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COMPARATIVE ANALYSIS OF WATER SUPPLY AND CROP DEMAND UNDER PUBLIC AND CIVIL CANAL IRRIGATION SYSTEMS IN PESHAWAR

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ABSTRACT

Pakistan is becoming a water scarce country with declining per capita water availability (<1000 m^3), whereas its demand for domestic, industrial and environment is rapidly increasing resulting in to stress on sustainable water supply to irrigated land contributing >90% of the agricultural production. The present study was conducted to compare supply and demand under public and civil systems. Water demand was assessed through CROPWAT 8.0. Irrigation supply to the main, secondary and tertiary canals were regularly monitored while at farm level, irrigation water applied to major crops was determined using cutthroat flume.

Water supply remained well below the designed in *Rabi* (winter) due to prolonged break for annual repair and maintenance. In civil system, relative water supply (RWS) as well as relative irrigation supply (RIS) was found greater than public system. During *Rabi*, RWS at primary, secondary, tertiary and farm level under public and civil canal systems was 1.74, 1.05, 0.93, 1.14 and 1.93, 1.56, 1.61, 1.69, respectively. In *Kharif* (summer), RWS at primary, secondary, tertiary and farm level under public and civil canal systems was 1.26, 0.93, 0.86, 0.72 and 1.31, 1.26, 1.13, 1.00, respectively. Statistically, there was a significant difference in RWS of the two systems at secondary and tertiary level, while the difference at primary and farm level was non-significant. Civil system had more generous water supply with an average RWS of more than 1.5. It can be safely concluded that public system relies on rainfall, especially in *Rabi* season and would not be able to meet the crop water demand in a dry year, especially in *Kharif.* To maintain RWS > 1.0 throughout the season, especially critical growth stages, consistent water supply needs to be ensured in public systems by minimizing the annual operation and maintenance period and reducing the conveyance losses.

KEYWORDS: Ris, Rws, Public Canal System, Civil Canal System, *Rabi*, *Kharif*

INTRODUCTION

The fact that food is becoming scarce has given into global insecurity which has now become a big challenge around the globe with strong implications both for environmental management as well as socio-economic development. This is exaggerated by persistent drought and uneven distribution of rainfall resulting in low crop yield in arid and semi-arid regions. The use of economic arrangements for water resource management seems increasingly promising in arid regions of the world.

A global ‘water crisis’ looms large for many developing countries. As water scarcity is increasingly recognized, most of the countries are expected to experience structural water stress, whereas, numerous others are facing problems in securing sufficient water resources during occasional periods of drought. Increasing population has threatened millions of lives with starvation, particularly in world's water scarce regions.

The second best irrigation system after Egypt is not free of weaknesses. Pakistan is facing a severe challenge due to limited opportunities for exploitation of new water sources coupled with the rapidly growing demand. The main cause of poor performance of irrigation system has been seen by many as lying in the age of the system which dates back to the British colonial times (Halsema, 2002). It has a number of common problems like, water logging and salinity, low efficiency in delivery, rigid system designs, inequitable distribution, over-exploitation of fresh ground water, low productivity, insufficient cost recovery and high cost of operation and maintenance. The source of these problems is that instead of addressing the root cause, the government has continued to treat irrigation water as a public good, causing inefficient pricing of water, misallocation of resources, and deterioration of systems. A huge amount of funds is being spent on management, operation and maintenance of irrigation system out of public exchequer. In contrast, the civil system have minimal burden on the government sector and even than working well since centuries. The present study was designed to compare the supply and demand under public and civil canal system. For this purpose, two systems (public and civil) were selected in Peshawar. The site selected for this study provides an excellent opportunity to compare the two systems as KRC (public) and JSC (civil), emerge from Kabul River System at the same point and run parallel commanding a huge area of of Peshawar and Nowshera districts.

REVIEW OF LITERATURE

Salvador *et al.* (2011) assessed the seasonal irrigation requirement in Spain to find variances among different crops and irrigation systems and reported average net irrigation requirement fluctuated from 2683 m^3 ha^{-1} in controlled deficit irrigation vineyard to 957 m^3 ha^{-1} in rice and the application of irrigation water fluctuated from 1491 m^3 ha^{-1} to 1140 m^3 ha^{-1}, respectively. A standard deviation value of 0.4 revealed large variations in annual relative irrigation supply index (ARIS). Yang *et al.* (2010) observed irrigation requirement of wheat, maize, vegetables, fruits trees and cotton in Hebel Plain using DSST and COTTNN2K models with crop coefficient approaches. Their study revealed that irrigation requirement of wheat was 40% of the irrigation requirement. Same was the case for irrigation requirement of cotton, maize and wheat was 64% of the overall irrigation requirement. The irrigation requirement was higher for the months of April and May. Changes in irrigation requirement were higher as compared to statistical data both spatial and temporal. The CWR for pineapple descended from 4.6 mm/day in the vegetative growth stage to 3.5 mm/day during middle stage. Total water consumed by the crop was 1421 mm during the season whereas the cumulative ET_o was 1615 mm. Nisar *et al.* (2007) measured the water supplies and conveyance, seepage and leakage losses at tertiary level under JSC. They also evaluated the farmers' water distribution practices using a set of primary as well as secondary data. The actual water supplies were less than the allocation most of the time it was reported. Similarly, the DPRs were also below unity most of the time. Conveyance losses were 4.7 to 9.56 Ls^{-1} per 1000 meter whereas the leakage losses of 8.58 to 14.34 Ls^{-1} were determined. The study further indicated that water distribution among farmers was inequitable with Coefficient of Variation ranging from 18.83 to 88.38%. Family water distribution was practiced in the command areas of the watercourses. Abbas *et al.* (2006) found that crops were under and over irrigated for a certain period during growth stage. The results indicate that an integrated management plan is needed to regulate irrigation needs in accordance with the crop water requirements. It is noticed that there exists critical water shortage during restricted flows. Conversely, surplus water supplies and surface runoff is wasted during the forced irrigation turns and seasonal monsoon rains. Kuo *et al.* (2006) calculated the irrigation requirement of rice and other crops using CROPWAT at Chai-Nan, Taiwan. For the first and second crops of rice the seepage was 1114 and 296 mm while net irrigation requirement (NIR) was 962 and 295 mm, respectively. In the upland, NIR for maize gown in autumn and spring was 273 and 358 mm, respectively. The results of CROPWAT for double and single rice cropping irrigation system showed CWR of 1019 and 507 mm, respectively. Roe (2006) observed that the main characteristics of community management of irrigation systems in Afghanistan were; irrigation requirement embedded by the beneficiaries being supported by the owners themselves. Main decisions are taken by the beneficiaries on the basis of land and contribution in respect of maintenance. Those were based on contributions in cash or kind the beneficiaries. There is a minimum role of state and issues / conflicts are settled mutually.

MATERIALS AND METHODS

Description of Research Site

Peshawar is a district in the Khyber Pakhtunkhwa province of Pakistan which derives its name from a Sanskrit word '*Pushpapura*', meaning the city of flowers and its flowers were even mentioned in Mughal Emperor Babar's memoirs. The Kushan Kings of Gandhara founded Peshawar over 2,000 year's age. Akbar, grandson of Mughal emperor Babar, who visited Peshawar in 1530 A.D., formally gave the name Peshawar that means 'The *Plae* of the Frontier'. The city of Peshawar, as well as being the provincial capital, is the capital of the district with an area of 1,257 km^2, and population of 6.65 million according to 1998 Pakistan Census. *Pashtu* is the predominant language followed by *Hindko* and the national language *Urdu* (DCR Peshawar, 1998). The Federally Administered Tribal Areas (FATA) adjoining Peshawar, the Khyber Agency which lies to its West, Mohmand Agency to its North, Frontier Region (Semi-Tribal regions) and Kohat district to its South. The two settled districts of Charsadda and Nowshera are situated to its North and North-East, respectively, whereas the Afghan border is approximately 40 km in the West (Nasreen, 2006).

Peshawar valley is covered with consolidated deposits of silt, sands and gravel of recent geological times. There is a small hilly area in the Southeast, which is a part of main Khattak range. The district is almost a fertile plain. The central part of the district consists of fine alluvial deposits. The cultivated tracts consists of a rich, light and porous soil, composed of a pretty even mixture of clay and sand which is good for cultivation of wheat, sugarcane and tobacco. It is approximately 1173 feet (358 m) above sea level. The highest point is at Tarakai with a height of about 700 m. In general the sub-soil strata are composed of gravels, boulders, and sands overlain by silts and clays. Sand, gravel and boulders are important aquifer extends to a depth of about 200 feet (DCR Peshawar, 1998).

The research area located in district Peshawar is an intra-mountain basin (>5500 km^2) situated at the southern margin of the Himalaya. Peshawar lies between 33° 44′ and 34° 15′ north latitude and 71° 22′ and 71° 42′ east longitude (DCR Peshawar, 1998). Peshawar features a semi-arid climate with very hot summers and mild winters. Winter in Peshawar, starts in mid-November and ends in late March while summer months are May to September. The highest temperature of 50°C has been recorded on June 18, 1995, while the lowest −3.9°C occurred on January 7, 1970. Wind speeds vary during the year from 9.3 km hr^{-1} in December to 44 km hr^{-1} in June (DCR Peshawar, 1998). Mean daily minimum and maximum temperature of 39.37°C (June & July) and 0.32°C (December), respectively, was recorded during study period with a relative humidity of 60% (August) to 41% (May).

Peshawar basin is mainly irrigated by the Kabul River and its tributaries. River Kabul originates from the base of Unai Pass in the Paghman Mountains near Kabul and enters Pakistan at Sheen Pokh in the Khyber Agency (north-west) and flows through the mountains until it reaches Warsak Dam. About eight kilometers downstream of the Warsak Dam, the river debouches and gets divided in to three main channels irrigating Peshawar, Charsadda and Nowshera districts of

Khyber Pakhtunkhwa (Gresswell and Huxley, 1965). The two major canal systems of the area are Warsak Canal System and Kabul River Canal Systems. These two systems with a network of about 320 km long canals/ distributaries/minors irrigate 72,637 ha with a design capacity of 39.5 $m^3 s^{-1}$ (Nasreen, 2006). Kabul River Canal system comprises Kabul River Canal (KRC) and Joe Sheikh Canal (JSC) irrigating an area of 26,827 ha with a design capacity of 22.65 $m^3 s^{-1}$.

KRC is 61 km long regular canal commanding an area of 16,715 ha in district Peshawar and Nowshera with a designed discharge of 12.74 $m^3 s^{-1}$. The water allowance for the canal is 0.76 L s^{-1} ha^{-1}. KRC, which runs through Peshawar and is recalled as a trendsetter for the other large canals, establishing the typical environment in the Province (Murray-Rust *et al*. 1997). The canal is completely managed by the provincial Irrigation department through its team of technical and support staff under a specific set of rules and regulations. Under this canal, irrigation water scheduled to the watercourses on the basis of culturable command area for 24 hours through *Paka Warabandi*.

JSC is 43 km long canal irrigating with a command area of 10,112 ha in district Peshawar with a designed discharge of 9.91 $m^3 s^{-1}$ and water allowance of 0.98 L s^{-1} ha^{-1}. This is a civil canal, originally dug as an inundation canal by the farmers on self-help basis during the Aurangzeb Alamgir, a Mughal Emperor's rule close to the end of 17th century. The canal is named after then Governor of the area "Sheikh Usman". It was handed over to the local authorities during colonial British time. While constructing KRC system, the British also enlarged and upgraded the existing JSC and left it to be operated as a civil canal by the local people. Each canal under civil system is unique, and it is impossible to characterize them in a more systematic manner (Murray-Rust, 1997). Presently, Irrigation department is looking after the technical aspects and water supplies to the main canal whereas distribution of water is managed by the farmers according to the local customs prescribed under *Rawajat-e-Aabpashi*. The role of state is limited to the delivery of a fixed ratio of water into the system. There are no fix operational rules of the provincial government, at primary, secondary or tertiary level. Water is diverted to the civil system either by the Government owned (public) systems or diverted directly from the river by the beneficiaries but in both the cases the Irrigation department is not involved in water distribution within the system. Khyber Pakhtunkhwa Irrigation department is the only institution either completely or partially regulating these irrigation systems in the province.

KRC (public) and JSC (civil) providing a good chance of carrying out such a comparative study, were selected. Keeping the size of the above canals, two minors, one each from public and civil systems were selected as samples at secondary level to conduct this study (Table 1).

A multi-stage sampling scheme was adopted to study the crop water productivity under both the systems. Three watercourses were selected at head, middle and tail regions of each of the above selected minors (Table 1). Two farms each at head, middle and tail regions on six watercourses under both the systems were selected randomly, except under Shahi Mahal minor, where it was not possible to select farms at the head region due to small land holdings. Thus a total of 31 farms were selected on both the systems. Surface area of all the selected farms was also measured. The particulars of selected outlets are mentioned in Table 2.

Table 1: Detail of Selected Sample Watercourses and Farms

Minor	Watercourse			Farms	
	Location	Nos	Outlet No/RD	Location	Nos
Wazir Garhi (Public)	Head	1	11000/R (PWC-1)	Head	2
				Middle	2
				Tail	2
	Middle	1	17250/R (PWC-2)	Head	2
				Middle	2
				Tail	2
	Tail	1	24500/TR (PWC-3)	Head	2
				Middle	2
				Tail	2
Total		**3**	**-**	**-**	**18**
Shahi Mahal (Civil)	Head	1	7000/L (CWC-1)	-	1
	Middle	1	17050/L (CWC-2)	Head	2
				Middle	2
				Tail	2
	Tail	1	26205/TF (CWC-3)	Head	2
				Middle	2
				Tail	2
Total		**3**	**-**	**-**	**13**

Table 2: Particulars of Selected Outlets under Public and Civil System

System	WC No.	CCA (Ha)	Outlet Type	Flow Type	Area (M^2)/Bt (M)
Public	PWC-1	63.5	Open Flume	Modular	0.23
	PWC-2	43.7	Open Flume	Modular	0.29
	PWC-3	65.2	Open Flume	Modular	0.20
Civil	CWC-1	1.00	Pipe	Modular	0.03
	CWC-2	163.9	Open Flume	Modular	0.20
	CWC-3	72.4	Open Flume	Modular	0.20

In regression analysis, a dummy variable approach is used to test the significance in difference in average values. The dummy variable is one that takes the value 0 or 1 to indicate the absence or presence of some categorical effect that may be expected to shift the outcome. Dummy variables are "proxy" variables or numeric stand-ins for qualitative facts and are used as devices to sort data into mutually exclusive categories in a regression model. In regression analysis, the dependent variables may be influenced not only by quantitative variables (income, output, prices, etc.), but also by qualitative variables (gender, religion, geographic region, etc.). Dummy variables are used frequently in time series analysis with regime switching, seasonal analysis and qualitative data applications. Since such variables usually indicate the presence/absence of an attribute, one way to quantify such attribute is by constructing artificial variables that take values of 1 and 0 indicating the absence of that attribute. Variables which assume such 0 and 1 values are called dummy variables which can be incorporated in regression models as quantitative variables and are are known as analysis of variance (ANOVA) models. These models are used to assess the statistical significance of the relationship between a quantitative regressand and qualitative or dummy repressors. They are often used to compare the differences in the mean values of two or more groups or categories (Gujarati, 2008). In the present study, this approach was used to determine the significance in difference of mean values of cropping pattern, relative water supply, seasonal water applied, yield and crop water productivity using, computer software “EViews 6”. In order to test the significance of difference between the two systems in the average cropped area under different crops, dummy variable approach was used. Using civil irrigation system as a benchmark, following dummy variables regression model was used to compare the average copped area of two irrigation systems:

$$CA_i = \beta_0 + \beta_1 D_i + v_i \tag{3.2}$$

Irrigation Water Supply and Crop Demand

Water supply in both public as well as civil system was determined at primary, secondary, tertiary and farm level during study period on daily, decade-wise, monthly, seasonal and annual basis. In order to obtain information for the selected public and civil systems, Irrigation department for data In addition to this, actual gauge reading were also obtained to verify the data obtained from from Irrigation department. To ensure the required water supply, additional water of 0.75 $m^3 s^{-1}$ is pumped into the system through a series of tube wells (07 Nos). Daily discharge data of these tubewells for the study period was also obtained from the Irrigation department. Daily, monthly and annual irrigation water supplied to the system at primary level during the study period was calculated by processing the available data. Daily discharge was determined in the selected watercourses during the study period using head-discharge relationship method. The outlets calibration involves measurement of actual different flow rates and corresponding heads at upstream sides of the outlet. In this method, coefficient of discharge (K) is calculated for each set of measurements and multiplied to theoretical discharge so that the results match with the measured discharge (IIMI, 1998).

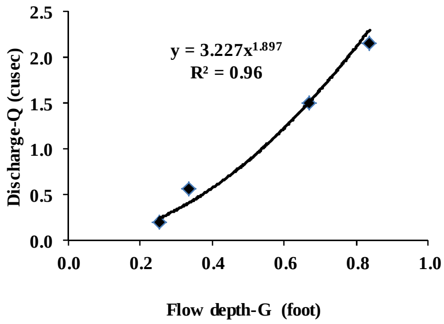
In present study, the selected outlets were calibrated and head-discharge relationship curves were established for each of the selected outlets under both the systems using following steps:

- Reference points were established at each outlet using white paint before the start of the study at selected watercourses and dimensions of were recorded in a pre-designed format.
- Type and dimensions/geometrical parameters like outlet width (Bt) and outlet opening (Y) of the selected outlets were obtained by actual measurements at site.
- Depth of water above the crest level (H), FSL in canal and crest of *moga* were measured using engineer's level and staff rod.
- Flow rate at the downstream end of each outlet was measured using portable cut-throat flumes of different sizes (Ahmed *et al*; 1991). Corresponding heads (water depth) in the canal were recorded for every discharge reading. The process was repeated for several times and discharge at selected outlet was measured for different flow depths (by decreasing/increasing the flow in canal with the help of Irrigation department's representatives).
- Coefficient of discharge was calculated for open flume and pipe outlets, respectively using following equations (Iqtedar 2003):

$$Q = K \times B_t \times G^{3/2} \tag{3.3}$$

$$Q = CA(2gH)^{1/2} \tag{3.4}$$

- Head-discharge relationship curves were developed (Figure 1-6) for each of the selected outlet in both the systems using discharge and depth readings.



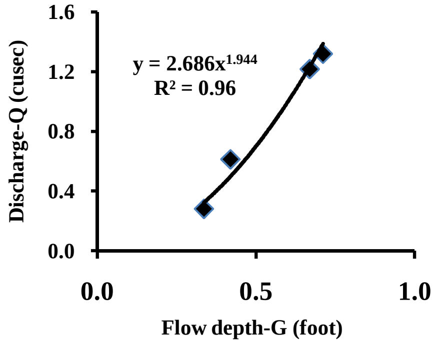
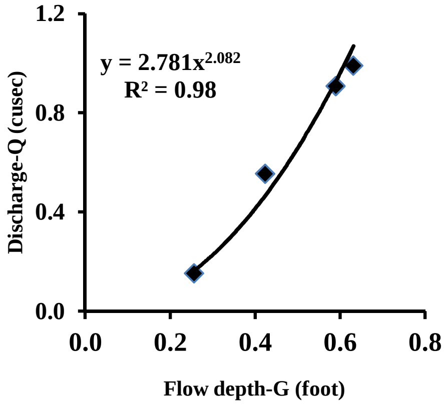


Figure 1: Head-Discharge Relationship for PWC-1 Figure 2: Head-Discharge Relationship for PWC-2



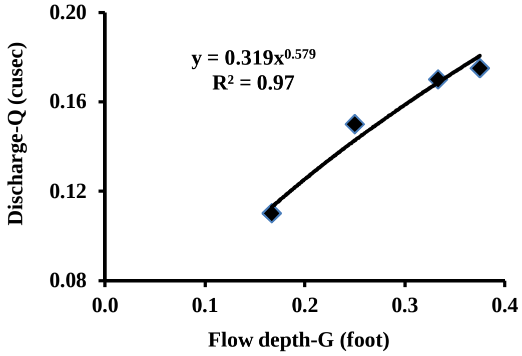
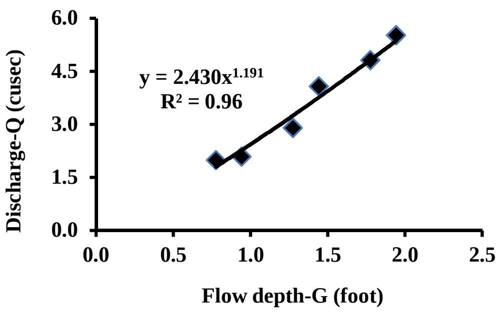


Figure 3: Head-Discharge Relationship for PWC-3 Figure 4: Head-Discharge Relationship for CWC-1



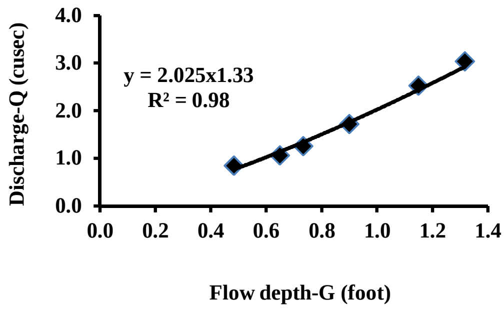


Figure 5: Head-Discharge Relationship for CWC-2 Figure 6: Head-Discharge Relationship for CWC-3

- Daily water level was recorded for each outlet on especially designed formats.
- Equations 3.1 and 3.2 were used to calculate the daily discharge (cusec) in the selected watercourses during the study period in both the systems using head-discharge relation curves. Water supply was calculated at each of the selected outlet under both the systems for the study period on daily, decade and monthly basis. Average water supply of the selected outlets in both the systems was also calculated from the data obtained.

Weekly water supply to each of the selected farm in two systems was measured using cut-throat flume and monthly as well as seasonal water supplied to each farm was calculated during the study period.

Metrological data of maximum, minimum temperature, humidity, wind speed, sunshine hours and rainfall was obtained from Agricultural Research Institute (ARI), Tarnab Peshawar for the study period. Effective rainfall is generally taken as 80% probability level (FAO 1992). It is the minimum assured rainfall that will be available in 3 out of 4 years. Daily rainfall data for the study period was obtained from ARI, Tarnab Peshawar. P_{eff} was calculated using CROPWAT (Palanisami and Ramesh, 1997). Based on FAO Penman-Montieth method (FAO, 1998), ET_o was calculated for the study period using CROPWAT 8.0. Khan (1991) also used CROPWAT Model using weather data. In order to calculate E_c at tertiary level, discharge (m^3s^{-1}) was measured at head of each outlet (Q_{in}) and at Farm gate (Q_{out}) once during the study period under both the systems using cut-throat flumes. Following relationship was used to calculate E_c for both the systems:

$$Q = 100[Q_{out} \div Q_{in}] \tag{3.5}$$

DWS in the root-zone was determined for wheat and maize crops under two systems. Soil samples at 0–30 cm, 30-60 cm and 60-100 cm depths were taken and analyzed for moisture content using Gravimetric method (Black 1965). Soil Bulk Density (BD) was determined using computer software “Hydraulic Properties Calculator” (Saxton and Walter 2009). Following equation was used to determine water depth in the root-zone for each irrigation event:

$$DWS = D_{rz}(FC - \theta) \div 100 \tag{3.6}$$

Similarly, DWA to the wheat, maize, sugarcane and tomato crops was determined during each irrigation event including under both the systems using following expression:

$$DWA = [(QT) \div A] \times 100 \tag{3.7}$$

However, DWA in the pre-sowing irrigation was assumed as the average depth DWA during routine irrigations. Application efficiency at each selected farm for wheat and maize crops was determined during the study period under for both the systems using following equation:

$$E_a = (DWS \div DWA) \times 100 \tag{3.8}$$

It is useful to have the concept of efficiency to enable comparison of different management strategies for a particular system. The efficiency of any system is an indicator of the losses, which occur in the system in view of its input and output. In general, efficiency is defined as the ratio of output to input. Thus, the overall efficiency of a farm irrigation system is the percentage of water supplied to the farm that is beneficially used for irrigation on the farm. E_i of two systems was determined using following equation at tertiary levels):

$$E_i = E_c \times E_a \tag{3.9}$$

ET_c for the study period was determined on well established procedures using the following equation through CROPWAT 8.0 (FAO, 1992) for all the crops at farm level.

$$ET_c = K_c \times ET_o \tag{3.10}$$

NIR of the wheat, maize, sugarcane, tomato, fodder, vegetables and orchards for the full growing season at farm level during the study period under both the systems was calculated using CROPWAT 8.0 (FAO 1992) wherein following equation:

$$NIR = ET_c \times P_{eff} \tag{3.11}$$

GIR for the wheat, maize, sugarcane, tomato, vegetables, fodder and orchards at the selected farms was calculated under both the systems during study period using following equation:

$$GIR = NIR \div E_i \tag{3.12}$$

Two most crucial factors in irrigation planning, design and operation are water supply and water demand. The ratio of water supply to demand constitutes an important concept of RWS as described by Lavine (1982). RWS was calculated for both the systems at primary, secondary, tertiary & farm levels during both *Rabi* & *Kharif* season using following equation:

$$RWS = SWA \div GIR \tag{3.13}$$

In order to test the significance of difference in RWS in two systems, dummy variable approach was used. Using civil irrigation system as a benchmark, following dummy variables regression model was used to compare the average RWS of two irrigation systems:

$$RWS_i = \beta_0 + \beta_1 D_i + v_i \tag{3.14}$$

RESULTS AND DISCUSSIONS

In this chapter, the results related to cropping pattern during the study period (2010-11), cropped area and changes in cropping pattern, irrigation water supply, crop water demand, water productivity and irrigation performance of public and civil canal systems are presented and discussed.

Irrigation Water Supply

Water supplies during *Rabi* and *Kharif* seasons for the study period at primary, secondary, tertiary and farms levels were determined and compared for public as well as civil canal system. At primary level, irrigation water supplies in Kabul River Canal (Public) and Joe Sheikh Canal (Civil) were determined. At secondary level, water supplies were determined in Wazir Garhi (Public) and Shahi Mahal (Civil). Water supplies at tertiary level were determined in the selected watercourses whereas supplies at farm level were determined in the selected farms. Irrigation water supply during *Rabi* season varied from 0 to 6.66 mm day^{-1} with an average of 3.82 mm day^{-1} in public system while in civil system it ranged from 0 to 8.47 mm day^{-1} with an average of 4.98 mm day^{-1} (Figure 7).

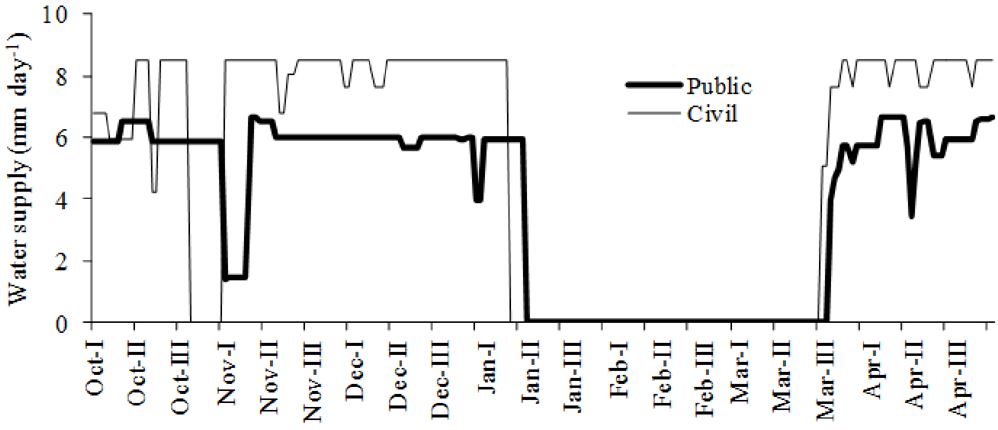


Figure 7: Water Supply at Primary Level in *Rabi*

Total volume of water supplied to the command area in the season was 74% and 70% less than the design flow in public and civil system, respectively. The canal remained closed for routine annual de-siltation and maintenance for 71 days in public canal and 81 days in civil canal system which is 34% and 38% of the total period of *Rabi* season, respectively. According to the approved schedule of Irrigation department, the closure period is 30 days i.e. 1st to 31st January each year. During the study period, the prolonged suspension of water supply in the canals was mainly due to rehabilitation of canal head-works under both the systems coupled with heavy rains during February and March, 2011. The civil canal remained closed during the last week of October, 2010 due to rehabilitation of canal head works and there was no supply in the canal from 24th to 31st October, 2010. The coefficient of variation (C.V) for two systems was 74% and 80%, respectively. Overall, 23% more water was recorded in civil system as compared to public system during the season.

In *Kharif* season, both public as well as civil system received full designed discharge. Average supply record under public system was 6.37 mm day^{-1} with a range of 3.26 to 6.63 mm day^{-1}. In civil system, the supply recorded was 6.77 to 8.47 mm day^{-1} with an average of 8.38 mm day^{-1} (Figure 8).

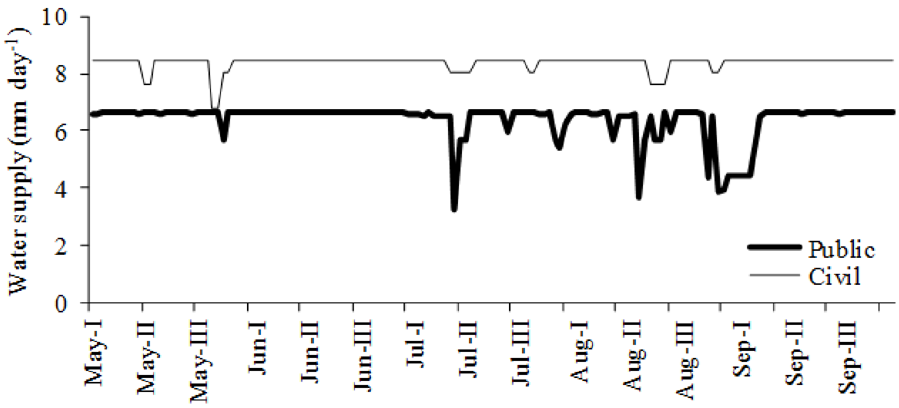


Figure 8: Water Supply at Primary Level in *Kharif*

Total volume of water supplied during the season was 4% and 1% less than the design flow in public and civil system, with C.V. of 10% and 3%, respectively. Average supply in civil system was recorded 24% high as compared to public system.

Water supply in the selected secondary canals was determined during the study period to know the variation in supply between the public and civil canal system in the study area. Supply in the public canal system varied from 0 to 4.13 mm day^{-1} with an average of 2.28 mm day^{-1} during the study period. In case of civil canal system, the supply varied from 0 to 10.11 mm day^{-1} with an average of 4.42 mm day^{-1} (Figure 9).

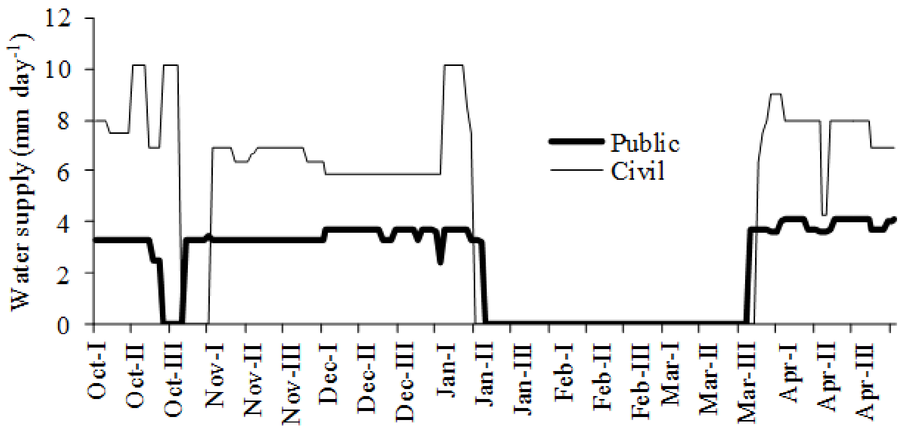


Figure 9: Water Supply at Secondary Level in *Rabi*

A break in the water supply was also noted from 19th to 24th October, 2010 under public canal system while from 24th to 31st October, 2010 in civil canal system. Volume of water supplied was 79% and 129% less than the designed flow under public and civil system, respectively due to canal closure. Average water supply in civil canal system remained 94% higher than public system showing a significant difference. C.V of was 76% and 84% under public and civil system, respectively. In *Kharif* season, water supply in the public canal system varied from 0 to 4.35 mm day^{-1} with an average of 3.82 mm day^{-1}. In case of civil canal system, the supply varied from 0 to 10.11 mm day^{-1} with an average of 7.43 mm day^{-1} (Figure 10).

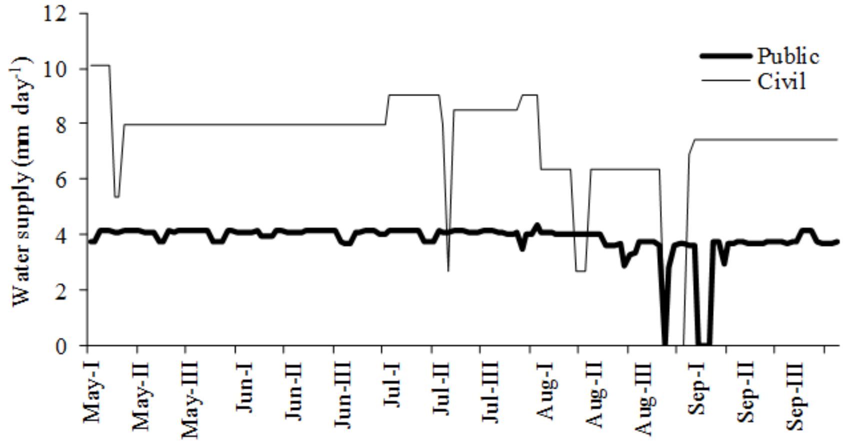


Figure 10: Water Supply at Secondary Level in *Kharif*

The irrigation supply during *Kharif* was observed relatively smooth as compared to *Rabi*. More fluctuation in civil system was due to break in supply on 26th to 30th August, 2011 and 2nd to 4th September, 2011. In case of civil system, there was a break of five days during August 2011. Civil system received 95% more water as compared to the public system which is quite significant. Water supplies in the selected at tertiary level system was determined during the study period in both the systems. During *Rabi* season, the average supply under public canal system was recorded as 2.36 mm day^{-1} with a range of 0 to 4.01 mm day^{-1} during the study period. Under civil canal system, average supply of 4.56 mm day^{-1} with a range of 0 to 9.27 mm day^{-1} (Figure 11).

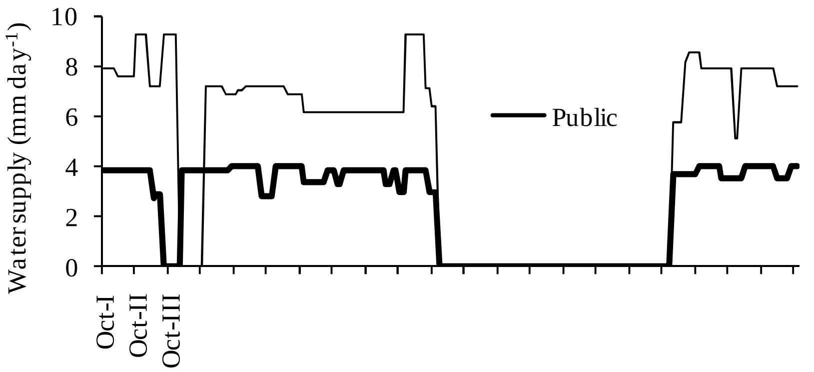


Figure 11: Water Supply at Tertiary Level in *Rabi*

Water supply during the season remained suspended for 77 and 79 days in public and civil system, respectively. C.V. of 77% and 79% for public and civil system was observed. Water supplies in the civil system were 93% higher than public system.

In *Kharif*, average supply under public canal system in selected watercourses remained 3.79 mm day^{-1} with a range of 0 to 4.01 mm day^{-1}. Under civil canal system, the supplies ranged from 0 to 9.27 mm day^{-1} with an average of 7.58 mm day^{-1}(Figure 12).

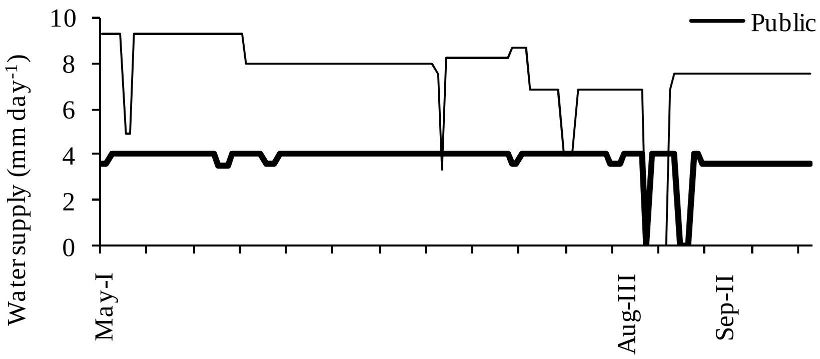


Figure 12: Water Supply at Tertiary Level in *Kharif*

During the season, 100% more water was recorded in civil system as compared to public system. Water supply in this season remained suspended for 4 and 5 days in public and civil system, respectively. The C.V. in average water supplies at tertiary level was 17% and 23% which is attributed to canal closure. Ahmad *et al.* (1999) reported that actual water supply below the allocation might be due to variation in water supply in the system, closing and opening of outlets and rainfall. Water supplies to the selected farms were determined under both the systems during the study period on weekly-turn basis.

During the *Rabi* season, average monthly water supply to selected farms was 2.2 mm day^{-1}, however, it varied from 0 mm day^{-1} (Feb) to 3.7 mm day^{-1} (Nov) under public system while in civil canal system it ranged from 0 mm day^{-1} (Feb) to 6.7 mm day^{-1} (April) with an average of 3.2 mm day^{-1}. Maximum supply was noted during November, 2010 in public and April, 2011 in civil system. Due to annual de-silting/maintenance and repair/rehabilitation of head works, the water supply remained suspended for 11 turns out total 30 turns in both the systems. Average water supply in the civil system was 49% more than public system. C.V. of variation of 64% and 73% in public and civil system, respectively.

In *Kharif* season, average monthly water supply in the selected farms was 3.8 mm day^{-1}, however, it varied from 3.4 mm day^{-1} (Jun) to 4.3 mm day^{-1} (Jul and Aug) under public system while in civil canal system it ranged from 5.0 mm day^{-1} (Aug) to 7.6 mm day^{-1} (Jul and Sep) with an average of 6.7 mm day^{-1}. Out of total 22 turns, the supply in public system remained suspended one turn due to rotation with tail farmers while no break was observed in civil system during *Kharif* season. The C.V. in the seasonal water supply observed was 13% and 16% in public and civil system, respectively. Average water supply in the civil system was 78% more than public system.

Crop Water Demand

Crop water demand/crop water requirement (CWR) was calculated at primary, secondary, tertiary and farm level using CROPWAT Model 8.0 for the present study. Estimation of potential water requirements for agriculture allows assessing the expected level of water stress and helps in improved planning, allocation of water resources and sustainable groundwater management. The variation in climate at the regional scale effects the selection of crop and the evaporative needs of crops. Potential evapotranspiration (ET_o) for the study period was calculated using CROPWAT Model 8.0. ET_o varied from 0.89 mm day^{-1} (December) to 5.07 mm day^{-1} (Jun and July). Pongput *et al*. (1998) reported similar results regarding ET_o for Peshawar. Khan (1991) calculated ET_o of 510 mm for Peshawar during *Rabi* season using 20 years (1970 to 1989) weather data through CROPWAT Model. He reported net monthly irrigation requirement of 164 mm (Min) and 282.3 mm (Max) for Peshawar valley in *Rabi* season. A total of 310.8 mm rainfall was recorded during the study period with effective rainfall (P_{eff}) of 248.8 mm. Average rainfall varied from 0 to 5.3 mm day^{-1} with an average of 0.67 mm day^{-1}. Uneven rainfall was recorded during the study period showing significant variation with C.V. of 170%. August, 2011 remained the wettest month with a total of 84.6 mm rainfall, whereas no rain was recorded in October and November, 2010. Application efficiency (E_a) of 61% and 62% was recorded under public system during *Rabi* and *Kharif*, respectively while in civil canal system the Ea was 57% and 56% in *Rabi* and *Kharif* seasons respectively. Similar findings were reported for Right Bank Canal (RBC) by Pacha and Khan (2002). Khaliq (1980) also reported E_a of 68% and 71%. Subhash *et al*. (1985). FAO (1989) also reported similar results for canal irrigation systems. Hanks (1965); Clyma and Corey (1973,74); Johnson *et al*. (1978); WAPDA and CSU (1978), Colorado State University staff (1979); Thomas and Bower (1980); Ashraf and Munir (1981); Thomas (1984), WAPDA (1984), Rehmat *et al*. (1987); Copland (1987), Khan (1997); Ahmad and Fakhr-i-alam (1996); Ahmad *et al*. (1996), worked on the magnitude of conveyance losses in Pakistan, and irrigation water losses found were in the range of 30-50% in the unlined watercourses.

Irrigation efficiency (E_i) of both the systems primary, secondary and tertiary level was 51, 55 and 44% under public system during *Rabi* and 47, 50 and 41% in *Kharif*, respectively. While in case of civil canal system, the E_i remained 51, 55 and 45% in *Rabi* and 46, 50 and 40% during *Kharif*, respectively. The E_i mainly depends on canal length, type of soil and canal condition. More water is lost in long canals. Similarly, conveyance losses are higher in light soils. In lined canals, only small portion of water is lost. If canals are poorly maintained, bund breaks are not repaired properly and rats dig holes, a lot of water is lost. As both the canals under study are lined, E_c of 95% for lined and 70% for unlined canals was assumed (FAO, 1989) to calculate the E_i. In India, the on-farm irrigation efficiency of most canal irrigation systems ranges from 30 to 40% (Navalawala, 1999; Singh, 2000) whereas; the irrigation efficiency at basin level is as high as 70 to 80% (Chaudhary, 1997).

Average CWR during *Rabi* season under public canal system was 2.89 mm day^{-1}, however, it varied from 1.38 mm day^{-1} (December) to 4.94 mm day^{-1} (April) while in civil system, average CWR of 2.98 mm day^{-1} with a range of 1.61 mm day^{-1} (December) to 5.33 mm day^{-1} (April) was observed.

Higher CWR in the beginning of the season was due to maize crop which was harvested in October, 2010, resulting in to overlapping. Fluctuation in CWR was recorded with 40% and 37% C.V. under public and civil system, respectively. CWR in civil system were 3% higher as compared to public system during the season. In *Kharif*, CWR ranged from 2.84 to 8.92 mm day^{-1} with an average of 6.32 mm day^{-1} in public system while in civil system it varied from 3.95 to 10.63 mm day^{-1} with an average of 7.70 mm day^{-1}. CWR was maximum during July, 2011 and minimum in May, 2011 both in public as well as civil system. Fluctuation in CWR was recorded with C.V. of 32% and 30% in the two systems, respectively. During *Kharif* season, CWR under civil canal system remained 22% more than public system.

Relative water supply (RWS) ranged from 0 to 4.26 with an average of 1.74 during *Rabi* season under public system while in civil system it varied between 0 and 5.05 with an average of 1.93. Maximum RWS was recorded during December, 2010 while in January to March, 2011, it remained zero due to many reasons like, canal closure, low temperature; and lack of rainfall. Average RWS for civil system remained 11% higher than public system. Water supply remained higher than CWR most of the time in this season in both the systems. During *Kharif*, RWS varied between 0.74 and 2.44 with an average of 1.26 under public system while in civil system, it fluctuated from 0.79 and 2.22 with an average of 1.31. Maximum RWS was noted in May, 2011 while minimum in July, 2011 in both the systems. Average RWS in civil canal system was 4% higher than public system.

Average CWR during *Rabi* season under public canal system was 2.67 mm day^{-1}, however, it varied from 1.28 to 4.51 mm day^{-1} while in civil system, average CWR of 2.94 mm day^{-1} with a range of 1.46 to 5.25 mm day^{-1} was observed. Higher CWR at this level was also observed due to maize crop under both the systems. Fluctuation in CWR was 39% under both the systems. CWR in civil system remained 10% higher than public system. During *Kharif* season, CWR ranged from 2.34 to 7.86 mm day^{-1} with an average of 5.53 mm day^{-1} in public system while in civil system it varied from 3.56 to 9.54 mm day^{-1} with an average of 7.10 mm day^{-1}. CWR was maximum during July, 2011 and minimum in May, 2011 in public system while in case of civil system, maximum CWR was recorded in July, 2011 and minimum in September, 2011. Significant fluctuation in CWR was recorded with 33% and 29% C.V. under public and civil system, respectively. During *Kharif*, CWR under civil system was 28% more than public system.

RWS ranged from 0 to 3.06 with an average of 1.05 during *Rabi* season under public system while in civil system it varied between 0 and 4.41 with an average of 1.56. Maximum RWS was recorded during December, 2010 and January, 2011 under public and civil systems, respectively. RWS was zero in January-II to March-II due to canal closure as well as lack of rainfall. Average RWS for civil system remained 49% higher than public system. Average water supply remained higher than CWR at secondary level in both the systems. During *Kharif* season, RWS varied between 0.48 and 1.90 with an average of 0.93 under public system while in civil system it fluctuated from 0.68 to 2.10 with an average of 1.26.

Maximum RWS was recorded in May, 2011 in public system while minimum in September, 2011. In case of civil system, the supply was maximum in September, 2011 and minimum in August, 2011. Average RWS in civil system was 35% higher than public system**.** Average, water supply in the public system remained less than the CWR during the season due high temperatures. During *Rabi* season, CWR ranged from 1.50 to 5.50 mm day^{-1} with an average of 3.30 mm day^{-1} in public system while in civil system it varied from 1.67 to 5.91 mm day^{-1} with an average of 3.45 mm day^{-1}. CWR was maximum during April, 2011 and minimum in December, 2010 in both the system. Fluctuation of 41% and 38% in CWR was recorded under public and civil system, respectively. During the season, CWR under public canal system remained 5% higher than the civil system. In *Kharif* season, CWR ranged from 2.12 to 9.66 mm day^{-1} with an average of 6.29 mm day^{-1} in public system while in civil system it varied from 2.93 to 11.11 mm day^{-1} with an average of 7.53 mm day^{-1}. CWR was maximum during August-I and minimum in May-II in both the system. Fluctuation in CWR was recorded as 40% and 37% C.V. under public and civil system, respectively. During *Kharif*, 20% higher CWR was recorded under public system as compared to the civil system.

During *Rabi* season, RWS varied between 0 and 2.52 with an average of 0.93 under public system while in civil system it fluctuated from 0 and 3.74 with an average of 1.61. Average RWS in civil system remained 68% higher than the public systems. Maximum RWS was noted in December-III and minimum in January-II, III and March II in both the systems. In *Kharif*, RWS varied between 0.43 and 2.04 with an average of 0.86 under public system while in civil system it fluctuated from 0.49 and 2.60 with an average of 1.13. Average RWS in civil canal system remained 31% higher than public systems during the study period. In *Rabi* season, CWR ranged from 1.02 to 4.99 mm day^{-1} with an average of 2.81 mm day^{-1} in public system while in civil system it varied from 1.08 to 6.85 mm day^{-1} with an average of 3.35 mm day^{-1}. Maximum CWR was recorded in October, 2010 in public and April, 2011 in civil system while minimum CWR was recorded in December, 2010 in both the systems. Low values of CWR during December, 2010 were due to low temperatures together with heavy rainfall of 10.72 mm during the month. Significant fluctuation in CWR was recorded with 55% and 65% C.V; under public and civil system, respectively. During the season, CWR under public canal system remained 19% more than civil system due to more water demanding crops like vegetables. During *Kharif*, CWR ranged from 3.78 mm day^{-1} (May) to 8.44 mm day-1 (June) with an average of 6.66 mm day^{-1} in public system while in civil system it varied from 5.73 mm day^{-1} (May) to 9.45 mm day^{-1} (July) with an average of 7.83 mm day^{-1}. Maximum CWR was recorded in July, 2011 while minimum values were recorded during May, 2011 in both the systems. Low values of CWR in May were due to low cropping intensity. Fluctuation of 29% and 21% in CWR was noted under public and civil system. During the season, CWR under public canal system remained 18% more than civil system due to more vegetable crops. During the season, RWS varied between 0.39 and 2.44 with an average of 1.14 under public system while in civil system it fluctuated from 0.43 and 4.18 with an average of 1.69. During November and December, 2010, abnormally high values of RWS in both the systems were due to low crop demand and more water supplies. RWS in civil system was 48% higher than public system. RWS in *Kharif* varied between 0.42 and 0.97 with an average of 0.72 under public system while in civil system it fluctuated from 0.82 and 1.19 with an average of 1.00. RWS in civil canal remained higher than public system throughout the season except August, 2011. On average, RWS in civil system remained 39% higher than public system.

During *Rabi* season, both the systems have more water than the crop demand at all levels, except tertiary level in public system, where only 93% demand is met. During *Kharif*, public system remained short of water by 7, 14 and 28% at secondary, tertiary and farm levels, respectively. Large range of fluctuation in RWS at all the levels both in *Rabi* and *Kharif* indicate that canal water supply is determined principally by considerations of system operation and has no relationship to the crop requirements. Comparing the two systems, RWS for the civil system remained greater than public system during the study period with significant difference at all levels. Statistically, there was a significant difference in the RWS of two systems at secondary and tertiary level between the two systems, however, the difference at primary and farm level remained non-significant. The distribution evidently is the crucial activity in an irrigation system. The objective of any scheme is an adequate, timely and reliable supply of the water demanded at the farm gate. In schemes where water is scarce in relation to crop demand, the effective and judicious distribution is the most important function of irrigation management (Bottrall 1980). Inadequate water supply has always been a great problem in any system. The tail region has chronic water shortage in case of public system. The higher values in RWS show that the availability of water is not a problem as far as the civil canal system is concerned but in contrast public system is suffering shortage of water during *Kharif*. In addition, it can be inferred that the issue of water management is in jeopardy. The main reasons for this problem are the meager attention given by the farmer for irrigation water management. Better management can improve the situation as about 40% water is lost in the system mostly at field level. One of the attempts made by the Irrigation department is installation of additional tube wells to supplement the supply in water scarce areas.

CONCLUSIONS AND RECOMMENDATIONS

Volume of water supply remained well below the designed flow during *Rabi* season due to prolonged break for repair and maintenance of primary and secondary canals. Both relative water supply as well as relative irrigation supply was found greater in civil system as compared to public system. With relatively better water supply, farmer applied more water under civil system as compared to public system. It can be concluded that public system relies on rainfall, especially in *Rabi* season and would not be able to meet the crop water demand in a dry year, especially in peak period (*Kharif*). In order to maintain RWS of above 1.0 throughout the season, especially critical growth stages, consistent water supply needs to be ensured in public systems by minimizing the annual operation and maintenance period and reducing the conveyance losses. Following are fewrecomendations to improve the RWS in both the system:

- Irrigation supplies should be according to crop demand keeping rainfall pattern in view and relative water supply should be kept within the range of 1.0 to 1.5 for optimum productivity.
- Annual maintenance period notified by the Irrigation department shall strictly be followed to increase relative irrigation supply and reduce its dependence on rainfall.
- Application as well as conveyance losses need to be reduced to ensure sustainable water supply to the crops and improve the water productivity of both the systems.
- Farmers in both the systems need to be educated to change the cropping system from wheat-maize to high value crops (vegetables) and judicious use of available water for their crops.

REFERENCES

1. Abbas, A., M. Saeed and M. Hussain. 2006. Existing irrigation practices and their improvement for enhancing water productivity. Pak. J. Water Res. 10(1).
2. Ahmed, S., M. Yasin., and M. M. Ahmad. 1991. Flow measurements with portable cut-throat flume &broad crested weir in flat gradient channels. Irr. & Drange Sys. 5(2): 141-150.

3. Ahmad, N., FakhriAlam, M. Jamal and M. Tariq. 1996. Evaluation of water distribution and estimation of conveyance losses in watercourses downstream of outlet. Sarhad J. Agr. XII (5): 527-536.

4. Black C.A. 1965. Methods of soil analysis: Part-I physical and mineralogical properties. American Society of Agronomy, Madison, Wisconsin, USA: 545-5.

5. Chaudhary, T.N. 1997. Vision-2020. DWMR Perspective Plan. Directorate of Water Research, Patna, India.

6. Clyma, W. And G.L. Coery. 1974. The importance of farm water management in Pakistan. Water Management Res. CS V, Pakistan field Reports No. 2.

7. Copland. 1987. Technical economic feasibility report for Khushab Salinity Control and Reclamation Project. Copland and Co., Consulting Economists to ADB

8. Food and Agriculture Organization. 1989. Irrigation water management: Irrigation scheduling". Training manual No.4, FAO, UN, and Rome, Italy.

9. Food and Agriculture Organization. 1992. Crop water requirement. Guidelines for predicting crop water requirement. Irrigation and Drainage Paper-24, FAO, UN, Rome, Italy.

10. FAO (Food and Agriculture Organization), 1998. Crop evapotranspiration: Guidelines for computing crop water requirements. Authors, Allen RG, Pereira LS, Raes D & Smith M. Irrigation and Drainage Paper 56. Rome, Italy.

11. Gujarati, D.N. 2008. Basic Econometrics. 4th Ed. McGraw-Hill. 297-339.

12. Halsema, V. and E. Gerado. 2002. Trail and retrial: The evolution of irrigation modernization in NWFP, Pakistan. Rome, Italy.

13. Hanks, R.J. 1965. Estimating infiltration from soil moisture properties. J. Soil and water conservation, 20: 49-51.

14. Iqtedar, H.S. 2003. Irrigation and drainage engineering. Royal Book Company BG-5 Rex Centre, Karachi, Pakistan (8-1, 8-22).

15. IWMI Annual report 1998. Colombo, Sri Lanka: IWAMi Institute 6p. [DOI].

16. Johnson, S.I., W. D. Kamper and W. K. Lowdermik. 1978. Improving irrigation water management in the Indus Basin. Water Res. Bulletin. WN, USA: 11-105.

17. Khaliq, I.A. 1980. Irrigation systems in Pakistan: measures to improved irrigation efficiencies at farm level. Paper-445, Water Res. Planning, Govt. of Pakistan.

18. Khan, M Z. 1991. Net monthly and seasonal irrigation requirements for wheat crop in Peshawar Valley. Sarhad J. Agri. VII (4): 454-460.

19. Khan, M.J. 1997. Assessment of irrigation conveyance losses in Peshawar Valley. In Murray-Rust, D.H. et al. ("eds"). "Water Mgt. in NWFP." Part 4. Jointly published by Deptt. of Water Management, NWFP Agric. Univ. Peshawar and Dept. of Irrigation and Soil and Water Con., Wageningen Agric. Uni. The Netherlands: 210-211.

20. Kuo, S. F., S. S. Ho, and C. W. Liu. 2006. Estimation of irrigation requirements with derived crop coefficients for upland and paddy crops in ChiaNan Irrigation Association, Taiwan. Agr. Water Mgt. 82: 433-451.

21. Levine, G. 1982. Relative water supply: an explanatory variable for irrigation systems. Cornell Uni. Tech. Rep. No. 6.

22. Murray-Rust, D H., V. Velde, J. Edward and H. Rehman “eds”. 1997. Water management in NWFP”. Jointly published by Dept. of Water Mgt. NWFP Agri. Uni. Peshawar and Deptt. of Irrigation and Soil and Water Cons., Wageningen Agri. Uni. The Netherlands: 50-60, 210-211.

23. Nasreen, S. 2006. Monitoring of surface water groundwater air and soil in Peshawar basin against time the 3rd dimension. A Thesis - Excellence in Geology, Uni. of Peshawar.

24. Nisar A., J. A. Tariq, M. Z. Khan and M. A. Shah. 2007. Evaluation of water mgt. practices at three outlets of Joe-Sheikh Canal Peshawar, Pakistan. Sarhad J. Agri. 23(4).

25. Palanisami, K. and T. Ramesh. 1997. Water productivity at farm level in Bhavani Basin, Tamilnadu - Estimation, challenges and approaches. Water Technology Centre, Tamilnadu Agricultural University, Coimbatore.

26. Pongput, K; J.C. Alurralde and G.V. Skogeboe. 1998. Scheduling model for crop based irrigation operations. Pakistan National Program, IIMI, Lahore.

27. Rehmat, A., Konard and S.D.Muhammad. 1978. Review of water issue in 15 watercourses in NWFP. Joint Co-operative study of WAPDA on Farm manag. NWFP & CSU USA.

28. Roe, A. 2006. Water management, livestock and the opium economy. Afghanistan Research and Evaluation Unit, 38.

29. Salvador, R., A. M. Cob, J. Cavero and E. Playan. 2011. Seasonal on farm irrigation performance in the Ebro basin (Spain): Crops and irrigation systems. Agri. Water Mgt. 98: 577-587.

30. Saxton, K.E;, and R. Walter. 2009. Hydraulic properties calculator. USDA - Agricultural Research Service and USDA-ARS, Hydrology & RS Laboratory.

31. WAPDA and CSU. 1978. Operational irrigation evaluations of three watercourse systems. Water and Power Development Authority and CSU, USA.

32. WAPDA. 1984. Monitoring and evaluation of nn-farm water management programme (Pre-improvement) evaluation. Watercourse monitoring and evaluation directorate of Water and Power Development Authority, Pakistan.

33. Yang, Y., J. P. Moiwo and Y. Hu. 2010. Estimation of irrigation requirement for sustainable water resources re-allocation in North China. Agri. Water Mgt.97: 1711-1721.