Research Article

Spatio-temporal Assessment of Reliability in Pehur Main Canal System, Khyber Pakhtunkhwa, Pakistan

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Abstract | The main aim of this research article is to assess the Spatio-temporal reliability in Pehur Main Canal system. Reliability of irrigation service is a pre-requisite for higher productivity of irrigated agriculture. Both primary and secondary sources were tapped for data acquisition. An extensive field survey was undertaken in Rabi 2012-13 and Kharif Miana 2013 to acquire actual flow data of individual outlets. The reliability is measured on a scale of 0-1, 1 for complete reliable and 0 for unreliable services. The analysis shows the majority of reliability values closer to 0. Rabi season has better reliability than the Kharif Miana. The spatial reliability in different sections of the system as a whole, distributaries and minors are unpredictable. This situation points towards lack of operational maintenance of the canal system.

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Introduction

Reliability is the measurement of how closely operational performance matches planned performance of an irrigation system (Usman *et al.*, 2015). The reliability is inversely proportional to the extent of failure (Lamaddalena, 2012). The extent of failure in irrigation system is calculated from the difference of actual and planned water distributions. Increased reliability in irrigation system is an important factor for the improvement of water productivity and the farmer's prosperity (Chandran *et al.*, 2016; Bhadra *et al.*, 2010; Renault and Vehmeyer, 1999). In irrigation, the concept of reliability is important not only at system level but should also include the farmer's perspectives to make best use of the water resources. From the farmers perspective low reliability of irrigation water is a hindrance to increase productivity (Yakubov, 2012). Previous studies show a strong relationship between reliability and productivity (Awan *et al.*, 2011; Haq, 2010; Clemmens and Molden, 2007). The areas where the irrigation supplies are predominantly reliable, the farmers will prefer high value crops with high investment and the areas where water supply is unreliable the farmers will favour low value crops with lower investment (Hussain *et al.*, 2011; Javaid and Tariq, 2010; Perry, 2005). The study by (Kahlown *et al.*, 2007) in Pakistan show that when the reliability of surface water delivery increases the productivity also increases by 56% in gross terms and 32% per unit of water consumed. In the warabandi irrigation system the productivity of scarce water supply can be increased significantly when the reliability of water delivered to farmers is reasonably high (Nam *et al.*, 2016; Pereira *et al.*, 2012). Farmer will prefer inadequate and reliable water supply over adequate but unreliable one.

The irrigation schemes having same climatic and agro-economic conditions may show a wide variation of productivity depending on reliability in different sections of the system (Latif *et al*., 2014; Rowshon *et al*., 2006). The spatial and temporal variation in the performance of canal systems is dependent on the situation of water supply within the system (Ozmen and Kaman, 2015; Montazar *et al*., 2013). Other inputs being equal, the farmers will invest more on a set of crops depending upon the degree of certainty of water deliveries to increase yield. On the other hand, if irrigation supplies are uncertain farmers will opt for drought resistant crops and will invest little more to get a low but reliable yield (Molden *et al*., 2007). When reliability of irrigation improves the prospects for higher yield also increases (Turral *et al*., 2010; Rowshon *et al*., 2009). The management strategy which improves the reliability of water deliveries will certainly change farmer expectations overtime and their actions will lead to increase crop yield (Morenzo-Perez and Ronald-Canas, 2013; Shah *et al*., 2016; Memon and Thapa, 2011). Improvement in reliability of water supply in the system requires information on water delivery schedules, seasonal water shortages and rationing of water deliveries for the next irrigation season to be made available to the water users in advance (Tariq and Latif, 2010). Thus, the relationship of reliability and yield show vital implications for the irrigation water management (Smout and Gorantiwar, 2005; Uysal and Atis, 2010; Ward, 2010).

The main objective of warabandi irrigation system is to match water supply to allocations which are often less than the highest demand of crops (Ghumman *et al*., 2012; Shakir *et al*., 2010; Zardari and Cordery, 2009). Water delivered to farmers according to planned schedule of the irrigation scheme is considered reliable and if otherwise then it is unreliable. The highest reliability of water deliveries is mostly preferred over maximum but unreliable adequacy (Ghumman *et al*., 2014; Kilic and Anac, 2010; Hussain *et al*., 2007; Gorantiwar and Smout, 2006). The reliability has to be estimated on the basis of data acquired when the system is operational. Like other performance indicators reliability has spatial and temporal attributes (Kukul *et al*., 2008).

This study is aimed at the assessment of reliability in different sections of Pehur Main Canal (PMC) system during Rabi and Kharif Miana growing seasons. The study area is located in district Swabi along the right bank of Indus River (Figure 1). The canal takes its water supply from Ghazi Barrage and distributes it over the command area through 250 outlets located on main canal and 12 distributaries and minors (GoKP, 2012).

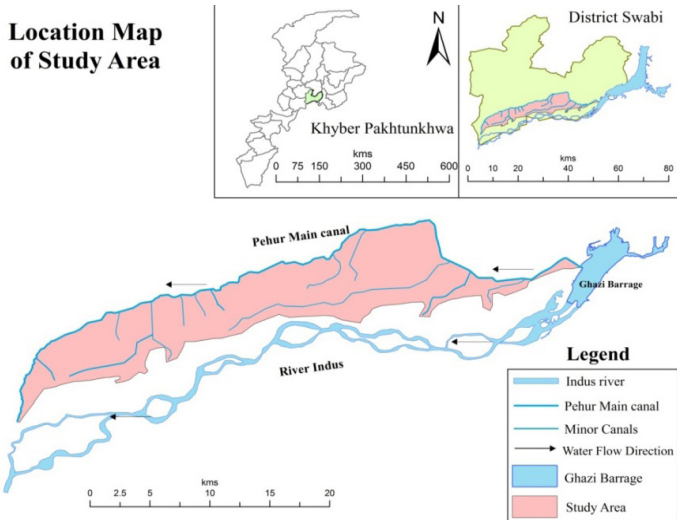

Figure 1: *Location of study area.*

Materials and Methods

In irrigation the concept of reliability is borrowed from other disciplines and then it is modified to make it compatible with the perspective of irrigation services (Srivastaya *et al*., 2010; Yercan *et al*., 2009; Gorantiwar and Smout, 2005). Within the irrigation systems there are slight variations depending upon the mode of water distribution under which the systems are operated. On one hand demand-based irrigation systems are operated to provide water to farmers to fulfill maximum water demand for crops (Garcia-Bolanos *et al*., 2011; Santos *et al*., 2010). While, on the other hand the supply based (*warabandi*) systems are operated under the deficit irrigation regime where deficient water is provided equitably throughout the scheme (Zardari and Cordery, 2010). In the demand-based systems the highest demand of crops has to be matched by the delivery system while in the supply based (warabandi) systems the water delivery has to match the allocation of each unit (Arif and Haq, 2013). Bos *et al*. (1994) underlined the idea of 'predictability' as a key element for understanding the reliability of irrigated agriculture. They defined 'reliability' of irrigation system as the ratio of delivered and target duration of water supply.

$$Reliability\ of\ duration = \frac{actual\ duration\ of\ water\ delivery}{intended\ duration\ of\ water\ delivery} \quad \ldots(1)$$

The other indicator of water delivery reliability is the ratio of the actual to the planned interval between deliveries.

$$Reliability\ of\ irrigation\ interval = \frac{actual\ irrigation\ interval}{intended\ irrigation\ interval} \quad ....(2)$$

The above equations are applicable to a single event or interval but can be easily modified for a set of events or whole season. These equations are intended for use by irrigation managers rather than the water users. The actual duration of water delivery or actual irrigation interval is related with time and does not essentially indicate actual amount of water delivered to the farmers. Water users are more interested in actual amount of water delivered than the time duration of water delivery. Bos (1997) and Ghosh *et al.* (2005) modified the above equations to use water delivery performance ratio similar to adequacy on the basis of delivered and intended volume of water for reliability.

$$Reliability = \frac{Delivered\ volume\ of\ water}{Allocated\ volume\ of\ water} \quad ....(3)$$

This equation is again applicable to single event or interval. According to (Gorantiwar and Smout, 2005) this equation can be modified for measurement of temporal and spatial reliability of the irrigation system as;

$$Reliability = \frac{\sum_{i=1}^{na}\sum_{j=1}^{J} min\left(Va_{ji},\ Vd_{ji}\right)}{\sum_{i=1}^{na}\sum_{j=1}^{J} Vd_{ji}} \quad ..... (4)$$

Va*ji* the volume of water allocated to i^{th} allocation unit during j^{th} irrigation, Vd*ji* the volume of water delivered to i^{th} allocation unit during j^{th} irrigation, *J* the total number of irrigations during the irrigation season and 'na' is the number total allocation units.

This equation is derived for reliability measurement of the demand based operated systems where the maximum volume of water delivered could be the maximum demand of crops. In other words, the highest allocation could be the highest crop water requirement. The Pehur Main Canal is a supply based warabandi irrigation system. In supply-based systems the highest volume of water that can be delivered corresponds to the allocation of each unit. In this case the maximum volume of water that can be delivered will also be the water allocated to each allocation unit in the irrigation plan. Under these conditions the 'Vd_{ji}' will change to 'Va_{ji}' and vice versa. The above equation will become;

$$Reliability = \frac{\sum_{i=1}^{na}\sum_{j=1}^{J} min\left(Vd_{ji},\ Va_{ji}\right)}{\sum_{i=1}^{na}\sum_{j=1}^{J} Va_{ji}} \quad ..... (5)$$

This equation was used to measure reliability during Rabi and summer season in head, middle and tail sections of the canal.

Data collection

The data for this study was collected both from primary and secondary sources. The sub-divisional offices of Provincial Irrigation Department (PID) keep records of the irrigation activities. Among the records kept are Outlet Registers (*Mogawar*) maintained by the irrigation staff. The 'Outlet Registers' refer to designed discharge, area to be irrigated, area actually irrigated, crops assessed in each growing season, water tax (*abiana*) collected in each growing season. The allocated discharge flow of each outlet was obtained from the allocation plans. For delivered volume of water an extensive survey was conducted from 1st October 2012 to 15th January 2013 for Rabi season and from 1st April to 30th June 2013 for Kharif Miana season. The total 250 outlets were divided into ten groups of 25outlets in each. Only one group of outlets was surveyed on daily basis so that each group had its turn on every tenth day. The flow data was recorded and compiled for each individual outlet for both seasons. The data was analyzed for assessment of reliability in both seasons and in different sections of main and secondary canals.

Results and Discussion

Reliability is an important performance measurement of irrigation system. Reliability can affect cropping pattern of an irrigated area. Highly reliable water deliveries and unreliable water deliveries will certainly affect other performance measures. The reliability is measured on a scale of zero (0) to one (1); 1 means complete reliability and 0 means no reliability. The overall reliability of the PMC system remains low. Rabi season shows a relatively higher reliability in comparison to summer season but in few instances the values cross half of scale. The seasonal analysis of reliability is as under.

Reliability of Pehur main canal system during Rabi season

Rabi season extends from October to March. This

season is characterized by low requirement of water owing to lower demand. The rotation interval is increased from seven to fourteen days in this season due to water shortage in the reservoir. Low rainfall is received during season and evapotranspiration also remains low. These conditions keep the crop water requirement at the lowest, this help to improve water availability in the system. Improved availability of water during this season makes the reliability better than the summer season. This does not mean that the reliability is up to the expectations. The average figure for whole of the system stands at 0.296 in head, 0.252 in middle and 0.196 at the tail (Table 1). Reliability in different sections of the PMC system and the respective secondary canals is discussed in the following pages.

Table 1: *Overall reliability of PMC canal system.*

Pehur main canal (PMC) system			
Season	**Head**	**Middle**	**Tail**
Rabi (Winter season)	0.296	0.252	0.196
Kharif miana (dry summer season)	0.082	0.089	0.045

Source: GoKP (2012).

Reliability in head section of Pehur main canal system (Rabi)

The head section of the Pehur Main canal system comprises of the head section of main canal, Kotha distributary, Topi minor, Zarobi minor and Kaddi minor. This part of the PMC system exhibits an overall higher reliability in the head section followed by middle and tail. Although the average reliability in this section shows a declining trend from head to tail in the secondary canals but on individual basis this is not the case for all secondary canals. The main canal has a higher reliability (0.358 and 0.306) in the head and tail while the mid-section has a much lower value (0.038). Zarobi minor has a higher reliability in the middle section (0.36) than the head (0.232). The Kotha distributary has a higher reliability in the tail section rather than head or tail. This is due to the presence of Badri Lift Irrigation Scheme at RD 44-400, adding ten (10) cusecs of water to the tail of distributary. With improve water supply the tail section has a reliability value of (0.423) as compared to head (0.234) and middle (0.239). The lowest reliability (0.038) in the head section of the system is observed in the tail of Topi minor and in the middle of PMC head section (Table 2).

Table 2: *Reliability in head-section of PMC system during Rabi season.*

Name of canal	Rabi season		
	Head	**Middle**	**Tail**
PMC main (head-section)	0.358	0.038	0.306
Topi minor	0.215	0.160	0.038
Zarobi minor	0.232	0.360	0.209
Kotha distributary	0.234	0.239	0.423
Kaddi minor	0.613	0.246	0.338

Source: GoKP (2012).

The inter-canal comparison in the head of the system also shows a trend which goes against normal. The normal trend would have been higher reliability at the upper head declining towards the lower head of the system. The location of the Topi minor, Zarobi minor, Kotha distributary and Kaddi minor are in a sequence from upper to lower head of main canal. Theoretically, the reliability should be higher in Topi minor decreasing towards Kaddi minor but in reality, it is low in Topi minor increasing towards Kaddi minor. The values are Topi minor (0.215), Zarobi minor (0.232), Kotha distributary (0.234) and Kaddi minor (0.613). The highest value for reliability indicator (0.613) has been found out in the head of Kaddi minor, located in the lower head of the system and not in the upper head of the system. The corresponding values of reliability for middle section of these four sub-canals as mentioned above are Topi minor (0.160), Zarobi minor (0.360), Kotha distributary (0.239) and Kaddi minor (0.246) and for tail section are Topi minor (0.038), Zarobi minor (0.209), Kotha distributary (0.423) and Kaddi minor (0.338). These values also indicate an increasing trend of the reliability indicator from upper to lower head section of the system. With exception of Topi minor all canals recorded a successive increase from upper to lower parts of the system (Table 2).

Reliability in middle-section of Pehur main canal system (Rabi)

The middle section of the PMC system comprises of middle part of main canal, Zaida minor, Sheikh Dhari minor, Zakarya Minor and Lahore minor. Part of the main canal record values for reliability indicator as (0.252) in head, (0.151) in middle and (0.262) in the tail. The reliability values in sequence of head, middle and tail are (0.159), (0.117) and (0.101) for Zakarya minor and (0.335), (0.133) and (0.106) for Lahore minor. The Zaida minor shows an increasing

trend from head (0.314) to middle (0.413) and then decreasing to tail (0.276). The Sheikh Dhari minor has an increasing trend from head (0.235) to middle (0.889) and then a decrease to tail (0.459) but the tail value still remains higher than the head (Table 3). The highest value of reliability indicator is found in this section of the system in the middle part of Sheikh Dhari minor which is located in the middle section of the PMC system.

Table 3: *Reliability in middle section of PMC system in Rabi season.*

Name of canal	Rabi season		
	Head	Middle	Tail
PMC main (mid-section)	0.252	0.151	0.262
Zaida minor	0.314	0.413	0.267
Sheikh dhari minor	0.235	0.889	0.459
Zakarya minor	0.159	0.117	0.101
Lahore minor	0.335	0.133	0.106

Source: GoKP (2012).

The inter-canal comparison shows an irregular sequence of reliability values from upper to lower mid-section of the PMC system. The Lahore minor has a highest value (0.335) compared to other canals in the head sections while Sheikh Dhari minor show highest reliability values in middle (0.889) and in tail among canals in this part of the system.

Reliability in the tail section of Pehur main canal system (Rabi)

The tail of PMC system is made up of tail of main canal, Thanodher distributary, Bazar minor, Manki minor and Jahangira minor in a descending order from upper to lower tail. The reliability issues get severe in the middle and tail of Thanodher distributary and Bazar minor with the figures dropping as low as (0.006, 0.009) respectively. The Thanodher distributary takeoff directly from the main canal and bifurcates downstream to give rise to Bazar minor. Bazar minor and tail of Thanodher distributary has low reliability due to water shortage. These both canals are located in the upper tail section of the system. The Manki minor located in the lower tail of the system show an unusually high level of reliability. The head of Manki minor records a value of reliability (0.577) which is the third highest value of reliability in the whole system. The values of reliability for middle and tail of the same canal (0.310, 0.217) are also reasonably high with respect to its location in the tail end section of the system (Table 4).

Table 4: *Reliability in tail-section of PMC system in Rabi season.*

Name of canal	Rabi season		
	Head	Middle	Tail
PMC main (tail-section)	0.400	0.309	0.140
Thanodher distributary	0.270	0.191	0.006
Bazar minor	0.141	0.026	0.009
Manki minor	0.577	0.310	0.217
Jahangira minor	0.109	0.209	0.070

Source: GoKP (2012).

The inter-canal comparison shows a decreasing trend in descending order in the head sections of sub-canals with exception of Manki minor. In the mid sections there in no proper trend of change which ranges from (0.310) to (0.026). The tail ends of sub-canals also show a decreasing trend from top to bottom only Manki minor breaking the sequence. The lowest values (0.006 and 0.009) were found out in the upper tail section of the system while lower tail of the system shows higher values of reliability (0.217 and 0.070). The values are erratic and do not follow a proper sequence.

Reliability of Pehur main canal system during Kharif miana

The hot-dry summer season extends from the month of April to June. This season is characterized by very low rainfall and high temperature which often fluctuates around 40 °C during day in the months of May and June. The crop water requirements during this period increases rapidly owing to very high evapotranspiration and low rainfall. Water losses through direct evaporation from canals, illegal withdrawal by communities living along the canal, thefts and other interferences causes overall water shortage in the canal system. Crops grown during this period are also water intensive especially Tobacco and fodder crops. These conditions keep the reliability of the PMC system at very low level. The average figure for the system as a whole remains very low at head 0.082, middle 0.089 and tail 0.045 (Table 1). The reliability in different sections of the system is analyzed and discussed.

Reliability in head-section of Pehur main canal system (Kharif miana)

The overall reliability situation in the head section is very low not even crossing the 0.150 value. This condition points to very low level of performance of

the irrigation system during this season. The highest figure for reliability observed in this section is 0.135 in the head of Pehur Main Canal. The lowest value of reliability 0.017 is in the tail of Topi minor and head of Zarobi minor. With the exception of Kaddi minor 0.099, 0.046 and 0.025 none of other canals show any sequence of change in reliability values from head to tail (Table 5).

Table 5: *Reliability in head section of PMC system in Kharif Miana.*

Name of canal	Summer season		
	Head	Middle	Tail
PMC main (Head-Section)	0.135	0.024	0.072
Topi minor	0.065	0.083	0.017
Zarobi minor	0.017	0.074	0.038
Kotha distributary	0.089	0.042	0.068
Kaddi minor	0.099	0.046	0.025

Source: GoKP (2012).

The inter-canal comparison indicates no proper sequence of change in either direction in the respective head, middle and tail sections of secondary canals. This situation indicates poor operational management of the canal system.

Reliability in middle-section of Pehur main canal system (Kharif miana)

The mid-section of the system shows having better reliability than other parts of the system. The highest reliability of the system is observed in the middle section of the Sheikh Dhari canal 0.681 and the second highest in the head of Lahore minor 0.215. In the upper mid-section, the main canal has higher reliability in the tail 0.139 than head and middle sections; Zaida minor has high in middle and tail than head and Sheikh Dhari minor record higher reliability in the middle section than head and tail. These values are 0.072 for middle and tail of Zaida minor and 0.048 for the head section, while for Sheikh Dhari minor 0.681 in the middle and 0.188 in the head section (Table 6). The lower mid-section of the system indicates a logical behavior. The Zakarya minor and Lahore minor record a decreasing reliability values from their heads to tails respectively.

The inter-canal comparison in this part of the system shows a complete disharmony from the upper to lower mid-section of the system. In the heads of main mid-section and all the four secondary canals the overall reliability increases from upper to lower mid-section of main canal 0.056, Zaida Minor 0.048, Sheikh Dhari Minor 0.188, Zakarya Minor 0.168 and Lahore Minor 0.215 of the system. The mid-sections of main and all the four secondary canals in the middle of the system, reliability has a decreasing trend except the Sheikh Dhari minor. This indicates an overall erratic behavior of this part of system.

Table 6: *Reliability in middle section of PMC system in Kharif Miana.*

Name of canal	Summer season		
	Head	Middle	Tail
PMC main (mid-section)	0.056	0.108	0.139
Zaida minor	0.048	0.072	0.072
Sheikh dhari minor	0.188	0.681	0.129
Zakarya minor	0.168	0.051	0.033
Lahore minor	0.215	0.070	0.039

Source: GoKP (2012).

Reliability in tail-section of Pehur main canal system (Kharif miana)

The overall reliability remains very low in this part of the system. In this part of the system reliability does not exceeds (0.048) value. All the canals show a pattern of decreasing reliability from heads towards tails. The lowest reliability values are recorded in this part of the system in the tail of Thanodher distributary (0.002) and Bazar minor (0.002, 0.001) in middle and tail respectively (Table 7).

Table 7: *Reliability of Tail section of PMC system in Kharif Miana.*

Name of canal	Summer season		
	Head	Middle	Tail
PMC main (Tail-section)	0.048	0.040	0.023
Thanodher distributary	0.043	0.024	0.002
Bazar minor	0.017	0.002	0.001
Manki minor	0.029	0.007	0.020
Jahangira minor	0.017	0.016	0.004

Source: GoKP (2012).

The inter-canal comparison indicates a decreasing pattern of reliability in the heads of all secondary canals with the exception of Manki minor while in the middle and tail sections, change in values does not follow any sequence. These values indicate a very low level of performance.

Conclusions and Recommendations

The reliability in irrigation is the ability of the system to deliver water on time according to the growth needs of crops and farmers expectations. The Pehur Main Canal system is a warabandi based irrigation system. The warabandi based system has to be operated at least at 70% or more of full capacity of the canal. When a canal is run below 70% of full capacity then the system behavior becomes unpredictable due to the sensitivity of water drawing structures. The reliability analysis indicates a low and unpredictable performance in both seasons and different reaches of the system. The spatial variability is also erratic and often better reliability values are observed in the middle and tail sections constituent canals rather than the head section. This abnormal behavior of the system indicates lack of operational maintenance on part of the irrigation department and lack of organization among farmers.

Novelty Statement

This study is first of its kind in Khyber Pakhtunkhwa based on performance assessment of a whole irrigation system which brings out low and erratic performance.

Authors Contribution

Muhammad Siyar presented the original idea of this research, collected and analused the data and drafted the initial manuscript. Anwar Saeed Khan reviewed and revised the manuscript. Fazlur Rahman organised and supervised the whole research process. Muhammad Jamal Nasir prepared the study area map. The final draft was approved by all authors.

Conflict of interest

The authors have declared no conflict of interest.

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