelectric power, tourism, and navigation, among other items [17]. Thus, in the light of the above facts, the present study is focused on assessing conveyance losses from tertiary irrigation network.

2. Materials and Methods

This section, apart from presenting research methods, contains descriptions of the distribution system (belharo distributary) which feeds the watercourses under present study and the equations and instruments that were selected for the measurements of discharge are described.

2.1. Study Area

Present study was conducted in the command area of Belharo distributary off-taking at coordinates N 25° 21' 40.878"; E 68° 58' 22.6884", in the Mirpurkhas district of Sindh, Pakistan. This distributary feeds about 17,000 acres of irrigated land with its 30 water outlets (tertiary irrigation network) and 1 minor channel. This distribution system was completely lined in the year 2018 and comes under the management of Nara canal area water board while the tertiary water channels (watercourses) are operated and maintained by the local farmers. Water supply in this area is conducted via gravity flow and most of the area in the region of present study is waterlogged and underlain by saline aquifer [18]. After surveying the total length of the distribution system and its water outlets (watercourses), a total of 6 watercourses (tertiary level irrigation channels) off-taking from Belharo distributary at its head, middle and tail were selected and divided into 3 sections (reference points) to observe conveyance efficiency and conveyance losses at 30, 50, and 75% length of the total length of watercourses. All of the 6 irrigation channels under study were lined at 30% of the total length. The salient features of the tertiary level watercourses (irrigation channels/outlets) under study are given in Table 1 while Figure 1 depicts location map of the study area and Figure 2 gives base map of the experimental study area. During the data acquisition process, factors such as flow turbidity, deteriorated/non-geometric sections, sedimentation, and vegetation in the watercourses provided obstacles in the flow measurement process. Resultantly, some of the measured/recorded data were omitted and channel sections free of obstacles were included in the result analysis phase.

Table 1 Salient features of watercourses under study

Sr. No.	Watercourse No.	CCA	Design discharge	Total length	30% of Total length (lined)	50% of Total length (unlined)	75% of Total length (unlined)
		acre	cusecs	(m)	(m)	(m)	(m)
1	4L	690	1.98	1800	540	900	1350
2	5R	581	1.75	1800	540	900	1350
3	8R	271	1.02	1200	360	600	900
4	9R	872	2.84	2900	870	1450	2175
5	12AAL	565	1.72	1700	510	850	1275
6	12DL	456	1.41	1500	450	750	1125

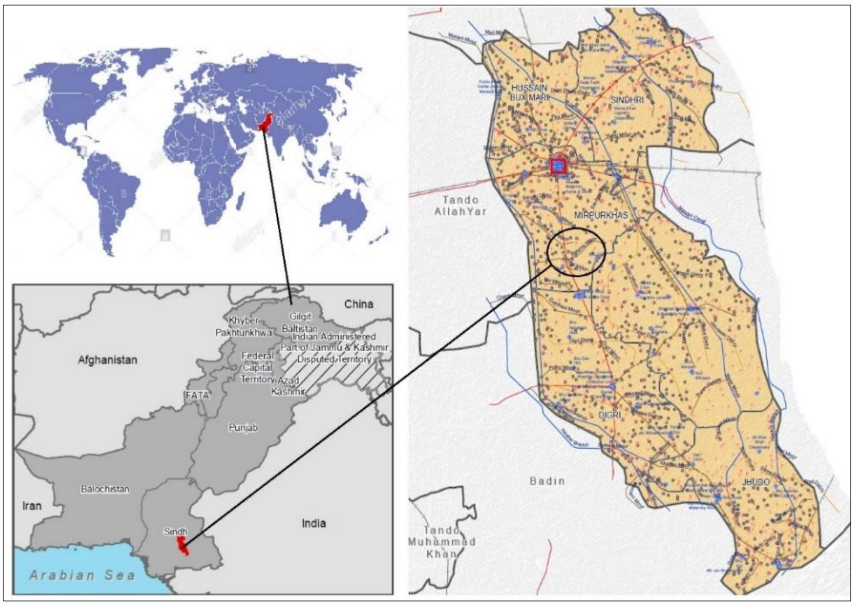

Figure 1. Location Map of Study Area

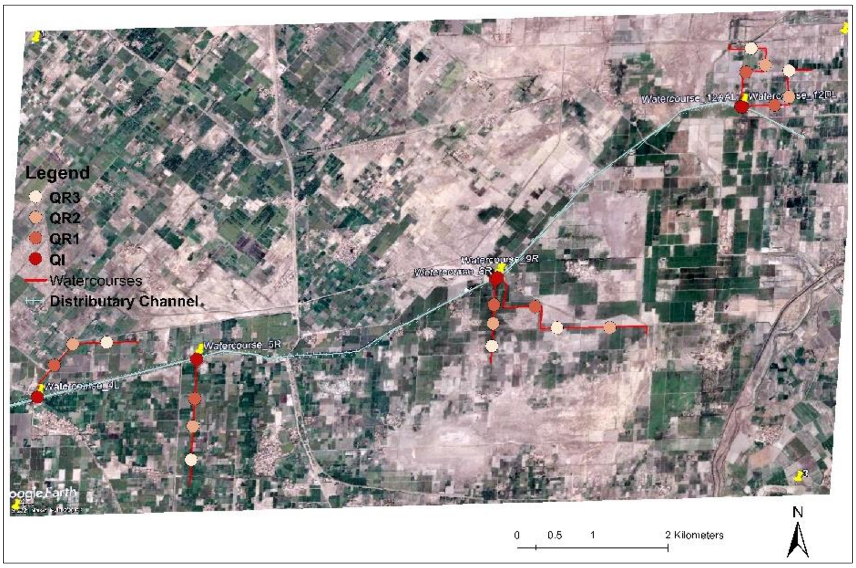

Figure 2. Base Map of Study Area

2.2. Reconnaissance Survey

Field reconnaissance survey was carried out to select suitable watercourses for study, observe field conditions with regards to usage of equipment for flow measurements and implementation methods, inspection path availability, and to analyze the impacts of waterlogging in the study area. Furthermore, Figure 3 gives detailed step by step road map of the research study.

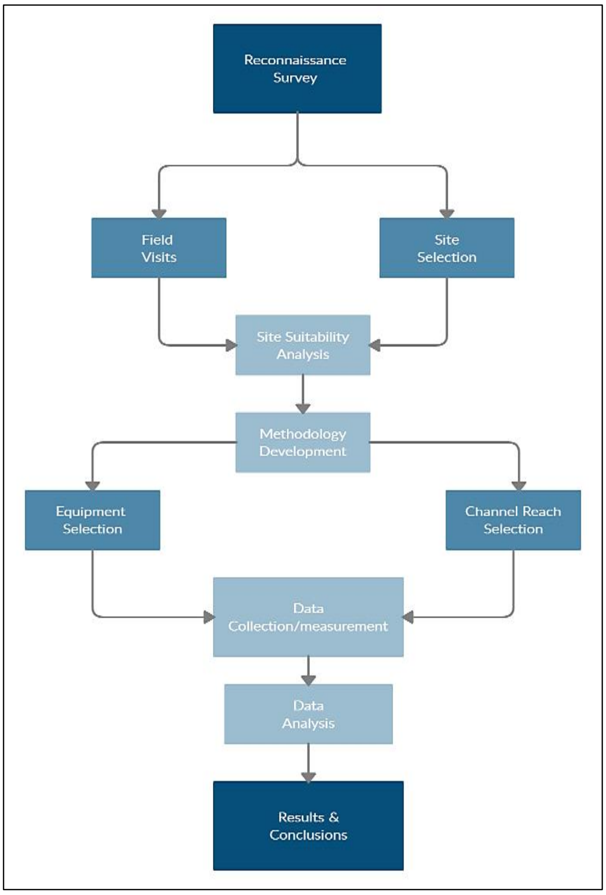

Figure 3. Technical road map of research methodology

2.3. Discharge Measurement

Discharge was measured by adopting area-velocity method at different reference points of the watercourses (tertiary irrigation channels) using current meter in case of lined section as described by Mangrio et al. (2015) [15] and cutthroat flume (having size 8”×3’ and 12”×3’) in the unlined portion of the irrigation channels [9, 19]. Two-point method was adopted where the water depth was more than or equal to 0.76 m whereas one-point method was used when flow depth was less than 0.76 m. Moreover, velocity at each reference point in the irrigation channels was observed with time duration of 40 sec.

$$Q = A \times V \tag{1}$$

where, Q is the discharge measured at each reference point (m^3/s); A is the flow area of each point (m^2); V is the velocity of the specific reference point (m/s).

Flow area at specific points of the watercourses was measured by the product of respective width and depth of that point. While width and depth of flow for each reference point was measured by measuring tape and wedding rod, respectively.

2.4. GIS Data Collection

On-site coordinates of watercourses and reference points were collected using Global Positioning System (GPS). Collected coordinates were then validated through Google Earth Pro Software. The validated image file was further processed in ArcGIS software to digitize and map the spatial data.

2.5. Conveyance Efficiency

In order to reduce the conveyance losses from the water transfer path, it is mandatory to find out the exact quantity of water conveyance efficiency. Conveyance efficiency of any irrigation system is defined as the ratio of the amount of water delivered by the irrigation system to the amount of water diverted from the distribution system [20]. The conveyance efficiency of any irrigation system depends on number of factors such as channel length, conditions of lining, soil and channel characteristics [21]. In this study 30, 50 and 75% length of the total length of tertiary level irrigation network (watercourses) was selected to determine the amount of water conveyance losses from the watercourses underlain by saline aquifer. Selected length points of the studied water channels were in good conditions with respect to access and control of flow during the measurements stage. The conveyance efficiency of the studied watercourses from these reference points was measured using inflow-outflow method by observing the outflow discharge (Q_{rn}) reached at the specific reference point to the inflow discharge (Q_i) introduced by the system [15].

$$\text{Conveyance efficiency } (\%) = \frac{Q_{rn}}{Q_i} \times 100 \tag{2}$$

where, Q_{rn} is the outflow recorded at each reference point (m^3/s) and Q_i is the inflow introduced by the distribution system to the watercourse/outlet head.

2.6. Conveyance Losses

Conveyance losses are affected by number of factors such as depth of water, quality of channel lining, channel dimensions, bed slope, volume of sediment, age of channel, volume of flow, velocity of flow and the quality of operations and maintenance of water channels [20]. Conveyance losses in this study were simply computed by subtracting obtained conveyance efficiency at each reference point from 100 [22]. Mathematically;

$$\text{Conveyance losses } = 100 - \text{Conveyance efficiency} \tag{3}$$

3. Results and Discussions

3.1. Conveyance Efficiency

Using the water balance method, observed conveyance efficiency at each section viz 30, 50 and 75 percent of the total length of studied watercourses is given in Table 2. The results revealed that lining improves conveyance efficiency of water channels on an average of about 97 percent at 30% lined length. However, it was also observed that with the increase in unlined length of the watercourses – conveyance efficiency decreased as can be observed at 50% and 75% unlined length of the watercourses. This decrease in conveyance efficiency of the irrigation channels is mainly due to seepage from bed and banks at unlined sections, irregular profile of channel banks, variable cross-sections of watercourses, vegetation in the water path as well as evaporation.

Similar results have been reported by Kilic & Tuylu (2010) [23] from Ahmetli regulator irrigation system, lower Gediz basin, Turkey where they found about 98% conveyance efficiency from lined watercourses while Mangrio et al. (2015) [15] concluded that lining improved the conveyance efficiency to about 97% from the tertiary irrigation network off-taking from Mureed minor in Jamrao canal command of Sindh, Pakistan and Eshetu & Alamirew (2018) [24] reported around 94% conveyance efficiency from the lined field channels of Tendaho sugar estate, Ethiopia. Sultan et al. (2014) [25] reported 87% conveyance efficiency from the lined tertiary irrigated water outlets of Egypt. Moreover, Shaikh et al. (2016) [22] observed 78% efficiency from the lined sections of watercourses while 52% conveyance efficiency from the unlined sections of the water channels in the Barani area of Karachi, Pakistan. Tareen et al. (2016) [26] reported 97% and 69% conveyance efficiency from the lined and unlined sections of field channels, respectively, off-taking from Mubarak Wah, Sindh, Pakistan. Jadhav et al. (2014) [27] reported about 35% conveyance efficiency from the unlined field channels in the Panchnadi Minor Irrigation Project in India and projected about 75% conveyance efficiency from field channels after lining. Saeed (2014) [8] also computed 92 and 73% conveyance efficiency from the lined and unlined sections of watercourses, off-taking from Urmar minor, Warsak Canal, Pakistan. Solangi et al. (2018) [28] measured 98% and 74% conveyance efficiency from the lined and unlined sections of watercourses off-taking from Gadeji minor, Sindh, Pakistan.

The research studies analyzed above also attributed reduced conveyance efficiency from the tertiary irrigation network to no or less maintenance, improper operations of the water channels, age of lining, lining material quality, deteriorated channel cross-sections at unlined reaches, no technical expertise of local farmers. Furthermore, conveyance efficiency observed at each reference point is graphically represented in Figure 4 for each of the studied watercourses (tertiary level irrigation channel/outlet).

Table 2. Observed Conveyance efficiency of studied watercourses at 30, 50 and 75 % length of the total length

Sr. No.	Watercourse No.	Inflow at outlet head (cusecs)	Outflow at each reference point (cusecs)			Conveyance efficiency (%)		
		Q_i	Q_{R1}	Q_{R2}	Q_{R3}	30% length	50% length	75% length
1	4L	1.98	1.90	1.44	1.13	96.24	73.10	57.28
2	5R	1.75	1.70	1.31	1.05	97.37	74.68	59.79
3	8R	1.02	0.99	0.79	0.58	97.52	77.38	57.16
4	9R	2.84	2.74	2.23	1.54	96.57	78.57	54.45
5	12AAL	1.72	1.66	1.28	0.97	96.72	74.38	56.72
6	12DL	1.41	1.37	1.09	0.79	97.06	76.97	55.73

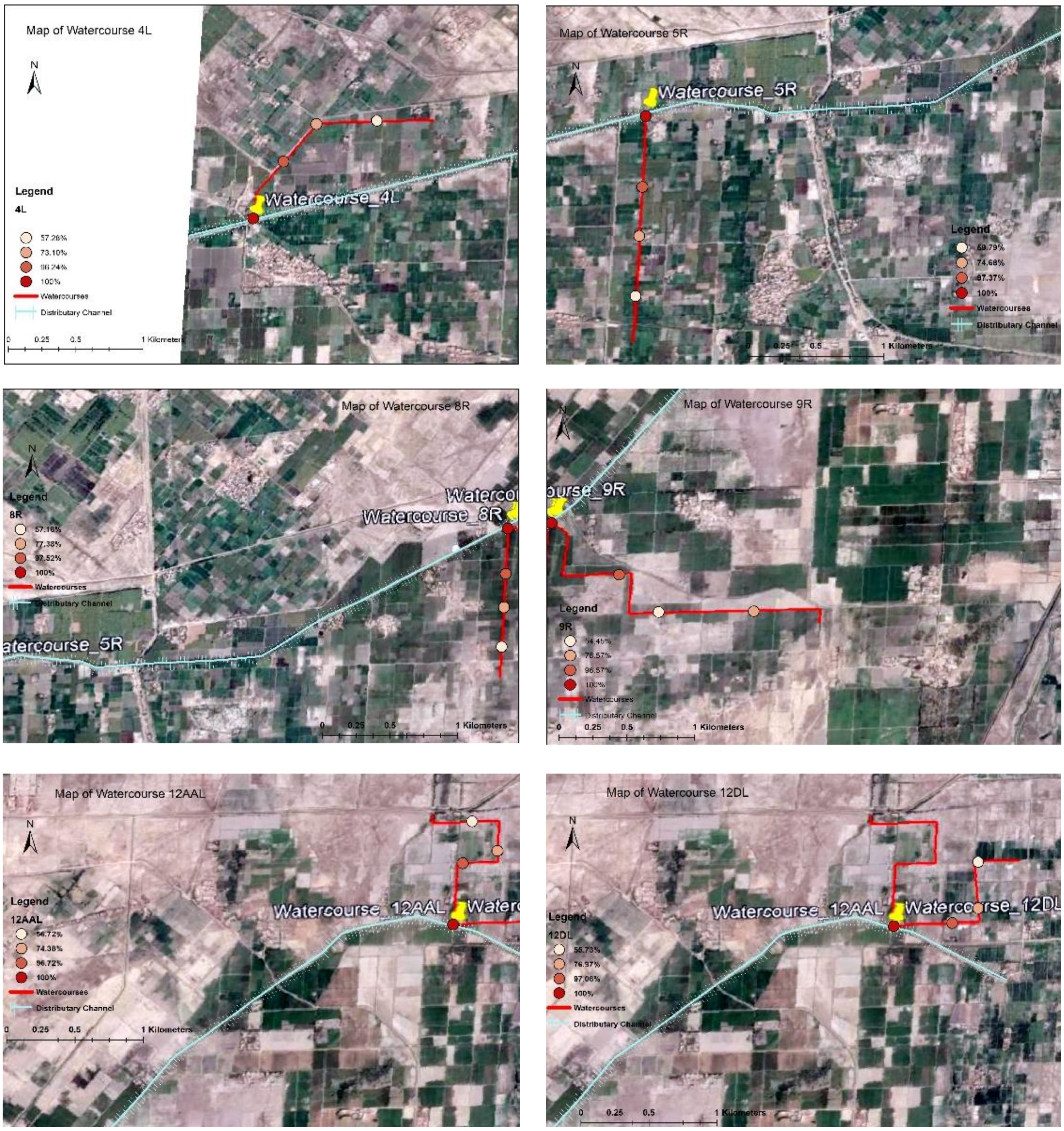

Figure 4. Maps of watercourses under study showing conveyance efficiency observed at each reference point (30, 50 and 75 percent of total length)

3.2. Conveyance Losses

Table 3 portrays the conveyance losses recorded at 30, 50 and 75% length of the watercourses. On an average, 3% losses were observed from lined sections of the studied watercourses. These observed losses from the brick lined sections of watercourses were occurring due to the seepage from inter-brick spacing (vertical joints), and from the deteriorated/damaged precast concrete slabs or improperly installed joints of such slabs of the water channels along with time and weathering effects and in the absence of proper maintenance as well as due to evaporation. However, in the unlined sections of watercourses an average of 24 and 43% conveyance losses were observed at 50 and 75% length, respectively. These losses were mainly due to the poor conditions of watercourses, improper maintenance, siltation causing flow restrictions and overtopping, widening of sections, vegetation in the path of water, bank cutting practices in frequent manner to abstract water, and rodent effect resulting in seepage from bed and banks of the channel along with evaporation losses.

Analogous results have been reported by Sultan et al. (2014) [25] where they observed about 66 and 23% conveyance losses from the unlined water outlets of Pakistan and India while 10 and 11% from the lined field channels of India and Turkey while [29] observed around 10% losses from the lined water outlets in the Rechna Doab area of Indus Basin of Pakistan. Shaikh et al. (2016) [22] computed 48 and 22% conveyance losses from the unlined and lined tertiary field channels in Barani area of Karachi, Pakistan. While Tareen et al. (2016) [26] reported 26 and

3% conveyance losses from the earthen and lined sections of watercourses off-taking from Mubarak wah, Sindh, Pakistan. Saeed (2014) [8] reported 27 and 14% operational losses from the unlined and lined watercourses of Urmar minor, Warsak canal, Pakistan. And Solangi et al. (2018) [28] observed about 26% conveyance losses from the unlined field channels in the command area of Gadeji minor, Sindh.

These studies also highlighted that various factors such as variable cross-sections of water outlets, zigzag alignments of watercourses, irregular profile of the water outlets, leakages at junctions, deposition of silt in the bed of water outlets either restricting or overtopping flow, growth of aquatic plants in the flow path, frequent cutting and plugging of channel banks for abstraction of irrigation water, low or no technical expertise of farmers, improper operations of the water-outlets, no or less maintenance in the absence of funds, lining age and lining material quality and type, soil characteristics all contribute to high conveyance losses from the unlined and lined tertiary irrigation network.

On an average, conveyance losses from the studied unlined tertiary water courses were observed to be 43% of the total water diverted to the tertiary irrigation network from distribution system. These conveyance losses raise groundwater table that results in waterlogging and hence negatively impacts fertile agricultural lands [15]. Our experimental study area is underlain by saline groundwater as reported by Aslam et al. (2015) [18] and according to them the surface salinity has increased due to waterlogging over the years in the Nara canal command area (command area where region of present study is situated). Besides, according to van Steenbergen et al. (2015) [14] around 70% of the groundwater in the province of Sindh is too saline for irrigation purposes. The extent of waterlogging reported in these studies was validated through field reconnaissance survey. Figures 5 and 6 further portray the status of waterlogging and salinity affected lands in the study area. Thus, in the light of above stated facts, it is inferred that majority of these losses observed from the tertiary water channels under study result into non-beneficial losses. As reported by Marsden (2003) [13] conveyance losses become non-beneficial when water is lost to saline aquifers. Moreover, these losses become non-usable and results in disasters in the shape of return flows into freshwater bodies downstream.

Table 3. Conveyance losses observed at 30, 50, and 75 % length of watercourses

Sr. No.	Watercourse No.	Conveyance losses (%)		
		30% length	50% length	75% length
1	4L	3.76	26.90	42.72
2	5R	2.63	25.32	40.21
3	8R	2.48	22.62	42.84
4	9R	3.43	21.43	45.55
5	12AAL	3.28	25.62	43.28
6	12DL	2.94	23.03	44.27

Figure 5. Waterlogging caused saline land in the study area

Figure 6. Patchy crop germination due to waterlogging and salinity in the Mirpurkhas irrigation district [14]

4. Conclusion

This experimental research attempted to study water conveyance efficiency and losses from the tertiary irrigation network with a slight change of the usual approaches by dividing the studied channels into 3 reference points to observe the status of operational losses from the watercourses. The results showed that, the conveyance efficiency for the lined reaches of the watercourses was determined to be about 97% while in the unlined reaches, it was about 76 and 57% respectively. In the assessment of conveyance losses, the achieved results of these losses should be declared versus the volume of water diverted from the distribution system. By means of this, the performance of tertiary level water channels is not satisfactory at unlined reaches as these channels face high conveyance losses affecting overall conveyance efficiency. Whereas, at the lined reaches, the performance of watercourses was observed satisfactory. In this regard, proper and timely maintenance of the tertiary network will improve the overall performance. Tertiary irrigation network has more operational losses related to conveyed water and low conveyance efficiency. Factors affecting these losses from tertiary network are influenced by the age of lining, its material and quality, and any damage in the structure causing cracks and joints as well as structure deterioration, accumulation of debris, sedimentation, reduction in the bed slope, growth of weeds, aquatic plants, and bushes in the water path. Such barriers cause reduction in the flow velocity, thereby increasing the operational losses. Thus, awareness and technical education of farmers in the operation and management of the watercourses is necessary as farmer interactions are generally low for proper maintenance of these channels. Moreover, the concerned authorities should also provide financial and technical aid to the farmers in the reconstruction efforts. With proper awareness of the problem, authorities should at least provide 75% lining of the tertiary irrigation network to avoid majority of losses into saline aquifer. It is also inferred that the using impermeable materials (such as geo-membrane) can control sizeable part of the conveyance losses.

5. Declarations

5.1. Author Contributions

Conceptualization, N.S.B.S. and Z.S.; methodology, N.S.B.S.; software, N.S.B.S.; validation, Z.S., M.M.B. and R.K.S.; formal analysis, N.S.B.S.; investigation, N.S.B.S.; resources, M.M.B.; data curation, N.S.B.S.; writing—original draft preparation, N.S.B.S.; writing—review and editing, M.M.B. and R.K.S.; visualization, R.K.S.; supervision, Z.S.; project administration, Z.S.; funding acquisition, Z.S. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author. The data are not publicly available due to the reason that the data is being used for extension studies by the authors.

5.3. Funding

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5.5. Conflicts of Interest

The authors declare no conflict of interest.

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